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Ambient Measurement Methods and Properties of the 188 Clean Air Act Hazardous Air Pollutants

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Abstract

This final report describes work conducted by Battelle to identify ambient air measurement methods for the 188 Hazardous Air Pollutants (HAPs) designated in Title III of the Clean Air Act Amendments of 1990. The main objective of this study was to document the state of development of measurement methods for each of the 188 HAPs in ambient air. This report is essentially an update of the measurement methods review previously conducted in 1993 for the U.S. EPA (Ambient Measurement Methods and Properties of the 189 Clean Air Hazardous Air Pollutants-NTIS No: PB95-123923). The current HAPs list contains 188 compounds-caprolactam has been removed from this list.

The survey of measurement methods for the 188 HAPs included standard methods published by EPA, NIOSH, OSHA, and other organizations, and wide-ranging literature searches and reviews of recent publications. Over two hundred (200) distinct measurement methods were identified, some applicable to several HAPs, and others applicable to a single HAP. The identified methods were assigned to one of three categories according to their degree of development, i.e.:

Applicable methods, are methods established and documented to a reasonable degree for measurement of the target HAP in ambient air. (This definition does not necessarily imply that all issues have been fully resolved regarding the sampling and analysis of the HAP in the atmosphere. An overly optimistic view of the state of HAPs measurement methods could result if these reservations are overlooked.)

Likely methods, represent methods established for the target HAP or for a closely similar HAP in a different environment (e.g. workplace air) but needing further development before application to ambient air.

Potential methods, are methods needing extensive further development before measurements in ambient air can be considered valid.

For each HAP, all identified methods were tabulated, so that each of the above categories may have more than one method assigned to it. Quantitative detection limits were also tabulated, for at least the most fully developed method for each HAP. Pertinent literature was also cited, to allow the reader to obtain details of each method if needed.

For 134 of the HAPs, *Applicable* methods of measurement were identified. For 43 other HAPs, *Likely* methods, but no *Applicable* methods, were found. These combined results suggest that ambient measurements should be achievable for most of the HAPs, with a reasonable further method development effort. However, that method development must include both *Applicable* and *Likely* methods, since methods currently identified as *Applicable* may not all be fully proven for all ambient conditions and for the full range of HAPs properties and reactivity. In addition, for 9 HAPs only *Potential* methods were found, implying extensive further development before

ambient measurements are achievable, and for 2 HAPs no methods were found at any stage of development.

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Section 1
Introduction

The presence of toxic contaminants in air has been a public health issue for many years. The Clean Air Act Amendments (CAAA) of 1990[1] greatly accelerated the pace of designating and regulating air contaminants by defining a list of 189 Hazardous Air Pollutants (HAPs). However, caprolactam is no longer considered a HAPs and the current list contains 188 compounds. These 188 HAPs are remarkably diverse, consisting of industrial chemicals and intermediates, pesticides, chlorinated and hydrocarbon solvents, metals, combustion byproducts, chemical groups such as polychlorinated biphenyls, and mixed chemicals such as coke oven emissions. Some of the HAPs are common air pollutants, such as volatile organic compounds (VOCs), but many other HAPs were assigned to the list based on their recognized toxicity in workplace environments, and had not previously been considered as ambient air contaminants. Some of the HAPs are not single compounds, but rather complex mixtures or groups of chemicals spanning broad ranges of chemical and physical properties. A few HAPs, such as titanium tetrachloride, phosphorus, and diazomethane, are unlikely to exist in ambient air because of their reactivity.

Title III of the CAAA is aimed at reducing the public health risks from HAPs in ambient air, and includes mandated risk reduction goals. For example, a 75 percent reduction in cancer incidence due to area sources of HAPs is a stated goal of Title III of the CAAA. However, determining the current health risks from HAPs, or quantifying reductions in health risks, requires knowledge of the ambient concentrations of the HAPs. Partly because of the diversity of the HAPs, information on ambient measurements and methods are severely lacking for many HAPs. As of 1993, only 70 of the 189 HAPs were included in the U.S. EPA's National VOC Data

Base.[2-4] A 1993 survey of ambient HAPs data conducted for U.S. EPA showed no ambient data for 74 of the 189 HAPs,[5-7] and furthermore found less than 100 ambient measurements for 116 of the HAPs. The main reason suggested for the absence of ambient data for many HAPs is the lack of suitable sampling and analysis methods.[5-7] This document is an update of the measurement methods review previously conducted in 1993 for the U.S. EPA (Ambient Measurement Methods and Properties of the 189 Clean Air Hazardous Air Pollutants-NTIS No: PB95-123923). The current HAPs list contains 188 compounds because caprolactam has been removed from the original list. The survey of measurement methods for the 188 HAPs drew upon standard methods published by EPA, NIOSH, OSHA, and other organizations and upon literature searches and reviews of recent publications. This report contains the following:

1. A primary table is provided in Appendix A which shows each of the 188 HAPs and the pertinent measurement methods. Each listed method is categorized by the degree of development of the method. For example, a method which is proven for ambient measurements is distinguished from a method proven only at higher concentration levels, as in workplace air. Methods are categorized as applicable, likely, or potential. Method detection or quantification levels are provided for the most fully developed method for each HAP. Each compound is also classified into various volatility classes.

2. More detailed information on each listed method is provided in the reference section of Appendix A. Information includes the method number, title, and the effective date. Methods include the pertinent U.S. EPA TO and IO methods, NIOSH methods, OSHA fully validated and partially valicated methods, and finally research methods.

3. Table B-1 in Appendix B provides chemical and physical properties of the 188 HAPs and was used as an aid in assigning methods as applicable, likely or potential.

Section 2
Conclusions

1. For 134 of the 188 HAPs, measurement methods designed for use in ambient air were identified. Most, but not all, of these methods have actually been used for ambient measurements of the pertinent HAPs.

2. For 43 other HAPs as shown in Table 2, measurement methods were identified which are likely to be applicable to ambient air after some further development.

3. Based on the two conclusions above, ambient measurement methods appear to be achievable for the great majority of the 188 HAPs.

4. For 9 HAPs as shown in Table 2, existing measurement methods would require extensive further development before application to ambient air should be considered.

5. For 2 HAPs as shown in Table 2, no measurement methods in any state of development were identified.

6. The 11 HAPs noted in conclusions 4 and 5 comprise the greatest gap in measurement capabilities for the HAPs.

Section 3
Recommendations

1. High priority should be given to further development of measurement methods for the 43 HAPs for which such effort is likely to lead to ambient air measurement capabilities.

2. Development of methods should be initiated for the 11 HAPs for which existing methods are most lacking. However, prioritization of that effort should be based on the reactivity, emitted quantities, and potential products of these HAPs.

3. Method verification efforts should continue for all HAPs, with the aim of consolidating or simplifying the wide variety of measurement methods currently identified.

Section 4
Survey Methods

This section describes the methods used in the original 1993 and the current surveys to obtain and compile information on the properties and measurement methods of the 188 HAPs. The HAPs property information was reviewed and also was of use in updating the measurement methods for the 188 compounds.

HAPs Properties

The chemical and physical properties of interest in this survey are those that affect the sampling and measurement of HAPs in the atmosphere. To organize the compilation of properties, the HAPs were divided into groups. As a starting point, the 188 HAPs were first divided into organic compounds and inorganic compounds (designated OC and INC, respectively). This initial distinction was based largely on the designation of chemicals in the CRC Handbook of Chemistry and Physics,[8] and on the known nature of the HAPs. The primary properties then obtained for all the HAPs were vapor pressure (in mm of Hg at 25C) and boiling point temperature. The vapor pressure data were the primary factor used to categorize the HAPs further, since vapor pressure indicates the likely physical state of a chemical in the atmosphere. The 188 HAPs were ranked in order of vapor pressure, with boiling point a secondary ranking factor.

Once ranked according to vapor pressure, the HAPs were grouped according to ranges in vapor pressure. Quantitative vapor pressure criteria were set up defining very volatile organic and inorganic compounds (i.e., VVOC and VVINC), volatile compounds (VOC and VINC), semivolatile compounds (SVOC and SVINC), and nonvolatile compounds (NVOC and NVINC). The vapor pressure criteria corresponding to each of these HAPs volatility classes are shown in

Table 1. The vapor pressure criteria shown are the same as those used in previous such categorizations,[9] except for the very volatile categories (VVOC and VVINC). This study denoted as very volatile any compound with a vapor pressure greater than 380 mm Hg (i.e., half an atmosphere); previous categorizations used a somewhat lower criterion of 10 kPa (i.e., 0.099 atm). The vapor pressure criteria are somewhat arbitrary, and compounds with vapor pressures near the criterion values generally fall into "gray areas" that define gradual transitions from one volatility class to the next. For the volatile and very volatile HAPs, further chemical and physical properties were compiled, consisting of electronic polarizability, water solubility, aqueous reactivity, and estimated lifetime relative to chemical reaction or deposition in the atmosphere. These properties were compiled because they determine the effectiveness with which a HAP may be sampled in the atmosphere, and the extent to which atmospheric processes may obscure emissions of HAPs to the atmosphere. Table 1 summarizes the properties reviewed for the various volatility classes of HAPs.

Table 1. Summary of HAP Categories With Corresponding Vapor Pressure Ranges and Properties Reviewed

Volatility Class[a]	Range of Vapor Pressures (mm Hg at 25E)	Properties Reviewed
VVOC (very volatile organic compounds)	>380	Vapor pressure; boiling point; polarizability; water solubility; aqueous reactivity; atmospheric lifetime
VVINC (very volatile inorganic compounds)	>380	Vapor pressure; boiling point; polarizability; water solubility; aqueous reactivity; atmospheric lifetime
VOC (volatile organic compounds)	0.1 to 380	Vapor pressure; boiling point; polarizability; water solubility; aqueous reactivity; atmospheric lifetime
VINC (volatile inorganic compounds)	0.1 to 380	Vapor pressure; boiling point; polarizability; water solubility; aqueous reactivity; atmospheric lifetime
SVOC (semivolatile organic compounds)	1×10^{-7} to 0.1	Vapor pressure; boiling point
SVINC (semivolatile inorganic compounds)	1×10^{-7} to 0.1	Vapor pressure; boiling point
NVOC (nonvolatile organic compounds)	$<1 \times 10^{-7}$	Vapor pressure; boiling point
NVINC (nonvolatile inorganic compounds)	$<1 \times 10^{-7}$	Vapor pressure; boiling point

The primary information sources used for the HAPs properties survey were handbooks and data bases of chemical and physical properties,[8-16] including an EPA computer data base specifically addressing the 188 HAPs.[10] Whenever possible, inconsistencies and errors were corrected by comparisons of data from various sources, and by consultation with EPA staff.

The chemical and physical property data compiled in this study are contained in detail in Appendix B, for the full list of 188 HAPs. Appendix C provides a separate list identifying the organic and inorganic HAPs in each of the volatility ranges.

HAPs Measurement Methods

The search for measurement methods for the HAPs was intended to be as wide-ranging as possible. Initial information sources included standard compilations of air sampling methods, such as EPA screening methods, EPA Contract Laboratory Program (CLP), Compendium (i.e., TO-) methods, the Intersociety Committee on Methods of Air Sampling and Analysis, the National Institute of Occupational Safety and Health (NIOSH), the Occupational Safety and Health Administration (OSHA), the American Society for Testing and Materials (ASTM), and EPA solid waste (SW 846) methods. However, after further analysis of available information, we excluded EPA screening methods, CLP methods, ASTM methods, and EPA solid waste methods from the current table.

Another useful resource was the EPA database on measurement methods for HAPs,[17] which includes primarily established EPA methods. Additional sources of information were two surveys on the ambient concentrations[5-7] and atmospheric transformations of the HAPs.[7,15,16] The ambient concentrations survey[5-7] was especially useful as a guide to measurement methods for HAPs, and assured that methods were identified for all HAPs that have been measured in ambient air. In addition, reports, journal articles, and meeting proceedings known to contain information on HAPs methods were obtained and reviewed. In general, highly complex and expensive research methods were considered unsuitable for widespread monitoring and were not included in this survey.

The aim of the methods survey was to provide information on methods immediately applicable to HAPs measurements, and on those still in development. As a result, measurement

methods for the 188 HAPs were organized into three categories, depending on the degree of development of the method. Those categories are:

Applicable

An *Applicable* method was defined as one which has been reasonably established and documented for measurement of the target HAP in ambient air. In most cases, methods identified as *Applicable* have actually been used for ambient measurements, i.e., ambient data are available illustrating the effectiveness of the method. A good example of an *Applicable* method is EPA Compendium Method TO-14A, which has been widely used for VOC measurements. In other cases, a method was identified as *Applicable* for a specific HAP because of the degree of documentation and standardization of the method, even though no ambient data were found. The primary examples of this are a few TO- methods. Although such methods are targeted for a number of HAPs, for a few of those HAPs no ambient measurements were found, and further development may be needed to document ambient measurement capabilities. It must be stressed that the existence of an *Applicable* method does not guarantee adequate measurement of the pertinent HAP(s) under all circumstances. Further development and evaluation may be needed to assure sensitivity, freedom from interferences, stability of samples, precision, accuracy, etc. under the range of conditions found in ambient measurements.

Likely

Two types of *Likely* measurement methods were defined. The most common type is a method which has been clearly established and used to measure the target HAP in air, but not in ambient air. The presumption is that further development (such as an increase in sensitivity or sampled volume) would allow measurements in ambient air. The primary examples of this type of *Likely* method are NIOSH or OSHA methods established for HAPs in workplace air. A specific example is OSHA Method No. 21, stated to have a detection limit of 1.3 ppbv in workplace air, and designated as a *Likely* method for acrylamide. In a few cases, such methods have been applied to ambient air, but in such limited conditions or time periods that demonstration of the method is judged to be incomplete. The second type of *Likely* method

consists of techniques identified as *Applicable* for one HAP, and consequently inferred as *Likely* for another HAP, based on close similarity of chemical and physical properties. An example of an inferred *Likely* method is TO-14A for 1,2-dibromo-3-chloropropane, based on the similarity of this compound to other VOCs in terms of volatility, water solubility, and reactivity.

Potential

A *Potential* method was defined as one which needs extensive further development before application to ambient air measurements will be justified. Many *Potential* methods have been evaluated under laboratory conditions, or for the target HAP in sample matrices other than air (e.g., water, soil). *Potential* methods were inferred for some HAPs, based on *Applicable* or *Likely* methods found for other HAPs having somewhat similar chemical and physical properties. The degree of similarity of properties between HAPs was used as the guide in designating *Potential* methods in those cases.

For HAPs for which no *Applicable* or *Likely* methods were found, further searches were conducted beyond the reviews outlined above. For such HAPs, detailed literature searches were conducted using the files of Chemical Abstracts Service (CAS) and the National Technical Information Service (NTIS). Such searches targeted the chemical name and CAS number of the HAP of interest, and used successive sets of keywords such as air; trace or ambient or workplace; and detect or measure or monitor. Abstracts obtained in such searches were reviewed, and whole papers were obtained for review if the abstracts appeared promising.

In all method searches and reviews, the chemical and physical properties compiled in this study were valuable. The quantitative similarity of properties such as vapor pressure, solubility, and reactivity of HAPs was used to suggest *Likely* and *Potential* methods, and the degree of similarity of properties determined the choice between designation as a *Likely* or *Potential* method.

HAPs Method Detection Limit

A key characteristic of an ambient air measurement method is the detection limit. As part of this methods survey, ambient air detection limits were indicated whenever they were reported

in method documentation. The various units in which detection limits were reported include parts-per-million by volume (ppmv), parts-per-billion by volume (ppbv), parts-per-trillion by volume (pptv), milligrams per cubic meter (mg/m3), micrograms per cubic meter (μg/m3), nanograms per cubic meter (ng/m3), and picograms per cubic meter (pg/m3). Detection limits were reported in this review as they were stated in the respective methods. An effort was made to indicate the detection limit for at least the most fully developed method(s) for each HAP. Estimation of detection limits, when they were not explicitly stated in the material reviewed, was generally not done. The detection limits reported should be considered primarily a guide to the relative capabilities of the various methods, rather than an absolute statement of method performance.

Citation of literature in the methods survey was aimed at providing the user of the survey enough information to review at least the basics of the identified method, and to locate further information if needed. No effort was made to compile all possible information on each method.

The results of the HAPs measurement method survey are summarized in Section 5, and the complete table and supporting data are presented in detail in Appendix A for the full list of 188 HAPs.

Section 5
Survey Results

This section of the report summarizes the data obtained during the update of measurement methods for the 188 HAPs. The complete table of measurement methods is contained in Appendix A, along with method identification details. Supporting chemical and physical data for each HAP is shown in Appendix B. For convenience, Appendix C provides a listing of the HAPs by volatility classes.

HAPs Measurement Methods

The primary product of this study was an updated listing of measurement methods for the 188 HAPs.

The complete listing of the HAPs method survey is presented in Appendix A in the form of a comprehensive table that presents the 188 HAPs in the same order as they appear in the CAAA. For each HAP entry, the name, CAS number, and major volatility class are shown. The ambient methods information is listed in successive columns for *Applicable*, *Likely*, and *Potential* methods. Within each of these columns, the identified methods are indicated by standard method designations (e.g., TO-14A, NIOSH 5514), or by citations to the pertinent literature (e.g., R-1, R-2, etc.). The final two columns of the Table show the limits of detection for selected methods, and provide explanatory comments on the entries, respectively.

The methods and literature compiled in conducting the methods survey are cited in a reference list in Appendix A. Standard methods, such as NIOSH, OSHA, TO- or IO- methods, are listed by title under a general reference heading. Research methods are listed in numerical order (R-1, R-2, etc.). For each research method, the citation includes a brief description of the method, and one or more literature citations pertinent to the method.

Figure 1 shows that for 134 HAPs (two-thirds of the HAPs list), *Applicable* ambient measurement methods were found. Note that Figure 1 shows only the most developed state of methods found; for some of these 134 HAPs, *Likely* and *Potential* methods were also found. Figure 1 also shows that for 43 HAPs, *Likely* methods were found, but no *Applicable* methods. Most of these *Likely* methods were specific for the HAP in question, but for some HAPs the identification of *Likely* methods was inferred based on HAP properties. For 9 HAPs only *Potential* methods could be identified, and of those, 3 were inferred on the basis of chemical and physical properties. For 2 HAPs no measurement methods could be identified at any level of development.

In terms of method development needs for the HAPs, the most cost-effective approach would probably be further development of the *Likely* methods that exist for the HAPs with no *Applicable* methods. The definition of a *Likely* method means that a reasonable degree of further development should result in a method applicable to ambient air. In addition, the large number of *Applicable* methods already available for volatile and semi-volatile organics should enhance development of methods for additional compounds. A good example is the recently completed TO-15 document which discusses canister sampling and its potential for sampling the 97 volatile HAPs. Validation on storage stability and analytical method detection needs to be determined for many of these compounds.

Continued evaluation of measurement methods for all the HAPs would be worthwhile. An important goal of that effort should be to consolidate and simplify the variety of methods available into a smaller number of well-characterized and broadly applicable methods. Although some of the standard EPA methods cited in this survey are intended to be broadly applicable, the diversity of the 188 HAPs calls for further work in this area. Another area of opportunity for consolidation of methods is the NIOSH and OSHA workplace methods, many of which are cited in this survey as *Likely* methods for various HAPs. Although generally targeted for a single chemical or a small group of chemicals, the workplace methods often share very similar operational and analytical procedures. Combination or consolidation of these methods thus would seem feasible. Finally, further verification of HAPs methods is needed, even for *Applicable* methods. The existence of *Applicable* methods for 134 of the HAPs may present an

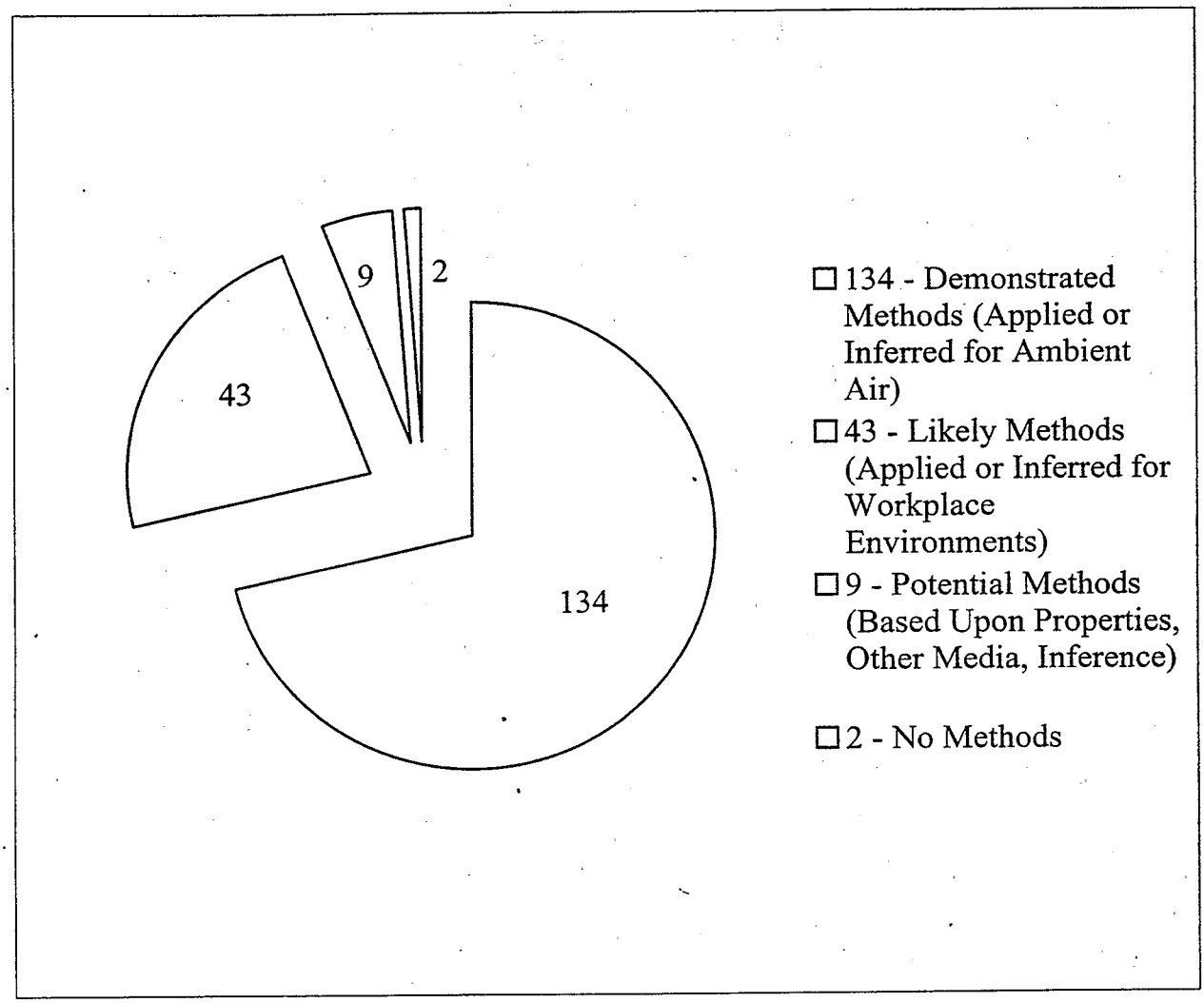

Figure 1. Distribution of the 188 HAPs by the most developed type of ambient measurement method currently available for each compound

optimistic picture of the state of HAPs measurement capabilities. However, the absence of ambient data from some *Applicable* methods, the reactivity of some HAPs, the variability of ambient sampling conditions, and the complexity of air composition that can be encountered in ambient measurements suggest that for many methods further testing is needed. The 84 research methods identified here, which have generally been applied only to a limited extent by a small number of investigators, are particularly appropriate candidates for further evaluation.

The 11 HAPs for which only *Potential* methods or no methods were found would seem to indicate the greatest current need for ambient method development. Those 11 compounds are identified in Table 2, which also indicates their respective volatility classes. These 11 HAPs are relatively unusual compounds, not normally regarded as ambient air contaminants, and some are highly reactive and not likely to be present for long in the atmosphere.[7,15,16] There are no ambient air concentration data for these 11 HAPs,[5-7] and virtually no information on potential atmospheric reaction products,[15,16] so it is difficult to determine whether they or their reaction products cause a significant health risk in ambient air. Method development should be pursued for these 11 HAPs. However, because of the very inadequate state of current methods, such method development should be prioritized based on information on the emissions, reactivity, and products of these HAPs. This approach will avoid spending time and resources on method development for a HAP or HAPs that are, for example, too reactive (e.g., titanium tetrachloride) or emitted in quantities too small to be present at measurable levels in the atmosphere. This linkage of method development with other information should be valuable for all HAPs, but especially so for the 11 HAPs shown in Table 1.

Table 2. Identification Of The HAPs For Which Ambient Methods Are Least Developed

Likely Methods Identified (43)

Acrylamide
Acrylic acid
4-Aminobiphenyl
o-Anisidine
Benzidine
Calcium cyanamide
Chloroacetic acid
2-Chloroacetophenone
Chloromethyl methyl ether
Diazomethane
3,3'-Dichlorobenzidine
Diethanolamine
3,3'-Dimethoxybenzidine
4-Dimethylaminoazobenzene
N,N-Dimethylaniline
3,3'-Dimethylbenzidine
Dimethylcarbamoyl chloride
Dimethyl phthalate
2,4-Dinitrotoluene
Epichlorohydrin (1-Chloro-2,3-epoxypropane)
1,2-Epoxybutane
Ethylene glycol
Ethyleneimine
Ethylene thiourea
Hexamethylene diisocyanate
Hydrazine
Hydroquinone
Methylhydrazine
Methyl isocyanate
4,4'-Methylenebis-(2-chloroaniline)
4,4'-Methylenediphenyl diisocyanate
4,4'-Methylenedianiline
p-Phenylenediamine
Phosphorus
Phthalic anhydride
1,3-Propane sultone
Quinone (p-Benzoquinone)
Toluene-2,4-diamine
2,4-Toluene diisocyanate
o-Toluidine
Triethylamine
Cyanide Compounds
Fine Mineral Fibers

Potential Methods Identified (9)

Acetamide
Acetophenone
2-Acetylaminofluorene
Benzotrichloride
Chloramben
1,2-Diphenylhydrazine
Hexamethylphosphoramide
N-Nitroso-N-methylurea
1,2-Propylenimine (2-Methylaziridine)

No Methods Identified (2)

Ethyl carbamate (urethane)
Titanium tetrachloride

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Appendices

Appendix A
Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class ^	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
Acetaldehyde	75-07-0	VVOC	TO-11A	R-4 [14] OSHA 68 NIOSH 2538 NIOSH 2539 NIOSH 3507		TO-11A: 1 ppbv [14]: 30 ppmv [2538]: 2 µg/sample [3507]: 0.1 mg/sample [68]: 580 ppb (1050 $\mu g/m^3$)	
Acetamide	60-35-5	SVOC			OSHA A625 R-37 R-47		R-47: method developed for analysis of water
Acetonitrile	75-05-8	VOC	TO-15 TO-17 R-1 R-3	NIOSH 1606		TO-17: ≤0.5 ppb R-1: 1 ppbv [1606]: 0.8 µg/sample	
Acetophenone	98-86-2	VOC			OSHA A169		
2-Acetylaminofluorene	53-96-3	NVOC			OSHA 0065		
Acrolein	107-02-8	VOC	TO-11A	OSHA 52 NIOSH 2501 NIOSH 2539		TO-11A: 1 ppbv [2501]: 2 µg/sample [52]: 2.7 ppb (6.1 $\mu g/m^3$)	
Acrylamide	79-06-1	VOC		OSHA 21	OSHA 0115	[21]: 1.3 ppbv	
Acrylic acid	79-10-7	VOC		OSHA 28	OSHA 0117	[28]: 42 $\mu g/m^3$ (14 ppbv)	
Acrylonitrile	107-13-1	VOC	TO-15 TO-17 R-1 R-3	OSHA 37 NIOSH 1604 R-4 [14]		R-1: 1 ppbv TO-17: ≤0.5 ppb [1604]: 1 µg/sample [37]: 0.026 mg/m^3 (0.1 ppm)	
Allyl chloride	107-05-1	VOC	TO-14A TO-15 R-3	NIOSH 1000		TO-14A: 0.1 ppbv 0.01 mg/sample	
4-Aminobiphenyl	92-67-1	SVOC		OSHA 93 R-36	R-37	R-36: 0.1 ng/m^3 [93]: 1 ppt (6.9 ng /m^3)	R-36: evaluated for particulate phase only
Aniline	62-53-3	VOC	TO-15 TO-17	NIOSH 2002 NIOSH 2017	OSHA 0220	TO-17: ≤0.5 ppb [2002]: 0.01 mg/sample	
o-Anisidine	90-04-0	SVOC		NIOSH 2514	OSHA 0225	[2514]: 0.35 µg/sample [0225]: 0.06 mg/m^3	[2514]: working range = 0.06 - 0.8 mg/m^3 (200L sample volume)

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class [A]	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
Asbestos	1332-21-4	NVINC	R-21	NIOSH 7400 NIOSH 7402 NIOSH 9000 NIOSH 9002 OSHA ID160 R-63		R-21: < 0.1 ng/m^3 (i.e., < 0.01 fibers/cc) [7400]: 7 fibers/mm^2 filter area [9002]: < 1% asbestos [ID160]: 5.5 fibers/mm^2	[7400] & [7402]: working range= 0.04 - 0.5 fiber/cc (1000-L sample volume)
Benzene	71-43-2	VOC	TO-14A TO-15 TO-17 R-1 R-3 R-6	OSHA 12 NIOSH 1500 NIOSH 1501 NIOSH 3700 NIOSH 2549		TO-14A: 0.1 ppbv TO-17: ≤0.5 ppb [1500]: 0.001 to 0.01 mg/sample with capillary column [3700]: 0.01 ppm for 1-ml injection [1501]: 0.001 to 0.01 mg/sample with capillary column	
Benzidine	92-87-5	SVOC		OSHA 65 NIOSH 5509 R-36	R-37	R-36: 1 ng/m^3 [5509]: 0.05 µg/sample [65]: 31 ng/m^3	R-36: Evaluated for particulate phase only
Benzotrichloride	98-07-7	SVOC			OSHA B408		
Benzyl chloride	100-44-7	VOC	TO-14A TO-15 R-3	NIOSH 1003		TO-14A: 0.1 ppbv [1003]: 0.01 mg/sample	
Biphenyl	92-52-4	SVOC	R-50 R-51	NIOSH 2530	OSHA 1011	R-50: 14 - 16 ng/m^3 [2530]: 0.09 µg/sample	[2530]: working range = 0.13 - 4 mg/m^3 (30-L sample volume) R-50: LOD is range of ambient data.
Bis (2-ethyl hexyl)phthalate (DEHP)	117-81-7	SVOC	R-28 R-57		OSHA 1015	R-28: 0.77 - 3.60 ng/m^3	R-28: LOD shown is range of reported ambient data
Bis (chloromethyl) ether	542-88-1	VOC	TO-15	OSHA 10		[10]: 1 μg/m^3	
Bromoform	75-25-2	VOC	TO-15	NIOSH 1003	OSHA 0400	[1003]: 0.01 mg/sample	
1,3-Butadiene	106-99-0	VVOC	TO-15 R-1 R-3	OSHA 56 NIOSH 1024 TO-14A		R-1: 1 ppbv [1024]: 0.2 µg/sample [56]: 90 ppb (200 μg/m^3)	[1024]: working range = 0.02 - 8.4 ppmv (25-L sample volume)

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class ^	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
Calcium cyanamide	156-62-7	Particulate		R-32	OSHA 0510	R-32: 0.08 mg/m³	R-32: recommended range in air = 0.24 mg/m³ (240-L sample volume)
Captan	133-06-2	SVOC	TO-10A R-27		OSHA 0529	TO-10A: 0.01 - 50 μg/m³ R-27: 1.6 - 14 ng/m³ [0529]: 6 ng/injection	
Carbaryl	63-25-2	SVOC	R-27	OSHA 63 NIOSH 5006		[63]: 0.028 mg/m³ R-27: 8 - 42 ng/m³ [5006]: 0.03 mg/sample	[5006]: working range = 0.5 - 20 mg/m³ (200-L sample volume) [63]: sample volume = 60 L
Carbon disulfide	75-15-0	VOC	TO-15 R-11	NIOSH 1600 R-4 [14]		R-11: 0.02 ppbv [14]: 20 ppmv [1600]: 0.02 mg/sample	LOD of R-11 estimated; range of ambient data 0.025 - 0.34 ppbv
Carbon tetrachloride	56-23-5	VOC	TO-14A TO-15 TO-17 R-3 R-6	NIOSH 1003		TO-14A: 0.1 ppbv TO-17: ≤0.5 ppb [1003]: 0.01 mg/sample	
Carbonyl sulfide	463-58-1	VVOC	R-10	R-4 [14]	OSHA R220	R-10: 0.03 ppbv [14]: 1 ppmv	LOD for R-10 estimated based on calibration data; range of ambient data 0.4 - 0.7 ppbv
Catechol	120-80-9	VOC	TO-8	R-2 R-25	OSHA 0571	TO-8: 1-5 ppbv	R-2 indicated by analogy with phenol based on similar properties R-2: 0.02 ppbv (estimated) R-25: 1 ppbv (estimated)
Chloramben	133-90-4	SVOC			R-27		R-27 indicated based on applicability of method for other pesticides
Chlordane	57-74-9	SVOC	TO-10A R-27 R-28 R-29 R-30 R-31	OSHA 67 NIOSH 5510		TO-10A: 0.01-50 μg/m³ R-27: 4 - 50 ng/m³ R-29: < 5 pg/m³ [5510]: 0.1 μg/sample [67]: 0.064 μg/m³	
Chlorine	7782-50-5	VVINC	R-4 [805]	OSHA ID101 NIOSH 6011		[ID101]: 14 ppbv	[805]: LOD not established [6011]: working range = 7 - 500 ppbv (90-L sample volume) [ID101]: sample volume = 15 L

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class [A]	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
Chloroacetic acid	79-11-8	VOC		R-42 NIOSH 2008		R-42: 0.2 mg/m^3 (51 ppbv) [2008]: 0.04 µg/sample	
2-Chloroacetophenone	532-27-4	SVOC		NIOSH II [291]	OSHA 0618	[291]: 0.18 - 0.62 mg/m^3	[291]: sample volume = 12 L (measurement range shown as LOD)
Chlorobenzene	108-90-7	VOC	TO-14A TO-15 TO-17 R-3	NIOSH 1003		TO-14A: 0.1 ppbv TO-17: ≤0.5 ppb [1003]: 0.01 mg/sample	
Chlorobenzilate	510-15-6	SVOC	TO-10A	R-46	OSHA 1113 R-27	TO-10A: 0.01-50 µg/m^3	R-46: No LODs or air concentrations reported (workplace exposure measurements)
Chloroform	67-66-3	VOC	TO-14A TO-15 R-6	OSHA 5 NIOSH 1003		TO-14A: 0.1 ppbv [1003]: 0.01 mg/sample [5]: 0.11 ppm	
Chloromethyl methyl ether	107-30-2	VOC		OSHA 10 NIOSH 220 R-56		[220]: 0.5 ppbv R-56: 1 ppbv [10]: 0.8 µg/m^3	[220]: sample volume = 10 L (measurement range shown as LOD)
Chloroprene	126-99-8	VOC	TO-15 R-7	OSHA 112 NIOSH 1002		R-7: 0.06 ppbv [1002]: 0.03 mg/sample [112]: 22 ppb (80 µg/m^3)	
Cresol/Cresylic acid (mixed isomers)	1319-77-3	VOC	TO-8	OSHA 32 NIOSH 2549 NIOSH 2546 R-60	OSHA 0760	TO-8: 1-5 ppbv [2546]: 1 to 3 µg/sample [32]: 0.046 mg/m^3 (0.01 ppm) [0760]: 14 ng/sample	
o-Cresol	95-48-7	VOC	TO-8	OSHA 32 NIOSH 2549 NIOSH 2546 R-2 R-25 R-60	OSHA 0760 R-59	TO-8: 1-5 ppbv [2546]: 1 to 3 µg/sample [32]: 0.046 mg/m^3 (0.01 ppm) [0760]: 14 ng/sample	R-2: 0.02 ppbv (estimated)

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class [A]	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
m-Cresol	108-39-4	SVOC	TO-8	OSHA 32 NIOSH 2549 NIOSH 2546 R-2 R-3 R-60	OSHA 0760 R-59	TO-8: 4.5 - 22.5 $\mu g/m^3$ R-2: 4.5 $\mu g/m^3$ R-3: 0.09 $\mu g/m^3$ [2546]: 1 to 3 μg/sample [32]: 0.046 mg/m^3 (0.01 ppm) [0760]: 14 ng/sample	
p-Cresol	106-44-5	SVOC	TO-8	OSHA 32 NIOSH 2549 NIOSH 2546 R-2 R-3 R-59 R-60	OSHA 0760	TO-8: 4.5 - 22.5 $\mu g/m^3$ R-2: 4.5 $\mu g/m^3$ R-3: 0.09 $\mu g/m^3$ [2546]: 1 to 3 μg/sample [32]: 0.046 mg/m^3 (0.01 ppm) [0760]: 14 ng/sample	
Cumene	98-82-8	VOC	TO-15 TO-14A R-6	NIOSH 1501		TO-14A: 0.1 ppbv [1501]: 0.001 to 0.01 mg/sample with capillary column	
2,4-D (2,4-Dichloro phenoxyacetic acid) (incl. salts and esters)		SVOC	TO-10A R-27	NIOSH 5001	R-38	TO-10A: 0.01 - 50 $\mu g/m^3$ R-27: < 0.8 ng/m^3 [5001]: 0.015 mg/filter	T-10A only for esters; 2,4-acid and salts would require filter for particulate; see R-38 [5001]: working range = 1.5 - 20 mg/m^3 (100-L sample volume) R-27: esters only
DDE (1,1-dichloro-2,2-bis(p-chloro phenyl)ethylene)	72-55-9	SVOC	TO-10A R-29 R-27 R-28			TO-10: 0.01- 50 ng/m^3 R-29: < 5 pg/m^3 R-27: 1.4 - 3.6 ng/m^3	
Diazomethane	334-88-3	VVOC		NIOSH 2515	OSHA 0861	[2515]: LOD not determined	[2515]: working range = 0.11 - 0.57 ppmv (10-L sample volume)
Dibenzofurans	132-64-9	SVOC	TO-9A R-50 R-5 R-51	R-4 [836]	OSHA D639	TO-9A: 1-5 pg/m^3 [836]: 3.3 ng/m^3 R-50: 13 - 26 ng/m^3 R-5: 0.02 pg/m^3 R-51: < 0.01 pg/m^3 [D639]: 2.3 ng/injection	[836]: sample volume = 1500 m^3, method is for total particulate aromatic hydrocarbons R-50: LOD is range of ambient data. Higher chlorinated species (e.g., octa-) are probably NVOC

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class [A]	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
1,2-Dibromo-3-chloropropane	96-12-8	VOC	TO-15 R-12	TO-14A	OSHA 0935	R-12: < 2 ng/m^3 (< 0.2 pptv) TO-14A: 0.1 ppbv	TO-14A, TO-15 indicated by analogy with VOC's having similar properties R-12: range of ambient data 2 - 21 ng/m^3
Dibutyl phthalate		SVOC	R-28 R-57	OSHA 104 NIOSH 5020		R-28: 0.48 - 3.6 ng/m^3 R-57: 5 - 370 ng/m^3 [5020]: 10 μg/sample [104]: 34 μg/m^3	R-28: LOD shown is range of reported ambient data R-57: LOD shown is range of ambient data for separate vapor and particulate measurements of various isomers.
1,4-Dichlorobenzene	106-46-7	VOC	TO-14A TO-15 R-3	NIOSH 1003		TO-14A: 0.1 ppbv [1003]: 0.01 mg/sample	
3,3'-Dichlorobenzidine	91-94-1	SVOC		NIOSH 5509 OSHA 65 R-36	R-37	[65]: 40 ng/m^3 R-36: 0.1 ng/m^3 [5509]: 0.05 µg/sample	[5509]: working range = 4 - 200 μg/m^3 (50-L sample volume) [65]: sample volume = 100 L R-36: evaluated for particulate phase only
Dichloroethyl ether (Bis[2-chloro ethyl]ether)	111-44-4	VOC	TO-15	NIOSH 1004		[1004]: 0.01 mg/sample	
1,3-Dichloropropene	542-75-6	VOC	TO-15 TO-14A R-3		OSHA D177	TO-14A: 0.1 ppbv	
Dichlorvos	62-73-7	SVOC	TO-10A R-27	OSHA 62	OSHA 0850	TO-10A: 0.01 - 50 μg/m^3 [62]: 1.9 μg/m^3 (0.21 ppb)	
Diethanolamine	111-42-2	SVOC		NIOSH 3509	OSHA D129	[3509]: 7 to 20 μg/sample [D129]: 1.6 μg/sample	[3509]: working range = 0.4 - 3 mg/m^3 (100-L sample volume)
Diethyl sulfate	64-67-5	VOC	TO-15	R-40 R-8	OSHA 0913	R-40: 8 pptv	R-40: not applied to ambient air analysis Indication of R-8 based on similarity of properties with dimethyl sulfate
3,3'-Dimethoxybenzidine	119-90-4	NVOC		R-36	OSHA 0873 R-37	R-36: 1 ng/m^3 [0873]: 5 ng/injection	R-36: Evaluated for particulate phase only

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class [A]	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
4-Dimethylaminoazo-benzene	60-11-7	NVOC		NIOSH 284	OSHA 0929	[284]: 4 - 2000 $\mu g/m^3$ [0929]: 6 ng/injection	[284]: sample volume = 50 L (measurement range shown as LOD)
N,N-Dimethylaniline	121-69-7	VOC		NIOSH 2002	OSHA 0931	[2002]: 0.01 mg/sample	[2002]: measurement range = 0.05 - 3.0 mg/sample (unknown sample volume)
3,3'-Dimethylbenzidine	119-93-7	SVOC		R-36	OSHA 2450 R-37	R-36: 1 ng/m^3 [2450]: 0.01 μg/sample	R-36: evaluated for particulate phase only
Dimethylcarbamoyl chloride	79-44-7	VOC		R-39		R-39: 0.05 ppbv	R-39: sample volume = 48 L
N,N-Dimethylformamide	68-12-2	VOC	R-9	OSHA 66 NIOSH 2004 R-4 [14]		R-9: 0.6 - 50 ppbv [2004]: 0.05 mg/sample [66]: 0.02 ppm (0.045 mg/m^3)	R-9: reports four separate methods
1,1-Dimethylhydrazine	57-14-7	VOC	TO-15	NIOSH 3515 R-22	OSHA 0940	R-22: 4 ppbv [3515]: 1 μg/sample	[S143]: working range = 0.04 - 4 ppmv (100-L sample volume) R-22: sample volume = 2 L
Dimethyl phthalate	131-11-3	SVOC		OSHA 104 R-26 R-28		R-26: 60 ng/m^3 [104]: 90 $\mu g/m^3$	R-28 suggested by analogy with di-n-butyl phthalate
Dimethyl sulfate	77-78-1	VOC	TO-15 R-8	NIOSH 2524	OSHA 0960	R-8: 0.05 ppbv [2524]: 0.25 μg/sample	LOD for R-8 estimated based on ranges of sampling durations, sampling rates, and analytical capabilities
4,6-Dinitro-o-cresol (including salts)	534-52-1	SVOC	TO-8		OSHA 0975 R-3	TO-8: 1-5 ppbv	R-3 suggested by analogy to other phenols
2,4-Dinitrophenol	51-28-5	SVOC	TO-8			TO-8: 1-5 ppbv	
2,4-Dinitrotoluene	121-14-2	SVOC		OSHA 44	OSHA 0990	[44]: 20 $\mu g/m^3$	
1,4-Dioxane (1,4-Diethyleneoxide)	123-91-1	VOC	TO-15	NIOSH 1602 R-4 [14]	OSHA 1010	[14]: 2 ppmv [1602]: 0.01 mg/sample	
1,2-Diphenylhydrazine	122-66-7	SVOC			R-22		Suggestion of R-22 based on chemical similarity to volatile hydrazines
Epichlorohydrin (1-Chloro-2,3-epoxypropane)	106-89-8	VOC		NIOSH 1010 R-4 [14]	OSHA 0645	[14]: 20 ppmv [1010]: 1.0 μg/sample	

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class [A]	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
1,2-Epoxybutane	106-88-7	VOC		NIOSH 1614 R-3	OSHA E225		R-3 and NIOSH methods indicated by similarity of properties with ethylene oxide
Ethyl acrylate	140-88-5	VOC	TO-15 TO-17 R-1 R-3	OSHA 92 NIOSH 1450		R-1: 0.2 ppbv TO-17: ≤0.5 ppb [1450]: 0.02 mg/sample [92]: 80 $\mu g/m^3$	
Ethylbenzene	100-41-4	VOC	TO-14A TO-15 TO-17 R-3 R-6	NIOSH 1501		TO-14A: 0.1 ppbv TO-17: ≤0.5 ppb [1501]: 0.001 to 0.01 mg/sample with capillary column	
Ethyl carbamate (urethane)	51-79-6	VOC					
Ethyl chloride	75-00-3	VVOC	TO-14A TO-15 R-3	NIOSH 2519 R-4 [14]	OSHA 1110	TO-14A: 0.1 ppbv [14]: 10 ppmv [2519]: 0.01 mg/sample	
Ethylene dibromide	106-93-4	VOC	TO-14A TO-15	OSHA 2 NIOSH 1008		TO-14A: 0.1 ppbv [1008]: 0.01 μg/sample [2]: 0.005 mg/m^3	
Ethylene dichloride	107-06-2	VOC	TO-14A TO-15 R-3	OSHA 3 NIOSH 1003		TO-14A: 0.1 ppbv [1003]: 0.01 mg/sample [3]: 0.05 ppm	
Ethylene glycol	107-21-1	SVOC		NIOSH 5500 NIOSH 5523	OSHA 1911	[5523]: 7 μg/sample	[5500]: working range = 7 - 330 mg/m^3 (3-L sample volume)
Ethyleneimine	151-56-4	VOC		NIOSH 3514 R-4 [14]		[14]: 15 ppmv [3514]: 0.3 μg/sample	
Ethylene oxide	75-21-8	VVOC	TO-15 R-13	OSHA 30 OSHA 49 OSHA 50 NIOSH 1614 NIOSH 3702 R-3		R-13: 0.001 - 0.1 ppbv [1614]: 1 μg/sample [3702]: 2.5 pg per 1-ml injection [30]: 24.0 $\mu g/m^3$ (13.3 ppb) [49]: 1.3 $\mu g/m^3$	[1614]: working range = 0.04 - 4.5 ppmv (24-L sample volume) R-13 evaluated five different methods

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class [A]	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
Ethylene thiourea	96-45-7	SVOC		OSHA 95 NIOSH 5011		[5011]: 0.75 μg/sample [95]: 1.39 μg/m³	[5011]: working range = 0.05 - 75 mg/m³ (200-L sample volume)
Ethylidene dichloride	75-34-3	VOC	TO-14A TO-15 R-3	NIOSH 1003	OSHA 1160	TO-14A: 0.1 ppbv [1003]: 0.01 mg/sample	
Formaldehyde	50-00-0	VVOC	TO-11A	OSHA 52 NIOSH 2539 NIOSH 3500 NIOSH 5700 NIOSH 2541 NIOSH 2016		TO-11A: 1 ppbv [3500]: 0.5 μg/sample [5700]: 0.08 μg/sample [2541]: 1 μg/sample [2016]: 0.09 μg/sample [52]: 16 ppb (20 μg/m³)	
Heptachlor	76-44-8	SVOC	TO-10A R-29 R-30 R-27		OSHA 1369	TO-10A: 0.01 - 50 μg/m³ R-29: 0.04 - 0.1 pg/m³ R-30: 1 ng/m³ [1369]: 0.43 pg/injection	
Hexachlorobenzene	118-74-1	SVOC	TO-10A R-29 R-28		OSHA 1376	TO-10A: 0.01 - 50 μg/m³ R-29: 0.04 - 0.1 pg/m³	
Hexachlorobutadiene	87-68-3	VOC	TO-14A TO-15 R-3	NIOSH 2543	OSHA H109	TO-14A: 0.1 ppbv [2543]: 0.02 μg/sample	
1,2,3,4,5,6-Hexachlorocyclohexane (all stereo isomers, including Lindane)		SVOC	TO-10A R-28 R-29 R-27	NIOSH 5502 R-30		TO-10A: 0.01 - 50 μg/m³ (g-BHC) R-30: 1 ng/m³ R-29: < 5 pg/m³ [5502]: 3 μg/sample	
Hexachlorocyclopentadiene	77-47-4	SVOC	TO-10A	NIOSH 2518		TO-10A: 0.01-50 μg/m³ [2518]: 5 ng/sample	
Hexachloroethane	67-72-1	VOC	TO-15	NIOSH 1003 TO-14A TO-3 TO-15	OSHA 1372	[1003]: 0.01 mg/sample	TO-14A indicated by analogy with VOC's having similar properties

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class [A]	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
Hexamethylene diisocyanate	822-06-0	SVOC		OSHA 42 NIOSH 5522 NIOSH 5521 R-23	R-4 [837] R-62	[42]: 2.3 $\mu g/m^3$ R-23: 1 $\mu g/m^3$ [5522]: 0.2 μg/sample [5521]: 0.1 μg diisocyanate/sample	[42]: sample volume = 15 L
Hexamethylphosphoramide	680-31-9	SVOC			OSHA H129		
Hexane	110-54-3	VOC	TO-14A TO-15 TO-17 R-6	NIOSH 1500 NIOSH 2549		TO-14A: 0.1 ppbv TO-17: ≤0.5 ppb R-6: 0.03 ppbv [2549]:	TO-14A by analogy to other VOC's with similar properties on TO-14A list
Hydrazine	302-01-2	VINC		OSHA 108 OSHA 20 NIOSH 3503 R-22, R-84	R-55	[20]: 1.2 ppbv R-22: 4 ppbv [3503]: 0.9 μg/sample [108]: 0.076 $\mu g/m^3$	[3503]: working range = 0.07 - 3 ppmv (100-L sample volume) [20]: sample volume = 20 L R-22: sample volume = 2 L
Hydrochloric acid (Hydrogen chloride)	7647-01-0	VINC	R-19	NIOSH 7903 OSHA ID174SG		R-19: 0.22 ppbv	[7903]: working range = 0.0066 - 3.3 ppmv (50-L sample volume)
Hydrogen fluoride (Hydrofluoric acid)	7664-39-3	VVINC	R-20	R-4[809/205] NIOSH 7903 NIOSH 7902 NIOSH 7906		R-20: 0.08 ppbv [7902]: 3 μg F^-/sample [7906]: 3 μg F^-/sample (gas); 120 μg F^-/sample (particulate)	[7903]: working range = 0.012 - 6.02 ppmv (50-L sample volume)
Hydroquinone	123-31-9	SVOC		NIOSH 5004	OSHA 1490	[5004]: 0.01 mg/sample	[5004]: working range = 2 - 25 mg/m^3 (30-L sample volume)
Isophorone	78-59-1	VOC	TO-15	NIOSH 2508	OSHA 1538	[2508]: 0.02 mg/sample	[2508]: working range = 0.35 - 70 ppmv (12-L sample volume)
Maleic anhydride	108-31-6	SVOC	TO-17	OSHA 25 OSHA 86 NIOSH 3512		TO-17: ≤0.5 ppb [25]: 0.005 mg/m^3 [86]: 33 $\mu g/m^3$ [3512]: 15 μg/sample	[25]: sample volume = 20 L [86]: sample volume = 60 L
Methanol	67-56-1	VOC	TO-15 TO-17 R-1 R-3	NIOSH 2549 NIOSH 2000 R-64		R-1: 1 ppbv TO-17: ≤0.5 ppb [2000]: 0.7 μg/sample	

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class [A]	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
Methoxychlor	72-43-5	SVOC	TO-10A R-27 R-29		OSHA 1646	TO-10A: 0.01 - 50 $\mu g/m^3$ R-27: 1 - 8 ng/m^3 R-29: < 5 pg/m^3	
Methyl bromide (Bromomethane)	74-83-9	VVOC	TO-14A TO-15 R-3	NIOSH 2520	OSHA 1680	TO-14A: 0.1 ppbv [2520]: 0.01 mg/sample	
Methyl chloride (Chloromethane)	74-87-3	VVOC	TO-14A TO-15 R-3	NIOSH 1001		TO-14A: 0.1 ppbv [1001]: 0.01 mg/sample	
Methyl chloroform (1,1,1-Trichloroethane)	71-55-6	VOC	TO-14A TO-15 R-3 R-6	OSHA 14 NIOSH 2549		TO-14A: 0.1 ppbv [14]: 0.4 mg/m^3 (0.07 ppm)	
Methyl ethyl ketone (2-Butanone)	78-93-3	VOC	TO-11A TO-15 TO-17 R-1 R-3	OSHA 16 OSHA 84 NIOSH 2549 NIOSH 2500 R-58		R-1: 0.2 ppbv TO-17: ≤0.5 ppb TO-11A: 1 ppbv [2500]: 0.004 mg/sample [16]: 1.4 ppm (4.0 mg/m^3)	
Methylhydrazine	60-34-4	VOC		NIOSH S149 R-22, R-84	OSHA 1794 R-55	R-22: 4 ppbv	[S149]: working range = 0.018 - 0.55 ppmv (20-L sample volume) R-22: sample volume = 2 L
Methyl iodide (Iodomethane)	74-88-4	VVOC	TO-15	NIOSH 1014 TO-14A		[1014]: 0.01 mg/sample TO-14A: 0.1 ppbv	[1014]: working range = 1.7 - 16.9 ppmv (50-L sample volume)
Methyl isobutyl ketone (Hexone)	108-10-1	VOC	TO-15 TO-17 TO-11A	NIOSH 2549 NIOSH 1300 R-4 [14] R-1 R-58		[14]: 10 ppmv R-58: < 1ppbv TO-17: ≤0.5 ppb [1300]: 0.02 mg/sample TO-11A: 1 ppbv	[1300]: measurement range = 2.1 - 8.3 mg/sample (1 - 10-L sample volumes) R-1 suggested by similarity of properties with methyl ethyl ketone
Methyl isocyanate	624-83-9	VOC		OSHA 54	R-62	[54]: 1.9 ppbv (4.8 $\mu g/m^3$)	
Methyl methacrylate	80-62-6	VOC	TO-15 TO-17	OSHA 94 NIOSH 2537 R-4 [14] R-1 R-3		[14]: 1 ppmv TO-17: ≤0.5 ppb [2537]: 0.01 mg/sample [94]: 617 $\mu g/m^3$	R-1 and R-3 indicated by similarity of properties with ethyl acrylate

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class [A]	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
Methyl tert-butyl ether	1634-04-4	VOC	TO-15 TO-17 R-1 R-3	NIOSH 1615 R-64		R-1: 1 ppbv TO-17: ≤0.5 ppb [1615]: 0.02 mg/sample	
4,4'-Methylenebis-(2-chloroaniline)	101-14-4	NVOC		OSHA 24 OSHA 71		[24]: 3.6 $\mu g/m^3$ [71]: 440 ng/m^3	[24]: sample volume = 100 L
Methylene chloride (Dichloromethane)	75-09-2	VOC	TO-14A TO-15 TO-17 R-3	OSHA 59 OSHA 80 NIOSH 1005 NIOSH 2549		TO-14A: 0.1 ppbv TO-17: ≤0.5 ppb [1005]: 0.4 μg/sample [59]: 29 ppb [80]: 0.697 $\mu g/m^3$	
4,4'-Methylenediphenyl diisocyanate	101-68-8	SVOC		OSHA 18 OSHA 47 NIOSH 5522 R-23 R-4 [831]	R-62	[831]: 3 - 1040 $\mu g/m^3$ R-23: 1 $\mu g/m^3$ [5522]: 0.3 μg/sample [18]: 1 $\mu g/m^3$ (0.10 ppb) [47]: 0.8 $\mu g/m^3$	[831]: sample volume = 20 L
4,4'-Methylenedianiline	101-77-9	NVOC		OSHA 57 NIOSH 5029		[57]: 81 ng/m^3 [5029]: 0.12 -1.2 μg/sample	[57]: sample volume = 100 L [5029]: working range = 0.0002 - 10 mg/m^3 (100-L sample volume)
Naphthalene	91-20-3	SVOC	TO-13A R-7	OSHA 35 NIOSH 1501 NIOSH 5506		TO-13A: <100 pg/m^3 [1501]: 0.001 to 0.01 mg/sample with capillary column [35]: 0.4 mg/m^3 (0.08 ppm)	R-7: range of measured ambient concentrations = 5.5 - 182 ng/m^3 Volatility presents collection problems with PUF/XAD at high sample volume
Nitrobenzene	98-95-3	VOC	TO-15 TO-17	NIOSH 2005 NIOSH 2017 R-53	OSHA 1870	TO-17: ≤0.5 ppb	[2005]: working range = 0.59 - 2.34 ppmv (55-L sample volume) R-53 by analogy to nitrotoluenes
4-Nitrobiphenyl	92-93-3	SVOC	R-53	R-52	OSHA 1875	R-53: 0.01 ng/m^3	R-52 reports ambient data for 3-nitrobiphenyl
4-Nitrophenol	100-02-7	SVOC	TO-8 R-53	R-2 R-54	OSHA N607	TO-8: 1-5 ppbv R-53: 0.04 ng/m^3 [N607]: 0.003 mg/m^3	R-2 by analogy with 2- and 3-nitrophenol R-54 by analogy with 2-nitrophenol

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class [A]	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
2-Nitropropane	79-46-9	VOC	TO-15	OSHA 15 OSHA 46 NIOSH 2528 R-4 [14]		[14]: 10 ppmv [2528]: 1 μg/sample [46]: 91 μg/m^3 [15]: 0.98 mg/m^3	[2528]: working range = 1.4 - 27 ppmv (2-L sample volume)
N-Nitroso-N-methylurea	684-93-5	VOC			TO-7	TO-7: < 0.32 ppbv	Based on similarity of properties with N-nitroso-dimethylamine
N-Nitrosodimethylamine	62-75-9	VOC	TO-7	OSHA 27 NIOSH 2522		TO-7: < 0.32 ppbv [2522]: 0.05 μg/sample [27]: 0.13 μg/m^3	
N-Nitrosomorpholine	59-89-2	VOC	TO-7	OSHA 17 OSHA 27		TO-7: < 0.32 ppbv [27]: 0.20 μg/m^3 [17]: 0.6 μg/m^3	Based on similarity of properties with N-Nitroso-dimethylamine
Parathion	56-38-2	SVOC	TO-10A	OSHA 62 NIOSH 5600 R-4 [835]		TO-10A: 0.01-50 μg/m^3 [62]: 3.1 μg/m^3 (0.26 ppb)	
Pentachloronitrobenzene (Quintobenzene)	82-68-8	SVOC	TO-10A	R-48 R-49		TO-10A: 0.01-50 μg/m^3 R-48: 0.1 - 10 ng/m^3 R-49: 10.7 - 1560 ng/m^3	R-48 and R-49: measurement range shown as LOD
Pentachlorophenol	87-86-5	SVOC	TO-10A	OSHA 39 NIOSH 5512 R-50 R-61	R-3	TO-10A: 0.01 - 50 μg/m R-3: 0.2 μg/m^3 R-50: < 1 ng/m^3 [5512]: 8 μg/sample [39]: 0.007 mg/m^3	Use of TO-10A would require filter for particulate material
Phenol	108-95-2	VOC	TO-8 TO-17 R-2 R-54	OSHA 32 NIOSH 2549 NIOSH 2546 R-25 R-60	R-53	TO-8: 1-5 ppbv R-2: 0.02 ppbv R-54: 56 - 110 pptv TO-17: ≤0.5 ppb [2546]: 1 to 3 μg/sample [32]: 0.041 mg/m^3 (0.01 ppm)	R-54: LOD shown is range of ambient data.
p-Phenylenediamine	106-50-3	SVOC		OSHA 87		[87]: 0.44 μg/m^3	[87]: sample volume = 100 L)
Phosgene	75-44-5	VVOC	TO-15	OSHA 61, R-81		0.014 mg/m^3 (3.5 ppb)	

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class [A]	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
Phosphine	7803-51-2	VVINC	R-33	OSHA ID180 NIOSH 6002		R-33: 0.15 ppbv; [ID180]: 9 ppbv [6002]: 0.1 μg/sample [180]: 0.015 ppm for 36-L air sample	R-33: LOD derived from reference abstract [ID180]: sample volume = 36 L
Phosphorus	7723-14-0	SVINC		NIOSH 7300 NIOSH 7905 R-77		[7300]: 1 μg/sample [7905]: 0.005 μg/sample	[7300]: working range = 0.005 - 2 mg/m³ (500-L sample volume) [7905]: working range = 0.04 - 0.8 mg/m3 (12-L sample volume)
Phthalic anhydride	85-44-9	SVOC		NIOSH S179 OSHA 90	R-26 R-28 R-9	[S179]: 1 - 36 ng/m³ [90]: 0.048 mg/m³	[S179]: sample volume = 100 L (measurement range shown as LOD) [90]: sample volume = 75 L
Polychlorinated biphenyl (Aroclors)	1336-36-3	SVOC	TO-10A R-29 R-28	NIOSH 5503	OSHA C107	TO-10A: 0.01-50 μg/m³ R-29: 0.04 - 0.1 pg/m³ [5503]: 0.03 μg/sample	Note: Higher chlorinated species, up to decachloro, are probably NVOC
1,3-Propane sultone	1120-71-4	VOC		R-41			
beta-Propiolactone	57-57-8	VOC	TO-15	R-40	OSHA 2163	R-40: 1.2 pptv	R-40: not applied to ambient air analysis
Propionaldehyde	123-38-6	VOC	TO-11A	NIOSH 2539		TO-11A: 1 ppbv	
Propoxur (Baygon)	114-26-1	SVOC	TO-10A R-27		OSHA 0318	TO-10A: 0.01-50 μg/m³ [0318]: 1 ng/injection	R-27: LOD shown is range of reported ambient data
Propylene dichloride (1,2-Dichloropropane)	78-87-5	VOC	TO-14A TO-15 R-3	NIOSH 1013	OSHA 2190	TO-14A: 0.1 ppbv [1013]: 0.1 μg/sample	
Propylene oxide	75-56-9	VVOC	TO-15	OSHA 88 NIOSH 1612 R-1 R-3 R-13		R-1: 1 ppbv [1612]: 0.01 mg/sample [88]: 83 μg/m³	R-1,R-3, and R-13 indicated by similarity of properties with ethylene oxide
1,2-Propylenimine (2-Methylaziridine)	75-55-8	VOC			OSHA 2213		
Quinoline	91-22-5	SVOC	R-6	R-57		R-6: 0.78 - 1100 ng/m³	R-6: LOD is range of measured concentrations

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class [A]	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
Quinone (p-Benzoquinone)	106-51-4	SVOC		NIOSH S181	OSHA 2222 R-57	[S181]: 0.17 - 0.75 mg/m^3	[S181]: sample volume = 24 L measurement range shown as LOD)
Styrene	100-42-5	VOC	TO-14A TO-15 TO-17 R-3 R-6	OSHA 9 OSHA 89 NIOSH 1501		TO-14A: 0.1 ppbv TO-17: ≤0.5 ppb [1501]: 0.001 to 0.01 mg/sample with capillary column [9]: 0.47 mg/m^3 [89]: 426 μg/m^3	
Styrene oxide	96-09-3	VOC	TO-15	R-40	OSHA E230 R-3 NIOSH 1614	R-40: 0.41 pptv	R-40: not applied to ambient air analysis R-3, [1614]: Based on comparison of properties with ethylene oxide and 1,2-epoxybutane
2,3,7,8-Tetrachloro dibenzo-p-dioxin	1746-01-6	SVOC	TO-9A R-5 R-51		OSHA 2326	TO-9A: 1-5 pg/m^3 R-5: 0.02 pg/m^3 R-51: < 0.01 pg/m^3	
1,1,2,2-Tetrachloroethane	79-34-5	VOC	TO-14A TO-15 TO-17 R-3	NIOSH 1019	OSHA 2340	TO-14A: 0.1 ppbv TO-17: ≤0.5 ppb [1019]: 0.01 mg/sample	
Tetrachloroethylene (Perchloroethylene)	127-18-4	VOC	TO-14A TO-15 TO-17 R-3 R-6	NIOSH 1003		TO-14A: 0.1 ppbv TO-17: ≤0.5 ppb [1003]: 0.01 mg/sample	
Titanium tetrachloride	7550-45-0	VINC					Hydrolyzes extremely rapidly in the ambient atmosphere

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class [A]	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
Toluene	108-88-3	VOC	TO-14A TO-15 TO-17 R-1 R-3 R-6	OSHA 111 NIOSH 1500 NIOSH 1501 NIOSH 2549 NIOSH 4000		TO-14A: 0.1 ppbv R-1: 0.2 ppbv TO-17: ≤0.5 ppb [1501]: 0.001 to 0.01 mg/sample with capillary column [4000]: 0.01 mg/sample [111]: 68.3 $\mu g/m^3$ (charcoal tubes)	
Toluene-2,4-diamine	95-80-7	SVOC		OSHA 65 NIOSH 5516		[5516]: 0.1 μg/sample [65]: 58 $\mu g/m^3$	[5516]: working range = 3 - 30 $\mu g/m^3$ (100-L sample volume)
2,4-Toluene diisocyanate	584-84-9	SVOC		OSHA 18 OSHA 42 NIOSH 5521 NIOSH 2535 NIOSH 5522 R-4 [837] R-23 R-24	R-62	R-23: 1 $\mu g/m^3$ R-24: 7.24 $\mu g/m^3$ [837]: 0.05 - 1.01 mg/m^3 [5522]: 0.1 μg/sample [5521]: 0.1 μg diisocyanate/sample [2535]: 0.1 μg/sample [18]: 1 $\mu g/m^3$ (0.15 ppb)	[2535]: working range = 0.03 - 2.5 mg/m^3 (10-L sample volume) [837]: sample volume = 20 L
o-Toluidine	95-53-4	SVOC		OSHA 73 NIOSH 2017 NIOSH 2002		[73]: 0.97 $\mu g/m^3$	[2002]: working range = 5 - 60 mg/m^3 (55-L sample volume) [73]: sample volume = 100 L
Toxaphene (chlorinated camphene)	8001-35-2	SVOC	R-31 R-28	NIOSH S67	OSHA 0612	R-31: < 0.1 ng/m^3	[S67]: working range = 0.05 - 1.5 mg/m^3 (15-L sample volume) R-31: LOD estimated
1,2,4-Trichlorobenzene	120-82-1	VOC	TO-14A TO-15 R-3	NIOSH 5517		TO-14A: 0.1 ppbv [5517]: 0.001 μg/mL in hexane	
1,1,2-Trichloroethane	79-00-5	VOC	TO-14A TO-15 TO-17 R-3	OSHA 11 NIOSH 1003		TO-14A: 0.1 ppbv TO-17: ≤0.5 ppb [1003]: 0.01 mg/sample [11]: 0.14 mg/m^3	
Trichloroethylene	79-01-6	VOC	TO-14A TO-15 R-6	NIOSH 3701		TO-14A: 0.1 ppbv [3701]: 0.25 ng per 1-mL injection	

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class [A]	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
2,4,5-Trichlorophenol	95-95-4	SVOC	TO-10A R-50	R-54	R-3	TO-10A: 0.01 - 50 $\mu g/m^3$ R-50: 0.07 ng/m^3	Use of TO-10A would require filter for particulate-phase material R-54 reports sum of 2,4,5- and 2,4,6-isomers
2,4,6-Trichlorophenol	88-06-2	SVOC	TO-10A R-50	R-54	R-3	TO-10A: 0.01-50 $\mu g/m^3$ R-3: 0.2 $\mu g/m^3$ R-50: 0.07 ng/m^3	TO-10A by analogy with 2,4,5-TCP. Use of TO-10A would require filter for particulate material R-54 reports sum of 2,4,5- and 2,4,6-isomers
Triethylamine	121-44-8	VOC		NIOSH S152 R-9	OSHA 2480	[S152]: 2 - 71 ppbv	[S152]: sample volume = 100 L (measurement range shown as LOD) R-9 indicated by comparison of properties with dimethylformamide
Trifluralin	1582-09-8	SVOC	TO-10A R-29		OSHA T338	TO-10A: 0.01-50 $\mu g/m^3$ R-29: < 100 pg/m^3	
2,2,4-Trimethylpentane	540-84-1	VOC	TO-14A TO-15 R-6			TO-14A: 0.1 ppbv R-6: 0.025 ppbv	TO-14A and TO-15 indicated by analogy with other VOC's having similar properties, and based on canister stability data.
Vinyl acetate	108-05-4	VOC	TO-15 R-1 R-3	OSHA 51 NIOSH 1453		R-1: 1 ppbv [1453]: 1 μg/sample [51]: 0.04 mg/m^3	
Vinyl bromide	593-60-2	VVOC	TO-15	OSHA 8 NIOSH 1009 TO-14A		[1009]: 3 μg/sample [8]: 0.2 ppm	TO-14A indicated by analogy to other VVOC's with similar properties
Vinyl chloride	75-01-4	VVOC	TO-14A TO-15 R-3	OSHA 4 OSHA 75 NIOSH 1007		TO-14A: 0.1 ppbv [1007]: 0.04 μg/sample [4]: 0.25 ppm [75]: 0.051 mg/m^3	
Vinylidene chloride (1,1-Dichloroethylene)	75-35-4	VVOC	TO-14A TO-15 R-3	OSHA 19	NIOSH 1015	TO-14A: 0.1 ppbv [1015]: 7 μg/sample [19]: 0.2 mg/m^3	

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class [A]	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
Xylene (mixed isomers)	1330-20-7	VOC	TO-14A TO-15 TO-17 R-3	NIOSH 1501 NIOSH 2549		TO-14A: 0.1 ppbv TO-17: ≤0.5 ppb [1501]: 0.001 to 0.01 mg/sample with capillary column	
o-Xylene	95-47-6	VOC	TO-14A TO-15 TO-17 R-3 R-6	NIOSH 1501 NIOSH 2549		TO-14A: 0.1 ppbv TO-17: ≤0.5 ppb [1501]: 0.001 to 0.01 mg/sample with capillary column	
m-Xylene	108-38-3	VOC	TO-14A TO-15 TO-17 R-6	NIOSH 1501 NIOSH 2549		TO-14A: 0.1 ppbv TO-17: ≤0.5 ppb [1501]: 0.001 to 0.01 mg/sample with capillary column	
p-Xylene	106-42-3	VOC	TO-14A TO-15 TO-17 R-6	NIOSH 1501 NIOSH 2549		TO-14A: 0.1 ppbv TO-17: ≤0.5 ppb [1501]: 0.001 to 0.01 mg/sample with capillary column	
Antimony Compounds		NVINC	IO-3 R-4 [301]	OSHA ID125g R-4 [804 & 822B]		[301]: 0.05 $\mu g/m^3$ [804]: 4 $\mu g/m^3$ [822B][2]: 17.5 ng/m^3	[301]: sample volume = 20 m^3 [804]: sample volume = 60 L
Arsenic Compounds (Inorganic including arsine)		VVINC/ NVINC	IO-3 R-4 [302]	OSHA ID125g NIOSH 6001 NIOSH 7300 NIOSH 7900 NIOSH 7901 NIOSH 79300 R-34 R-4 [804 & 822B]		R-34: 1 ppbv [302]: 0.1 $\mu g/m^3$ [804]: 0.4 $\mu g/m^3$ [822B][2]: 10 ng/m^3 [7900]: 0.02 µg/sample [7901]: 0.06 µg/sample [6001]: 0.004 µg/sample	[6001]: working range = 0.3 - 62 ppbv (10-L sample volume) R-34: chemiluminescence methods [302]: sample volume = 10 m^3 [804]: sample volume = 60 L
Beryllium Compounds		NVINC	IO-3 R-4 [822]	OSHA ID125g NIOSH 7102 NIOSH 7300		[822]: 0.08 $\mu g/m^3$ [7102]: 0.004 µg/sample	[822]: sample volume = 0.24 m^3

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class [A]	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
Cadmium Compounds		NVINC	IO-3 R-4 [822]	OSHA ID125g NIOSH 7300 NIOSH 7048 R-4 [822B]		[822]: 0.03 $\mu g/m^3$ [822B][2]: 22.5 ng/m^3 [7048]: 0.05 µg/sample	[822]: sample volume = 0.24 m^3
Chromium Compounds		NVINC	IO-3 R-4 [822]	OSHA ID125g NIOSH 7024 NIOSH 7300 R-4 [822B]		[822]: 0.2 $\mu g/m^3$ [822B][2]: 25 ng/m^3 [7024]: 0.06 μg/sample	[822]: sample volume = 0.24 m^3
Cobalt Compounds		NVINC	IO-3 R-4 [822]	OSHA ID125g NIOSH 7300 NIOSH 7027 R-4 [822B]		[822]: 0.3 $\mu g/m^3$ [822B][2]: 12.5 ng/m^3 [7027]: 0.6 μg/sample	[822]: sample volume = 0.24 m^3
Coke Oven Emissions: represented by: Naphthalene and Coronene (see also VOCs, e.g., benzene, toluene, xylene)		SVOC/ NVOC	TO-13A R-7 R-14	OSHA 35 OSHA 58 NIOSH 1501 NIOSH 5506 R-4 [836]		TO-13A: <100 pg/m^3 R-14: 0.09 - 1.4 ng/m^3 [1501]: 0.001 to 0.01 mg/sample with capillary column	R-7: range of measured ambient concentrations = 5.5 - 182 ng/m^3 R-14: LOD shown is range of measured ambient concentrations
Cyanide Compounds: Hydrogen Cyanide and Particulate Cyanide		VVINC/ NVINC		NIOSH 6010 R-35 NIOSH 7904		[7904]: 2.5 μg CN^- [6010]: 1 μg CN^-	[6010]: working range = 0.893 - 232 ppmv (3-L sample volume) R-35: 1 pg quantitation limit [7904]: working range (as CN^-) = 0.5 - 15 mg/m^3 (sample volume = 90 L)
Glycol ethers		SVOC	TO-17	R-45		R-45: > 0.74 mg/m^3 TO-17: ≤0.5 ppb	See also ethylene glycol R-45: developed for 9 different glycol ethers, LOD calculated for ethylene glycol monobutyl ether
Lead Compounds		NVINC	IO-3 R-4 [822]	OSHA ID125g NIOSH 7700 NIOSH 7300 NIOSH 7105 NIOSH 7082 NIOSH 7702 NIOSH 7701 R-4 [822B]		[822]: 0.8 $\mu g/m^3$ [822B]: 10 ng/m^3 [7105]: 0.02 μg/sample [7082]: 2.6 μg/sample [7702]: 6 μg/sample Pb [7701]: 0.09 μg/sample	[822]: sample volume = 0.24 m^3

Table A-1. Results of the Survey of Ambient Air Measurement Methods for the 188 HAPs

Compound	CAS No.	Compd. Class [A]	Ambient Measurement Method			Limit of Detection	Comment
			Applicable	*Likely*	*Potential*		
Manganese Compounds		NVINC	IO-3 R-4 [822]	OSHA ID125g NIOSH 7300 R-4 [822B]		[822]: 0.1 $\mu g/m^3$ [822B]: 20 ng/m^3	[822]: sample volume = 0.24 m^3
Mercury Compounds		SVINC/ NVINC	IO-3 IO-5 R-4 [317] R-18	OSHA ID140 OSHA ID125g OSHA ID145 NIOSH 6009 R-4 [822B]		[317]: 0.002 - 0.06 ppbv R-18: 0.001 - 0.06 pptv [6009]: 0.03 μg/sample [ID145]: 0.002 mg/m^3 for 10-L air sample	
Fine Mineral Fibers		NVINC		NIOSH 7400 R-21		[7400]: 7 fibers/mm^2 filter area	[7400]: working range= 0.04 - 0.5 fiber/cc (1000-L sample volume)
Nickel Compounds		NVINC	IO-3 R-4 [822]	OSHA ID125g NIOSH 7300 R-4 [822B]		[822]: 0.3 $\mu g/m^3$ [822B]: 10 ng/m^3	[822]: sample volume = 0.24 m^3
Polycyclic Organic Matter: represented by Naphthalene and Coronene		SVOC/ NVOC	TO-13A R-7 R-14	OSHA 35 NIOSH 1501 NIOSH 5506 R-4 [836]		TO-13A: <100 pg/m^3 R-14: 0.09 - 1.4 ng/m^3 [1501]: 0.001 to 0.01 mg/sample with capillary column	R-7: range of measured ambient concentrations = 5.5 - 182 ng/m^3 R-14: LOD shown is range of measured ambient concentrations
Radionuclides (including radon)		VVINC/ NVINC/ VINC	R-4 [606, A/B] R-16 R-17	OSHA 2560	OSHA R100	[606B]: 0.1 pCi/L Varies depending on radionuclide	Long-lived radionuclides in air include: ^{222}Rn, ^{220}Rn, ^{131}I, ^{85}Kr, ^{3}H (gases); ^{210}Po, ^{210}Pb, ^{7}Be, ^{239}Pn, ^{238}Pn, ^{144}Ce, ^{137}Cs, ^{90}Sr (particles)
Selenium Compounds		NVINC	IO-3	OSHA ID125g NIOSH 7300 R-4 [804 & 822B]		[804]: 0.4 $\mu g/m^3$; [822B][2]: 10 ng/m^3	[804]: sample volume= 60 L

A. Compound class description is provided in the text (Table 1, page 6).

References for Measurement Methods Listed in Table A-1

TO-1	Method for the Determination of Volatile Organic Compounds in Ambient Air Using Tenax Adsorption and Gas Chromatography/Mass Spectrometry (GC/MS), Revision 1.0	4/84
TO-2	Method for the Determination of Volatile Organic Compounds in Ambient Air by Carbon Molecular Sieve Adsorption and Gas Chromatography/Mass Spectrometry (GC/MS)	4/84
TO-3	Method for the Determination of Volatile Organic Compounds in Ambient Air Using Cryogenic Preconcentration Techniques and Gas Chromatography with Flame Ionization	4/84
TO-4A	Determination of Pesticides and Polychlorinated Biphenyls in Ambient Air Using High Volume Polyurethane Foam (PUF) Sampling Followed by Gas Chromatographic/Multi-Detector Detection (GC/MD), Second Edition	1/97
TO-5	Method for the Determination of Aldehydes and Ketones in Ambient Air Using High Performance Liquid Chromatography (HPLC), Revision 1.0	4/84
TO-6	Method for the Determination of Phosgene in Ambient Air Using High Performance Liquid Chromatography (HPLC), Revision 1.0	9/86
TO-7	Method for the Determination of N-Nitrosodimethylamine in Ambient Air Using Gas Chromatography, Revision 1.0	9/86
TO-8	Method for the Determination of Phenol and Methylphenols (Cresols) in Ambient Air Using High Performance Liquid Chromatography, Revision 1.0	9/86
TO-9A	Determination of Polychlorinated, Polybrominated And Brominated/Chlorinated Dibenzo-p-Dioxins (TCDDs) and Dibenzofurans In Ambient Air, Second Edition	1/97
TO-10A	Determination of Pesticides and Polychlorinated Biphenyls In Ambient Air Using Low Volume Polyurethane Foam (PUF) Sampling Followed By Gas Chromatographic/Multi-Detector Detection (GC/MD), Second Edition	1/97
TO-11A	Determination of Formaldehyde in Ambient Air Using Adsorbent Cartridge Followed by High Performance Liquid Chromatography (HPLC), Active Sampling Methodology, Second Edition	1/97
TO-12	Method for the Determination of Non-Methane Organic Compounds (NMOC) in Ambient Air Using Cryogenic Preconcentration and Direct Flame Ionization Detection (PDFID)	
TO-13A	Determination of Polycyclic Aromatic Hydrocarbons (PAHs) in Ambient Air Using Gas Chromatography/Mass Spectrometry (GC/MS), Second Edition	1/97
TO-14A	Determination of Volatile Organic Compounds (VOCs) in Ambient Air Using Specially Prepared Canisters With Subsequent Analysis By Gas Chromatography, Second Edition	1/97
TO-15	Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially Prepared Canisters And Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS), Second Edition	1/97
TO-16	Long-Path Open-Path Fourier Transform Infrared Monitoring Of Atmospheric Gases, Second Edition	1/97
TO-17	Determination of Volatile Organic Compounds in Ambient Air Using Active Sampling Onto Sorbent Tubes, Second Edition	1/97
OSHA ID180	Ion Chromatography using glass tube containing potassium hydroxide-coated carbon for Phosphine in Workplace Atmospheres	6/91
OSHA ID160	Fiber counting by Phase Contract Microscopy (PCM) using mixed-cellulose ester filter for Asbestos in Air	7/97
OSHA ID145	Cold Vapor-Atomic Absorption Spectrophotometry using mercury-containing ester filter for Particulate Mercury in Workplace Atmospheres	12/89
OSHA ID140	Cold Vapor-Atomic Absorption Spectrophotometry using solid sorbent sampling device (Hydrar or hopcalite) for Mercury Vapor in Workplace Atmospheres	6/91
OSHA ID125G	Inductively Coupled Plasma- Atomic Emission Spectroscopy using mixed-cellulose ester membrane filter in styrene cassette for Metal and Metalloid Particulates in Workplace Atmospheres	4/91

References for Measurement Methods Listed in Table A-1

OSHA ID101	Ion Specific Electrode using a midget fritted glass bubbler containing sulfamic acid for Chlorine in Workplace Atmospheres	5/91
OSHA 95	HPLC- UV Detector using cassette containing two glass fiber filters for Ethylene Thiourea	8/92
OSHA 94	Gas Chromatography- Flame Ionization Detector using glass sampling tubes containing 4-tert-butylcatechol-coated charcoal for Methyl Methacrylate	6/92
OSHA 93	Gas Chromatography- Electron Capture Detector using sampling device consisting of cassettes each containing two sulfuric acid-treated glass fiber filters for 4-Aminobiphenyl	1/92
OSHA 92	Gas Chromatography- Flame Ionization Detector using glass sampling tubes containing 4-tert-butylcatechol-coated charcoal for Ethyl Acrylate and Methyl Acrylate	12/91
OSHA 90	HPLC- UV Detector using sampling device containing two coated glass fiber filters for Phthalic Anhydride	10/91
OSHA 9	Gas Chromatography- Flame Ionization Detector using sorbent tubes (charcoal) for Styrene; Superceded by Method No. 89	2/80
OSHA 89	Gas Chromatography- Flame Ionization Detector using glass sampling tubes containing coated charcoal for Divinylbenzene, Ethylvinylbenzene, and Styrene	7/91
OSHA 88	Gas Chromatography- Flame Ionization Detector using Anasorb 747 sorbent tubes for Propylene Oxide	6/91
OSHA 87	HPLC- UV Detector using cassettes each containing sulfuric acid-treated glass fiber filters for m-, o-, and p-Phenylenediamine	2/91
OSHA 86	HPLC- UV Detector using coated glass fiber filters for Maleic Anhydride	12/90
OSHA 84	Gas Chromatography- Flame Ionization Detector using glass sampling tubes containing Carbosieve S-III adsorbent for 2-Butanone	7/90
OSHA 80	Gas Chromatography- Flame Ionization Detector using glass sampling tubes containing Carbosieve S-III adsorbent for Methylene Chloride	2/90
OSHA 8	Gas Chromatography- Flame Ionization Detector using sorbent tube (charcoal) for Vinyl Bromide	5/79
OSHA 75	Gas Chromatography- Flame Ionization Detector using glass sampling tubes containing Carbosieve S-III adsorbent for Vinyl Chloride	4/89
OSHA 73	Gas Chromatography- Electron Capture Detector using cassettes each containing two sulfuric acid-treated glass fiber filters for o-, m-, p-Toluidene	8/88
OSHA 71	Gas Chromatography Electron Capture Detector using cassettes each containing two sulfuric acid-treated glass fiber filters for 4,4'-Methylenebis(o-Chloroaniline)	7/89
OSHA 68	Gas Chromatography-Nitrogen Selective Detector using sorbent tubes (XAD-2) for Acetaldehyde	1/88
OSHA 67	Gas Chromatography- Electron Capture Detector using OSHA versatile sampler (OVS-2) tubes containing glass fiber filter and XAD-2 for Chlordane	12/87
OSHA 66	Gas Chromatography- Nitrogen/Phosphorous Detector using sorbent tubes (charcoal) for N,N-Dimethylformamide	8/87
OSHA 65	Gas Chromatography- Electron Capture Detector using sampling device consisting of cassettes each containing two sulfuric acid-treated glass fiber filters for Benzidine, 3,3'-Dichlorobenzidine, 2,4-Toluenediamine, and 2,6-Toluenediamine	7/89
OSHA 63	HPLC- UV Detector using OSHA versatile sampler (OVS-2) tubes containing glass fiber filter and XAD-2 for Carbaryl	3/87
OSHA 62	Gas Chromatography- Flame Photometric Detector (FPD) using glass sampling tubes each containing glass fiber filter and two sections of XAD-2 adsorbent for Chlorpyrifos, DDVP (Dichlorvos), Diazinon, Malathion, and Parathion	10/86
OSHA 61	Gas Chromatography- Nitrogen Selective Detector using coated XAD-2 sorbent tubes for Phosgene	8/86

References for Measurement Methods Listed in Table A-1

OSHA 59	Gas Chromatography- Flame Ionization Detector using special sorbent tubes (charcoal) for Methylene Chloride; Superceded by Method No. 80 when a standard size adsorbent tube is desired	4/86
OSHA 57	Gas Chromatography- Electron Capture Detector using sulfuric acid-treated glass fiber filters for 4,4'-Methylenedianiline (MDA)	7/89
OSHA 56	Gas Chromatography- Flame Ionization Detector using sorbent tubes (charcoal) for 1,3-Butadiene	12/85
OSHA 54	HPLC- UV or Fluorescence Detector using XAD-7 tubes coated with 1-2PP for Methyl Isocyanate (MIC)	4/85
OSHA 52	Gas Chromatography- Nitrogen Selective Detector using sorbent tubes (XAD-2) for Acrolein and Formaldehyde	6/89
OSHA 51	Gas Chromatography- Flame Ionization Detector using Ambersorb XE-347 sampling tubes for Vinyl Acetate	3/85
OSHA 50	Gas Chromatography- Electron Capture Detector using hydrobromic acid-coated charcoal tubes for Ethylene Oxide	1/85
OSHA 5	Gas Chromatography- Flame Ionization Detector using sorbent tube (charcoal) for Chloroform	5/79
OSHA 49	Gas Chromatography- Electron Capture Detector using 3M Ethylene Oxide Monitors (passive monitor) for Ethylene Oxide	11/84
OSHA 47	HPLC- UV or Fluorescence Detector using (1-2PP)-coated glass fiber filter for Methylene Bisphenyl Isocyanate (MDI)	3/89
OSHA 46	Gas Chromatography- Flame Ionization Detector using XAD-4 sampling tubes for 1-Nitropropane and 2-Nitropropane	1/84
OSHA 44	Gas Chromatography using a Thermal Energy Analyzer (TEA) equipped with an explosives analysis package (EAP) using a modified commercial Tenax resin tubes for 2,4-Dinitrotoluene	10/83
OSHA 42	HPLC- UV or Fluorescence Detector using glass fiber filters coated with 1-2PP in open-face cassettes for Diisocyanates: 1,6-Hexamethylrene Diisocyanate (HDI), Toluene-2,6-Diisocyanate (2,6-TDI), and Toluene-2,4-Diisocyanate (2,4-TDI)	3/89
OSHA 4	Gas Chromatography- Flame Ionization Detector using sorbent tube (charcoal) for Vinyl Chloride; Superceded by Method No. 75	4/79
OSHA 39	HPLC- UV Detector using XAD-7 sorbent tubes in series for Pentachlorophenol	10/82
OSHA 37	Gas Chromatography- Nitrogen/Phosphorous Detector using sorbent tubes (charcoal) for Acrylonitrile	5/82
OSHA 35	Gas Chromatography- Flame Ionization Detector using Chromosorb 106 tubes for Naphthalene	4/82
OSHA 32	HPLC- UV Detector using XAD-7 sampling tube for Phenol and Cresol	11/81
OSHA 30	Gas Chromatography- Electron Capture Detector using two charcoal tubes in a series for Ethylene Oxide; Superceded by Method No. 50	8/81
OSHA 3	Gas Chromatography- Electron Capture Detector using sorbent tube (charcoal) for Ethylene Dichloride	4/79
OSHA 28	HPLC- UV Detector using two XAD-2 sampling tubes in a series for Acrylic Acid	4/81
OSHA 27	Gas Chromatography- Thermal Energy Analyzer Detector using ThermoSorb/N air samplers for Volatile Nitrosamine: N-Nitrosodimethylamine (NDMA), N-Nitrosodiethylamine (NDEA), N-Nitrosodi-n-Propylamine (NDPA), N-Nitrosodi-n-butylamine (NDBA), N-Nitrosopiperidine (NPIP), N-Nitrosopyrrolidine (NPYR), and N-Notrosomorpholine (NMOR)	2/81
OSHA 25	Reverse phase HPLC- UV Detector using sorbent tubes (XAD-2) in a series for Maleic Anhydride; Superceded by Method No. 86	2/81
OSHA 24	HPLC- UV Detector using HCl bubbler for 4,4'-Methylenebis(o-Chloroaniline); Superceded by Method No. 71	2/81

References for Measurement Methods Listed in Table A-1

OSHA 21	Gas Chromatography- Nitrogen/Phosphorous Detector using glass fiber filter followed by silica gel tube for Acrylamide	10/80
OSHA 20	HPLC using sulfuric acid coated Gas Chrom R for Hydrazine	9/80
OSHA 2	Gas Chromatography- Electron Capture Detector using sorbent tube (charcoal) for Ethylene Dibromide	11/81
OSHA 19	Gas Chromatography- Flame Ionization Detector using sorbent tube (charcoal) for Vinylidene Chloride (1,1-Dichloroethene)	4/80
OSHA 18	HPLC using collection in a bubbler containing nitro reagent in toluene for Diisocyanates; Superceded by Method No. 47	2/80
OSHA 17	Gas Chromatography- Chemiluminescence Detector using two sampling tubes in series for N-Nitrosomorpholine; Superceded by Method No. 27	1/80
OSHA 16	Gas Chromatography- Flame Ionization Detector using collection tubes (silica gel) for 2-Butanone (Methyl Ethyl Ketone); Superceded by Method No. 84	1/80
OSHA 15	Gas Chromatography- Flame Ionization Detector using Chromosorb 106 tubes for 2-Nitropropane; Superceded by Method No. 46	1/80
OSHA 14	Gas Chromatography- Flame Ionization Detector using sorbent tube (charcoal) for 1,1,1-Trichloroethane	1/80
OSHA 12	Gas Chromatography using sorbent tubes (charcoal) desorbed with carbon disulfide for Benzene	8/80
OSHA 112	Gas Chromatography- ECD using sampling tubes (Chromasorb) for β-Chloroprene	
OSHA 111	Gas Chromatography- Flame Ionization Detector using sorbent tubes (charcoal or Anasorb 747) for Toluene	4/98
OSHA 11	Gas Chromatography- Flame Ionization Detector using sorbent tube (charcoal) for 1,1,2-Trichloroethane	2/80
OSHA 108	LC- UV Detector using cassettes each containing two sulfuric acid-treated glass fiber filters for Hydrazine	2/97
OSHA 104	Gas Chromatography- Flame Ionization Detector using OVS-Tenax sampling tubes for Dimethylphthalate, Diethylphthalate, Dibutylphthalate, Di-2-Ethyl Hexylphthalate, and Di-n-Octylphthalate	8/94
OSHA 10	Gas Chromatography- Electron Capture Detector using derivatizing reagent bubblers connected in a series for Bis-Chloromethyl Ether and Chloromethyl Methyl Ether	8/79
OSHA T338	Partially Validated Method- HPLC/UL56 using OSHA Versatile sampler (OVS-2) - 13mm XAD-2 tube with glass fiber filter for Trifluralin	
OSHA R220	Gas Chromatography/FPD using graphatized carbon black for Carbonyl Sulfide- Not Validated	
OSHA R100	E-PERM Sampler; passive monitor for Radon	
OSHA N607	HPLC/UL53 using midget impinger containing NaOH for p-Nitrophenol- Not Validated	
OSHA H109	Partially Validated Method- Gas Chromatography ECD using XAD-2 tube for Hexachlorobutadiene (NIOSH 307)	
OSHA E230	Partially Validated Method- Gas Chromatography FID using Tenax GC tube for Styrene Oxide (NIOSH 303)	
OSHA D639	HPLC/U using bulk sample for Dibenzofuran- Not Validated	
OSHA D177	Gas Chromatography FID using charcoal tube for 1,3-Dichloropropene- Not Validated (OSHA Modified NIOSH 1003)	
OSHA D129	Partially Validated Method- HPLC/UL59 using coated XAD-2 tube for Diethanolamine	
OSHA C107	Partially Validated Method- Gas Chromatography ECD using OSHA Versatile sampler (OVS-2) -13mm XAD-2 tube with glass fiber filter for Polychlorinated Biphenyls (Aroclors)	
OSHA B408	Gas Chromatography FID using Tenax GC tube for Benzotrichloride- Not Validated	

References for Measurement Methods Listed in Table A-1

OSHA A625	Partially Validated Method- Gas Chromatography with NPD using silica gel tube for Acetamide	
OSHA A169	Partially Validated Method- Gas Chromatography FID using Tenax GC tube for Acetophenone	
OSHA 2480	Partially Validated Method- Gas Chromatography FID using coated XAD-2 tube for Trimethylamine	
OSHA 2450	Gas Chromatography ECD using sulfuric acid-coated glass fiber filters in 3 piece cassette for 3,3'-Dimethylbenzidine (Fully Validated OSHA 71)	
OSHA 2340	Gas Chromatography- FID using petroleum base charcoal tube for 1,1,2,2-Tetrachloroethane	
OSHA 2326	Midget impinger containing Xylene for 2,3,7,8- Tetrachlorodibenzo-p-Dioxin- Not Validated	
OSHA 2222	HPLC/UL68 using XAD-2 tube for Quinone (Fully Validated Modified NIOSH S181)	
OSHA 2213	HPLC/UL53 using midget fritted glass bubbler containing Folins reagent for Propyleneimine- Not Validated	
OSHA 2190	Gas Chromatography- FID using charcoal tubes for 1,2-Dichloropropane	
OSHA 1911	Partially Validated Method- Gas Chromatography FID using OSHA Versatile sampler (OVS-7) -13mm XAD-7 tube with glass fiber filter for Ethylene Glycol (NIOSH 5523)	
OSHA 1875	Partially Validated Method- HPLC/UL56 using OSHA Versatile sampler (OVS-2) - 13mm XAD-2 tube with glass fiber filter for 4-Nitrobiphenyl OR Gas Chromatography FID using glass fiber filter in Swinnex ™ cassette in series with silica gel tube for 4-Nitrobiphenyl - Not Validated (OSHA 273)	
OSHA 1870	Gas Chromatography- FID using silica gel tube for Nitrobenzene	
OSHA 1794	HPLC/UL52 using sulfuric acid-coated Gas Chrom R tube for Methyl hydrazine- Not Validated	
OSHA 1680	Partially Validated Method- Gas Chromatography FID using two Anasorb 747 tubes in series for Methyl Bromide	
OSHA 1646	Partially Validated Method- Gas Chromatography ECD using OSHA Versatile sampler (OVS-2) -13mm XAD- tube with glass fiber filter for Methoxychlor	
OSHA 1538	Gas Chromatography- FID using petroleum base charcoal tube for Isophorone	
OSHA 1490	Gas Chromatography- FID using phosphoric acid- coated XAD-7 for Hydroquinone	
OSHA 1376	Gas Chromatography ECD using glass fiber filter for Hexachlorobenzene- Not Validated	
OSHA 1372	Gas Chromatography- FID using charcoal tube for Hexachloroethane	
OSHA 1369	Partially Validated Method- Gas Chromatography ECD using OSHA Versatile sampler (OVS-2) -13mm XAD-2 tube with glass fiber filter for Heptachlor	
OSHA 1160	Gas Chromatography FID using charcoal tube for Ethylidene dichloride (1,1-Dichloroethane) (Fully Validated NIOSH 1003)	
OSHA 1110	Gas Chromatography- FID using two charcoal tubes in series for Ethyl Chloride	
OSHA 1015	Gas Chromatography FID using OSHA Versatile sampler (OVS Tenax) with glass fiber filter for Bis (2-ethylhexyl)phthalate (Fully Validated OSHA 104)	
OSHA 1011	Partially Validated Method- Gas Chromatography FID using XAD-7 tube for Biphenyl	
OSHA 1010	Gas Chromatography- FID using charcoal tube for Dioxane	
OSHA 0990	Gas Chromatography TEA/EAP using glass fiber filter contained within Tenax-GC tube for 2,4-Dinitrotoluene (Fully Validated OSHA 44)	
OSHA 0975	HPLC/UL61 using mixed cellulose ester filter in series with midget impinger for 4,6-Dinitro-o-cresol (Fully Validated NIOSH S-166)	
OSHA 0960	Partially Validated Method- Gas Chromatography FPD using Porapak Q tube for Dimethyl Sulfate	

References for Measurement Methods Listed in Table A-1

OSHA 0940	Colorimetric analysis using midget fritted glass bubbler for 1,1-Dimethylhydrazine (Fully Validated NIOSH S-143)	
OSHA 0935	Partially Validated Method- Gas Chromatography ECD using petroleum base charcoal tube for 1,2-Dibromo-3-Chloropropane	
OSHA 0931	Partially Validated Method- Gas Chromatography FID using coated XAD-7 tube for N,N-Dimethylaniline	
OSHA 0929	HPLC/UL53 using glass fiber filter in series with Midget Impinger for 4-Dimethylaminoazobenzene -Not Validated	
OSHA 0913	Gas Chromatography FID using silica gel tube for Diethyl Sulfate -Not Validated	
OSHA 0873	Gas Chromatography ECD using coated glass fiber filters for 3,3'-Dimethoxybenzidine (Fully Validated OSHA 71)	
OSHA 0861	Gas Chromatography- FID usind XAD-2 coated tube for Diazomethane	
OSHA 0850	Gas Chromatography FPD using OSHA Versatile sampler (OVS-2) -13mm XAD-2 tube with glass fiber filter for Dichlorvos (Fully Validated OSHA 62)	
OSHA 0760	HPLC/UL33 or Gas Chromatography FID using XAD-7 tube for Cresol (All Isomers) (Fully Validated OSHA 32)	
OSHA 0645	Gas Chromatography- FID using charcoal tube for Epichlorohydrin	
OSHA 0618	Partially Validated Method- HPLC/UL66 using two Tenax- GC tubes in series for alpha-Chloroacetophenone (OSHA Modified NIOSH 291)	
OSHA 0612	Gas Chromatography ECD using mixed cellulose ester filter for Toxaphene (Fully Validated NIOSH S-67)	
OSHA 0571	Partially Validated Method- Gas Chromatography FID using XAD-2 for Catechol	
OSHA 0529	Partially Validated Method- HPLC/UL59 using OSHA Versatile sampler (OVS-2) - 13mm XAD-2 tube with glass fiber filter for Captan	
OSHA 0400	Gas Chromatography- FID using charcoal tube for Bromoform	
OSHA 0318	Partially Validated Method- HPLC/UL58 using OSHA Versatile sampler (OVS-2) - 13mm XAD-2 tube with glass fiber filter for Propoxur	
OSHA 0225	HPLC/UL58 using XAD-2 tube for Anisidine (o,p-Isomers)	
OSHA 0220	Partially Validated Method- Gas Chromatography FID using coated XAD-7 tube for Aniline	
OSHA 0117	Partially Validated Method- HPLC/UL62 using two Anasorb 747 tubes in series for Acrylic Acid	
OSHA 0115	Partially Validated Method- HPLC/UL58 using OSHA Versatile Sampler (OVS-7) for Acrylamide	
OSHA 0065	HPLC/UL53 using glass fiber filter for 2-Acetylaminofluorene- Not Validated	
NIOSH 9002	Microscopy- Stereo and Polarized Light with Dispersion Staining using bulk sample for Asbestos (Bulk) by PLM	8/94
NIOSH 9000	X-Ray Powder Diffraction using bulk sample for Asbestos, Chrysotile by XRD	8/94
NIOSH 7906	Ion Chromatography- Conductivity using cellulose ester filter and treated pad for Fluorides, aerosol and gas	8/94
NIOSH 7905	Gas Chromatography- Phosphorus FPD using solid sorbent tube (Tenax GC) for Phosphorus	8/94
NIOSH 7904	Ion-Specific Electrode using PVC membrane filter and bubbler for Cyanides, aerosol and gas	8/94
NIOSH 7903	Ion Chromatography using solid sorbent tube (silica gel) for Inorganic Acids	8/94
NIOSH 7902	Ion-Specific Electrode using cellulose ester filter and treated pad for Fluorides, aerosol and gas	8/94
NIOSH 7901	Atomic Absorption- Graphite Furnace using Na_2CO_3-impregnated cellulose ester filter for Arsenic Trioxide, as As	8/94
NIOSH 7900	Atomic Absorption- Flame Arsine Generation using cellulose ester filter for Arsenic and Compounds, as As (except AsH_3 and AS_2O_3)	8/94

References for Measurement Methods Listed in Table A-1

NIOSH 7702	X-Ray Fluorescence (XRF) Portable L-Shell Excitation using mixed cellulose ester filter for Lead	1/98
NIOSH 7701	Portable Anodic Stripping Voltammetry using mixed cellulose ester filter for Lead by Ultrasound	1/98
NIOSH 7700	Chemical Spot Test Kit using cellulose ester filter for Lead in Air	5/96
NIOSH 7402	Microscopy- Transmission Electron using cellulose ester filter for Asbestos by TEM	8/94
NIOSH 7400	Light Microscopy- Phase Contrast using cellulose ester filter for Asbestos and Other Fibers by PCM	8/94
NIOSH 7300	Inductively Coupled Argon Plasma- Atomic Emission Spectroscopy using cellulose ester filter for Elements by ICP	8/94
NIOSH 7105	Atomic Absorption Spectrophotometer, Graphite Furnace using cellulose ester filter for Lead	8/94
NIOSH 7102	Atomic Absorption- Graphite Furnace using cellulose ester filter for Beryllium and compounds, as Be	8/94
NIOSH 7082	Atomic Absorption Spectrophotometer, Flame using cellulose ester filter for Lead	8/94
NIOSH 7048	Atomic Absorption- Flame using cellulose ester filter for Cadmium and compounds, as Cd	8/94
NIOSH 7027	Atomic Absorption- Flame using cellulose ester filter for Cobalt and compounds, as Co	8/94
NIOSH 7024	Atomic Absorption- Flame using cellulose ester filter for Chromium and compounds, as Cr	8/94
NIOSH 6011	Ion Chromatography- Conductivity Detection using prefilter (PTFE) and silver membrane filter for Chlorine and Bromine	8/94
NIOSH 6010	Spectrophotometry, Visible Absorption using solid sorbent tube (soda lime) for Hydrogen Cyanide	8/94
NIOSH 6009	Atomic Absorption- Cold Vapor using solid sorbent tube (Hopcalite) for Mercury	8/94
NIOSH 6002	UV-VIS Spectrometer using sorbent tube (coated silica gel) for Phosphine	1/98
NIOSH 6001	Atomic Absorption- Graphite Furnace using solid sorbent tube (charcoal) for Arsine	8/94
NIOSH 5700	HPLC- UV Detection using inhalable dust sampler with PVC filter for Formaldehyde on Dust (Textile or Wood)	8/94
NIOSH 5600	GC- Flame Photometric Detection (FPD) using quartz filter and solid sorbent tube (XAD-2) for Organophosphorus Pesticides	8/93
NIOSH 5523	Gas Chromatography- FID using XAD-7 OVS tube for Glycols	5/96
NIOSH 5522	HPLC- Fluorescence Detector/Electrochemical Detector using tryptamine/DMSO impinger for Isocyanates	1/98
NIOSH 5521	HPLC- Electrochemical and UV Detection using impinger for Monomeric Isocyanates	8/94
NIOSH 5517	Gas Chromatography- ^{63}Ni ECD using PTFE filter and solid sorbent tube (XAD-2) for Polychlorobenzenes	8/94
NIOSH 5516	HPLC- UV Detection using impinger for 2,4- and 2,6- Toluenediamine (in the presence of isocyanates)	8/94
NIOSH 5512	HPLC- UV Detection using mixed cellulose ester filter and bubbler for Pentachlorophenol	8/94
NIOSH 5510	Gas Chromatography- Electron Capture Detector (GC/ECD) using cellulose ester filter and solid sorbent tube (Chromosorb 102) for Chlordane	8/94
NIOSH 5509	HPLC- UV Detector using glass fiber filter for Benzidine	8/94
NIOSH 5506	HPLC- Fluorescence/UV Detection using PTFE filter and sorbent tube (XAD-2) for Polynuclear Aromatic Hydrocarbons	
NIOSH 5503	Gas Chromatography- ^{63}Ni ECD using glass fiber filter and solid sorbent (Florisil) for Polychlorobiphenyls	8/94
NIOSH 5502	Gas Chromatography- Electrolytic Conductivity Detector using glass fiber filter and bubbler for Lindane and Aldrin	8/94

References for Measurement Methods Listed in Table A-1

NIOSH 5029	HPLC- UV and Electrochemical Detection using acid-treated glass fiber filter for 4,4'-Methylenedianiline	8/94
NIOSH 5020	Gas Chromatography- FID using cellulose ester filter for Bibutyl Phthalate	8/94
NIOSH 5011	Visible Absorption Spectrophotometry using PVC or cellulose ester filter for Ethylene Thiourea	8/94
NIOSH 5006	Visible Absorption Spectrophotometry using glass fiber filter for Carbaryl	8/94
NIOSH 5004	HPLC- UV Detection using cellulose ester filter for Hydroquinone	8/94
NIOSH 5001	HPLC- UV Detector using glass fiber filter for 2,4-D ((2,4-Dichlorophenoxy)acetic acid)	8/94
NIOSH 4000	Gas Chromatography- FID using diffusive sampler (activated carbon) for Toluene	8/94
NIOSH 3702	Gas Chromatography (Portable)- Photoionization Detector using ambient air or bag sample for Ethylene Oxide	8/94
NIOSH 3701	Gas Chromatography (Portable)- Photoionization Detector using Tedlar air bag for Trichloroethylene	8/94
NIOSH 3700	Gas Chromatography (Portable)- Photoionization Detector using Tedlar air bag for Benzene	8/94
NIOSH 3515	Visible Spectrophotometry using HCl bubbler for 1,1-Dimethylhydrazine	8/94
NIOSH 3514	HPLC- UV Detection using bubbler (Folin'd Reagent) for Ethylenimine	8/94
NIOSH 3512	HPLC- UV Detection using distilled water bubbler for Maleic Anhydride	8/94
NIOSH 3509	Ion Chromatography- Ion Pairing [2,3] using impinger for Aminoethanol compounds II	8/94
NIOSH 3507	HPLC- UV Detector using liquid in bubbler for Acetaldehyde	8/93
NIOSH 3503	Spectrophotometry, Visible Absorption using HCl bubbler for Hydrazine	8/94
NIOSH 3500	Visible Absorption Spectrometry using PTFE filter and sodium bisulfate impingers for Formaldehyde	8/94
NIOSH 2549	Thermal Desorption Gas Chromatography- Mass Spectrometry using thermal desorption tube for Volatile Organic Compounds (Screening)	5/96
NIOSH 2546	Gas Chromatography- FID using solid sorbent tube (XAD-7) for Cresol (all isomers) and Phenol	8/94
NIOSH 2543	Gas Chromatography- ECD using solid sorbent tube (XAD-2) for Hexachlorobutadiene	8/94
NIOSH 2541	Gas Chromatography- FID using solid sorbent tube (XAD-2) for Formaldehyde	8/94
NIOSH 2539	Gas Chromatography- FID & GC/MS using solid sorbent tube (XAD-2) for Aldehydes, Screening	8/94
NIOSH 2538-1	Gas Chromatography-FID using solid sorbent tube (XAD-2) for Acetaldehyde	8/93
NIOSH 2537	Gas Chromatography- FID using solid sorbent tube (XAD-2) for Methyl Methacrylate	8/94
NIOSH 2535	HPLC- UV Detection using tube with reagent coated glass wool for Toluene 2,4-Diisocyanate	8/94
NIOSH 2530	Gas Chromatography- FID using solid sorbent tube (Tenax GC) for Diphenyl	8/94
NIOSH 2528	Gas Chromatography- FID using solid sorbent tube (Chromosorb) for 2-Nitropropane	8/94
NIOSH 2524	Gas Chromatography- Electrolytic Conductivity Detector (Sulfur Mode) using solid sorbent tube (Poropak P) for Dimethyl Sulfate	8/94
NIOSH 2522	Gas Chromatography (TEA) using solid sorbent tube (Thermosorb/N) for Nitrosamines	8/94
NIOSH 2520	Gas Chromatography- FID using solid sorbent tubes (charcoal) for Methyl Bromide	8/93
NIOSH 2519	Gas Chromatography- FID using solid sorbent tube (charcoal) for Ethyl Chloride	8/94
NIOSH 2518	Gas Chromatography- ^{63}Ni ECD using solid sorbent tube (Porapak T) for Hexachloro-1,3-cyclopentadiene	8/94
NIOSH 2515	Gas Chromatography- FID using solid sorbent tube (XAD-2) for Diazomethane	8/94
NIOSH 2514	HPLC- UV Detector using solid sorbent tube (XAD-2) for Anisidine; UV Detection using bubbler for Ethylenimine	8/94

References for Measurement Methods Listed in Table A-1

NIOSH 2508	Gas Chromatography- FID using solid sorbent tube (charcoal) for Isophorone	8/94
NIOSH 2501	Gas Chromatography- Nitrogen specific detector using solid sorbent tube (XAD-2) for Acrolein	8/94
NIOSH 2500	Gas Chromatography- FID using solid sorbent tube (carbon molecular sieve) for Methyl Ethyl Ketone	8/94
NIOSH 2017	Gas Chromatography- FID using filter and solid sorbent tube (silica gel) for Aniline, o-Toluidine, and Nitrobenzene	1/98
NIOSH 2016	HPLC- UV Detection using silica gel cartridge for Formaldehyde	1/98
NIOSH 2008	Ion Chromatography- Conductivity Detection using solid sorbent tube (silica gel) for Chloroacetic Acid	8/94
NIOSH 2005	Gas Chromatography- FID using solid sorbent tube (silica gel) for Nitroaromatic compounds	1/98
NIOSH 2004	Gas Chromatography- FID using solid sorbent tube (silica gel) for Dimethylacetamide	8/94
NIOSH 2002	Gas Chromatography- FID using solid sorbent tube (silica gel) for Aromatic Amines	8/94
NIOSH 2000	Gas Chromatography- FID using solid sorbent tube (silica gel) for Methanol	1/98
NIOSH 1615	Gas Chromatography- FID using solid sorbent tubes (charcoal) for Methyl tert-Butyl Ether	8/94
NIOSH 1614	Gas Chromatography- ECD using solid sorbent tube (HBr-coated charcoal) for Ethylene Oxide	8/94
NIOSH 1612	Gas Chromatography- FID using solid sorbent tube (charcoal) for Propylene Oxide	8/94
NIOSH 1606	Gas Chromatography- FID using solid sorbent tube (charcoal) for Acetonitrile	1/98
NIOSH 1604	Gas Chromatography- FID using solid sorbent tube (charcoal) for Acrylonitrile	8/94
NIOSH 1602	Gas Chromatography- FID using solid sorbent tube (charcoal) for Dioxane	8/94
NIOSH 1600	Gas Chromatography- Sulfur FPD using solid sorbent tube (charcoal) and drying tube for Carbon Disulfide	8/94
NIOSH 1501	Gas Chromatography- FID using solid sorbent tube (charcoal) for Aromatic Hydrocarbons	8/94
NIOSH 1500	Gas Chromatography- FID using solid sorbent tube (charcoal) for Hydrocarbons, 36-126 °C BP	8/94
NIOSH 1453	Gas Chromatography- FID using solid sorbent tube (carbon molecular sieve) for Vinyl Acetate	1/98
NIOSH 1450	Gas Chromatography- FID using solid sorbent tube (charcoal) for Esters I	8/94
NIOSH 1300	Gas Chromatography- FID using solid sorbent tube (charcoal) for Ketones I	8/94
NIOSH 1024	Gas Chromatography- FID using solid sorbent tube (charcoal) for 1,3-Butadiene	8/93
NIOSH 1019	Gas Chromatography- FID using solid sorbent tube (charcoal) for 1,1,2,2-Tetrachloroethane	8/94
NIOSH 1015	Gas Chromatography- FID using solid sorbent tube (charcoal) for Vinylidene Chloride	8/94
NIOSH 1014	Gas Chromatography- FID using solid sorbent tube (charcoal) for Methyl Iodide	8/94
NIOSH 1013	Gas Chromatography- Electrolytic Conductivity Detector (Hall) using solid sorbent tube (charcoal) for Propylene Dichloride	8/94
NIOSH 1010	Gas Chromatography- FID using solid sorbent tube (charcoal) for Epichlorohydrin	8/94
NIOSH 1009	Gas Chromatography- FID using solid sorbent tube (charcoal) for Vinyl Bromide	8/94
NIOSH 1008	Gas Chromatography- ^{63}Ni ECD using solid sorbent tube (charcoal) for Ethylene Dibromide	8/94
NIOSH 1007	Gas Chromatography- FID using solid sorbent tubes (charcoal) for Vinyl Chloride	8/94
NIOSH 1005	Gas Chromatography- FID using solid sorbent tubes (charcoal) for Methylene Chloride	1/98
NIOSH 1004	Gas Chromatography- FID using solid sorbent tube (charcoal) for Dichloroethyl Ether	8/94
NIOSH 1003	Gas Chromatography- FID using solid sorbent tube (charcoal) for Halogenated Hydrocarbons	8/94
NIOSH 1002	Gas Chromatography- FID using solid sorbent tube (charcoal) for Chloroprene	8/94

References for Measurement Methods Listed in Table A-1

NIOSH 1001	Gas Chromatography- FID using solid sorbent tubes (charcoal) for Methyl Chloride	8/94
NIOSH 1000	Gas Chromatography- FID using solid sorbent tube (charcoal) for Allyl Chloride	8/94
IO-5	Sampling and Analysis for Atmospheric Mercury	1/97
IO-3	Chemical Species Analysis of Filter Collected SPM	1/97

R-1
Collection of whole air in canisters, separation of co-collected water using a two-stage sorbent trap, thermal desorption, and analysis by GC with ion trap MS detection.

Kelly, T.J., Callahan, P.J., Pleil, J.P., Evans, G.F., Method Development and Field Measurements for Polar Volatile Organic Compounds in Ambient Air, Environ. Sci. Technol., 1993, 27(6), 1146-53.

R-2
Sampling at 10 LPM using a Teflon microfiber matrix (4-in.-dia. filter) impregnated with 5 ?m particles of AG-1 anion exchange resin; analyzed using BSTFA derivatization and EI-GC/MS.

H. Burkholder, M. Brinkman, M. Nishioka, J. Hodgeson, and J. Pleil, Anion Exchange Resins for Collection of Phenols from Air and Water, in Proceedings of the 16th Annual EPA Conference on Analysis of Pollutants in the Environment, Norfolk, VA, May 1993.

Nishioka, M.G., Burkholder, H.M., Evaluation of an Anion Exchange Resin for Sampling Ambient Level Phenolic Compounds, Final Report for EPA Contract No. 68-02-4127/WA-69 and -80, Battelle, Columbus, Ohio, April 1990.

R-3
Collection using three-stage tubes packed with Carbosieve S-III, Carbotrap, and Carbotrap C; desorption and refocusing onto an electrically cooled Carbosieve-III and Carbotrap sorbent bed; analysis by GC/FID and ECD.

Pollack, A.J, Gordon, S.M., Moschandreas, D.J., Evaluation of Portable Multisorbent Air Samplers for Use with an Automated Multitube Analyzer, Final Report for EPA Contract No.. 68-D0-0007/WA-27, September 1992.

R-4
Methods of Air Sampling and Analysis, 3rd Ed., Lodge, J.P. Jr., editor, Intersociety Committee on Methods of Air Sampling and Analysis, Lewis Publishers, Inc., Chelsea, Michigan, 1989.

[14] Infrared Absorption Spectroscopy (using Saran or Mylar plastic bag sampler or silica gel) for VOCs

[205]: Determination of Fluoride Content of Plant Tissues (Potentiometric Method)

[301]: Determination of Particulate Antimony Content in the Atmosphere (using membrane, cellulose or glass fiber filters and visible absorption spectrophotometry)

[302]: Determination of Arsenic Content of Atmospheric Particulate Matter (using

membrane or glass fiber filters and visible absorption spectrophotometry)

[317]: Determination of Elemental Mercury in Ambient and Workroom Air by Collection on Silver Wool and Atomic Absorption Spectroscopy

[606A]: Estimation of Airborne Radon-222 by Filter Paper Collection and Alpha Activity Measurements of Its Daughters (Thomas Method or Modified Kusnetz Method)

[606B]: Determination of Airborne Radon-222 by Its Absorption from the Atmospheric and Gamma Measurement (using charcoal adsorbent)

[804]: As, Se, and Sb in Urine and Air by Hydride Generation and Atomic Absorption Spectrometry (using cellulose acetate membrane filter)

[805]: Determination of Chlorine in Air (using midget impinger with sodium acetate and potentiometric analysis)

[809]: Determination of Fluorides and Hydrogen Fluoride in Air (using impingers with sodium hydroxide)

[822]: General Atomic Absorption Procedure for Trace Metals in Airborne Material Collected on Filters (using membrane filters) for particulate inorganics

[822B]: X-Ray Fluorescence Spectrometry for Multielemental Analysis of Airborne Particulate and Biological Material

[829]: Determination of Chloromethyl Methyl Ether (CMME) and Bis-Chloromethyl Ether (Bis-CME) in Air (using GC-ECD and impingers with a methanolic solution of the sodium salt of 2,4,6-trichlorophenol)

[831]: Determination of p,p-Diphenylmethane Diisocyanate (MDI) in Air (using midget impingers with hydrochloric and acetic acids and visible absorption spectrophotometry)

[835]: Determination of EPN, Malathion and Parathion in Air (using glass fiber filters and GC-flame photometric detection)

[836]: Determination of Total Particulate Hydrocarbons (TpAH) in Air: Ultrasonic Extraction Method (using glass fiber filters and HPLC-UV)

[837]: Determination of 2,4-Toluene Diisocyanate (TDI) in Air (using midget impingers with hydrochloric and acetic acids and visible absorption spectrophotometry)

R-5

High volume air sampling with glass fiber filter and polyurethane foam sorbent; solvent extraction and chromatographic cleanup; analysis by high resolution gas chromatography and high resolution mass spectrometry (HRGC/HRMS), with multiple isotopically labelled internal surrogate standards. Analysis based on guidelines of EPA Methods 8280 and 8290.

Hunt, G.T., Maisel, B.E., Atmospheric Concentrations of PCDDs/PCDFs in Southern California, J. Air Waste Mgt. Assoc., 1992, 42:672-680.

R-6

Automated gas chromatography with detection by ECD and FID. Sample collection performed hourly using a three-stage sorbent trap, with refocusing on a cryogenic (-186?C) trap for analysis.

Purdue, L.J., Reagan, J.A., Lonneman, W.A., Lawless, T.C., Drago, R.J., Zalaquet, G.M.,

Holdren, M.W., Smith, D.L., Pate, A.D., Buxton, B.E., Spicer, C.W., Atlanta Ozone Precursor Monitoring Study Data Report, EPA/600/R-92/157, U.S. Environmental Protection Agency, Washington, D.C., September 1992.

R-7
Canister collection of whole air samples; analysis by gas chromatography/multiple detector (ECD, FID, PID) method.

McAllister, R., Bowles, E., DeGarmo, J., Rice, J., Jongleux, R.F., Merrill, R.G., Jr., and Bursey, J., 1990 Urban Air Toxics Monitoring Program. Report No. EPA-450/4-91-024, prepared for U.S. Environmental Protection Agency by Radian Corporation, Research Triangle park, NC, June 1991.

R-8
Sampling with denuder/filter/XAD resin combinations, extraction, and analysis by ion chromatography.

Eatough, D.J., White, V.F., Hansen, L.D., Eatough, N.L., Cheney, J.L., Identif-ication of Gas-Phase Dimethyl Sulfate and Monomethyl Hydrogen Sulfate in the Los Angeles Atmosphere, Environ. Sci. Technol., 1986, 20:867-872.

Hansen, L.D., White, V.F., Eatough, D.J., Determination of Gas-Phase Dimethyl Sulfate and Monomethyl Hydrogen Sulfate, Environ. Sci. Technol., 1986, 20:872-878.

R-9
Four distinct methods: 1) collection on Thermosorb A, solvent extraction, and analysis by GC with nitrogen-selective detector; 2) collection on Tenax, thermal desorption, and GC/MS analysis; 3) grab sampling with analysis by portable GC/FID; 4) atmospheric pressure ionization quadrupole MS.

Clay, P.F. (NUS Corp., Bedford, Mass), Spittler, T.M. (U.S. EPA, Region I, Lexington, Mass), Determination of airborne volatile nitrogen compounds using four independent techniques. Proceedings of Natl. Conf. Manage. Uncontrolled Hazard Waste Sites. Hazard. Mater. Control Res. Inst.: Silver Spring, Maryland, 1983, pp 100-104.

R-10
Cryogenic trapping, thermal desorption, and GC analysis with flame photometric detection

Maroulis, P.J., Torres, A.L., Bandy, A.R., Atmospheric concentrations of carbonyl sulfide in the southwestern and eastern United States, Geophys. Res. Lett., 1977, 4:510-512.

Torres, A.L., Maroulis, P.J., Goldberg, A.B., Bandy, A.R., Atmospheric OCS measurements on Project Gametag, J. Geophys. Res., 1980, C12:7357-7360.

R-11
Cryogenic trapping, thermal desorption, and sequential GC analysis of two samples collected simultaneously with flame photometric detection.

Maroulis, P.J., Bandy, A.R., Measurements of atmospheric concentrations of CS2 in the eastern United States, Geophys. Res. Lett., 1980, 7:681-684.

R-12
Collection on Tenax sorbent, thermal desorption to a cryogenic focussing trap, and GC/MS analysis.

Pellizzari, E.D., Bunch, J.E., Ambient air carcinogenic vapors: improved sampling and analytical techniques and field studies, EPA-600/2-79-081, NTIS No. PB-297-932, U.S. Environmental Protection Agency, Research Triangle Park, NC, May 1979.

R-13
Collection in canisters or cryogenically, with four detection methods. (1) Ion Trap GC/MS - detection limit of 1 pptv. (2) Quadrupole GC/MS with Selective Ion Monitoring - detection limit of 10 pptv. (3) Gas Chromatography with Photoionization Detection - detection limit 10 pptv. (4) Quadrupole GC/MS with Full Scan Monitoring - detection limit of 0.1 ppbv. Also Portable Gas Chromatograph with Photoionization Detection - detection limit of 0.1 ppbv.

Havlicek, S.C., Hilpert, L.R., Dai, G., Pierotti, D., Assessment of Ethylene Oxide Concentrations and Emissions from Sterilization and Fumigation Processes (PB93-216793; available NTIS). Final report by Coast-to-Coast Analytical Services, Inc., San Luis Obispo, CA, to California Air Resources Board, Sacramento, CA, Contract No. ARB-A832-125, 78 pp, May 1992.

R-14
Collection on XAD-4 resin Soxhlet extraction in dichloromethane and then in ethylacetate, analysis by GC/MS with positive chemical ionization.

Chuang, J.C., Mack, G.A., Kuhlman, M.R., Wilson, N.K., Polycyclic Aromatic Hydrocarbons and Their Derivatives in Indoor and Outdoor Air in an Eight-Home Study, Atmos. Envir., 1991, 25(3): 369-380.

R-15
Collection on XAD-2 or PUF, Soxhlet extraction in 10 percent ether/hexane or methylene chloride, analysis by GC/MS.

Chuang, J.C., Hannan, S.W., Wilson, N.K., Field Comparison of Polyurethane Foam and XAD-2 Resin for Air Sampling for Polynuclear Aromatic Hydrocarbons, Envir. Sci. Tech., 1987, 21(8): 798-804.

R-16
Air sampling methods discussed with references; minimum detectable levels provided for a number of particulate and gaseous radionuclides in air presented, assuming standard gamma-scan-400 to 512 multichannel analyzer - 4 x 4-inch NaI (Te) detector or liquid scintillation counting, with references.

CRC Handbook of Environmental Radiation, Ed. Alfred W. Clement, Jr., CRC Press, Inc., Boca Raton, FL, 1982.

R-17
Background information on radioactivity detectors, measurement procedures, quality assurance, and statistical analysis of radioactivity measurements.

Handbook of Radioactivity Measurements Procedures, NCRP Report No. 58, National Council on Radiation Protection and Measurements, Bethesda, MD, 1985.

R-18
Collection on Teflon filter and iodated activated carbon, acid digestion, and analysis by cold vapor atomic absorption.

Lindbergh, S.E., Turner, R.R., Meyers, T.P., Taylor, G.E., Jr., Schroeder, W.H., Atmospheric concentrations and deposition of Hg to a deciduous forest at Walker Branch Watershed, Tennessee, USA, Water, Air, Soil Poll., 1991, 56:577-594.

Turner, R.R., Bogle, M.A., Heidel, L., McCain, L., Mercury in ambient air at the Oak Ridge Y-12 plant July 1986 through December 1990, Y-12 report Y/TS-574, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1991.

R-19
Collection on alkaline-impregnated glass fiber filters, aqueous extraction, and ion chromatographic analysis using "negative" UV photometric detection with a strongly UV-absorbing eluent.

Grosjean, D., Liquid chromatography analysis of chloride and nitrate with "negative" ultraviolet detection: ambient levels and relative abundance of gas-phase inorganic and organic acids in southern California, Environ. Sci. Technol., 1990, 24:77-81.

R-20
Revision of ASTM Method D-3266, involving collection of HF on alkaline-impregnated tape, aqueous extraction, and analysis by ion-selective electrode.

Zankel, K.L., McGirr, R., Romm, M., Campbell, S.A., Miller, R., Measurement of ground-level concentrations of hydrogen fluoride, J. Air Poll. Control Assoc., 1987, 37:1191-1196.

R-21
Collection on Nuclepore (i.e., polycarbonate) filters, carbon coating by vapor deposition, and electron microscopic examination.

Samudra, A.U., Harwood, C.F., Stockhalm, J.D., Electron microscope measurement of airborne asbestos concentration. EPA-600/1-77-178, U.S. Environmental Protection Agency, Research Triangle Park, NC, 1977.

See also discussion in:
Asbestiform Fibers: Nonoccupational Health Risks, published by National Academy Press, National Academy of Sciences, Washington, D.C., pp 82-96, 1984.

R-22
Sampling using a chilled acetone collection medium to trap hydrazines and convert to stable derivatives; acetone solution analyzed directly for derivatives using a gas chromatograph with nitrogen-specific detectors.

Holtzclaw, J.R., Rose, S.L., Wyatt, J.R., Ronnbehler, D.P., Fine, D.H., Simultaneous Determination of Hydrazine, Methylhydrazine, and 1,1-Dimethyl Hydrazine in Air by Derivatization/Gas Chromatography, Anal. Chem., 1984, 56: 2952-2956.

R-23
Collection and derivatization in toluene solution containing N-(4-nitrobenzyl)-N-n-propylamine hydrochloride (NBPA); analysis by HPLC and UV detection.

Holdren, M.W., Spicer, C.W., Riggin, R.M., Gas phase reaction of toluene diisocyanate with water vapor, Am. Ind. Hygiene Assoc. J., 1984, 45:626-633.

Dunlap, K.L., Sandridge, R. L., Keller, J., Determination of isocyanates in working atmospheres by high-speed liquid chromatography, Anal. Chem., 1976, 45:497-499.

R-24
Continuous real-time monitoring based on color formation in a substrate-impregnated tape, with electro-optical measurement of color intensity. The unit has a useful range up to 200 ppbv of TDI, with a detection limit of 1 ppbv.

The monitor is sold as the TLD-1 by MDA Scientific, Inc., Lincolnshire, Illinois.

R-25
Sampling at 0.1 LPM using 200-400 mesh granular AG-1 anion exchange resin; analyzed using EI-GC/MS and/or GC/FID; methylation and GC/ECD for chlorinated phenols.

Nishioka, M.G., Burkholder, H.M., Evaluation of an Anion Exchange Resin for Sampling Ambient Level Phenolic Compounds, Final Report for EPA Contract No. 68-02-4127/WA-69 and -80, Battelle, Columbus, Ohio, April 1990.

R-26
Passive sampling using commercial samplers with activated carbon as sorbent; solvent extraction and concentration; analysis by GC/MS.

Shields, H.C., Weschler, C.J., Analysis of ambient concentrations of organic vapors with a passive sampler, J. Air. Poll. Control Assoc., 1987, 37:1039-1045.

R-27
Collection on polyurethane foam (sampling for 24 hours at 3.8 L/min), solvent extraction and evaporative concentration, analysis by GC/ECD and GC/MS (multiple ion mode).

Immerman, F.W., Schaum, J.L., Final Report of the Nonoccupational Pesticide Exposure Study (NOPES), EPA-600/3-90-003, U.S. Environmental Protection Agency, Research Triangle Park, NC, 1990.

Whitmore, R.W., Immerman, F.W., Camann, D.E., Bond, A.E., Lewis, R.G., Schaum, J.L., Nonoccupational Exposures to Pesticides for Residents of Two U.S. Cities, Arch. Environ. Contam. Toxicol., 1994, 26:47-59.

R-28
Collection on glass fiber filters and polyurethane foam or Florisil sorbents. Solvent extraction, cleanup on Florisil, evaporative concentration, and analysis by GC/ECD.

Atlas, E., Giam, C.S., Ambient concentration and precipitation scavenging of atmospheric organic pollutants, Water Air Soil Poll., 1988, 38:19-36.

Chang, L.W., Atlas, E., Giam, C.S., Chromatographic separation and analysis of chlorinated hydrocarbons and phthalic acid esters from ambient air samples, Int. J. Environ. Anal. Chem., 1985, 19:145-153.

R-29
Collection with glass fiber filters and polyurethane foam; solvent extraction, cleanup on Florisil, evaporative concentration; analysis by GC/ECD and GC/MS.

Hoff, R.M., Muir, D.C.G., Grift, N.P., Annual cycle of polychlorinated biphenyls and organohalogen pesticides in air in southern Ontario 1. Air concentration data, Environ. Sci. Technol., 1992, 26:266-275, and references therein.

R-30
High volume or low volume sampling of ambient air. Collection on glass fiber filters and polyurethane foam, solvent extraction, evaporative concentration, and analysis by GC/ECD or GC/MS.

Lewis, R.G., Bond, A.E., Johnson, D.E., Hsu, J.P., Measurement of atmospheric concentrations of common household pesticides: a pilot study, Environ. Monitoring and Assessment, 1988, 10:59-73.

R-31
Collection on glass fiber filters and on any of three sorbents: polyurethane foam, XAD-2 resin, or Tenax GC. Solvent extraction, cleanup, and analysis by GC/ECD.

Billings, W.N., Bidleman, T.F., High volume collection of chlorinated hydrocarbons in urban air using three solid sorbents, Atmos. Environ., 1983, 17:383-393.

R-32
Filter sampling at 1.5 LPM, total sampling volume of 240-L using PVC filters; extraction using buffer solution, pH = 4.5; trisodium pentacyanoaminoferrate reagent; colorimetric analysis in 30 min at 475 nm in 1-cm glass cells; paper provides sampling conditions, extraction solvents, reagents, analytical conditions, and detection ranges for colorimetric determination.

Freixa, A., Magti, A., Application of colorimetric techniques to the measurement of air pesticide content, Pergamon Ser. Environ. Sci., 1982, 7: 297-298.

R-33
Gas chromatography with flame photometric detection (GC-FPD) using a column (0.5 m x 2.5 mm i.d.) packed with GDX-101. Phosphene retention time 19 s at 80 C; ratio of H to 0 of 10:3.

Qi, Xiaofei, Quantitative determination of trace phosphine in ambient air by gas chromatography with a flame photometric detector, Sepn, 1987, 5(4): 243-5 (in Chinese).

R-34
Chemiluminescence emission from arsine due to reaction of sampled air with ozone.

Inone, K., Suzuki, M., Kawabayashi, O., Method and Apparatus for Chemiluminescence Analyses, Ger. Offen., DE 3525700/A1/860206 (German patent), 1986 (reports detection limit of 1 ppb for arsine).

Fraser, M. E., Stedman, D. H., Henderson, M. J., Gas-phase Chemiluminescence of Arsine Mixed with Ozone, Anal. Chem., 1982, 54(7): 1200-1.

R-35
Analysis using gas chromatography and an alkali flame ionization detector (N-detector); acidified aqueous solutions directly injected on the column.

Donike, M., Gas chromatographic trace analysis of hydrocyanic acid in the nano- and picogram range, Mitteilungsbl. GDCh-Fachgrappe Lebensmittelchem. Gerichtl. Chem., 1974, 28(1-2): 46-52 (in German).

R-36
Collection of particulate material from air, analysis by HPLC with electrochemical detection.

Riggin, R.M., Howard, C.C., Scott, D.R., Hedgecoke, R.L., Determination of benzidine, related congeners, and pigments in atmospheric particulate matter, J. Chromatogra. Sci., 1983, 21:321-325.

R-37
Derivatization of amines to the corresponding amides by reaction with a perfluoro-acid anhydride, gas chromatographic separation, and analysis by N-selective thermionic detection.

Skarping, G., Renman, L., Dalene, M., Trace analysis of amines and isocyanates using glass capillary gas chromatography and selective detection. II. Determination of aromatic amines as perfluorofatty acid amides using nitrogen-selective detection, J. Chromatogr., 1983, 270:207-218.

R-38
GC/ECD method for 2,4-D salts and acid.

Nishioka, M., Burkholder, H., Brinkman, M., Gordon, S., Lewis, R., "Simulation of track-in of lawn-applied herbicide acids from turf to home: Comparison of dislodgeable turf residues with carpet dust and carpet surface residues, prepared for submission to Environ. Sci. Technol., 1993.

R-39
Collection on Tenax-GK sorbent, thermal desorption; gas chromatography with Hall electrolytic chlorine-sensitive detection.

Matienzo, L.J., Hensler, C.J., Determination of N,N-dimethylcarbamoyl chloride (DMCC) in air, Am. Indus. Hygiene Assoc. J., 1982, 43:838-844.

R-40
Collection with glass fiber filter and Tenax GC sorbent, thermal desorption, cryogenic concentration, and analysis by GC/MS.

Krost, K.J., Pellizzari, E.D., Wlaburn, S.G., Hubbard, S.A., Collection and analysis of hazardous organic emissions, Anal. Chem.; 1982, 54:810-817.

R-41
Collection in methylisobutyl ketone, gas chromatography with sulfur-selective detection. Alternatively, collection and derivatization on the pre-coated walls of a diffusion denuder tube, and determination by HPLC with UV detection.

Oldeweme, J., Klockow, D., Chromatographic procedures for the determination of 1,3-propanesultone in workplace air, Fresenius Z. Anal. Chem., 1986, 325:57-63.

R-42
Collection in aqueous KOH solution containing methanol and hydroxyl amine, to form a derivative. The iron complex of that derivative is determined quantitatively by absorbance of 530 nm.

Jozwicka, J., Spectrophotometric method for determination of monochloroacetic acid vapors in workplace air, Wlokna Chem., 1990, 16:394-401.

R-43
Workplace air monitoring of caprolactam; collection on filter and XAD-2 tubes or XAD-2 tubes only; desorption with methanol containing 2 percent water, or with MeCN; analysis by GC or HPLC. Sampled air volume of 100 L yields detection limit of 0.20 mg/m3 using HPLC analysis, and 0.10 mg/m3 using GC analysis.

Nau, D.R., Darr, R.W., Gad, S.C., Pai, S.V., Validation study of a method for monitoring personnel exposure to caprolactam, Proc Symp. Ind. Approach Chem. Risk Assess.: Caprolactam Relat. Compd. Case Study, 275-91. Ind. Health Found.: Pittsburgh, PA, 1984.

R-44
Detection of caprolactam in workplace air and toxicol. studies; aerosols sampled on filter AFA-KhA-20 at 2 L/min, extracted with di-Et ether or a 1:1 EtOH/ether mixture; evaporated, and chromatographic drying in Cl, analysis by thin-layer chromatography with a mobile alcohol solvent system; and development with o-tolidine solution or fresh KI-starch reagent. Detection limit is 0.005 mg/m3; cyclohexanone, hydroxylamine, and NH3 stated not to interfere with method.

Ledovskikh, N.G., Sensitive method for the determination of caprolactam in air, Gig. r. Prof. Zabol., 1982, 10: 52-3 (in Russian).

R-45
Collection by charcoal adsorbent tube (or silica gel tube under high humidity conditions); desorption using distilled water then carbon disulfide; analysis of both layers by GC-FID.

Langhorst, M.L., Glycol Ethers - Validation Procedures for Tube/Pump and Dosimeter Monitoring Methods, Am. Ind. Hyg. Assoc. J., 1984, 45:416-424.

R-46
Personal air sampling through polyurethane foam plug; extraction in hexane; solvent transfer to toluene; analysis by GLC.

Nigg, H.N., Stamper, J.H., Exposure of Spray Applicators and Mixer-Loaders to Chlorobenzilate Miticide in Florida Citrus Groves, Arch. Environ. Contam. Toxicol., 1983, 12:477-482.

R-47
Headspace gas chromatography is applied for the analysis of water in liquid and solid samples with the preferred quantitation technique being standard addition.

Kolb, B., Auer, M., Analysis for Water in Liquid and Solid Samples by Headspace Gas Chromatography. Part I: Liquid and Soluble Solid Samples, Fresenius. Z. Anal. Chem., 1990, 336:291-6.

R-48
Sampling via an activated carbon fiber felt put between quartz filters and determination by gas chromatography-mass spectroscopy.

Suzuki, S., Simultaneous Determination of Airborne Pesticides by GC/MS, Bunseki Kagaku, 1992, 41:115-24 (in Japanese).

R-49
Collection on XAD resins and determination by gas chromatography-mass spectroscopy and a nitrogen-phosphorous detector.

Yeboah, P.O., Kilgore, W.W., Analysis of Airborne Pesticides in a Commercial Pesticide Storage Building, Bull. Environ. Contam. Toxicol., 1984, 32:629-34.

R-50
High volume sampling with collection on a cartridge containing PUF/Tenax/PUF. Multiple extraction, derivation, and analysis by GC/MS or GC/ECD.

McConnell, L.L., Patton, G.W., Zaranski, M.T., Bidleman, T.F., Development of a collection method for chlorophenolic compounds in air, in Proceedings of the 1989 EPA/AWMA Symposium on Measurement of Toxic and Related Air Pollutants, Publication VIP-13, EPA-600/9-89-060, Air and Waste Mgt. Assoc., Pittsburgh, pp 623-628, 1989.

R-51
Collection with glass fiber filters and polyurethane foam sorbent. Solvent extraction after spiking with 13C-labelled isomers, chromatographic cleanup of the extracts, and evaporative concentration. Analysis by GC/MS using electron impact or electron capture negative ion modes.

References for Measurement Methods Listed in Table A-1

Eitzer, B.D., Hites, R.A., Polychlorinated dibenzo-p-dioxins and dibenzofurans in the ambient atmosphere of Bloomington, Indiana, Environ. Sci. Technol., 1989, 23:1389-1395.

Edgerton, S.A., Czuczwa, J.M., Rench, J.D., Hodanbosi, R.F., Koval, P.J., Ambient air concentrations of polychlorinated dibenzo-p-dioxins and dibenzofurans in Ohio: Sources and health risk assessment, Chemosphere, 1989, 18:1713-1730.

R-52
High volume sampling with a Teflon-impregnated glass fiber filter and three PUF sorbent plugs in series; addition of deuterated internal standards; solvent extraction and evaporative concentration; analysis by HPLC with UV detection.

Arey, J., Zielinska, B., Atkinson, R., Winer, A.M., Polycyclic aromatic hydrocarbon and nitroarene concentrations in ambient air during a wintertime high-NOx episode in the Los Angeles basin, Atmos. Environ., 1987, 21:1437-1444.

R-53
Collection on Teflon-impregnated glass fiber filters and XAD-2 resin sorbent; multiple solvent extractions with addition of deuterated internal standards, and separation of acid and base/neutral fractions by HPLC. Analysis by negative chemical ionization GC/MS.

Nishioka, M.G., Lewtas, J., Quantification of nitro- and hydroxylated nitro-aromatic/polycyclic aromatic hydrocarbons in selected ambient air daytime winter samples, Atmos. Environ., 1992, 26A:2077-2087.

R-54
Sampling with glass fiber filters and Tenax-GC and polyurethane foam sorbent traps; solvent extraction with addition of deuterated internal standards; analysis by GC/MS with electron impact ionization.

Leuenberger, C., Ligocki, M.P., Pankow, J.F., Trace organic compounds in rain. 4. Identities, concentrations, and scavenging mechanisms for phenols in urban air and rain, Environ. Sci. Technol., 1985, 19:1053-1058.

R-55
Continuous monitoring in air using ion mobility mass spectrometry.

Leasure, C.S., Eiceman, G.A., Continuous detection of hydrazine and monomethylhydrazine using ion mobility spectrometry, Anal. Chem., 1985, 57:1890-1894.

R-56
Derivatization on-column with an alkali metal salt of 2,4,6-trichlorophenol to form a derivative, which is determined immediately by GC with electron capture detection.

Kallos, G.J., Albe, W.R., Solomon, R.A., On-column reaction gas chromatography for determination of chloromethyl methyl ether at one part-per-billion level in ambient air, Anal. Chem., 1977, 49:1817-1820.

R-57
Collection with glass fiber filters and Tenax-GC sorbent; solvent extraction, evaporative concentration, and analysis by GC/MS.

Cautreels, W., van Cauwenberghe, K., Experiments on the distribution of organic pollutants between airborne particulate matter and the corresponding gas phase, Atmos. Environ., 1978, 12:1133-1141.

R-58
Low volume collection on Tenax-GC, thermal desorption, cryofocusing, and GC/MS analysis in a mobile field sampling laboratory.

Haggert, B., Havkov, R., Design and implementation of a mobile monitoring unit (MMU) to measure ambient volatile organic compounds, paper 84-17.2, presented at the 77th Annual Meeting, Air Pollution Control Association, San Francisco, CA, June 1984.

R-59
Method stated to be collection of whole air in sampling bags, with analysis by GC with photoionization detection.

Hunt, W.F., Jr., Faoro, R.B., Freas, W., Report on the Interim Data Base for State and Local Air Toxic Volatile Organic Chemical Measurements, Report No. EPA-450/4-86-012, U.S. Environmental Protection Agency, Research Triangle Park, NC, 1986.

R-60
Modified version of Compendium Method TO-8, using C18 Sep-Pak cartridges coated with NaOH for sampling, with analysis by HPLC. The resolution of the HPLC analysis is improved by changing the pH of the acetate buffer, and by using a sequential bonding end-capped column.

Bratton, S.A., Sampling and measurement of phenol and methylphenols (cresols) in air by HPLC using a modified Method TO-8, in Measurement of Toxic and Related Air Pollutants, proceedings of the 1992 EPA/AWMA International Symposium, EPA Report No. EPA-600/R-92/131, Publication VIP-25, Air and Waste Mgt. Assoc., Pittsburgh, PA, pp. 719-724 (1992).

R-61
Adsorption of pentachlorophenol (PCP) onto OV-17 stationary phase, with collection /thermal desorption on a 2-minute cycle. Analysis of desorbed PCP by atmospheric pressure chemical ionization tandem mass spectrometry. Detection limit 40 ng/m3.

DeBrou, G.B., Ng, A.C., Karellas, N.S., Near real-time measurements of pentachlorophenol in ambient air by mobile mass spectrometry, in Measurement of Toxic and Related Air Pollutants, proceedings of the 1992 EPA/AWMA International Symposium, EPA Report No. EPA-600/R-92/131, Publication VIP-25, Air and Waste Mgt. Assoc., Pittsburgh, PA, pp. 838-843 (1992).

R-62
Collection of 2,4-toluene diisocyanate in a derivatizing solution of 1-(2-pyridyl)piperazine in toluene, in impingers. The stable TDI/urea derivative is determined by HPLC. Limit of detection for TDI is 116 ng/m3, limit of quantitation is 351 ng/m3.

Wilshire, F.W., Knoll, J.E., Foster, S.C., McGaughey, J.F., Development and validation of a source test method for 2,4-toluene diisocyanate, in Measurement of Toxic and Related Air Pollutants, proceedings of the 1993 EPA/AWMA International Symposium, EPA Report No. EPA-600/A93/024, Publication VIP-34, Air and Waste Mgt. Assoc., Pittsburgh, PA, pp. 399-407 (1993).

R-63
Collection of airborne asbestos on a polycarbonate or mixed cellulose ester filter, deposition of carbon under vacuum, and dissolution of the original filter material. Analysis and counting is conducted by analytical electron microscopy, with identification by electron diffraction and energy dispersive x-ray spectroscopy.

Doorn, S.S., Burris, S.B., Airborne asbestos analysis by analytical electron microscopy, in Measurement of Toxic and Related Air Pollutants, proceedings of the 1991 EPA/AWMA International Symposium, EPA Report No. EPA/600/9-91/018, Publication VIP-21, Air and Waste Mgt. Assoc., Pittsburgh, PA, pp. 226-230 (1991).

R-64
Cryogenic concentration of a 100 mL air sample, separation by two dimensional gas chromatography, with flame ionization detection.

Fung, K., A method for the measurement of alcohols and MTBE in ambent air, in Measurement of Toxic and Related Air Pollutants, proceedings of the 1991 EPA/AWMA International Symposium, EPA Report No. EPA/600/9-91/018, Publication VIP-21, Air and Waste Mgt. Assoc., Pittsburgh, PA, pp.770-775 (1991).

R-65
Sorbent collection on Porapak Q; thermal desorption; dual-column GC analysis with FID.

Frankel, L.S. and Black, R.F., Automatic gas chromatography monitor for the detection of part-per-billion levels of bis(chloromethyl) ether, Analyt. Chem., 48, p. 732-737 (1976).

R-66
Collection using filter and sorbent; analysis using gas chromatography/high-resolution mass spectrometry (GC/HRMS).

DeRoos, F.L., Watson, S.C., Miller, S.E., Tabor, J.E., Hatchel, J.A., Lewis, R.G., Wilson, N.K., Evaluation of the EPA high-volume air sampler for collection and retention of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans, in Measurement of Toxic and Related Air Pollutants, proceedings of the 1986 EPA/APCA International Symposium, EPA Report No. EPA/600/9-86/013, Publication VIP-7, Air Pollution Control Association, Pittsburgh, PA, pp.217-229 (1986); see also EPA Report No. EPA-600/4-86/037.

R-67
Collection using filter and sorbent; analysis using gas chromatography/high-resolution mass spectrometry (GC/HRMS).

Harless, R.L., Lewis, R.G., McDaniel. D.D., Dupuy, A.E., Jr., Determination of polychlorinated dibenzo-p-dioxins and dibenzofurans in stack gas emissions and ambient air, in in Measurement of Toxic and Related Air Pollutants, proceedings of the 1988 EPA/APCA International Symposium, EPA Report No. EPA/600/9-88/015, Publication VIP-10, Air Pollution Control Association, Pittsburgh, PA, pp.613-620 (1988).

R-68
The report documents the measurement of airborne levels of two pesticides, carbofuran and captan. The sampling medium was XAD-4 resin. Analyses were carried out with a gas chromatograph equipped with a Hall electrolytic conductivity detector.

Shibamoto, T., Mourer, C., Hall G., Pilot Monitoring Study of Two Pesticides in Air, Final Report to California State Air Resources Board, Sacramento, Research Div., Report No. ARB/R-95/579 (1993).

R-69
The sampling method consisted of a combined filter and XAD-2 adsorbent bed. Analysis was accomplished with HPLC-UV detection. Fourteen organonitrogen pesticides were evaluated using NIOSH guidelines and procedures.

Kennedy, E.R., Lin, J-J., Reynolds, J.M., Perkins, J.B., A Sampling and Analytical Method for the Simultaneous Determination of Multiple Organonitrogen Pesticides in Air, Am. Ind. Hyg. Assoc. J., 58(1):720-725 (1997).

R-70
A method is presented which details procedures used to enhance peak identification. Procedures include changing column types, column parameters, fractionating the sample, etc.

Lewis, R.G., Determination of Pesticides and Polychlorinated Biphenyls in Indoor Air by Gas Chromatography, IARC Sci. Publ., 109 (Environmental Carcinogens, Methods of Anlysis, and Exposure Measurement, Vol. 12), 353-376 (1993).

R-71
Air samples were taken indoors after application of chemicals. Residues were low (ca. 0.1 $\mu g/m^3$) during the 30 day sampling period.

Leidy, R.B. and Stout, D.M. II, Residues of Chlorpyrifos and Dichlorvos Indoors Following a Perimeter House Application, Book of Abstracts, 211th ACS National Meeting, New Orleans, LA, AGRO-192 Publisher, American Chemical Society, Washington, D.C. (1996)

R-72
Samples were collected on a combination cellulose ester membrane (MCEM) filter and a silica gel Sep-Pak adsorbent. Each was extracted with 1% acetic acid. HPLC with fluorescence detection was used. Method detection was 0.3 $\mu g/m^3$.

Risner, C.H., The Quantification of Hydroquinone, Catechol, Phenol, 3-Methylcatechol, Scopoletin, m+p-Cresol and o-Cresol in Indoor Air Samples by High-Performance Liquid Chromatography, J. Liq. Chromatogr., 16(18):4117-4140 (1993).

R-73
Derivatization with pentafluorobenzyl bromide followed by gas chromatography/ion trap mass spectrometry is used to determine oxidation products of biogenic emissions. Acrylic acid was also identified and quantified with this method.

Chien, C-J., Charles, M. J., Sexton, K. G., Jeffries, H.E., Analysis of Airborne Carboxylic Acids and Phenols as Their Pentafluorobenzyl Derivatives: Gas Chromatography/Ion Trap Mass Spectrometry with a Novel Chemical Ionization Reagent, PFBOH, Environ, Sci, Technol., 32(2):299-309 (1998).

R-74
Nine residences were monitored for crop-related pesticides and PAH compounds.

Mukerjee, S., Ellenson, W.D., Lewis, R.G., Stevens, R.K., Somerville, M.C., Shadwick, D.S., Willis, R.D., An Environmental Scoping Study in the Lower Rio Grande Valley of Texas – Part III, Residential Microenvironmental Monitoring for Air, House Dust, and Soil, Environ. Int., 23(5):657-673 (1997).

R-75
Organochlorine pesticides and polychlorinated biphenyls at pg/m^3 concentrations were determined using high volume air sampling techniques.

McConnell, L.L., Bidleman, T.F., Cotham, W.E., Walla, M.D., Air Concentrations of Organochlorine Insecticides and Polychlorinated Biphenyls Over Green Bay, Wisconsin, and the Four Lower Great Lakes, Environ. Pollut., 101(3):391-399 (1998).

R76
Cartridges containing florisil and foam plugs were used to collect air. Supercritical fluid extraction was used to extract material. Gas chromatography with electron capture detection was used for analyses. Detection limits of 0.1 ng/m^3 were obtained.

Swami, K., Narang, A.S., Narang, R.S., Determination of Chlordane and Chlorpyrifos in Ambient Air at Low Nanogram-Per-Cubic Meter Levels by Supercritical Fluid Extraction, J. AOAC Int., 80(1):74-78 (1997).

R-77
A patent was filed for a procedure to measure phosphorus. Phosphorus is converted to phosphorus monoxide which is reacted with ozone to convert the monoxide to a dioxide. A light measuring device then measures the intensity of emitted light.

Stedman, D.H. and Meeks, P.A., Method to Detect Phosphorus, U.S., patent number 5702954A.

R-78
Ion mobility spectroscopy was used to monitor gases such as HF, HCl, Cl_2, ClO_2, and HCN. Limits of detection were 1 ppb.

Bacon, T. and Webber, K., Acid and Halogen Gas Monitoring Utilizing Ion Mobility Spectroscopy (IMS), Proc., Annu. Meet. – Air Waste Manage. Assoc. (1996).

R-79
PCB and PAHs were measured at various locations. Daytime vs. nighttime and urban vs. non-urban results were compared.

Simcik, M.F., Zhang, H., Eisenreich, S.T., Franz, T.P., Urban Contamination of the Chicago/Coastal Lake Michigan Atmosphere by PCBs and PAHs during AEOLOS, Environ. Sci. Technol., 31(7):2141-2147 (1997).

R-80
Analytical method was developed to determine PAHs in house dust and soil. The purpose was concentration profiles of PAHs in house dust and track-in soil.

Chuang, J.C., Callahan, P.J., Menton, R.G., Gordon, S.M., Lewis, R.G., Wilson, N.K., Monitoring Methods for Polycyclic Aromatic Hydrocarbons and Their Distribution in House Dust and Track-In Soil, Environ. Sci. Technol., 29(2):494-500 (1995).

R-81
A sorbent-based gas chromatographic method provides near real time monitoring of toxic gases. The system was demonstrated on-site. Deactivation and passivation techniques were critical to optimize method performance.

Lattin, F.G. and Paul, D.G., A Method for Near Real Time Continuous Air Monitoring of Phosgene, Hydrogen Cyanide, and Cyanogen Chloride, Proc. SPIE-Int. Soc. Opt. Eng., 2835 (Advanced Technologies for Environmental Monitoring and Remediation) 180-188 (1996).

R-82
XAD-7 is the adsorbent for the collection of each analyte. Methanol was used as the extracting solvent. The use of a Stabilwax-DA analytical column resulted in enhanced peak shape and lower detection limits.

Pendergrass, S.M., An Alternative Method for the Analysis of Phenol and o-, m-, and p-Cresol by Capillary GC/FID, Am. Ind. Hyg. Assoc. J., 55(11):1051-1054 (1994).

R-83
The impinger method has a limit of detection of 25 ng per 40 mL of solution. The method compared well with two NIOSH methods.

Wyatt, J.R., Rose-Pehrsson, S.L., Cecil, T.L., Crossman, K. P., Mehta, N.K., Young R., Coulometric Method for the Quantification of Low-Level Concentrations of Hydrazine and Monomethylhydrazine, Am. Ind. Hyg. Assoc. J., 54(6):285-292 (1993).

R-84
Air is drawn through a paper tape treated with vanillin (4-hydroxy-3-methoxybenzaldehyde). The contaminated air reacts with vanillin to develop a yellow color. The density of the color is proportional to the concentration of hydrazine and methylhydrazine. Method detection is low ppb.

Young, R.C., McBrearty, C.F., Curran, D.J., Active Hydrazine Vapor Sampler (AHVS), NTIS Report N93-22149/7 (1993).

Appendix B
Results of the Survey of Chemical and Physical Properties of the 188 HAPs

1. Table of Physical and Chemical Properties (Table B-1).

2. Discussion of Polarizability and Water Solubility Characteristics of VOCs.

Table B-1. Results of the Survey of Chemical and Physical Properties of the 188 HAPs

Compound	CAS No.	MW	Compound Class[1]	VP[2] (mm Hg/ 25°C)	BP[2] (°C)	Water Solubility[3] (g/L at °C)	Reactivity & $t_{1/2}$ Range[13]		Polarizability[1]	Other[15]	Comment
							Aqueous[14]	Air			
Acetaldehyde; C_2H_4O	75-07-0	44.0	VVOC	952.0	21	33.0 / 25	-- --	--	11.6	Polar	--
Acetamide; C_2H_5NO	60-35-5	59.0	SVOC	7.2E-02	222	>100 / 22	-- --	--	--	Polar	--
Acetonitrile; C_2H_3N	75-05-8	41.0	VOC	74.0	82	>100 / 22	aab 7-28d	54-541d	11.0	Polar	--
Acetophenone; C_8H_8O	98-86-2	120.0	VOC	1.0	202	6.3 / 25	-- --	--	36.3	Polar	--
2-Acetylaminofluorene; $C_{15}H_{13}NO$	53-96-3	223.3	NVOC	1.1E-12 (?)	444	<0.1 / 20.5	-- --	--	--	--	--
Acrolein; C_3H_4O	107-02-8	56.0	VOC	220.0	53	>100 / 21	aab 7-28d	3-34h	16.2	Polar	Reactive [5]
Acrylamide; C_3H_5NO	79-06-1	71.0	VOC	0.53	125/25 mm	>100 / 22	-- --	--	--	Polar	Reactive [5]
Acrylic acid; $C_3H_4O_2$	79-10-7	72.0	VOC	3.2	141	>100 / 17	aab 1-7d	3-24h	17.4	Polar	--
Acrylonitrile; C_3H_3N	107-13-1	53.0	VOC	100.0	77	716.0 / 25[4]	aab 1-23d	0.6-8d	15.6	Polar	--
Allyl chloride; C_3H_5Cl	107-05-1	76.5	VOC	340.0	45	19.5 / 20[4]	ah 7-14d	3-29h	20.5	Non-Polar	--
4-Aminobiphenyl; $C_{12}H_{11}N$	92-67-1	169.0	SVOC	6.0E-05	302	<0.1 / 19	-- --	--	--	--	--
Aniline; C_6H_7N	62-53-3	93.0	VOC	0.67	184	1.0 / 25[4]	-- --	--	30.6	Polar	--
o-Anisidine; C_7H_9NO	90-04-0	123.0	SVOC	0.1	224	<0.1 / 19	-- --	--	--	--	Reactive[6]
Asbestos	1332-21-4	--	NVINC	Very low	Decom-poses at 1112°C	Insoluble	-- --	--	--	--	--
Benzene; C_6H_6	71-43-2	78.0	VOC	76.0	80	1-5 / 18	aab 5-16d	2-21d	26.2	Non-Polar	--
Benzidine; $C_{12}H_{12}N_2$	92-87-5	184.2	SVOC	1.0E-05	402	< 1 / 22	-- --	--	--	--	--
Benzotrichloride; $C_7H_5Cl_3$	98-07-7	195.5	SVOC	7.6E-02	213	Reacts	-- --	--	--	--	Reactive[5]
Benzyl chloride; C_7H_7Cl	100-44-7	126.6	VOC	1.0	179	Reacts	ah 12d	1-9d	36.0	Non-Polar	Reactive (?)[8]
Biphenyl; $C_{12}H_{10}$	92-52-4	154.0	SVOC	3.9E-04	254	Insoluble	-- --	--	--	--	--
Bis(2-ethylhexyl) phthalate; $C_{24}H_{38}O_4$	117-81-7	390.5	SVOC	1.4E-07	384	<0.1 / 22	-- --	--	--	--	--

Table B-1. Results of the Survey of Chemical and Physical Properties of the 188 HAPs

Compound	CAS No.	MW	Compound Class[1]	VP[2] (mm Hg/ 25°C)	BP[2] (°C)	Water Solubility[3] (g/L at °C)	Reactivity & $t_{1/2}$ Range[13]		Polarizability[1]	Other[15]	Comment
							Aqueous[14]	Air			
Bis(chloromethyl) ether; $C_2H_4Cl_2O$	542-88-1	115.0	VOC	30.0	104	Reacts	ah 0.01-0.1h	0.2-2h	22.8	Polar	Reactive[7]
Bromoform; $CHBr_3$	75-25-2	252.8	VOC	5.6	149	<0.1 / 22.5	aab 28-180d	54-541d	29.8	Non-Polar	--
1,3-Butadiene; C_4H_6	106-99-0	54.0	VVOC	2000.0	-5	Insoluble	aab 7-28d	1-8h	22.4	Non-Polar	Reactive (?)[8]
Calcium cyanamide; $CaCN_2$	156-62-7	80.0	NVINC	<<1.0E-10	1175	Insoluble	-- --	--	--	--	Reactive[5]
Captan; $C_9H_8Cl_3NO_2S$	133-06-2	300.6	SVOC	9.7E-07	479	<1 / 20	-- --	--	--	--	Pesticide
Carbaryl; $C_{12}H_{11}NO_2$	63-25-2	201.2	SVOC	1.4E-06	331	40 /	-- --	--	--	--	Pesticide
Carbon disulfide; CS_2	75-15-0	76.0	VOC	260.0	47	<1 / 20	-- --	--	21.5	Non-Polar	--
Carbon tetrachloride; CCl_4	56-23-5	153.8	VOC	90.0	77	<1 / 21	aab 0.5-1y	2-18y	26.5	Non-Polar	--
Carbonyl sulfide; COS	463-58-1	60.1	VVOC	3700.0	-50	>100 / 20	-- --	--	12.6	Polar	--
Catechol; $C_6H_6O_2$	120-80-9	110.0	VOC	0.2	240	>100 / 21.5	aab 1-7d	3-26h	32.9	Polar	--
Chloramben; $C_7H_5Cl_2NO_2$	133-90-4	206.0	SVOC	4.7E-06	350	<0.1 / 22	-- --	--	--	--	Pesticide
Chlordane; $C_{10}H_6Cl_8$	57-74-9	409.8	SVOC	9.8E-6	175/2 mm	<1 / 23	-- --	--	--	--	Pesticide - mixture of compds; VP for α- or γ- chlordane
Chlorine; Cl_2	7782-50-5	70.9	VVINC	4000.0	-34	>100 / 0	-- --	--	--	--	--
Chloroacetic acid; $C_2H_3ClO_2$	79-11-8	94.5	VOC	0.7	189	>100 / 20	aab 1-7d	9-86d	17.6	Polar	--
2-Chloroacetophenone; C_8H_7ClO	532-27-4	154.6	SVOC	1.2E-02	245	<1 / 19	-- --	--	--	--	--
Chlorobenzene; C_6H_5Cl	108-90-7	112.6	VOC	8.8	132	<1 / 20	aab 68-150d	3-30d	31.1	Non-Polar	--
Chlorobenzilate; $C_{16}H_{14}Cl_2O_3$	510-15-6	325.2	SVOC	2.2E-06	415	<0.1 / 22	-- --	--	--	--	Pesticide
Chloroform; $CHCl_3$	67-66-3	119.0	VOC	160.0	61	0.85 / 20 - 24[4]	aab 28-168d	26-260d	21.4	Non-Polar	--

Table B-1. Results of the Survey of Chemical and Physical Properties of the 188 HAPs

Compound	CAS No.	MW	Compound Class[1]	VP[2] (mm Hg/ 25°C)	BP[2] (°C)	Water Solubility[3] (g/L at °C)	Reactivity & $t_{1/2}$ Range[13]		Polarizability[1]	Other[15]	Comment
							Aqueous[14]	Air			
Chloromethyl methyl ether; C_2H_5ClO	107-30-2	80.5[9]	VOC	224.0	59	Reacts	ah 0.01-	1-10d	18.2	Polar	Reactive[7]
Chloroprene (2-chloro-1,3-butadiene); C_4H_5Cl	126-99-8	88.5	VOC	226.0	59	Slightly soluble	aab 28-180d	3-28h	25.2	Non-Polar	--
Cresol/Cresylic acid (isomer mixture); C_7H_8O	1319-77-3	108.0	VOC	0.3	202		aab 0.04-29d	1-16h	32.5	Polar	--
o-Cresol; C_7H_8O	95-48-7	108.0	VOC	0.2	191	25.9 / 25	aab 1-7d	2-16h	32.2	Polar	--
m-Cresol; C_7H_8O	108-39-4	108.0	SVOC	4.0E-02	202	10-50 / 20	-- --	--	--	--	--
p-Cresol; C_7H_8O	106-44-5	108.0	SVOC	4.0E-02	202	<1 / 21	-- --	--	--	--	--
Cumene; C_9H_{12}	98-82-8	120.0	VOC	3.2	153	Insoluble	aab 3-22d	10-97h	40.5	Non-Polar	--
2,4-D (2,4-dichlorophenoxyacetic acid, incl salts & esters); $C_8H_6Cl_2O_3$	--	--	SVOC/NVOC	1.0E-04 to 1.0E-10	135 / 1 mm		-- --	--	--	--	Pesticide; VP range for acid, esters, and salts; BP for acid
DDE (1,1-dichloro-2,2-bis(p-chlorophenyl) ethylene); $C_{14}H_8Cl_4$	72-55-9	318.0	SVOC	2.4E-05	350	<0.1 / 22	-- --	--	--	--	Pesticide
Diazomethane; CH_2N_2	334-88-3	42.1	VVOC	2800.0	-23	Reacts	-- --	--	--	Polar	Highly reactive[5]
Dibenzofurans: 1,2,4,8-Tetrachloro-dibenfuran	--	322	SVOC	2.0E-05	305(mp)	Insoluble	-- --	--	--	--	Properties for 2,3,7,8-TCDD[10]
Octachlorodibenzofuran	--	460	NVOC	8.4E-10	332(mp)	Insoluble	-- --	--	--	--	Properties for OCDD[10]
1,2-Dibromo-3-chloropropane; $C_3H_5Br_2Cl$	96-12-8	236.4	VOC	0.8	196	<0.1 / 18	aab 14-180d	6-61d	36.3	Non-Polar	--

Table B-1. Results of the Survey of Chemical and Physical Properties of the 188 HAPs

Compound	CAS No.	MW	Compound Class[1]	VP[2] (mm Hg/ 25°C)	BP[2] (°C)	Water Solubility[3] (g/L at °C)	Reactivity & $t_{1/2}$ Range[13]		Polarizability[1]	Other[15]	Comment
							Aqueous[14]	Air			
Dibutylphthalate; $C_{16}H_{22}O_4$	84-74-2	278.4	SVOC	4.2E-05	340	<1 / 20	-- --	--	--	--	--
1,4-Dichlorobenzene (p-); $C_6H_4Cl_2$	106-46-7	147.0	VOC	0.6	173	<1 / 23	aab 28-180d	8-84d	36.3	Non-Polar	--
3,3'-Dichlorobenzidine; $C_{12}H_{10}Cl_2N_2$	91-94-1	253.0	SVOC	2.6E-06	402	Insoluble	-- --	--	--	--	--
Dichloroethyl ether (Bis[2-Chloroethyl]ether); $C_4H_8Cl_2O$	111-44-4	143.0	VOC	0.7	178	Reacts	aab 28-180d --	10-97h	32.0	Polar	Reactive (?)[8]
1,3-Dichloropropene; $C_3H_4Cl_2$ (cis)	542-75-6	111.0	VOC	27.8	112	<0.1 / 16.5	ah 5-11d	5-80h	25.5	Non-Polar	--
Dichlorvos; $C_4H_7Cl_2O_4P$	62-73-7	221.0	SVOC	5.3E-02	140/20 mm	0.01 /	-- --	--	--	--	Pesticide
Diethanolamine; $C_4H_{11}NO_2$	111-42-2	105.0	SVOC	1.0E-02	269	>100 / 14	-- --	--	--	--	Reactive (?)[8] ; strong base
Diethyl sulfate; $C4H_{10}O_4S$	64-67-5	154.0	VOC	0.29	208	Reacts	ah 2-12h	4-36h	31.6	Polar	Reactive (?)[8]
3,3'-Dimethoxybenzidine; $C_{14}H_{16}N_2O_2$	119-90-4	244.0	NVOC	3.2E-13	458	<0.1 / 20	-- --	--	--	--	--
4-Dimethyl aminoazobenzene; $C_{14}H_{15}N_3$	60-11-7	225.3	NVOC	6.8E-10	407	<1 / 22	-- --	--	--	--	--
N,N-Dimethylaniline; $C_8H_{11}N$	121-69-7	121.0	VOC	0.5	192	<1 / 21	aab 17-180d	3-21h	40.8	Polar	--

Table B-1. Results of the Survey of Chemical and Physical Properties of the 188 HAPs

Compound	CAS No.	MW	Compound Class[1]	VP[2] (mm Hg/ 25°C)	BP[2] (°C)	Water Solubility[3] (g/L at °C)	Reactivity & $t_{1/2}$ Range[13]		Polarizability[1]	Other[15]	Comment
							Aqueous[14]	Air			
3,3'-Dimethylbenzidine; $C_{14}H_{16}N_2$	119-93-7	212.3	SVOC	2.9E-07	300	<1 / 19	-- --	--	--	--	--
Dimethylcarbamoyl-chloride; C_3H_6ClNO	79-44-7	107.6	VOC	4.9	166	Reacts	ah 0.05h	1-10h	--	Polar	Highly reactive[7]
N,N-Dimethylformamide; C_3H_7NO	68-12-2	73.0	VOC	2.7	153	>100 / 22	-- --	--	19.9	Polar	--
1,1-Dimethylhydrazine; $C_2H_8N_2$	57-14-7	60.0	VOC	157.0	63	Reacts	aab 8-24d	1-8h	18.7	Non-Polar	Reactive (?)[8]
Dimethyl phthalate, $C_{10}H_{10}O_2$	131-11-3	194.0	SVOC	8.9E-03	282	<1 / 20	-- --	--	--	--	--
Dimethyl sulfate; $C_2H_6O_4S$	77-78-1	126.1	VOC	1.0	188	>100 / 20	ah 1-12h	2-15d	--	Polar	Reactive (?)[8]
4,6-Dinitro-o-cresol & salts; $C_7H_6N_2O_5$	534-52-1	198.1	SVOC	8.3E-05	312	slightly soluble	-- --	--	--	--	Pesticide; VP, BP for the cresol; salts are probably NVOCs
2,4-Dinitrophenol; $C_6H_4N_2O_5$	51-28-5	184.0	SVOC	1.0E-05	Sublimes on heating	<1 / 19.5	-- --	--	--	--	--
2,4-Dinitrotoluene; $C_7H_6N_2O_4$	121-14-2	182.0	SVOC	3.7E-03	300	<0.1 / 17	-- --	--	--	--	--
1,4-Dioxane (1,4-Diethylene oxide); $C_4H_8O_2$	123-91-1	88.0	VOC	37.0	101	>100 / 20	aab 28-180d	0.3-3d	21.4	Polar	--
1,2-Diphenylhydrazine; $C_{12}H_{12}N_2$	122-66-7	184.3	SVOC	8.0E-02	220	Insoluble	-- --	--	--	--	Reactive (?)[8]

Table B-1. Results of the Survey of Chemical and Physical Properties of the 188 HAPs

Compound	CAS No.	MW	Compound Class[1]	VP[2] (mm Hg/ 25°C)	BP[2] (°C)	Water Solubility[3] (g/L at °C)	Reactivity & $t_{1/2}$ Range[13]		Polarizability[1]	Other[15]	Comment
							Aqueous[14]	Air			
Epichlorohydrin (1-chloro-2,3-epoxy propane); C_3H_5ClO	106-89-8	92.5	VOC	12.0	117	50-100 / 22	aab 7-28d	6-61d	20.5	Polar	Highly reactive[6]
1,2-Epoxybutane; C_4H_8O	106-88-7	72.0	VOC	163.0	63	>100 / 17	ah 12d	1-13d	20.3	Polar	Reactive[6]
Ethyl acrylate; $C_5H_8O_2$	140-88-5	100.0	VOC	29.3	100	4.2 / 20[4]	aab 1-7d	2-23h	26.6	Polar	--
Ethylbenzene; C_8H_{10}	100-41-4	106.0	VOC	7.0	136	<1 / 23	aab 3-10d	9-86h	35.7	Non-Polar	--
Ethyl carbamate (urethane); $C_3H_7NO_2$	51-79-6	89.0	VOC	0.54	183	>100 / 22	aab 1-7d	3-30h	22.6	Polar	--
Ethyl chloride; C_2H_5Cl	75-00-3	64.5	VVOC	1000.0	13	>100 / 20	aab 7-28d	7-67d	16.2	Non-Polar	--
Ethylene dibromide; $C_2H_4Br_2$	106-93-4	187.9	VOC	11.0	132	<1 / 21	aab 28-180d	11-107d	27.0	Non-Polar	Pesticide
Ethylene dichloride; $C_2H_4Cl_2$	107-06-2	99.0	VOC	61.5	84	5-10 / 19	aab 100-180d	12-122d	21.0	Non-Polar	Pesticide
Ethylene glycol; $C_2H_6O_2$	107-21-1	62.0	SVOC	5.0E-02	198	>100 / 17.5	-- --	--	--	--	--
Ethyleneimine; C_2H_5N	151-56-4	43.0	VOC	160.0	56	Miscible	aab 7-28d	11-105h	--	Polar	Reactive (?)[8]
Ethylene oxide; C_2H_4O	75-21-8	44.0	VVOC	1100.0	11	Miscible	ah 11d	38-382d	11.2	Polar	Reactive[6]
Ethylene thiourea; $C_3H_6N_2S$	96-45-7	102.0	SVOC	1.5E-06	450	1-5 / 18	-- --	--	--	--	--
Ethylidene dichloride; $C_2H_4Cl_2$	75-34-3	99.0	VOC	230.0	57	<1 / 20	aab 32-150d	10-103d	21.1	Non-Polar	--
Formaldehyde; CH_2O	50-00-0	30.0	VVOC	2700.0	-20	>100 / 20.5	aab 1-7d	1-6h	8.4	Polar	--
Heptachlor; $C_{10}H_5Cl_7$	76-44-8	373.3	SVOC	2.3E-04	145/1.5 mm	<0.1 / 18	-- --	--	--	--	Pesticide
Hexachlorobenzene; C_6Cl_6	118-74-1	284.8	SVOC	9.5E-04	324	<1 / 20	-- --	--	--	--	Pesticide
Hexachlorobutadiene; C_4Cl_6	87-68-3	260.8	VOC	0.4	215	<0.1 / 22	aab 28-180d	0.3-3y	49.8	Non-Polar	--

Table B-1. Results of the Survey of Chemical and Physical Properties of the 188 HAPs

Compound	CAS No.	MW	Compound Class[1]	VP[2] (mm Hg/ 25°C)	BP[2] (°C)	Water Solubility[3] (g/L at °C)	Reactivity & $t_{1/2}$ Range[13]		Polarizability[1]	Other[15]	Comment
							Aqueous[14]	Air			
1,2,3,4,5,6-Hexachlorocyclo-hexane (Lindane) (all isomers); $C_6H_6Cl_6$	58-89-9	290.8	SVOC	5.6E-05	323	<1 / 24	-- --	--	--	--	Pesticide
Hexachlorocyclo pentadiene; C_5Cl_6	77-47-4	272.8	SVOC	4.0E-02	234	<0.1 / 21.5	-- --	--	--	--	Reactive (?)[8]
Hexachloroethane; C_2Cl_6	67-72-1	236.7	VOC	0.4	Sublimes at 186	<1 / 21	aab 28-180d	7-73y	--	Non-Polar	--
Hexamethylene-1,6-diisocyanate; $C_8H_{12}N_2O_2$	822-06-0	168.2	SVOC	1.9E-03	255	--	-- --	--	--	--	Reactive (?)[8]
Hexamethylphosphoramide; $C_6H_{18}N_3OP$	680-31-9	179.2	SVOC	9.0E-02	233	>100 / 18	-- --	--	--	--	--
Hexane; C_6H_{14}	110-54-3	86.2	VOC	120.0	69	<1 / 16.5	-- --	--	29.9	Non-Polar	--
Hydrazine; H_4N_2	302-01-2	32.1	VINC	16.0	113	Miscible	-- --	--	--	--	--
Hydrogen chloride; HCl	7647-01-0	36.5	VINC	23.5	110	>100 / 20	-- --	--	--	--	--
Hydrogen fluoride; HF	7664-39-3	20.0	VVINC	900.0	20	Very soluble	-- --	--	--	--	--
Hydroquinone; $C_6H_6O_2$	123-31-9	110.0	SVOC	7.2E-06	218	10-50 / 20	-- --	--	--	--	--
Isophorone; $C_9H_{14}O$	78-59-1	138.2	VOC	0.38	215	0.1-1 / 18	aab 7-28d	0.4-3h	42.1	Polar	--
Maleic anhydride; $C_4H_2O_3$	108-31-6	98.0	SVOC	5.0E-05	202	Soluble	-- --	--	--	--	Reactive[5]
Methanol; CH_4O	67-56-1	32.0	VOC	92.0	65	>100 / 21	aab 1-7d	3-30d	8.2	Polar	--
Methoxychlor; $C_{16}H_{15}Cl_3O_2$	72-43-5	345.7	SVOC	1.4E-06	447	<1 / 23	-- --	--	--	--	Pesticide
Methyl bromide; CH_3Br	74-83-9	94.9	VVOC	1800.0	4	Slightly soluble	aab 28-180d	68-680d	15.0	Non-Polar	Pesticide

Table B-1. Results of the Survey of Chemical and Physical Properties of the 188 HAPs

Compound	CAS No.	MW	Compound Class[1]	VP[2] (mm Hg/ 25°C)	BP[2] (°C)	Water Solubility[3] (g/L at °C)	Reactivity & $t_{1/2}$ Range[13]		Polarizability[1]	Other[15]	Comment
							Aqueous[14]	Air			
Methyl chloride; CH_3Cl	74-87-3	50.5	VVOC	3800.0	-24	Slightly soluble	ah 292d	61-613d	11.5	Non-Polar	
Methyl chloroform (1,1,1-trichloroethane); $C_2H_3Cl_3$	71-55-6	133.4	VOC	100.0	74	<1 / 20	aab 0.4-0.5y	0.6-6y	26.2	Non-Polar	--
Methyl ethyl ketone (2-butanone); C_4H_8O	78-93-3	72.0	VOC	77.5	80	>100 / 19	aab 1-7d	3-27d	20.7	Polar	--
Methylhydrazine; CH_6N_2	60-34-4	46.1	VOC	49.6	88	<1 / 24	aab 13-24d	0.1-0.4h	13.7	Non-Polar	Highly reactive[7]
Methyl iodide (iodomethane); CH_3I	74-88-4	141.9	VVOC	400.0	42	10-50 / 18	aab 7-28d	22-223d	19.3	Non-Polar	--
Methyl isobutyl ketone (hexone); $C_6H_{12}O$	108-10-1	100.2	VOC	6.0	117	1-5 / 21	aab 1-7d	5-46h	30.0	Polar	--
Methyl isocyanate; C_2H_3NO	624-83-9	57.1	VOC	348.0	60	Reacts	ah 0.14-	2-19h	14.0	Polar	Highly reactive[7]
Methyl methacrylate; $C_5H_8O_2$	80-62-6	100.1	V	28.0	101	15.9 / 20	aab 7-28d	1-10h	26.5	Polar	--
Methyl ter-butyl ether; $C_5H_{12}O$	164-04-4 3	86.0	VOC	249.0	55	Soluble	aab 28-180d	1-11d	26.2	Polar	--
4,4'-Methylenebis(2-chloroaniline); $C_{13}H_{12}Cl_2N_2$	101-14-4	267.2	NVOC	3.9E-16	517	<1 / 25	-- --	--	--	--	--
Methylene chloride; CH_2Cl_2	75-09-2	84.9	VOC	349.0	40	10-50 / 21	aab 7-28d	19-191d	16.4	Non-Polar	--
4,4'-Methylenediphenyl diisocyanate (MDI); $C_{15}H_{10}N_2O_2$	101-68-8	250.3	SVOC	1.0E-03	538	Insoluble	-- --	--	--	--	Reactive (?)[8]

Table B-1. Results of the Survey of Chemical and Physical Properties of the 188 HAPs

Compound	CAS No.	MW	Compound Class[1]	VP[2] (mm Hg/ 25°C)	BP[2] (°C)	Water Solubility[3] (g/L at °C)	Reactivity & $t_{1/2}$ Range[13]		Polarizability[1]	Other[15]	Comment
							Aqueous[14]	Air			
4,4'-Methylenedianiline; $C_{13}H_{14}N_2$	101-77-9	198.3	NVOC	1.7E-10	393	<1 / 19	-- --	--	--	--	--
Naphthalene; $C_{10}H_8$	91-20-3	128.2	SVOC	4.9E-02	218	<1 / 22	-- --	--	--	--	--
Nitrobenzene; $C_6H_5NO_2$	98-95-3	123.0	VOC	0.15	211	1.9 / 25	aab 13-200d	0.5-5h	32.7	Polar	--
4-Nitrobiphenyl; $C_{12}H_9NO_2$	92-93-3	199.2	SVOC	4.0E-07	340	Insoluble	-- --	--	--	--	--
4-Nitrophenol; $C_6H_5NO_3$	100-02-7	139.0	SVOC	1.3E-06	279	<0.1 / 21	-- --	--	--	--	--
2-Nitropropane; $C_3H_7NO_2$	79-46-9	89.0	VOC	10.0	120	1.7 / 20	aab 28-180d	5-49h	21.6	Polar	--
N-Nitroso-N-methylurea; $C_2H_5N_3O_2$	684-93-5	103.0	VOC	10.0	124	<1 / 18	ah 0.01-3.5h	0.5-5h	--	Polar	Reactive[7]
N-Nitroso-dimethylamine; $C_2H_6N_2O$	62-75-9	74.0	VOC	3.7	152	>100 / 19	aab 21-180d	0.5-1h	19.3	Polar	Reactive[7]
N-Nitrosomorpholine; $C_4H_8N_2O_2$	59-89-2	116.1	VOC	0.32	225	>100 / 19	aab 28-180d	0.9-18h	--	Polar	--
Parathion; $C_{10}H_{14}NO_5PS$	56-38-2	291.3	SVOC	9.7E-06	375	<1 / 23	-- --	--	--	--	Pesticide
Pentachloronitrobenzene (quintobenzene); $C_6Cl_5NO_2$	82-68-8	295.3	SVOC	2.4E-03	328	<1 / 22	-- --	--	--	--	--
Pentachlorophenol; C_6Cl_5OH	87-86-5	266.3	SVOC	1.1E-04	310	<1 / 20	-- --	--	--	--	Pesticide
Phenol; C_6H_6O	108-95-2	94.0	VOC	0.2	182	50-100 / 19	aab 6-84h	2-23h	28.0	Polar	--
p-Phenylenediamine; $C_6H_8N_2$	106-50-3	108.2	SVOC	2.6E-04	267	Soluble	-- --	--	--	--	--

Table B-1. Results of the Survey of Chemical and Physical Properties of the 188 HAPs

Compound	CAS No.	MW	Compound Class[1]	VP[2] (mm Hg/ 25°C)	BP[2] (°C)	Water Solubility[3] (g/L at °C)	Reactivity & $t_{1/2}$ Range[13]		Polarizability[1]	Other[15]	Comment
							Aqueous[14]	Air			
Phosgene; CCl_2O	75-44-5	99.0	VVOC	1200.0	8	Slightly soluble	aab 7-28d	113->>y	--	Polar	Reactive (?)[8]
Phosphine; PH_3	7803-51-2	34.0	VVINC	2000.0	-88	Slightly soluble	-- --	--	--	--	Pesticide
Phosphorus; P	7723-14-0	124.0	SVINC	2.6E-02	280	0.0003%	-- --	--	--	--	Highly reactive (red and white forms)
Phthalic anhydride;	85-44-9	148.0	SVOC	2.2E-04	285	Reacts	-- --	--	--	--	Reactive[5]
$C_8H_4O_3$ Polychlorinated biphenyls: Dichlorobiphenyl	25512-42-9	222	SVOC	1.9E-05	317	Insoluble	-- --	--	--	--	4,4[1]-isomer[11]
Hexachlorobiphenyl	26601-64-9	358	SVOC	5.2E-06	103(mp)	Insoluble	-- --	--	--	--	2,2[1],4,4[1],5,5[1]-isomer[11]
1,3-Propane sultone; $C_3H_6O_3S$	1120-71-4	122.1	VOC	2.0	180/30 mm	0.1	ah 0.4-28d	4-40h	--	Polar	Reactive (?)[8]
Beta-Propiolactone; $C_3H_4O_2$	57-57-8	72.0	VOC	3.4	Decom-poses at 162	37.0 / 20	ah 3-22d	8-75d	15.7	Polar	--
Propionaldehyde; C_2H_5CHO	123-38-6	58.1	VOC	235.0	49	50-100 / 18	aab 1-7d	3-33h	16.1	Polar	--
Propoxur (Baygon); $C_{11}H_{15}NO_3$	114-26-1	209.2	SVOC	7.8E-07	400	Slightly soluble	-- --	--	--	--	Pesticide
Propylene dichloride (1,2-dichloropropane); $C_3H_6Cl_2$	78-87-5	113.0	VOC	42.0	97	<0.1 / 21.5	aab 0.5-4y	3-27d	25.7	Non-Polar	Pesticide
Propylene oxide; C_3H_6O	75-56-9	58.0	VVOC	445.0	34	400 / 20	ah 7-13d	--	15.7	Polar	Reactive[6]

Table B-1. Results of the Survey of Chemical and Physical Properties of the 188 HAPs

Compound	CAS No.	MW	Compound Class[1]	VP[2] (mm Hg/ 25°C)	BP[2] (°C)	Water Solubility[3] (g/L at °C)	Reactivity & $t_{1/2}$ Range[13]		Polarizability[1]	Other[15]	Comment
							Aqueous[14]	Air			
1,2-Propyleneimine (2-methylaziridine); C_3H_7N	75-55-8	57.1	VOC	112.0	66	>100 / 19	aab 7-28d	1-11h	17.6	Polar	Highly Reactive (?)[8]
Quinoline; C_9H_7N	91-25-5	129.2	SVOC	9.5E-02	238	<0.1 / 22.5	-- --	--	--	--	--
Quinone; $C_6H_4O_2$	106-51-4	108.0	SVOC	1.0E-02	201	Slightly soluble	-- --	--	--	--	--
Styrene; C_8H_8	100-42-5	104.0	VOC	6.6	145	<1 / 19	aab 14-28d	0.9-7h	36.4	Non-Polar	--
Styrene oxide; C_8H_8O	96-09-3	120.2	VOC	0.3	194	<1 / 19.5	ah 0.004-	0.5-5d	35.5	Polar	Highly reactive[7]
2,3,7,8-Tetrachlorodibenzo-p-dioxin; $C_{12}H_4Cl_4O_2$	1746-01-6	322.0	SVOC	3.6E-06	495	<1 / 25	-- --	--	--	--	--
1,1,2,2-Tetrachloroethane; $C_2H_2Cl_4$	79-34-5	167.9	VOC	5.0	146	<0.1 / 22	ah 45d	9-89d	30.7	Non-Polar	--
Tetrachloroethylene; C_2Cl_4	127-18-4	165.8	VOC	14.0	121	<0.1 / 17	aab 180-360d	16-160d	30.3	Non-Polar	--
Titanium tetrachloride; $TiCl_4$	7550-45-0	154.2	VINC	0.3	136	Soluble	-- --	--	--	--	Highly reactive in air; forms TiO_2
Toluene; C_7H_8	108-88-3	92.0	VOC	22.0	111	<1 / 18	aab 4-22d	10-104h	31.0	Non-Polar	--
2,4-Toluenediamine; $C_7H_{10}N_2$	95-80-7	122.2	SVOC	3.2E-05	292	1-5 / 21	-- --	--	--	--	--
2,4-Toluene diisocyanate; $C_9H_6N_2O_2$	584-84-9	174.2	SVOC	1.0E-02	251	Reacts	-- --	--	--	--	Reactive[5]
o-Toluidine; C_7H_9N	95-53-4	107.2	SVOC	0.1	200	5-10 / 15	-- --	--	--	--	--
Toxaphene (chlorinated camphene); $C_{10}H_{10}Cl_8$	8001-35-2	413.8	SVOC	1.1E-05	155/0.4 mm	<1 / 19	-- --	--	--	--	Pesticide; complex mixture of isomers

Table B-1. Results of the Survey of Chemical and Physical Properties of the 188 HAPs

Compound	CAS No.	MW	Compound Class[1]	VP[2] (mm Hg/ 25°C)	BP[2] (°C)	Water Solubility[3] (g/L at °C)	Reactivity & $t_{1/2}$ Range[13]		Polarizability[1]	Other[15]	Comment
							Aqueous[14]	Air			
1,2,4-Trichlorobenzene; $C_6H_3Cl_3$	120-82-1	181.5	VOC	0.2	213	<1 / 21	aab 28-180d	5-54d	41.0	Non-Polar	--
1,1,2-Trichloroethane; $C_2H_3Cl_3$	79-00-5	133.4	VOC	19.0	114	1-5 / 20	aab 100-180d	8-82d	25.9	Non-Polar	--
Trichloroethylene; C_2HCl_3	79-01-6	131.4	VOC	20.0	87	<1 / 21	aab 180-360d	1-11d	25.4	Non-Polar	--
2,4,5-Trichlorophenol; $C_6H_3Cl_3O$	95-95-4	197.5	SVOC	2.2E-02	252	<0.1 / 18	-- --	--	--	--	Pesticide
2,4,6-Trichlorophenol; $C_6H_3Cl_3O$	88-06-2	197.5	SVOC	1.1E-03	245	<1 / 21	-- --	--	--	--	Pesticide
Triethylamine; $C_6H_{15}N$	121-44-8	101.2	VOC	54.0	90	Soluble	-- --	--	33.8	Polar	Reactive (?)[8] ; strong base
Trifluralin; $C_{13}H_{16}F_3N_3O_4$	1582-09-8	335.3	SVOC	1.0E-04	140/4.2 mm	<0.1 / 22.5	-- --	--	--	--	Pesticide
2,2,4-Trimethyl pentane; C_8H_{18}	540-84-1	114.0	VOC	40.6	99	Insoluble	-- --	--	39.2	Non-Polar	--
Vinyl acetate; $C_4H_6O_2$	108-05-4	86.0	VOC	83.0	72	Insoluble	aab 1-7d	--	22.2	Polar	--
Vinyl bromide (bromoethene); C_2H_3Br	593-60-2	107.0	VVOC	1100.0	16	Insoluble	aab 28-180d	9-94h	18.9	Non-Polar	--
Vinyl chloride (chloroethene); C_2H_3Cl	75-01-4	62.5	VVOC	3200.0	-14	Slightly soluble	aab 28-168d	10-97h	15.5	Non-Polar	--
Vinylidene chloride (1,1-dichloroethylene); $C_2H_2Cl_2$	75-35-4	97.0	VVOC	500.0	32	5-10 / 21	aab 28-168d	10-99h	20.4	Non-Polar	--
Xylene (isomer mixture); C_8H_{10}	1330-20-7	106.2	VOC	6.7	142	<1 / 22	aab 7-28d	3-44h	36.1	Non-Polar	--
o-Xylene; C_8H_{10}	95-47-6	106.2	VOC	5.0	144	Insoluble	aab 7-28d	4-44h	35.8	Non-Polar	--

Table B-1. Results of the Survey of Chemical and Physical Properties of the 188 HAPs

Compound	CAS No.	MW	Compound Class[1]	VP[2] (mm Hg/ 25°C)	BP[2] (°C)	Water Solubility[3] (g/L at °C)	Reactivity & $t_{1/2}$ Range[13]			Polarizability[1]	Other[15]	Comment
							Aqueous[14]		Air			
m-Xylene; C_8H_{10}	108-38-3	106.2	VOC	6.0	139	Insoluble	--	--	--	--	--	--
p-Xylene; C_8H_{10}	106-42-3	106.2	VOC	6.5	138	Insoluble	aab	7-28d	4-42h	36.0	Non-Polar	--
Antimony Compounds: particulate	--	--	NVINC	1 mm / 574°C	656 °C (mp)	Insoluble	--	--	--	--	--	VP and MP for antimony trioxide[2c]; Volatile forms exist, e.g., stibene, SbH_3
Arsenic compounds: Arsine, AsH_3	7784-42-1	78.0	VVINC	> 760	-63	20 mL / 100 cc cold water	--	--	--	--	--	--
Particulate	--	--	NVINC	1 mm / 212°C	313 (mp)	Insoluble	--	--	--	--	--	VP and MP given for arsenic trioxide[2c]
Beryllium compounds: particulate	--	--	NVINC	--	--	Insoluble	--	--	--	--	--	--
Cadmium compounds: particulate	--	--	NVINC	1 mm / 1000°C	--	Insoluble	--	--	--	--	--	VP given for cadmium oxide[2c]
Chromium compounds: particulate	--	--	NVINC	--	--	Insoluble	--	--	--	--	--	Semi-volatile forms can also exist in air, e.g., $Cr(CO)_6$
Cobalt compounds: particulate	--	--	NVINC	--	--	Insoluble	--	--	--	--	--	Semi-volatile forms can also exist in air, e.g., $Co(CO)_4$

Table B-1. Results of the Survey of Chemical and Physical Properties of the 188 HAPs

Compound	CAS No.	MW	Compound Class[1]	VP[2] (mm Hg/ 25°C)	BP[2] (°C)	Water Solubility[3] (g/L at °C)	Reactivity & $t_{1/2}$ Range[13]		Polarizability[1]	Other[15]	Comment
							Aqueous[14]	Air			
Coke Oven Emissions: Naphthalene; $C_{10}H_{18}$	91-20-3	128.2	SVOC	8.7E-02	218	Insoluble	--	--	--	--	--	Emissions include VOCs, e.g., benzene, toluene , xylenes
Coronene	191-07-1	300.4	NVOC	1.5E-12	525	Insoluble	--	--	--	--	--	--
Cyanide Compounds: Hydrogen Cyanide; HCN	74-90-8	27.0	VVINC	630.0	26	Soluble	--	--	--	--	--	--
Particulate	--	--	NVINC	--	--	Insoluble	--	--	--	--	--	--
Glycol ethers	--	76.1 - 206.3	SVOC/VOC	0.022 to 10.9	120 - 249	10 - 100 / 22 °C	--	--	--	--	--	--
Lead compounds: particulate	--	--	NVINC	1 mm / 943°C	890 (mp)	Insoluble	--	--	--	--	--	VP and MP given for lead oxide[2c]
Manganese compounds: particulate	--	--	NVINC	--	--	Insoluble	--	--	--	--	--	--
Mercury Compounds: Mercury Vapor	7439-97-6	200.6	SVINC	0.0012 mm/ 20°C	356	--	--	--	--	--	--	--
Particulate	--	--	NVINC	--	--	Insoluble	--	--	--	--	--	--
Fine mineral fibers (incl. glass)	--	--	NVINC	--	--	Insoluble	--	--	--	--	--	--
Nickel compounds: particulate	--	--	NVINC	---	--	Insoluble	--	--	--	---	--	Volatile forms can also exist briefly in air, e.g., $Ni(CO)_4$
Polycyclic Organic Matter: Naphthalene; $C_{10}H_{18}$	91-20-3	128.2	SVOC	8.7E-02	218	Insoluble	--	--	--	--	--	PAH
Coronene	191-07-1	300.4	NVOC	1.5E-12	525	Insoluble	--	--	--	--	--	PAH

Table B-1. Results of the Survey of Chemical and Physical Properties of the 188 HAPs

Compound	CAS No.	MW	Compound Class[1]	VP[2] (mm Hg/ 25°C)	BP[2] (°C)	Water Solubility[3] (g/L at °C)	Reactivity & $t_{1/2}$ Range[13]		Polarizability[1]	Other[15]	Comment
							Aqueous[14]	Air			
Radionuclides: Various (particulate and gaseous)	10043-92-2	--	NVINC	--	--	--	-- --	--	--	--	Reactive (?)[8]
Radon; Rn-222	14859-67-7	222.0	VVINC	--	-62	224 cc	-- --	--	--	--	Noble gas
Selenium compounds: particulate	--	--	NVINC	1 mm / 157°C	340 (mp)	Insoluble	-- --	--	--	--	VP and MP given for selenium dioxide[2c]

Footnotes:

[1] Compound Classes:

VVOC = Very Volatile Organic Compounds (Vapor Pressure at 25°C >380 mm Hg)
VVINC or Gases = Very Volatile Inorganic Compounds (Vapor Pressure at 25°C >380 mm Hg)
VOC = Volatile Organic Compounds (1.0E-01< Vapor Pressure at 25°C <380 mm Hg)
VINC or Gases = Volatile Inorganic Compounds (1.0E-01< Vapor Pressure at 25°C <380 mm Hg)
SVOC = Semi-Volatile Organic Compounds (1.0E-07< Vapor Pressure at 25°C <1.0E-01 mm Hg)
SVINC = Semi-Volatile Inorganic Compounds (1.0E-07< Vapor Pressure at 25°C <1.0E-01 mm Hg)
NVOC = Non-Volatile Organic Compounds (Vapor Pressure at 25°C < 1.0E-07 mm Hg)
NVINC = Non-Volatile Inorganic Compounds (Vapor Pressure at 25°C < 1.0E-07 mm Hg)

[2] Vapor Pressure (VP) and Boiling Point (BP)/Melting Point (MP) data from:

(a) D.L. Jones and J. Bursey, "Simultaneous Control of PM-10 and Hazardous Air Pollutants II: Rationale for Selection of Hazardous Air Pollutants as Potential Particulate Matter, "Report EPA-452/R-93/013, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 1992.

(b) R.C. Weber, P.A. Parker, and M. Bowser, Vapor Pressure Distribution of Selected Organic Chemicals, Report EPA-600/2-81-021, U.S. Environmental Protection Agency, Cincinnati, OH, February 1981.

(c) R.C. Weast, ed., "CRC Handbook of Chemistry and Physics," 59th edition, CRC Press, Boca Raton, 1979.

[3] Solubility data from (unless otherwise indicated):

D. Mackay, W.Y. Shui, and K.C. Ma, "Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals: Volume III Volatile Organic Chemicals," Lewis Publishers, Ann Arbor, MI, 1993.

[4] Obtained from the STN International computer database (BEILSTEIN file).

[5] The Merck Index, 11th Edition, S. Budavari, ed., Merck & Co., Inc., Rahway, NJ, 1989.

[6] R.T. Morrison and R.N. Boyd, "Organic Chemistry," 2nd Edition, Allyn and Bacon, Inc., Boston, MA, 1966.

[7] From reactivity data in Table B-1.

[8] Reactive (?) or Highly Reactive (?) indicates judgment based on properties, personal communication from Robert G. Lewis, U.S. EPA, March 1994.

[9] Personal communication from Robert G. Lewis, U.S. EPA, June, 1994; cited from U.S. EPA Pesticide Reference manual.

[10] Data for 2,3,7,8-TCDD and OCDD from: "Physical-Chemical Properties of Chlorinated Dibenzo-p-dioxins", W.Y. Shiu, et al., Environmental Science Technology, 22, 651-659, 1988.

[11] "Analytical Chemistry of PCBs", M.D. Erikson, Butterworth Publ., Boston, 1986.

[12] Electronic Polarizability = $(MW/r)[n^2 - 1]/[n^2 + 2]$ from:

E. B. Sansone, Y. B. Tewari, and L. A. Jonas, Prediction of Removal of Vapors from Air by Adsorption on Activated Carbon, Environ. Sci. Technol., **13**, 1511-1513 (1979).

Values for molecular weight (*MW*), density (r), and refractive index (*n*) are taken from:

(a) R. C. Weast, ed., "CRC Handbook of Chemistry and Physics," 59th edition, CRC Press, Boca Raton, 1979.

(b) L. H. Keith and M. M. Walker, eds., "EPA's Clean Air Act Air Toxics Database: Air Toxics Chemical and Physical Properties," Vol. II, Lewis Publishers, Boca Raton, 1993.

[13] Reactivity and Half-Life data from:

(a) P. H. Howard, R. S. Boethling, W. F. Jarvis, M. W. Meylan, and E. M. Michalenko, "Handbook of Environmental Degradation Rates," Lewis Publishers, Boca Raton, 1991.

(b) C. W. Spicer, A. J. Pollack, T. J. Kelly and R. Mukund, "A Literature Review of Atmospheric Transformation Products of Clean Air Act Title III Hazardous Air Pollutants,

Final Report to U.S. EPA, Contract No. 68-D80082, Battelle, Columbus, Ohio, July 1993. The reactivity parameter for air is the atmospheric half-life.

[14] aab = aqueous aerobic biodegradation; ah = aqueous hydrolysis

[15] Customary classification of VOCs as either Nonpolar or Polar.

Discussion of Polarizability and Water Solubility Characteristics of Polar Volatile Organic Compounds

Volatile organic compounds (VOCs) in air consist largely of hydrocarbons and oxygenated hydrocarbons, as well as some nitrogen- and sulfur-containing compounds. The oxygenated hydrocarbons, in turn, consist of several compound classes, including alcohols, aldehydes, ketones, ethers, carboxylic acids, etc. For analytical purposes, airborne organic compounds may be considered as either nonpolar (i.e., hydrocarbons) or polar (i.e., compounds containing oxygen, sulfur, nitrogen, etc.).

Nonpolar VOCs can be characterized at the part-per-billion by volume (ppbv) level using currently available methods. However, polar VOCs tend to be difficult to sample and analyze at trace levels because of their chemical reactivity, affinity for metal and other surfaces, and solubility in water. Because polar VOCs include compound classes generally associated with higher polarizabilities, we have investigated the general classification of the VOCs of interest as a function of electronic polarizability (molar refractivity). Polarizabilities were calculated from the relationship:

$$\textit{Molar Refractivity} = \frac{MW}{\rho}\,\frac{n^2-1}{n^2+2}$$

where MW = molecular weight; ρ = density; and n = refractive index. Figure B-1 shows the data generated in this way for the VOCs. This plot ranks the VOCs that are customarily identified as either nonpolar (N) or polar (P) compounds as a function of their electronic polarizability. Figure B-1 shows that the N and P compounds are well mixed in the ranking by polarizability. It is clear from this plot that there is no clear distinction between the N and P compounds, based on polarizability, as both groups of compounds are distributed over the entire polarizability range.

Because of the collection and analysis problems known to be associated with the water solubility of certain VOCs, we also ranked the VOCs on the basis of their solubility in water at 25°C. The most useful literature compilations found were those of Keith and Walker (1993) and Mackay et al. (1993) (see references 10 and 11 in the body of this report). As Coutant has

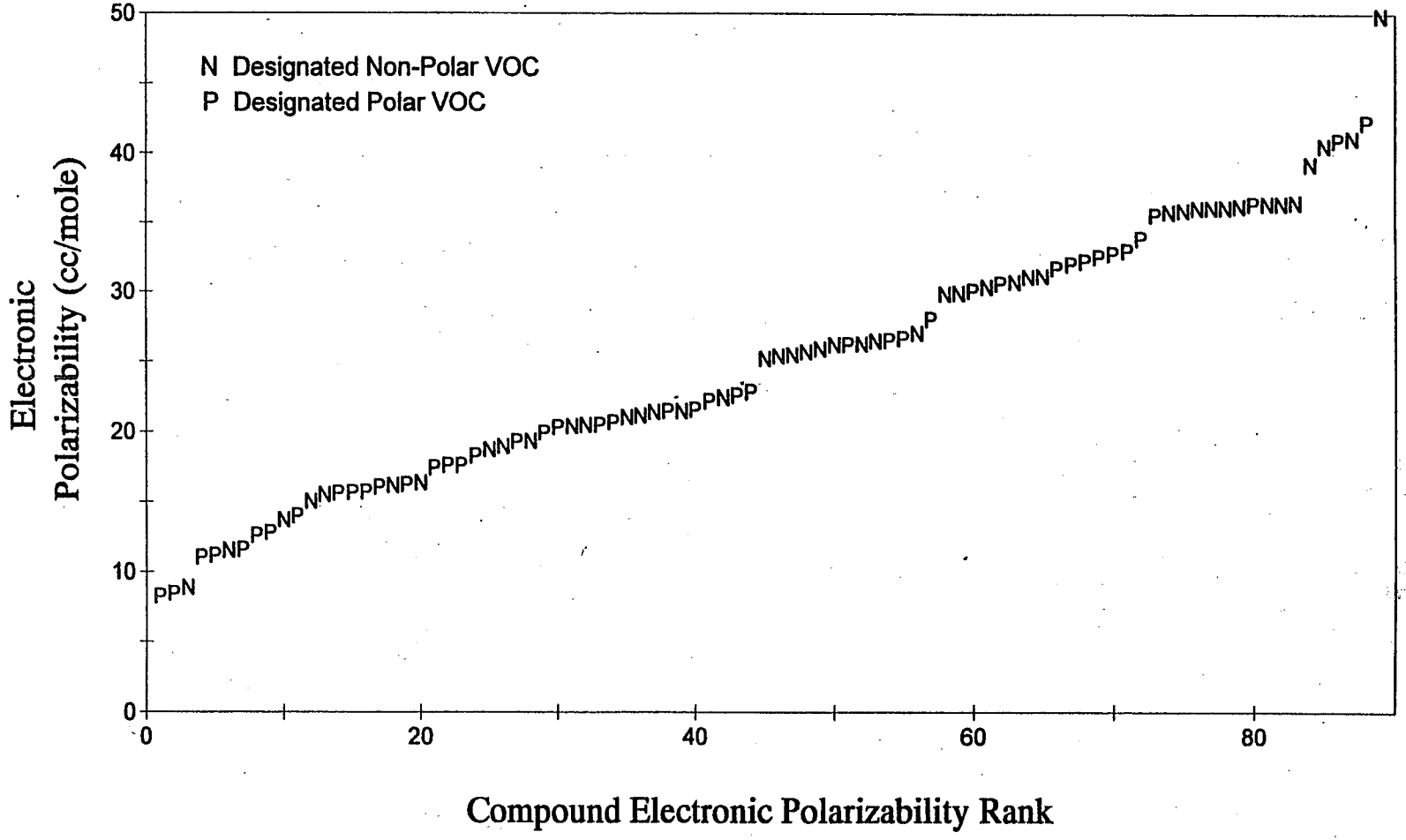

Figure B-1. Distribution of electronic polarizabilities for Volatile Organic Compounds (VOCs) on the HAPs list.

already noted (reference 24), in many cases values reported for the same compound in the literature differ widely; in many other cases, only solubility ranges are available. As a result, we have been forced to group several compounds or make selections based on chemical similarity with other compounds on the target compound list. We have also conducted several literature searches, using the STN computer data base, for solubility data on individual VOCs. Figure B-2 shows a plot ranking the VOCs as a function of their water solubility. Here, it is seen that compounds that have conventionally been identified as nonpolar VOCs are characterized by relatively low water solubilities, whereas compounds that are generally regarded as polar VOCs are characterized by relatively high water solubilities. Classifying VOCs on the basis of their solubility in water therefore provides a more realistic distinction between polar and nonpolar compounds than does classification on the basis of polarizability.

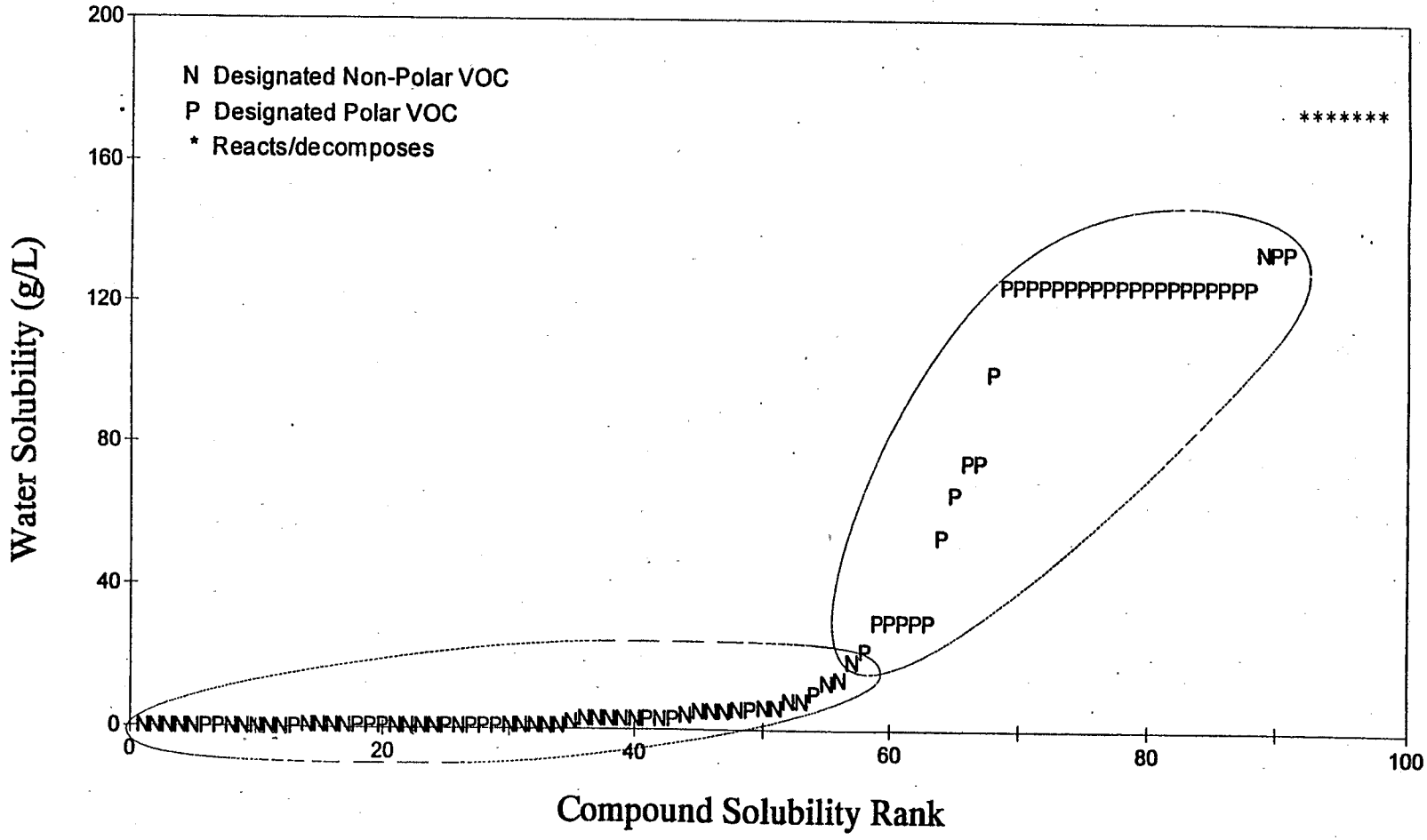

Figure B-2. Distribution of water solubilities for Volatile Organic Compounds (VOCs) on the HAPs list.

Appendix C
Listing of the 188 HAPs by Volatility Classes

Table C-1. HAPs grouped by class of compounds, listed in alphabetical order

VVOCs (*Total of 15 HAPs*) **(VP25°C > 380 mm Hg)**	**VOCs (*Total of 82 HAPs*)** **(0.1mm Hg < VP25°C < 380 mm Hg)**	N-Nitrosodimethylamine
		N-Nitrosomorpholine
		Phenol
		1,3-Propane sultone
		beta-Propiolactone
Acetaldehyde	Acetonitrile	Propionaldehyde
1,3-Butadiene	Acetophenone	Propylene dichloride
Carbonyl sulfide	Acrolein	1,2-Propylenimine
Diazomethane	Acrylamide	Styrene
Ethyl chloride	Acrylic acid	Styrene oxide
Ethylene oxide	Acrylonitrile	1,1,2,2-Tetrachloroethane
Formaldehyde	Allyl chloride	Tetrachloroethylene
Methyl bromide	Aniline	Toluene
Methyl chloride	Benzene	1,2,4-Trichlorobenzene
Methyl iodide	Benzyl chloride	1,1,2-Trichloroethane
Phosgene	Bis (chloromethyl) ether	Trichloroethylene
Propylene oxide	Bromoform	Triethylamine
Vinyl bromide	Carbon disulfide	2,2,4-Trimethylpentane
Vinyl chloride	Carbon tetrachloride	Vinyl acetate
Vinylidene chloride	Catechol	Xylene (mixed isomers)
	Chloroacetic acid	o-Xylene
	Chlorobenzene	m-Xylene
	Chloroform	p-Xylene
	Chloromethyl methyl ether	Ethylene dichloride
		Ethyleneimine
	Chloroprene	Ethylidene dichloride
	Cresol/Cresylic acid (mixed isomers)	Hexachlorobutadiene
		Hexachloroethane
	o-Cresol	Hexane
	Cumene	Isophorone
	1,2-Dibromo-3-chloropropane	Methanol
		Methyl chloroform
	1,4-Dichlorobenzene	Methyl ethyl ketone
	Dichloroethyl ether (Bis[2-chloroethyl]ether)	Methylhydrazine
		Methyl isobutyl ketone
	1,3-Dichloropropene	Methyl isocyanate
	Diethyl sulfate	Methyl methacrylate
	N,N-Dimethylaniline	Methyl tert-butyl ether
	Dimethylcarbamoyl chloride	Methylene chloride
		Nitrobenzene
	N,N-Dimethylformamide	2-Nitropropane
	1,1-Dimethylhydrazine	N-Nitroso-N-methylurea
	Dimethyl sulfate	N-Nitrosodimethylamine
	1,4-Dioxane	N-Nitrosomorpholine
	Epichlorohydrin	Phenol
	1,2-Epoxybutane	1,3-Propane sultone
	Ethyl acrylate	beta-Propiolactone
	Ethylbenzene	Propionaldehyde
	Ethyl carbamate	Propylene dichloride
	Ethylene dibromide	1,2-Propylenimine
	Ethylene dichloride	Styrene
	Ethyleneimine	Styrene oxide
	Ethylidene dichloride	1,1,2,2-Tetrachloroethane
	Hexachlorobutadiene	Tetrachloroethylene
	Hexachloroethane	Toluene
	Hexane	1,2,4-Trichlorobenzene
	Isophorone	1,1,2-Trichloroethane

Table C-1. HAPs grouped by class of compounds, listed in alphabetical order

SVOCs (*Total of 63 HAPs*)
(10-7 mm Hg < VP25: C < 0.1 mm Hg)

Acetamide
4-Aminobiphenyl
o-Anisidine
Benzidine
Benzotrichloride
Biphenyl
Bis (2-ethylhexyl)phthalate
Captan
Carbaryl
Chloramben
Chlordane
2-Chloroacetophenone
Chlorobenzilate
m-Cresol
p-Cresol
2,4-D (2,4-Dichloro phenoxy-acetic acid) (incl. salts, esters)
DDE
Dibenzofurans
Dibutyl phthalate
3,3'-Dichlorobenzidine
Dichlorvos
Diethanolamine
3,3'-Dimethylbenzidine
Dimethyl phthalate
4,6-Dinitro-o-cresol (incl. salts)
2,4-Dinitrophenol
2,4-Dinitrotoluene
1,2-Diphenylhydrazine
Ethylene glycol
Ethylene thiourea
Heptachlor
Hexachlorobenzene
1,2,3,4,5,6-Hexachloro cyclohexane (all stereo isomers, including Lindane)
Hexachlorocyclo pentadiene
Hexamethylene diisocyanate
Hexamethylphosphoramide
Hydroquinone
Maleic anhydride
Methoxychlor
4,4'-Methylenediphenyl-diisocyanate
Naphthalene
4-Nitrobiphenyl
4-Nitrophenol
Parathion
Pentachloronitrobenzene
Pentachlorophenol
p-Phenylenediamine
Phthalic anhydride
Polychlorinated biphenyl
Propoxur (Baygon)
Quinoline
Quinone
2,3,7,8-Tetrachlorodibenzop-dioxin
Toluene-2,4-diamine
2,4-Toluene diisocyanate
o-Toluidine
Toxaphene (chlorinated camphene)
2,4,5-Trichlorophenol
2,4,6-Trichlorophenol
Trifluralin
Coke Oven Emissions
Glycol ethers
Polycyclic Organic Matter

Table C-1. HAPs grouped by class of compounds, listed in alphabetical order

NVOCs (*Total of 5 HAPs*) **(VP25°C < 10-7 mm Hg)** 2-Acetylaminofluorene 3,3'-Dimethoxybenzidine 4-Dimethylaminoazobenzene 4,4'-Methylenebis- (2-chloroaniline) 4,4'-Methylenedianiline **VVINCs (*Total of 6 HAPs*)** **(VP25°C > 380 mm Hg)** Chlorine Hydrogen fluoride (Hydrofluoric acid) Phosphine Arsenic Compounds (Inorganic including arsine) Cyanide Compounds Radionuclides (including radon) **VINCs (*Total of 3 HAPs*)** **(0.1mm Hg < VP25°C < 380 mm Hg)** Hydrazine Hydrochloric acid (Hydrogen chloride) Titanium tetrachloride **SVINCs (*Total of 2 HAPs*)** **(10-7 mm Hg < VP25°C < 0.1 mm Hg)** Phosphorus Mercury Compounds	**NVINCs (*Total of 12 HAPs*)** **(VP25°C < 10-7 mm Hg)** Asbestos Calcium cyanamide Antimony Compounds Beryllium Compounds Cadmium Compounds Chromium Compounds Cobalt Compounds Lead Compounds Manganese Compounds Fine mineral fibers Nickel Compounds Selenium Compounds

Note: A number of HAPs can be categorized in more than one compound class, e.g. mercury compounds in vapor and particulate forms (SVINC and NVINC). In such cases, the HAPs have been assigned in this table based on the vapor pressure of the most volatile species present in ambient air. Thus, for example, mercury compounds have been assigned to the SVINC category using this rationale, although they are present in ambient air in both SVINC and NVINC forms.

TECHNICAL REPORT DATA

(PLEASE READ INSTRUCTIONS ON THE REVERSE BEFORE COMPLETING)

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

THIS FINAL REPORT DESCRIBES WORK CONDUCTED BY BATTELLE TO IDENTIFY AMBIENT AIR MEASUREMENT METHODS FOR THE 188 HAZARDOUS AIR POLLUTANTS (HAPS) DESIGNATED IN TITLE III OF THE CLEAN AIR ACT AMENDMENTS OF 1990. THE MAIN OBJECTIVE OF THIS STUDY WAS TO DOCUMENT THE STATE OF DEVELOPMENT OF MEASUREMENT METHODS FOR EACH OF THE 188 HAPS IN AMBIENT AIR. THIS REPORT IS ESSENTIALLY AN UPDATE OF THE MEASUREMENT METHODS REVIEW PREVIOUSLY CONDUCTED IN 1993 FOR THE U.S. EPA (AMBIENT MEASUREMENT METHODS AND PROPERTIES OF THE 189 CLEAN AIR HAZARDOUS AIR POLLUTANTS - NTIS NO: PB95-123923). THE CURRENT HAPS LIST CONTAINS 188 COMPOUNDS-CAPROLACTAM HAS BEEN REMOVED FROM THIS LIST.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI FIELD/GROUP
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