A SURVEY OF MONITORING INSTRUMENTS FOR MEASUREMENT OF AIRBORNE POLLUTANTS

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NEW YORK STATE
ENERGY RESEARCH AND
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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

What follows is the final report for the Ambient and Indoor Monitoring Survey, Contract number 500-99-013, Work Authorization 24, conducted by Clarkson University. The report is entitled *A Survey of Monitoring Instruments for Measurement of Airborne Pollutants.* This project contributes to the PIER Energy-Related Environmental Research program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

Executive Summary

The overall goal of the Survey of Monitoring Instruments for Measurement of Airborne Pollutants project was to survey the monitoring instruments used to measure airborne pollutants, to determine their ability to meet the needs of California's decision makers and air regulators.

Objectives

This project addresses two PIER program objectives. It (1) improves the environmental, public health, and safety impacts of power generation, and (2) supports the judicious use of distributed generation (DG) technologies, which can increase electricity system reliability and quality.

Currently, power plant siting determinations are based on existing ambient air monitors and meteorological sites that may be located miles from the site of the proposed project. These monitoring and meteorological data are used to estimate ambient air quality in the siting location and surrounding area, as well as to evaluate the potential impact of the proposed power plant on the site and surrounding area. This approach can be problematic, because ambient air quality levels have tremendous spatial and temporal variation and are difficult to interpret. Moreover, routine air quality measurement devices are expensive and require trained technicians to operate. These limitations hinder our ability to identify areas disproportionately affected by air pollution (i.e., environmental justice (EJ) communities) and to determine the air quality impacts of new sources (e.g., power plants)—particularly for DG technologies.

More and better air quality data are needed for power plant siting cases, to evaluate the air quality impacts of DG, and to address EJ concerns. Current monitors are too expensive to purchase, install, and maintain to provide the desired air monitoring coverage. The use of portable monitors may improve the data available for power plant siting cases, EJ concerns, local community monitoring, and indoor/personal exposures, while significantly reducing the cost of obtaining monitoring data. An increased use of advanced DG will affect outdoor, indoor, and personal exposures, and portable monitoring technologies with low power requirements are needed to measure these exposures.

This study surveyed monitoring methods currently available and in development. It also identified instruments and technologies suitable for use in ambient and indoor air monitoring. The pollutants of concern included those on the Photochemical Assessment Monitoring Stations (PAMS) list (i.e., particulate matter (PM_{10} and $PM_{2.5}$), carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and voltaic organic carbons (VOCs)); toxic air contaminants, such as those on the California Air Resources Board (ARB) Toxic Air Contaminant List; particle-bound elemental carbon (EC) and organic carbon (OC); and other PM components.

Outcomes

The survey identified the strengths and weaknesses of a host of monitoring instruments. The conclusions and recommendations for each of the areas surveyed are described below.

Conclusions, Recommendations, and Benefits to California

Much new monitoring system development has focused on the measurement of PM mass and constituents. For PM mass, difficult questions remain about the loss of semivolatile components from $PM_{2.5}$. The Federal Reference Method (FRM) is the basis for determining for National Ambient Air Quality Standards (NAAQS) attainment, but it does not necessarily provide an accurate estimate of the airborne particle mass. A variety of continuous monitoring designs are being tested, including the differential Tapered Element Oscillating Microbalance (TEOM®), the Filter Dynamics Measurement System (FDMS™), and the Continuous Aerosol Mass Monitor (CAMM). At this time, there needs to be further monitor testing and refinement, but this is a need for further development, rather than additional research or other new concepts. It is the responsibility of the vendors to provide a better-defined measurement method to the measurement community.

At this time, there are adequate ambient monitoring systems to measure particulate and gaseous nitrate, although they are neither portable nor inexpensive. The speciation network samplers use annular denuders to separate the gaseous nitric acid (HNO_3) from the particulate nitrate. By capturing the particles on a base-impregnated fiber filter or a Nylasorb® filter, the nitrate is retained on the filter until it is leached from it for analysis. It is labor-intensive to collect and analyze the filters from this system, and it provides only multihour (typically 24-hour) data.

Given the nature of emissions that are likely to arise from DG facilities, there is a need for new systems to measure NO_2 and gaseous NO_y, fine particles, and carbon. There are current research methods for NO_2 and NO_y measurement, but they are complex and difficult to use. The current standard network NO_2 monitors suffer from significant interference from NO_y, and new systems are needed for making the measurements required to manage ozone concentrations.

Currently, it is possible to measure particle size distributions effectively, but at high cost and with a complex measurement system. It is possible to obtain particle size distributions with existing systems at typical ambient concentrations, and such measurements are routine in remote areas. Thus, the existing systems have adequate sensitivity for the measurements typically needed. However, with the increasing interest in particle number as a potential indicator for exposure—particularly with respect to the health effects of ultrafine particles—there is a need for smaller, less expensive particle counters, especially if size information can also be obtained.

There are still many uncertainties with respect to the measurement of particulate carbon species. It is expensive to collect and analyze a large number of samples for the identification and quantification of specific organic compounds. In order to use current methods, it is necessary to collect a large mass of material, which increases the difficulty of making indoor or personal measurements. Therefore, other aspects of the carbonaceous aerosol are measured in order to provide information on the possible origins of the particles. There have recently been monitors that purport to measure "diesel," polycyclic aromatic hydrocarbons (PAH), or environmental tobacco smoke (ETS). The value of ultraviolet (UV) light absorption or photoionization for specific identification of diesel emissions or ETS is not yet clear, and more work on the value of these methods is needed. New, portable OC/EC measurement systems are available, but expensive. There is a need for better personal and indoor measurements of exposure to carbonaceous particles. However, a major part of this problem is that the discussion has been framed by what the current carbon techniques measure, rather than by defining what information might be useful to air quality managers in terms of decision making.

Sufficient attention has not been paid to the measurement of VOCs at concentrations typically encountered in home or office environments. Passive adsorptive badges are available for personal or indoor measurements at the high concentrations typically encountered in industrial workspaces. However, there is not yet an adequate capability to provide comparable monitoring in home and commercial spaces, unless the measurements are made over an extended time period. Because temporal information is often useful in identification of sources and exposure patterns, improved measurement methods are needed.

Although monitoring methods have improved substantially, there remain important problems with monitoring systems—particularly with respect to cost, sensitivity, and selectivity—that need to be resolved. Once these issues are resolved, these monitors can be deployed widely throughout California to make the indoor and personal measurements necessary to obtain exposure information that decision makers need to better assess potential health impacts for siting cases, EJ reviews, and the increased use of DG technologies.

Abstract

More and better air quality data are needed for power plant siting cases, to evaluate the air quality impacts of distributed generation (DG) technologies, and to address environmental justice (EJ) concerns. Current monitors are too expensive to purchase, install, and maintain to provide the desired air monitoring coverage. The use of portable monitors may improve the data available for these applications, while significantly reducing the cost of obtaining monitoring data. An increased use of DG will affect outdoor, indoor, and personal exposures; and portable monitoring technologies with low power requirements are needed to measure these exposures.

This report surveys monitoring methods currently available and in development, and identifies instruments and technologies suitable for use in ambient and indoor air monitoring. It focuses on measurement of particulate matter (PM) mass and constituents, gaseous nitrate, nitrogen dioxide (NO_2) and gaseous NO_y, particle size distributions, particulate carbon species, and volatile organic compounds (VOCs). The pollutants of concern include those on the Photochemical Assessment Monitoring Stations (PAMS) list, toxic air contaminants, particle-bound elemental carbon and organic carbon; and other particulate matter components.

This effort concluded that there remain important problems with monitoring systems—particularly with respect to cost, sensitivity, and selectivity. Specifically, there needs to be further refinement of existing PM mass and constituent monitoring; cheaper and more portable particulate and gaseous nitrate measurement; simplification of NO_2 and NO_y measurement; simplification and reduced cost of particle size distribution measurement; reduced uncertainty of particulate carbon species measurement; and improved home and commercial VOCs monitoring.

1.0 Introduction

1.1. Background

Currently, power plant siting determinations are based on existing ambient air monitors and meteorological sites that may be located miles from the site of the proposed project. These monitoring and meteorological data are used to estimate ambient air quality in the siting location and surrounding area, as well as to evaluate the potential impact of the proposed power plant on the site and surrounding area. This approach can be problematic, because ambient air quality levels have tremendous spatial and temporal variation and are difficult to interpret. Moreover, routine air quality measurement devices are expensive and require trained technicians to operate. These limitations hinder our ability to identify areas disproportionately affected by air pollution (i.e., environmental justice (EJ) communities) and to determine the air quality impacts of new sources (e.g., power plants)—particularly for distributed generation (DG) technologies.

More and better air quality data are needed for power plant siting cases, to evaluate the air quality impacts of DG, and to address EJ concerns. Current monitors are too expensive to purchase, install, and maintain to provide the desired air monitoring coverage. The use of portable monitors may improve the data available for power plant siting cases, EJ concerns, local community monitoring, and indoor/personal exposures, while significantly reducing the cost of obtaining monitoring data.

Advanced electricity generation from DG technologies will affect indoor and personal exposures. The measurement of these exposures requires portable technologies with low power needs, so that they can be used at any location. There has only been limited development and commercialization of relatively inexpensive devices that can be used by the general public (e.g., passive monitoring badges, portable samplers).

Ideally, the desired ambient and indoor air monitoring system would have the following characteristics:

- Portable and suitable for collecting measurement in a variety of locations
- Rugged
- Real-time
- Require no laboratory analysis
- Automatically record on a data logger capable of interfacing with a personal computer
- Be accurate across the full range of expected concentrations (indoor and outdoor)
- Be considerably less expensive compared to current technology
- Be free of interference from other air pollutants
- Show performance commensurate with the standardized and accepted monitoring methods currently in use
- Be easily deployed and operated by a non-technical person
- Have modest electrical power requirements (e.g., battery-operated or low power demand)

This survey has been prepared for the California Energy Commission (Commission) and the New York State Energy Research and Development Authority (NYSERDA) to identify instruments and technologies suitable for use in an ambient and indoor air monitoring. This survey reviews three aspects of monitoring instruments:

1. Current instruments and technologies (both commercial and research grade)
2. Instruments and technologies under development (identifying their stage of development and the developer)
3. Instruments and technology gaps (including organizations that have the expertise to develop instruments and technologies to address those gaps)

The pollutants of concern include those on the Photochemical Assessment Monitoring Stations (PAMS) list (i.e., particulate matter (PM_{10} and $PM_{2.5}$), carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and voltaic organic carbons (VOCs)); toxic air contaminants, such as those on the California Air Resources Board (ARB) Toxic Air Contaminant List; particle-bound elemental carbon (EC) and organic carbon (OC); and other PM components. Appendix I lists the companies that were queried or whose Web sites were examined for this report.

1.2. Information Gathering

To compile the survey, the authors sent inquiries to the individuals and companies listed in Table 1, indicated the nature of the survey, and requested information regarding instruments that the respondents considered likely to be available in the near future.

Table 1 . List of Individuals and Companies Included in the Survey

Company	Location	Instruments/Technologies
Rupprecht & Patashnick	Albany, NY	Particle measurement instruments
TSI, Inc	St. Paul, MN	Particle measurement instruments
Alan Rossner Clarkson University	Potsdam, NY	Personal VOC sampling canister
Dr. C. Sioutas University of Southern California	Los Angeles, CA	Personal particle impactor
Dr. P. Koutrakis Harvard School of Public Health	Boston, MA	Personal multipollutant monitor
Dr. D. Leith University of North Carolina	Chapel Hill, NC	Passive personal particle monitor
Dr. J. Stetter Illinois Institute of Technology	Chicago, IL	Electrochemical monitors
Thermo Andersen	Smyrna, GA	Particle monitors; HAPS samplers
Aerosol Dynamics, Inc.	Berkeley, CA	Particle monitors
MSP, Inc.	Minneapolis, MN	Particle samplers
SKC, Inc.	Eighty Four, PA	Industrial hygiene and indoor air instruments
Quest Technologies, Inc.	Oconomowoc, WI	Industrial hygiene and indoor air instruments

An extensive search of the Internet identified additional potential devices and vendors.

1.3. Report Organization

The report is organized in sections that deal with the mass classes of species to be monitored: particles, gases other than organic compounds, and VOCs. Each section is further divided into fixed-site monitors and indoor and/or personnel monitors. Appendix I provides a complete list of vendors and contact information. Appendix II summarizes the capabilities of commercially available systems.

2.0 Particulate Matter Measurements

2.1. Mass Measurements, Fixed Site

2.1.1. Gravimetric, Filter-Based

A major problem with the measurement of airborne particulate mass concentrations is that they are complex mixtures of nonvolatile and semi-volatile materials. Although mass is thought to be a fundamental property of a material, in the case of particles, it is really an operationally defined quantity. In other words, the mass concentration is what is obtained as a result of the measurement process. Because different measurement processes will give rise to different results, there is no absolute comparison standard against which to compare techniques. The National Ambient Air Quality Standard (NAAQS) defined a Federal Reference Method (FRM) for $PM_{2.5}$ that provides relatively high precision, but totally unknown accuracy. That is, side-by-side samplers will produce very similar mass concentration measurements, but the values may be quite different from the actual concentrations of condensed matter suspended in the atmosphere. Because it is defined by regulation to be the basis of attainment or non-attainment decisions with respect to the standard, it has become the basis of comparison with other methods.

Mass measurements have traditionally involved passage of air through a filter, resulting in a variety of positive and negative artifacts. The samples are collected over a 24-hour period and because of the high cost of equilibrating, weighing, deploying, retrieving, re-equilibrating, and reweighing the filter, measurements are only required to be made every third day. The FRM protocol only requires 75% data capture, so attainment decisions can be made on <25% of the possible data that could be obtained if continuous measurement methods were available. As a result, only limited data are available for health studies and implementation purposes.

As a result of a decision by the Third Circuit of the U.S. Court of Appeals that was not disputed by the U.S. Environmental Protection Agency (EPA), the 1997 PM_{10} standard was invalidated. Currently, the 1987 standard remains in place, but it is clear that the EPA intends to promulgate a coarse-particle standard and has been discussing a $PM_{(10-2.5)}$ standard that will likely be proposed in the Staff Paper for Particulate Matter that the EPA Office of Air Quality Planning and Standards will present to the Clean Air Scientific Advisory Committee for review in the summer of 2003. However, California has set a state standard for PM_{10} that is more stringent than the 1987 NAAQS for PM_{10} that remains in effect until the new coarse particle standard is promulgated. The initial proposal for a FRM for a $PM_{(10-2.5)}$ fraction was to utilize two side-by-side samplers. One would use the current FRM for $PM_{2.5}$ and the other would use a $PM_{2.5}$ FRM with the Well Impactor Ninety-Six (WINS) impactor removed to make it a PM_{10} sampler. However, EPA is now reviewing other alternative technologies for making these measurements.

A new dichotomous sampler with volumetric flow control has been developed by Rupprecht & Patashnick (R&P). This sampler has been tested in a recent study (Poor et al. 2002) and compared well with the $PM_{2.5}$ FRM in one city. This sampler has not been tested for its ability to measure $PM_{(10-2.5)}$. The EPA is making additional field tests through the spring of 2003.

2.1.2. Continuous Mass Measurements

2.1.2.1. Commercial Systems

In addition to the FRM samplers listed in Appendix II, various "continuous" mass monitors have been developed. These systems are really semi-continuous, because there are integration periods necessary to provide a measurement with an acceptable level of measurement uncertainty. The appropriate quantity that these monitoring systems should measure remains unresolved. Should they attempt to mimic the FRM, should they measure the mass under a well-defined set of thermodynamic conditions, or should they attempt to measure the actual particle mass concentration that was present in the atmosphere? Various manufacturers and academic researchers have taken different approaches to address these questions.

There are two direct approaches to the measurement of aerosol mass: (1) the tapered element oscillating microbalance (TEOM®), and (2) the beta gauge. Both methods are based on basic physical principles. The TEOM operates on the theory of the vibrating reed. A vibrating reed that is anchored at one end vibrates with a single frequency, with no harmonics. Thus, as mass is added to one end of the vibrating element, the resonant frequency changes, and this change is directly proportional to the accumulated mass. In the beta gauge, the passage of electrons through a material is attenuated by the presence of the areal mass concentration between the radioactive source and the detector.

There are also indirect mass methods. In the Continuous Aerosol Mass Monitor (CAMM) method, the pressure drop across a pore-type filter increases with increasing mass loading within a limited range of particle sizes. Thus, after a period of time, the change in pressure drop across the filter can be related to the amount of accumulated particle mass. Another indirect method for fine particles is through the measurement of light scattering. Light scattering from a polydisperse aerosol is a complex phenomenon involving particle size and a refractive index. However, many of these complexities average out sufficiently that reasonable estimates of the fine particle mass can be obtained from the amount of scattered light.

In order to use these mass measurement methods, the aerosol must be conditioned in some fashion. Because we are interested in the mass primarily because there are efforts to protect public health, and water associated with the particles is not thought to pose a health risk, the "dry" mass concentration is the quantity of interest. However, it is very difficult to remove the water without removing any other semivolatile component. For the filter-based methods, water is removed by equilibration of the same with air at 35% relative humidity and 23°C for 24 hours. However, depending on the particle composition, this strategy may not thoroughly dry the sample. At the same time, semivolatile materials can evaporate during the equilibration period.

For the continuous monitors, alternative methods have been used. The initial work with a TEOM used elevated temperatures to remove the water and any other material that would be volatile at 50°C. This temperature provides a well-defined set of thermodynamic conditions, but ensures the loss of any ammonium nitrate and most high-vapor-pressure semivolatile organic constituents. To provide a sample to the sensing element without water at a lower temperature, a Nafion® drier is incorporated in the inlet line. Nafion is a material that permits small, polar gas molecules like water to pass through a membrane. These driers have been used in a number of systems. However, heating the sensing element to 30°C will still remove semivolatile components, particularly when the ambient temperature is significantly below this value.

Initial development of a continuous coarse monitor is currently under way, based on the work of Misra et al. (2001). This system has not been extensively field tested, but initial studies have been performed in Tampa, Florida. The EPA is conducting additional testing in 2003, so that it could be considered as a FRM or a Federal Equivalent Method (FEM) for $\mathrm{PM}_{(10-2.5)}$.

2.1.2.2. Developing and Research Systems

Research systems have been developed to address the shortcomings of the commercially available systems. Eatough and coworkers (Eatough et al. 2001; Pang et al. 2001, 2002a,b; Obeidi and Eatough 2002; Obeidi et al. 2002) have developed the Real-time Ambient Monitoring System (RAMS), which involves a very complicated system of denuders and driers and a dual TEOM detection system. This system is currently undergoing evaluation in comparison to other conventional and research monitoring techniques (Lewtas et al. 2001). The RAMS system is very large and complex and does not represent a practical routine monitoring tool.

The RAMS has led to the development of another differential TEOM system (Patashnick et al. 2001). This differential system uses dual electrostatic precipitators (ESP) and two ambient-temperature TEOMs connected to a common inlet and drier system. The air is split and passes through two channels, each with an ESP and a TEOM. One ESP is on and the other is off. The on/off states are switched frequently (every five minutes) so that in the *on* channel, the sampling artifacts (adsorption of organics on the filter, volatilization of materials from the deposit collected on the filter) are duplicated. Thus, the subtraction of the *on* channel from the *off* channel should provide a better estimate of the actual airborne particle masses.

From this concept, an alternative system has been developed that uses a Filter Dynamics Measurement System (FDMS)—the R&P FDMS series 8500. The FDMS instrument computes its running PM mass concentration average based upon independent measurements of the volatile and nonvolatile fractions of the ambient particulate matter. To accomplish this, the FDMS unit constantly samples ambient air and uses a switching valve to change the path of the main flow every six minutes. The sampling process consists of alternate sample and purge (filtered) air streams passing through the exchangeable filter in the TEOM mass sensor. The purge filter in the FDMS main enclosure effectively removes both organic and inorganic aerosols at 4°C. The exchangeable purge filter can provide a time-integrated sample that can be used for subsequent chemical analysis. A standard R P FRM-style molded filter cassette allows for the use of a variety of 47-mm diameter filter media as the purge filter.

The sample and purge air flows alternately pass through the exchangeable filter in the TEOM microbalance, which generates a direct measurement of the collected mass. The system automatically adjusts the mass concentration from the particle-laden air stream by referencing it to the mass change that may occur during purging. For example, if the FDMS unit measures a decrease of filter mass during the six-minute purging period, this mass decrease is added back to the mass measurement obtained with particle-laden air. Recent tests of this system by ARB have suggested it would provide satisfactory measurement of $PM_{2.5}$, with adequate correspondence to FRM measurements.

2.2. Particulate Constituent Measurements, Fixed Site

2.2.1. Commercial Instruments

One approach to obtaining continuous information on airborne particulate matter is embodied in the development of measurement systems for major constituents (nitrate, sulfate, and organic and elemental carbon). Particulate nitrate can be continuously determined using the R&P Model 8400N. This system is based on the work of Stolzenburg and Hering (2000). A $PM_{2.5}$ sharp cut cyclone (SCC) removes the larger particles from the sample stream. A bypass flow, which shortens the residence time of the sample stream in the sampling section, passes through a critical orifice. An activated charcoal denuder removes acidic gases that would otherwise interfere with the measurement of the ambient particulate nitrate concentration. The monitor collects fine particulate matter by means of critical impaction. To achieve high collection efficiencies even for very small secondary aerosols, a humidifier moistens the sample stream and causes the hygroscopic nitrate particles to grow. The remaining part of the sample stream forms a jet as it passes through a critical orifice. Particles collect on an impactor/flashing strip during the sample collection phase (which takes eight minutes by default). The sample and bypass flows then combine and exit from the instrument on their way to an external pump. The monitor purges the analysis cell with nitrogen (N_2), and then sends a high current through the impactor/flashing strip that lasts approximately 0.05 second and heats the collected particulate matter to about 350°C. The vaporization decomposition process converts the particulate nitrate contained in the collected sample to NO_x. The NO_x pulse monitor, a specially tuned chemiluminescent NO_x analyzer, quantifies the amount of NO_x generated by this process. The sulfate monitor, Model 8400S, uses a similar process, except that it uses an SO_2 monitor. Initial indications have shown that the sulfate and nitrate instruments provide reasonable results when compared to side-by-side integrated samples. Much better characterizations of these instruments will come from the EPA Supersite activities that are currently in progress.

The Aethalometer™ is an instrument that has been available for light-absorbing carbon measurements for quite some time. It was originally developed by A. Hansen and marketed by Magee Scientific, but is now distributed by Thermo Andersen. Initial models used a single wavelength light source; however, newer models use two to seven wavelengths, to better discriminate among different types of light-absorbing carbon. Absorbance at 350 nanometers (nm) appears to provide some indication of significant concentrations of polycyclic aromatic hydrocarbons (PAHs), which are often associated with diesel particles. Figure 1 shows the trace from a dual-wavelength Aethalometer.

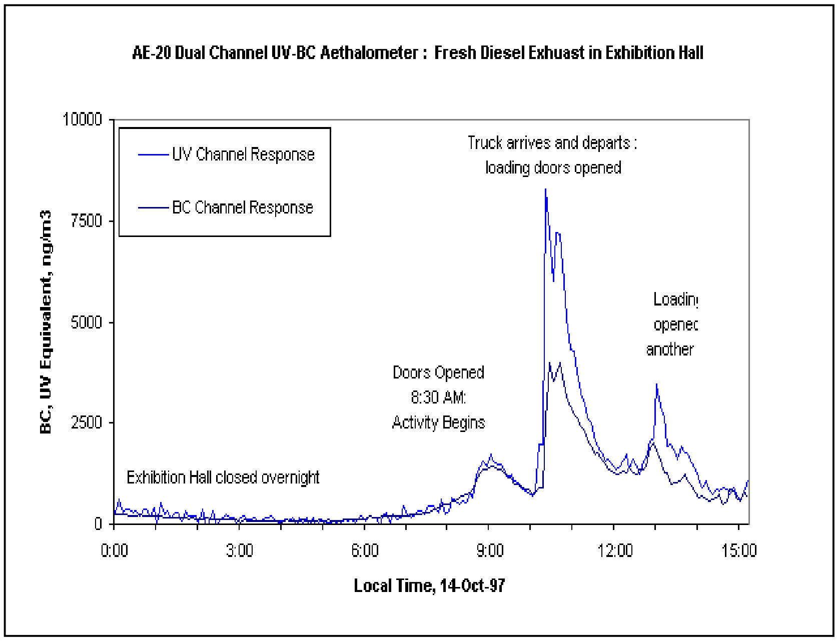

Figure 1. Traces in a Dual-Wavelength Aethalometer, Showing the Presence of Diesel Vehicle Exhaust. (*Source:* Magee Scientific Web site.)

A new device developed in Japan has just been introduced in the U.S. market by BGI, Inc. This instrument measures absorbance at 370 and 620 nm and assumes that, in indoor air, the primary source of the UV absorbance is PAH compounds associated with environmental tobacco smoke.

Another set of instruments has been developed to measure ambient PAH compounds. Ecochem Analytics has produced both a field and a hand-held monitor (models PAS 2000 and PAS 2000CE), both of which operate on the principle of photoionization. Polycyclic aromatic hydrocarbon compounds can be readily ionized by photons in the UV range, and the current generated is measured. These instruments measure PAH compounds with three or more rings and provide an estimate of the total PAH concentration.

Carbon in particulate matter can be quantified in terms of organic carbon (OC) and elemental carbon (EC), based on the evolution of material from the sample as it is heated in inert and oxidizing atmospheres, respectively. Chow et al. (2001) provides a good review of the issues involved in the measurement of OC and EC and the problems involved in defining these quantities. An OC/EC instrument (R&P model 5400) also uses impaction, flash volatilization, and conversion to CO_2 for quantification. There is uncertainty in the measurements of OC/EC with this instrument, because the impactor cuts off at approximately 150 nm. Thus, it may not capture smaller particles, and particularly may not collect all of the diesel exhaust particles. Only two evolution temperatures are available, with one for the inert gas cycle (OC) and one for the oxygen-containing gas cycle (EC)—as opposed to multiple temperatures for OC and EC, as in the laboratory procedures. In addition, there is no correction for pyrolysis during the OC evolution. Unpublished reports have suggested that this system provides a good estimate of the total OC+EC, but the fractions do not correspond well with the lab measurements of integrated samples taken simultaneously with the continuous measurements.

An OC/EC field instrument has been developed by Sunset Laboratory—the company that developed the laboratory instrument to implement a modified National Institute for Occupational Safety and Health (NIOSH) 5040 method (Birch and Cary 1996). This instrument collects the particles on a filter and makes a pyrolysis correction using reflectance. It has been available for less than a year and it is still being characterized. However, initial experience with it as a useful continuous measure of OC and EC, with better correspondence to the laboratory measurements, appears quite promising.

2.2.2. Research Instrument Development

Dr. George Allen, while he was at the Harvard School of Public Health (HSPH), developed a continuous sulfate analyzer. It utilizes catalytic reduction of sulfate to SO_2 in a stainless steel tube and detection of the generated SO_2 with a conventional SO_2 monitor. Several variations of this system have been built under licenses from HSPH while the instrument is being commercialized by Thermo Andersen. Initial experience in the Southeastern Aerosols Research and Characterization (SEARCH) monitoring network has been very encouraging (E. Edgerton, private communication).

Several groups have been working on collection of fine particulate matter by increasing the particle size through hygroscopic growth and then analyzing the collected slurry. An initial size separation is obtain using a size-selective inlet. Steam is injected and the resulting droplets are collected in an impactor. The slurry from this impaction stage can then be introduced into an appropriate analytical instrument.

Dr. Rodney Weber (Weber et al. 2001) uses ion chromatography to analyze for major cations and anions. This system is a modification of the Dutch system developed by Slanina and coworkers (Khlystov et al. 1995). A similar system is also being developed by Thermo Andersen. In this system, colorimetry is also used to determine the ammonium ion concentration. In the Weber system, denuders are used to remove gaseous interferences such as nitric acid (HNO_3) and SO_2. It is being tested at several of EPA's Supersites.

Ondov has been developing a similar system for metals determination. The Semi-continuous Elements in Aerosol System (SEAS) is made entirely of glass to avoid contamination. Currently there are no denuders on it, so the slurry would contain gaseous as well as particulate species. At this time, the only documentation on this system is the doctoral thesis of Kidwell (2000). Results from this system can be seen on the Baltimore Supersite Web page (www.chem.umd.edu/supersite/keyinstruments/SEASnew.htm).

2.3. Particulate Matter Mass, Personal Monitors

2.3.1. Commercial Instruments, Gravimetric

Many personal samplers have been available for years; primarily those designed for industrial hygiene purposes. Several companies (e.g., SKC and MSA) sell various cyclones and portable pumps. However, these systems do not provide as well-defined particle size discrimination as is desirable.

The Personal Environmental Monitor (PEM™) (Marple et al. 1987, Kamens et al. 1991) is an inertial impactor system manufactured by MSP Corporation of St. Paul, Minnesota and is marketed by several other companies. It uses 37-mm substrates like Teflo® filters. It has been used in a number of exposure studies and provides an integrated filter sample for gravimetric and/or chemical analysis.

2.3.2. Research Instruments, Gravimetric

With the interest in specific exposure to fine particles, several groups have been developing new samplers. Misra et al. (2002) developed a new personal cascade impactor. The Personal Cascade Impactor Sampler (PCIS) is a miniaturized cascade impactor, consisting of four impaction stages, followed by an after-filter. Particles are separated in the following aerodynamic particle diameter ranges: <0.25, 0.25–0.5, 0.5–1.0, 1.0–2.5, and 2.5–10 μm. The PCIS operates at a flow rate of 9 liters per minute (lpm), using a very-high-efficiency, battery-operated, lightweight pump at a pressure drop of 11 in. H_2O (2:7 kilopascals (kPa)). This device will be developed as a commercial product by SKC, Inc. New 10-lpm personal sampling pumps are now available from SKC and BGI, Inc. The resulting impaction stage media can be analyzed for mass and chemical species, using conventional analytical methods.

New systems have been developed to provide measurement of both gaseous and particulate matter concentrations. Demokritou et al. (2001) describe a multipollutant sampler. This sampler can be used for measuring exposures to PM_{10} and $PM_{2.5}$ and mass and criteria gases. The system uses a single personal sampling pump that operates at a flow rate of 5.2 lpm. The basic unit consists of two impaction-based samplers for $PM_{2.5}$ and PM_{10} attached to a single elutriator. Two mini $PM_{2.5}$ samplers are also attached to the elutriator for OC, EC, sulfate, and nitrate measurements. For the collection of nitrate and sulfate, the mini-sampler includes a miniaturized honeycomb glass denuder that is placed upstream of the filter to remove nitric acid and sulfur dioxide and to minimize artifacts. Two passive samplers can also be attached to the elutriator for measurements of gaseous co-pollutants such as O_3, SO_2, and NO_2.

With support from the Health Effects Institute (HEI), Aerosol Dynamics has been developing a personal sampler, the Personal Micro-Environmental Aerosol Speciation Sampler (PMASS™). A draft report describing this device is currently under review at HEI and should be released soon. The prototype, all-aluminum, PMASS includes a 2.5 μm cut-point cyclone inlet with dual channels for simultaneous collection on two filter trains and includes provision for denuders in either, or both, channels. It is being commercialized by the MSP Corporation.

A passive sampler has been developed at the University of North Carolina (UNC) for long-term collection of particles for analysis by scanning electron microscopy (SEM) (Wagner and Leith 2001a,b,c). In the passive sampler, particles travel through a protective, stainless-steel mesh and deposit on a smooth collection surface by gravity, inertia, and diffusion. For particle concentrations found outdoors, in the home, or in other nonindustrial environments, the appropriate sampling time is about one week. After use, the sampler is capped and analyzed by SEM. The particle concentration and size distribution to which the sampler was exposed is then found using techniques developed by Wagner and Leith (2001a,b,c). These techniques have been verified in a wind tunnel and used previously to determine occupational exposures.

The passive sampler has important advantages over conventional, active samplers for aerosol particles. It is small and unobtrusive. The passive sampler is completely silent as it requires no pumps or electrical power. Passive samplers cost only a few dollars each. No professional instruction or monitoring is necessary; a single page of instructions is sufficient to show how a passive sampler should be used. After exposure, samplers can be mailed back to the laboratory for analysis. The data obtained can be used to determine PM_{10}, $PM_{2.5}$, thoracic mass, respirable mass, or other size-related concentrations. If appropriate, elemental analyses can characterize the particle makeup. The UNC holds patent rights for this sampler, and is very interested in promoting its commercialization.

2.3.3. Commercial Instruments, Continuous

The principal personal mass monitors have been light-scattering devices such as the Thermo MIE *personal* DataRAM. This is a versatile, real-time monitor, available for active sampling applications. The *p*DR-1200 uses a pump module (*p*DR-PU) or other sampling pump to perform particle size selective measurements. Compact, lightweight, and easy to use, it is ideal for respirable, thoratic, and $PM_{2.5}$ monitoring, as well as for continuous emission and test chamber monitoring. An earlier model, the RAM-1 has been modified by adding a diffusion drier in order to reduce the influence of humidity on the particles and provide a mass estimate that is closer to that which would be determined using gravimetric methods (Sioutas et al. 2000).

2.3.4. Research Systems

2.3.4.1. Continuous

Rupprecht and Patashnick, Inc. under contract from the Mine Safety and Health Administration (MSHA), have been developing a small, portable TEOM system. The element is made of metal and the system provides data storage for an 8-hour period. It is anticipated that this device will be offered as a commercial product in the near future. With additional funding, it is anticipated that this advance in TEOM technology will be deployed in two different configurations: the personal monitor described below and the indoor monitor described in Section 2.4.

2.3.4.2. Personal Monitor

A personal monitor that is similar to the MSHA TEOM monitor, but with modifications to the inlet system, internal energy management, and data handling and communication is under development. Rupprecht and Patashnick's aim is for this unit to be about the same size as the one being developed for MSHA, but with a user interface that is more flexible than that for the mining application. They project that this monitor will provide a 15-minute running average of the ambient mass concentration of the industrial hygiene measure of exposure (ISO respirable particles, D_{50} of about 4.5 µm) or $PM_{2.5}$. The measurement is updated every five seconds or less, and has a resolution of 10 $\mu g/m^3$ (2 sigma). Further development will be needed for this instrument to be useful at ambient $PM_{2.5}$ concentrations. The performance of this unit will be somewhat degraded when worn as a personal monitor, as compared with the tabletop operation described in the next section.

2.4. Particulate Matter Mass, Indoor Monitors

A major consideration for indoor PM mass monitors is that their flow should not be high enough to distort the indoor environmental concentrations. Many of the ambient air sampling systems use too high a flow rate, which would actively reduce the particle concentrations. Typically, the flow rates should be less than 10 lpm. Any of the personal monitors can be used as indoor area monitors.

For example, a configuration of the R&P MSHA TEOM described in the previous section can be used either indoors or in moderate outdoor environments (at temperatures higher than approximately -5°C with no additional protection), and have a straight vertical downtube that would allow for the measurement of total suspended particulate matter (TSP) through PM_1 (particulate matter less than 1 µm). The mass resolution of the monitor unit would be the same as for the personal monitor above. The unit could be operated either off of an exchangeable battery pack or from AC power. In addition, R&P is investigating some of the new gas measurement capabilities offered by the newest generation of thick film sensors, and is seriously investigating the incorporation of some sensitive gas monitoring capabilities in the unit down to ambient levels (as opposed to industrial hygiene concentrations). Because this device can be used as a sensor in many types of monitoring applications—such as in tunnels, along roadways, or for chamber measurements—it will be equipped with a number of data transfer possibilities, including USB, IR, and direct Internet connection through an RJ-45 port. A handle provided for this instrument would allow it to be used as a survey tool.

3.0 Particle Counts and Size Distributions

3.1. Ambient Measurement Systems

3.1.1. Commercially Available Particle Counters

With increased interest in ultrafine particles, there need to be methods to count particles or to measure the size distributions of individual particles. Particles can be detected if they are charged, scatter light, or are radioactive. The most commonly used method is scattered light. For particles below 100 nm, the intensity of scattered light is quite low, and its detection requires sophisticated and expensive photon-counting methods. These counters function by inducing nucleation of a working fluid onto the particles. The commercially available units are described in Appendix II.

An aerodynamic particle sizer (APS) measures time-of-flight in an accelerating air flow. There are several variations of this concept. These are systems that are applicable to sizes above 0.3 µm up to sizes on the order of 20 µm. They are described in Appendix II. These systems have been used in fixed-site monitoring programs such as EPA Supersites. A similar system, the Aerosizer®, extends the measurement range up to 200 µm.

In addition to particle counters, the Electrical Aerosol Detector (EAD) measures a unique aerosol parameter called *total aerosol length.* Reported as mm/cm^3, aerosol length can be thought of as number concentration times average diameter, or simply as d^1 weighting. This measurement falls between number concentration (d^0) and surface area (d^2).

3.1.2. Research Particle Counting Systems

With the support of NYSERDA and the New York State Office of Science, Technology, and Academic Research (NYSTAR), a turbulent mixing condensation nuclei counter (CNC)[a] is being developed into a commercial prototype at Clarkson University. The instrument is described by Mavliev (2002). It should provide detection with 50% efficiency to particle sizes of 2 nm and provide improved flexibility in particle detection by permitting the user to define the minimum detectable size. It will be equipped with diffusion driers on the system to permit the use of a perfluorocarbon working fluid, rather than butanol, which is used in all commercial CNCs.

A turbulent mixing CNC using water as the working fluid has been described by Parsons and Mavliev (2001). Parsons was a principal at Particle Measuring Systems, so it is anticipated that they will be commercializing this system, but there is no mention of it on their Web site, nor did they respond to an inquiry.

3.2. Ambient Particle Size Measurement Systems

3.2.1. Commercially Available Systems

Size distributions can be measured using instruments based on several physical principles. For larger particles (diameter > 0.090 µm), light scattering can be used to provide size and count information. Depending on the configuration, these systems have an upper size limit of 3 to 20 µm. A number of systems are available and are listed in Appendix II.

For particle sizes below 1.0 µm, charged particles can be separated based on differences in their electrical mobility (Knutson and Whitby 1975a,b). The polydisperse aerosol is passed through a radioactive source, resulting in an approximately Botzmannian charge distribution on the particles. The charged particles then pass through a cylindrical condenser with a central electrode. The positively charged particles are attracted toward the central rod, and particles within a small range of electrical mobilities can enter a slit and exit the instrument in the monodisperse flow. These particles can then be counted with a condensation nuclei counter. The voltage on the central rod can be sequentially stepped upward or downward. This configuration is called a differential mobility particle spectrometer (DMPS). Alternatively, the central rod voltage can be continuously ramped to provide a sequence of measured particle counts from which users can deduce a size distribution (Wang and Flagan 1990). Such a system is called a Scanning Mobility Particle Sizer (SMPS). These systems are currently complex and require research personnel to operate. A new commercial system from MSP Corporation is reported to become available in the first quarter of 2003. The company describes this system as an integrated, easy-to-use system that will not require as much expertise to use.

3.2.1.1. Indoor and Personal Monitoring

These systems run at relatively low flow rates and thus, can be used for indoor monitoring. The light-scattering systems can be used indoors without any problems. The major problem with

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[a] These devices are also known as *condensation particle counters*, or *CPCs.*

the use of condensation particle counters is that they typically use n-butanol as the working fluid. Butanol is flammable, toxic, and has a bad odor, so it is important to vent the counter to the outside adequately. There is a portable condensation particle counter (TSI P-Trak™) that uses isopropanol as the working fluid. It can be carried, but does not really represent a personal monitor. It can be used as an indoor area monitor or carried to measure microenvironmental concentrations.

There are no portable systems for ultrafine particle size distribution measurements. Thus, there are no personal monitors for such measurements at this time.

4.0 Gas Monitoring Systems

4.1. Fixed Site Monitors

Continuous monitors for the gaseous criteria pollutants have been in active use for more than 20 years and will not be presented here. However, for several species (CO and NO_x [NO and NO_2]), the reductions in the ambient concentrations have led to the need for new systems. The reduced ambient CO concentrations currently encountered cannot be measured accurately with the current NAAQS monitors. The catalytic reduction of NO_2 to NO in the conventional NO_x system suffers from interferences from NO_y species, including gaseous HNO_3 and organic nitrates. Although these problems are not important in the context of NAAQS attainment measurements, they are problems for model validation or improving our understanding of the atmospheric chemistry needed to fully design ozone control strategies. Better NO_2 and NO_y measurements are needed to provide critical information for future ozone management decisions, and this may be an area in which research investment is warranted.

4.2. Personal Monitors

Several types of monitors have been developed for personal monitoring of gaseous pollutants, including criteria pollutants (CO, NO_x, SO_2, and O_3). These devices include the Ogawa Model 3300 Passive Sampling System that provides an effective means of determining the average concentration of atmospheric gases (NO, NO_2, NO_x, SO_2 and O_3) in indoor and outdoor environments. The low cost of the system makes it feasible to use the device as a saturation sampler to map the concentration gradients of atmospheric pollutants. The Ogawa Sampler allows for passive simultaneous monitoring of NO and NO_2. This small sampler can be clipped to clothing, or installed in an outdoor protective shelter. Samples are generally taken over periods of 1 to 14 days and then sent to a laboratory for analysis.

There are several color-changing badges that provide a qualitative to semi-quantitative indication of exposure. The SafeAir and ChromAir badges from K&M Environmental provide direct reading capabilities. However, nothing provided in the company information would suggest that there is information available to explain the measured values in terms of potential risks or comparisons to various environmental or occupational standards.

The only research unit identified as being under development is the multipollutant sampler (Demokritou et al. 2001). This sampler can be used for measuring exposures to particulate matter and criteria gases. The basic unit consists of two impaction-based samplers for $PM_{2.5}$ and

PM_{10}, attached to a single elutriator. Two mini $PM_{2.5}$ samplers are also attached to the elutriator for OC, EC, sulfate, and nitrate measurements. For the collection of nitrate and sulfate, the mini-sampler includes a miniaturized honeycomb glass denuder that is placed upstream of the filter to remove nitric acid and sulfur dioxide, and to minimize artifacts. Two passive samplers can also be attached to the elutriator for measurements of gaseous co-pollutants such as O_3, SO_2, and NO_2.

5.0 Organic Compound Monitors

5.1. Fixed Site Monitors

Any area that has been in moderate to serious non-attainment of the ozone standard had to institute additional monitoring identified as Photochemical Assessment Monitoring Stations (PAMS). Unlike the State and Local Air Monitoring Station (SLAMS) and National Air Monitoring Station (NAMS) design criteria, which are pollutant-specific, PAMS design criteria are site specific. Design criteria for the PAMS network are based on selection of an array of site locations relative to O_3 precursor sources and predominant wind direction associated with peak O_3 events. Four PAMS site types are described in the regulations. The number and type of monitoring sites and sampling requirements is dependent on the population of the Metropolitan Statistical Area (MSA) or Consolidated Metropolitan Statistical Area (CMSA). Table 2 presents the specified minimum sampling requirements for VOCs and carbonyl compounds for each site type. Monitoring for O and NO_x (including NO and NO_2) requires continuous measurements. The sampling schedule applicable to a specific area is dependent on population and PAMS site types.

The EPA has also prepared a guidance document on enhanced O_3 monitoring network design and siting criteria that outlines the number of PAMS required, station location, and probe siting criteria. The PAMS site types are described as follows: Type 1 PAMS characterize upwind background and transported O_3 and precursor concentrations entering the MSA or CMSA and are used to identify those areas subjected to overwhelming transport. Type 2 PAMS monitors measure the magnitude and type of precursor emissions in the area where maximum O_3 precursor emissions are expected and are also suited for monitoring urban air toxic pollutants. Type 3 PAMS characterize O_3 precursor concentrations occurring downwind from the area of maximum emissions. Type 4 PAMS characterize extreme downwind transported O_3 and its precursor concentrations exiting the area, and identify those areas that are potential contributors.

Table 2. PAMS Minimum Monitoring Network Requirements

Population of MSA/CMSA[1]	Required Site Type	Minimum VOCs Sampling Frequency[2]	Minimum Carbonyl Compounds Sampling Frequency[2]
Less than 500,000	(1)	A or C	-
	(2)	A or C	D or F
500,000 to 1,000,000	(1)	A or C	-
	(2)	B	E
	(3)	A or C	-
1,000,000 to 2,000,000	(1)	A or C	-
	(2)	B	E
	(3)	A or C	-
More than 2,000,000	(1)	A or C	-
	(2)	B	E
	(3)	A or C	-
	(4)	A or C	-

[1] Whichever area is larger.

[2] Frequency requirements are as follows:

A = Eight 3-hour samples every third day and one additional 24-hour sample every sixth day during the monitoring period.

B = Eight 3-hour samples every day during the monitoring period and one additional 24-hour sample every sixth day year-round.

C = Eight 3-hour samples on the 5 peak O_3 days plus each previous day, eight 3-hour samples every sixth day and one additional 24-hour sample every sixth day during the monitoring period.

D = Eight 3-hour samples every third day during the monitoring period.

E = Eight 3-hour samples on the 5 peak O_3 days plus each previous day and eight 3-hour samples every sixth day during the monitoring period.

F = Eight 3-hour samples on the 5 peak O_3 days plus each previous day, eight 3-hour samples every sixth day and one additional 24-hour sample every sixth day during the monitoring period.

Two methods are presented for collecting and analyzing VOC samples: (1) an automated method using field gas chromatographs, and (2) a manual method using canisters. Either of the two VOC methods (automated or manual) described in this section is capable of satisfying the sampling frequency and sample integration requirements. Samples collected for either method should represent a time-integrated average for the required sampling period. It is important to understand that the 3-hour sample integration period is a maximum requirement, in the sense that samples can be collected more frequently at shorter sampling intervals (i.e., three 1-hour periods) but not less frequently for longer sampling intervals. The manual methodology, where samples are collected in canisters, is primarily applicable to the less-frequent sampling required for site types 1, 3, and 4 (i.e., eight 3-hour samples every third day or during peak O_3 events) and the 24-hour sample requirement (Pate et al. 1992). The automated method, which allows for direct on-line sample collection, is primarily applicable to the more frequent sampling requirements for Site Type 2 (eight 3-hour samples every day during the monitoring period). The automated method provides a viable option for the continuous collection of hourly samples. Though not required, continuous collection of hourly samples also offers a more definitive assessment of the temporal and diurnal distribution of VOCs.

The EPA is developing a new monitoring network for hazardous air pollutants (HAPs). The goal of this national-scale air toxics assessment (NATA) is to identify those air toxics that are of greatest potential concern, in terms of contribution to population risk. The results will be used to set priorities for the collection of additional air toxics data (e.g., emissions data and ambient monitoring data). Table 3 lists the compounds identified by EPA.

Table 3. Air Toxics of the Greatest Potential Concern

acetaldehyde	coke oven emissions	mercury compounds
acrolein	1, 3-dichloropropene	methylene chloride
acrylonitrile	diesel particulate matter	nickel compounds
arsenic compounds	ethylene dibromide	perchloroethylene
benzene	ethylene dichloride	polychlorinated biphenyls (PCBs)
beryllium compounds	ethylene oxide	polycyclic organic matter (POM)*
1, 3-butadiene	formaldehyde	propylene dichloride
cadmium compounds	hexachlorobenzene	quinoline
carbon tetrachloride	hydrazine	1, 1, 2, 2-tetrachloroethane
chloroform	lead compounds	trichloroethylene
chromium compounds	manganese compounds	vinyl chloride

*Also represented as 7-PAH

Source: U. S. Environmental Protection Agency

Volatile organic compound sampling using solid sorbent materials has been conducted for many years for environmental and occupational hygiene investigations (Dietrich 1997, EPA 1997, Lodge 1989). Sorbent materials, such as activated charcoal and Tenax® used with air sampling pumps have long been considered the primary standard for collecting many organic vapors from air. Selection of an appropriate sorbent is important because the chemical characteristics of different VOCs affect their affinity for the sorbents (McClenny and Colon 1998). Also, sorbents can be affected by environmental conditions such as humidity and temperature, and by factors such as competition for active sites and concentration of the contaminants. Although sorbent materials have been effective, inherent limitations of the methods may make the evacuated canisters an appropriate alternative when developing a sampling strategy, because the canisters can provide more complete quantitative samples for subsequent analysis. Methods for sampling and analyses of these toxic substances are currently defined by EPA in the Compendium of Methods available at www.epa.gov/ttn/amtic/airtox.html.

5.2. Personal and Indoor Sampling

Currently there are several types of diffusion badge samplers that can be used to monitor for specific compounds. These badges do not require a pump and can either be worn as a personal monitor or be placed in a room to monitor indoor air. Table 4 lists three companies that supply these badges, along with what they measure. These badges contain an adsorbent that is solvent-extracted to provide a sample for Gas Chromatography/Mass Spectrometry (GC/MS) analysis.

Table 4. Suppliers for Passive Sampling Badges

Material Sampled	Assay Technology	3M	SKC
Organics Vapors (VOCs)	X	X	X
Very Volatile VOCs	X	X	X
Ethylene Oxide	X	X	X
Glutaraldehyde	X	–	–
Nitrous Oxide	X	–	–
Formaldehyde	X	X	X
Aldehydes	X	–	–
Anesthetics	X	X	–
Methanol	X	–	–
Mercury	X	–	X
Ammonia	X	–	–
Acrolein	X	–	–
Amines	X	–	–
Ozone	X	–	–

Table 5 lists typical compounds that can be detected and detection limits for an 8-hour sample. Such samplers are appropriate for measurements of concentrations that are close to occupational standards, but are generally not very effective for typical concentrations in homes and for most common personal exposures. Generally it is necessary to use an active sampling system to obtain an adequate amount of material for analysis.

There has been the development of a capillary flow control system that would permit the use of 300 ml canisters to be used as personal monitors without a pump (Rossner et al. 2002). The flow controllers were configured to perform long-term passive sampling to collect gaseous contaminants. Sampler configurations depended upon whether the samplers were going to be used for personal sampling or area (micro-environment) sampling. This system has been commercialized by General Oceanics, Inc. in the form of a 300-cm^3-volume personal canister sampler.

Table 5. Organic Compounds Determined with Passive Badges and Typical Detection Limits Based on an 8-hour Sample.

CAS No.	Chemical Name	Det. Limit (ppm)	CAS No.	Chemical Name	Det. Limit (ppm)
141-79-7	Mesityl oxide	0.075	67-64-1	Acetone	0.1
109-86-4	Methoxyethanol (Me Cellosolve)	0.3	75-05-8	Acetonitrile	0.2
110-49-6	Methoxyethyl acetate (MeCSAc)	0.1	107-13-1	Acrylonitrile	0.1
96-33-3	Methyl acrylate	0.1	107-18-6	Allyl alcohol	0.1
67-56-1	Methyl alcohol (methanol)	0.3	107-5-1	Allyl chloride	0.8
71-55-6	Methyl chloroform (1,1,1-TCA)	0.2	628-63-7	Amyl acetate	0.1
108-87-2	Methyl cyclohexane	0.05	71-43-2	Benzene	0.05
78-93-3	Methyl ethyl ketone (2-butanone)	0.1	106-99-0	Butadiene	0.1
107-31-3	Methyl formate	0.3	71-36-3	Butanol	0.1
110-12-3	Methyl isoamyl ketone	0.1	75-65-0	Butanol	0.1
108-11-2	Methyl isobutyl carbinol	0.1	78-92-2	Butanol (sec-butyl alcohol)	0.1
108-10-1	Methyl isobutyl ketone (hexone)	0.1	111-76-2	Butoxyethanol (Butyl Cellosolve)	0.1
80-62-6	Methyl methacrylate	0.1	123-86-4	Butyl acetate	0.1
107-87-9	Methyl propyl ketone (2-pentanone)	0.1	540-88-5	Butyl acetate	0.1
109-87-5	Methylal (dimethoxymethane)	0.2	141-32-2	Butyl acrylate	0.1
108-87-2	Methylcyclohexane	0.05	1634-04-4	Butyl methyl ether (MTBE)	0.8
75-09-2	Methylene-chloride	0.3	56-23-5	Carbon tetrachloride	0.2
91-20-3	Naphthalene	0.3	108-90-7	Chlorobenzene	0.05
111-84-2	Nonane	0.04	74-97-5	Chlorobromomethane	0.3
111-65-9	Octane	0.04	67-66-3	Chloroform	0.2
109-66-0	Pentane	0.1	126-99-8	Chloroprene	0.7
127-18-4	Perchloroethylene (PCE)	0.1	98-82-8	Cumene	0.3
108-65-6	Prop. Glycol.; methyl ether acetate	0.1	110-82-7	Cyclohexane	0.1
109-60-4	Propyl acetate	0.1	108-93-0	Cyclohexanol	0.05
71-23-8	Propyl alcohol	0.2	108-94-1	Cyclohexanone	0.05
106-94-5	Propyl bromide	1.5	123-42-2	Diacetone alcohol	0.1
78-87-5	Propylene dichloride	0.1	1717-00-6	Dichloro-1-fluoroethane (HCFC141b)	0.25
107-98-2	Propylene glycol methyl ether	0.2	75-71-8	Dichlorodifluoromethane (CFC12)	2.4
110-86-1	Pyridine	0.1	75-34-3	Dichloroethane	0.1

Table 5 (cont'd). Organic Compounds Determined with Passive Badges and Typical Detection Limits Based on an 8-hour Sample.

CAS No.	Chemical Name	Det. Limit (ppm)	CAS No.	Chemical Name	Det. Limit (ppm)
100-42-5	Styrene	0.04	107-06-2	Dichloroethane (EDC)	0.1
540-59-0	Dichloroethylene	1	76-11-9	Tetrachloro-2,2-difluoroethane	0.5
75-43-4	Dichlorofluoromethane (CFC21)	1	109-99-9	Tetrahydrofuran (THF)	0.1
76-14-2	Dichlorotetrafluoroethane (CFC114)	0.6	108-88-3	Toluene	0.04
68-12-2	Dimethyl formamide (DMF)	0.1	79-00-5	Trichloroethane	0.1
123-91-1	Dioxane	1.1	71-55-6	Trichloroethane (methylchloroform)	0.2
106-89-8	Epichlorohydrin	0.1	79-01-6	Trichloroethylene (TCE)	0.1
110-80-5	Ethoxyethanol (Cellosolve)	0.1	76-13-1	Trichlorotrifluoroethane (CFC113)	0.2
111-15-9	Ethoxyethyl acetate (EthylCell)	0.1	108-67-8	Trimethylbenzene (mesitylene)	0.04
141-78-6	Ethyl acetate	0.1	108-05-4	Vinyl acetate	0.1
140-88-5	Ethyl acrylate	0.1	593-60-2	Vinyl bromide	0.1
64-17-5	Ethyl alcohol (ethanol)	0.5	75-01-4	Vinyl chloride	0.1
60-29-7	Ethyl ether	0.1	75-35-4	Vinylidene Chloride (1,1 DCE)	0.1
687-47-8	Ethyl lactate	1.5	1330-20-7	Xylenes	0.05
100-41-4	Ethylbenzene	0.04	872-50-4	1-Methyl-2-pyrrolidinone	1
107-07-3	Ethylene chlorohydrin	0.125	100-44-7	Benzyl chloride	0.1
106-93-4	Ethylene dibromide	0.1	8/6/2426	Butyl(n)glycidyl ether	0.6
110-71-4	Ethylene glycol dimethyl ether	0.8	76-22-2	Camphor	0.05
75-69-4	Fluorotrichloromethane (CFC11)	2.1	2039-87-4	Chloro(o)styrene	0.1
142-82-5	Heptane	0.05	95-49-8	Chloro(o)toluene	0.1
110-43-0	Heptanone (methyl amyl ketone)	0.1	106-46-7	Dichlorobenzene	0.05
110-54-3	Hexane	0.4	95-50-1	Dichlorobenzene	0.4
591-78-6	Hexanone (MBK)	0.1	111-44-4	Dichloroethyl ether	0.1
123-92-2	Isoamyl acetate	0.1	77-73-6	Dicyclopentadiene	0.1
123-51-3	Isoamyl alcohol	0.1	108-83-8	Diisobutylketone	0.1
110-19-0	Isobutyl acetate	0.1	34590-94-8	Dipropylene Glycol Methyl Ether	1
78-83-1	Isobutyl alcohol	0.1	78-59-1	Isophorone	0.05
108-21-4	Isopropyl acetate	0.1	4016-14-2	Isopropyl glycidyl ether (IGE)	0.1
67-63-0	Isopropyl alcohol	0.25	98-83-9	Methyl styrene	0.04
108-20-3	Isopropyl ether	0.1	101-84-8	Phenyl ether	0.1
5989-27-5	Limonene (as dipentene)	0.1	25013-15-4	Vinyl toluene (methyl styrene)	0.04

6.0 Monitoring for Distributed Generation Emissions

6.1. Strategy for Air Monitoring

6.1.1. Ambient Impacts of Power Plant Siting

6.1.1.1. Emissions

The major distributed power generation systems are combined-cycle, natural-gas-fired turbines, and possibly diesel-powered units. Natural-gas-powered systems have relatively low direct particle emissions; whereas, diesel generation systems will have emissions similar to those from diesel-powered vehicles. Recent, unpublished tests being conducted by the GE Energy and Environmental Research Corporation (GE-EER) on a gas combustion system showed that the particle concentrations were relatively low, compared with those from oil or coal combustion. The typical particle size was in the size range of 15 to 25 nm. It is anticipated that these particles will be elemental carbon.

In addition, gas generators produce NO_x emissions. In the atmosphere, the primary particles will rapidly coagulate into the accumulation mode, while the NO_x will undergo oxidation to HNO_3. In the presence of sufficient ammonia (NH_3), ammonium nitrate (NH_4NO_3) will be formed. It can either deposit on the surface of the existing atmospheric aerosol or nucleate into a new ultrafine aerosol. Thus, the principal contaminants to measure are ultrafine particles, gaseous HNO_3, and particulate NH_4NO_3. Thus, monitoring systems for gas-powered generators would need to focus on these components.

For diesel generators, the major emissions characteristics are elemental or black carbon particles. The major emissions from diesel engines are particles in the 40 to 200 nm size range, and they tend to be chain aggregate elemental particles. In older diesel vehicles, there was substantial emission of organic carbon, but newer engines tend to produce the elemental carbon particles with relatively little organic carbon adsorbed onto their surface. The main feature of these particles is their light absorption. Diesel motor vehicles have been extensively studied, but there has been less characterization of stationary diesel equipment. A major question then is the extent of emissions controls that will be used on these systems and what effect those controls would have on the resulting particle size and absorption properties of the emitted particles. Unpublished studies in New York City by the Atmospheric Sciences Research Center from the University at Albany suggest that catalytic regenerative traps reduce the mass emissions, but produce additional numbers of ultrafine particles. Thus, particle numbers and size distributions most likely need to be measured in addition to light absorption.

6.1.1.2. Ambient Monitoring Strategy

Results of measurements by Kim et al. (2002) suggest there is a sharp reduction in particle numbers, black carbon, and CO as a function of distance from a gasoline-vehicle-dominated freeway. There is also a decrease in the smallest sizes as the aerosol undergoes coagulation, dilution, and dry deposition. Thus, we might expect similar sharp gradients from a gas-fired generating system. Particle number concentrations or size distributions can be measured using conventional aerosol monitoring equipment, although that equipment has not been designed to operate under ambient conditions. However, it is not difficult to use available enclosures to provide adequate protection from weather and to control temperature. Particle numbers are measured with CNCs. When coupled with a differential mobility analyzer (DMA), the DMA-CNC combination becomes a scanning mobility particle sizer (SMPS) that can provide size distribution measurements every few minutes. The range of particle size that can be determined varies depending on the specific DMA and CNC used in the system. The size distributions can be measured at fixed locations with respect to the plant site to provide a clear indication of the particle number concentration gradients.

The distribution of NO_x that is emitted from the power plant and the resulting increase in NO_y will be harder to detect, depending on the volume of local traffic and other likely high temperature combustion sources and the extent of upwind sources that provide a background of transported NO_y. Depending on the local atmospheric chemistry, there will be limited contribution of the locally emitted NO_x to the measured local NO_y concentrations.

Zhu *et al.* (2002) present results showing that there were slower decreases in particle number and black carbon downwind of a diesel-truck-dominated freeway than were observed for a freeway with few diesel vehicles.

Diesel equipment emits larger particle sizes than gas-fired combustion sources, and these particles will also be larger than particles emitted by stationary oil combustion sources, such as home or hot water heating equipment. It is extremely difficult to distinguish among the emissions from home heating, diesel generators, and diesel vehicles. Home combustion emissions provide a significant background upon which the diesel generator emissions will be superimposed. Monitoring systems based on light absorption (e.g., an Aethalometer) purport to provide a measure of diesel particle concentrations, as shown in Figure 1. In the absence of other sources, these systems work well. However, there will be two major problems with the monitoring of diesel particles based on light absorption at multiple wavelengths. First, diesel particles from stationary diesel power generation will be indistinguishable from home heating and diesel truck emissions. There will also be masking of diesel by black carbon particles from wood combustion. There are other tracers for wood smoke particles, but those require detailed chemical analysis. By using a sufficient number of monitors, gradients in concentrations from major sources (e.g., highways and power generators) can be measured and used to separate the relative contributions of these two ambient sources from those emitted by home combustion sources. A low-cost monitor is needed, so that a sufficient number of units can be deployed to quantify the contributions from these various sources.

6.1.1.3. Indoor and Personal Monitoring Strategy

In order to assess exposure in homes and to individuals, it is necessary to have multiple monitors that can be deployed so as to make a large number of measurements inside and outside of many houses. It is anticipated that because of its strong sorption onto surfaces, gaseous HNO_3 will not effectively penetrate indoors from the ambient environment unless the ventilation rate is very high. However, ammonium nitrate particles should be able to penetrate and then may decompose to un-ionized ammonia (NH_3) and HNO_3. Thus, measurement of gaseous and particulate nitrate will be needed to characterize indoor and personal exposures.

In indoor air, ETS and wood smoke also contain components that are strongly absorbing in the UV region. Any particle source that produces significant concentrations of PAHs will be detected by the dual light absorption system. These other particle sources could therefore confound the monitor's ability to assess exposure to diesel particles accurately. The combustion of oil for home and hot water heating also produces particles with some similarities to diesel emissions, because the basic mix of hydrocarbon compounds are the same. There are some additives in diesel oil that do not appear to be in home heating oil, but making measurements that could detect additional chemical species characteristic of these additives would require filter sample collection and analysis or sophisticated measurement methods like an Aerosol Time of Flight Mass Spectrometer (ATOFMS) with a cost of $350,000. Thus, there are significant problems in chemically distinguishing diesel from other oil-combustion sources in a low-power-use, portable, inexpensive monitor.

6.2. Monitor Needs

6.2.1. General Requirements

There are very different requirements for measurements, depending on whether they are to be made at a fixed site to evaluate the ambient air quality or for the measurement of indoor air quality or personal exposure. There are relatively few limitations on ambient monitors, depending on the cost limitations imposed on the system. Given sufficient power and appropriate protection from weather, very sophisticated systems can be deployed. However, for monitoring DG systems, more spatial variability in the emissions can be anticipated; therefore, there is a need for more monitors. As a result, cost becomes an important consideration in the development and deployment of such systems. Air quality agencies will need multiple monitors to examine the impacts of the multiple facilities that are being developed.

For indoor air, the volume of air sampled must be sufficiently low that the collection of the sample is not perturbing the nature of the indoor atmosphere. That is, the flow rate through the sampler should be sufficiently low that it does not significantly raise the effective ventilation rate of the room. The passage of the air through the particle sampler typically serves as an air cleaning system, and thus, the exhaust of the monitor provides an increased clean air delivery rate into the room volume. This rate should be chosen to be small compared to the natural infiltration rate. Again, costs need to be low, so that it is possible for an interested person to monitor in and around their homes for the effects of the new DG sources.

Personal sampling is limited by the size and weight of pumps that can be used. The maximum flow rate in these systems is 10 lpm and more typically is 2 to 5 lpm. Thus, it is typically difficult to collect sufficiently large quantities of mass on a filter to provide high-precision compositional data.

6.2.2. Ambient Air Monitors

6.2.2.1. $PM_{(10-2.5)}$

There is no need for any further development of PM_{10} monitors, as there will not be a NAAQS for this indicator after 2004, because there will be a coarse particle standard ($PM_{(10-2.5)}$). There is an adequate sequential dichotomous sampler already commercially available to address current needs. With respect to a continuous coarse monitor, it should be possible to ascertain the effectiveness of the existing system (Misra et al. 2001) with the field testing that will be done by the EPA in 2003. It will probably be useful to examine alternatives to continuous coarse particle monitoring that employ other measurement principles such as beta monitors. These units will be priced comparably to existing FRM-type samplers and thus, can be deployed in the normal compliance monitoring.

No inexpensive monitors comparable to the Airmetrics MiniVol can be used for coarse particle saturation sampling. The MiniVol is available in $PM_{2.5}$ and PM_{10} models, but there is no comparable sampler for $PM_{(10-2.5)}$.

6.2.2.2. $PM_{2.5}$

There remain questions about the loss of semivolatile components from $PM_{2.5}$ that are not easily answered. The FRM is the basis for the determination of NAAQS attainment, but it does not necessarily provide an accurate estimate of the airborne particle mass. A variety of continuous monitoring designs are being tested, including the differential TEOM, the FDMS, and the CAMM. At this time, there needs to be further monitoring, testing, and refinement, but this is a need for further development rather than additional research or other new concepts. It is the responsibility of the vendors to provide a better-defined measurement method to the measurement community.

At this time, there are adequate ambient monitoring systems to measure particulate and gaseous nitrate, although they are neither portable nor inexpensive. The speciation network samplers use annular denuders to separate the gaseous HNO_3 from the particulate nitrate. By capturing the particles on a base-impregnated fiber filter or a Nylasorb® filter, the nitrate is retained on the filter until it is leached from the filter for analysis. Such a system is labor-intensive, because users must collect and analyze the filters, and it provides only multihour (typically 24-hour) data.

With respect to continuous speciation monitors, the current nitrate monitor and the multiple-size fraction sampler that has been developed by Aerosol Dynamics and is being tested at the Los Angeles Supersite appear to be likely to provide the necessary measurements. From the limited data yet available, it appears that the new HSPH-design continuous sulfate monitor is likely to perform better than the commercially available system. However, it has yet to be developed into a commercial prototype. It may be put onto the market in early 2003. Thus, for these two well-defined major chemical species, development of adequate monitors is progressing well.

For organic and elemental carbon, the problem is similar to that of the mass problem, in that these species are operationally defined, and there is not yet agreement on what to measure, nor on the sequence of temperatures or the degree of pyrolysis and its effect on the separation between OC and EC. There are clearly problems with the R P OC/EC system, but there is not sufficient experience to evaluate the performance of the field Sunset Laboratory OC/EC system relative to the comparable laboratory system. The development of better OC/EC field instruments depends on the development of a clearer definition of the OC/EC laboratory protocols.

6.2.2.3. NO_x

The standard ambient air monitor uses the chemiluminescent reaction between NO and O_3 to produce light in proportion to the amount of NO in the air stream. The problem with existing systems is that the catalyst used to reduce NO_2 to NO will also reduce some amount of NO_y to NO. When concentrations were higher, this interference was not as critical, but it would now be useful to have accurate NO and NO_2 measurements for current ambient concentrations. Thus, new systems are needed at costs comparable to current ambient gas monitors.

6.2.2.4. NO_y

Currently, no monitors for gaseous NO_y are available. It would be useful to have an ambient monitor that would continuously measure gaseous HNO_3. Such a unit should be sufficiently low in cost that a local multiple-site monitoring network could be established around DG facilities.

6.2.2.5. Particle Number Concentration

Although CNCs are available, they have not been designed for ambient monitoring. Such systems have not been designed to be placed directly in the ambient environment, and there are problems of humidity control in these systems when placed in monitoring trailers or equivalent enclosures. The available systems are quite expensive, so they cannot be used in a multiple-site network to look at gradients of ultrafine particles across a potentially exposed population.

6.2.3. Indoor and Personal Monitors

The most critical needs are for new systems for indoor and personal monitoring. Many of the problems with the ambient monitors are under active investigation. Vendors are likely to develop and/or improve those systems that can be used now or may be incorporated in the near future into the compliance monitoring networks. The primary needs are for smaller, lighter, lower-flow systems that still have sufficient sensitivity to be able to make time-resolved measurements without distortion of the microenvironment into which the sampler is placed. Portable systems that can be used for indoor monitoring should be light enough that they can be easily moved (< 25 to 30 pounds). For personal monitoring systems, the units must be sufficiently small and light (5 to 10 pounds) that they do not interfere with the participants' normal activities. In many cases, the individuals to be monitored are elderly or are children with existing disease (e.g., asthmatics). Thus, there must be even more stringent restrictions on size and weight than if these monitors are to be worn by healthy adults. It would be useful if these monitors could be integrated with the physiological monitoring systems that are often used to record the heart and/or lung function of a patient under study.

6.2.3.1. PM$_{(10–2.5)}$

There are no indoor or personal monitors to measure PM$_{(10–2.5)}$. Because the decision invalidating PM$_{10}$ as an indicator for NAAQS was made only a relatively short time ago, there have not yet been efforts to develop such samplers. There will be a need for such samplers for exposure assessments. It will be useful to have systems for continuous mass measurements, as well as samplers that will provide integrated filter samples for subsequent chemical analysis.

6.2.3.2. PM$_{2.5}$

Reasonable personal samplers are available for integrated filter sample collection. The most commonly used system, the MSP PEM™, uses a 37-mm filter. It would be helpful to produce a 25-mm version, so that the areal density of the particle deposit is higher for improved X-ray fluorescence (XRF) analysis. It also would be useful to move to a continuous PM$_{2.5}$ mass monitor. Rupprecht Patashnick have developed a new metal TEOM with support from the MSHA. However, it was developed for high PM concentrations in mines, where concern about treating particle-bound water was not a consideration. Thus, it is necessary to develop a monitor that removes the particle-bound water to yield a mass measurement that is comparable to ambient monitors. Such a system could be adapted for both personal and indoor monitoring needs.

As discussed above, there is a need to develop monitors that will permit the measurement of diesel exhaust particles characterized by black or elemental carbon and possibly PAHs. However, PAH compounds are also present in ETS and wood smoke. Magee Scientific has introduced a portable Aethalometer (Magee Scientific AE41), but it is relatively expensive (approximately $18,500), making it impractical to deploy in large numbers. BGI Incorporated has also developed a monitor for ETS measurement (the TM-1Tobacco Smoke Monitor). However, it uses the same basic principle as the Aethalometer to estimate the extent of diesel exhaust. Therefore, there is a need to be able to measure diesel particulate matter in the presence of other competing sources, and at a much lower cost than existing instruments.

6.2.3.3. Particle Number Concentrations

Particle number concentrations can be measured indoors using a portable CNC, such as the TSI P-Trak. This CNC uses isopropyl alcohol; whereas, most of the other commercial CNCs use the much more toxic n–butanol. However, these systems are not inexpensive, with the typical cost being thousands of dollars. It would be possible to use personal particle samplers to collect filter samples that could then be analyzed by electron microscopy for particle size, shape, and total number. It is also possible to collect samples using a passive sampler where there is no need for a pump (Wagner and Leith 2001a,b,c). Such an approach would be quite time-consuming, but can provide a time-integrated sample. The use of the microscope would make this approach expensive for routine monitoring, although it could be used for research studies.

Further development of inexpensive particle counting systems could provide monitors capable of ascertaining exposure to ultrafine particles.

6.2.3.4. NO_x and NO_y

No commercial systems make continuous indoor or personal measurements of gaseous HNO_3 or particulate NO_3^-. The new Aerosol Dynamics PMASS will provide a personal sampler with denuder technology that permits measurement of particulate nitrate using filter collection and off-line analysis. However, it has not yet been commercialized. The HEI report describing this system should be available soon.

The HSPH multipollutant sampler (Demokritou et al. 2001) provides a denuder to remove the gaseous HNO_3 for an appropriate filter sample. However, from the information available, it is not clear if the collected HNO_3 can be extracted from the denuder in the sampler for analysis. There are no systems for continuous, portable monitoring of the gases NH_3, NO_x, HNO_3, or particulate NH_4NO_3. Ambient NO_x monitors could be adapted for indoor use; however, these units are too large and expensive for widespread use. The technology in these systems has remained largely unchanged for 20 years, and it may be possible to develop systems based on newer technology that makes the systems smaller and less expensive. However, it again needs to be recognized that there is a need to separate NO_2 from NO_x derived from NO_y.

Thus, there is a need for inexpensive, new monitoring technologies to measure these nitrogenous species, as well as ultrafine particle numbers.

7.0 Reporting Measurement Results

Air quality based on criteria pollutants is measured by the SLAMS network across the country. Raw measurements are converted into values on the Air Quality Index (AQI) using standard formulas developed by the EPA. A major feature of the AQI calculation is that it standardizes the measurement of pollutants to one scale, where an AQI of 100 equals the national ambient air quality standard. An AQI value is calculated for each of the individual pollutants—ground-level O_3, PM, CO, SO_2, and NO_x—in an area. The highest of the AQI values for the individual pollutants becomes the AQI value for that day. In large metropolitan areas (> 350,000 people), state and local agencies are required to report the AQI to the public daily. When the AQI is above 100, they must also report which groups (e.g., children, people with asthma or heart disease) may be sensitive to the specific pollutant. If two or more pollutants have AQI values above 100 on a given day, agencies will report all the groups that are sensitive to those pollutants. Although it is not required, many smaller communities also report the AQI as a public health service, and many metropolitan areas report an AQI forecast that enables local residents to plan their activities to protect their health. For indoor or personal measurements of the criteria pollutants, the AQI approach could be adopted to present a context for the measured values.

Community environmental groups throughout the country are using portable air sampling and monitoring devices to monitor the ambient air quality. Some of these groups use passive monitoring badges or home-made "buckets." Both types of devices require samples to be sent to a qualified laboratory for analysis. Other groups use portable, handheld, or "suitcase" monitors that display and log real-time data. These various community groups have also developed means of disseminating their air quality data to the public. Many groups post data and other air quality information on their organization's Web site. Some groups publish their information in newsletters; other groups host community forums or use the local press to disseminate information. Below are summaries of some of these groups' activities:

The Houston/Galveston (Texas) Citizens Air Monitoring Project (HGCAMP) grew out of an EPA grant to test the comparative effectiveness of the suitcase/Tedlar® bag, citizen-made bucket/Tedlar bag, and a canister in collecting ambient air samples. The EPA, Texas Natural Resources Conservation Commission (TNRCC), Harris County Pollution Control, and the City of Houston—as well as numerous citizen activist organizations such as Mothers for Clean Air, CLEAN, Unidos Contros Environmental Racism and the Environmental Justice Clinic at Texas Southern University all pooled resources to organize a Technical Working Group. This group designed procedures for use with equipment, created a training curriculum and materials, and eventually organized and conducted a training session for citizen monitors. It maintains a system that receives samples, restocks the monitors with bags and other equipment, and delivers the samples to the EPA lab in Houston for analysis. Many of the bucket instruments used in this study were built by citizen monitors. There is also an Information Working Group that is developing a format for publishing test results. The information group will also be involved in the development of an online warning system and will seek to educate the public on toxic air chemistry issues. **Web site:** www.epa.gov/earth1r6/6lab/hgcamp/hgcamp.htm

AirNET is a consortium of multidisciplinary science education programs (**AirNET NH, AirNET NW, AirCurrents, and GASP**) that share a common air quality monitoring curriculum. The AirNET curriculum encourages participants to study both indoor and outdoor air quality, interpret the data collected and share it with other AirNET participants via the Internet. Data on environmental air quality indicators is collected using a portable, battery-operated ACCESS EMS (Environmental Monitoring System). This apparatus measures with direct probes for CO_2, CO, NO_2, O_3, and SO_2, and also measures physical and meteorological parameters. The data are collected every ten seconds, averaged per minute, and are downloaded onto a Macintosh computer, where they are then automatically graphed and analyzed within the context of regulatory limits. The software component of the ACCESS system considers EPA and other regulatory limits, then automatically generates analytical reports and graphs that put the collected data into a context that immediately shows users how that data compares with established standards. The software calculates the maximum, minimum, and average values, as well as the standard deviation over the sampling period and the number of samples that exceeded a pre-set value, such as an EPA limit. Users are encouraged to become "members" of AirNET.

AirNET currently uses four main tools for sharing data and information via the Internet:

- The AirNET mailing list is used for exchanging e-mail about AirNET-related topics with other AirNET members. Using their Web site, anyone can send a message to all members in the mailing list.
- The e-mail address for the AirNET staff is used for exchanging data and information directly and is also accessible through the Web site.

- The AirNET FTP file transfer site is used as a central Internet location where AirNET participants can store and retrieve data. Each school has a separate folder identified with its name.
- AirNET Communicator software can be used by Macintosh computer users to simplify data transfer and e-mail use.

Web site: www.airnet-us.org/index.html

GASP (Group Against Smog and Pollution) makes the ACCESS monitoring system available for school and community use. GASP is a citizens' group based in Southwestern Pennsylvania that focuses on Allegheny County environmental issues. In 1996, GASP received a grant from the Howard Heinz Foundation to purchase an ACCESS monitoring system available for middle and high school use or environmental education in other settings. Teachers are trained how to use the equipment, and they in turn teach their students. The information they collect can be disseminated to other schools. The program provides a 1–2 week use of the monitor with training, delivery/pick up of equipment, and guide books with suggested investigations and use instruction. At the end of each school year, a team of students from each participating school is invited to present their most interesting investigation at a GASPER Air Congress.

Web site: www.prc.org/envposs/antismog.html

Air CURRENTS (Collaboration of Urban, Rural and Regional Environmental Networks of Teachers and Students) is a curriculum designed for middle and high school math, science, and social studies classes to educate students about air, air pollution, and air monitoring techniques (www.aircurrents.org). This program is managed by the Northeast States for Coordinated Air Use Management (NESCAUM), an interstate association of air quality control divisions in the Northeast states. NESCAUM coordinates with local project partners in Brooklyn and Buffalo, New York, and Camden and Newark, New Jersey. The curriculum includes the use of the portable ACCESS air quality monitor. Teachers and students, in collaboration with community groups, conduct air monitoring studies in their schools and communities. The curriculum can be taught with or without employing the ACCESS air monitor. The Air CURRENTS Project is funded by a grant through EPA's Environmental Monitoring for Public Access and Community Tracking (EMPACT) program. Data files are posted on the group's Web site, along with the required ACCESS software, which that can be downloaded easily and used to create graphs and reports.

The **"Bucket Brigade"** a low-tech, but effective air monitoring system that is employed by a number of communities nationwide, uses an ordinary paint bucket, valve, handheld vacuum, and sampling bag. Communities for a Better Environment (CBE) and the SouthWest Organizing Project (SWOP), in Albuquerque, New Mexico has initiated an air monitoring project in response to possible air pollution by local computer chip manufacturer, Intel. Residents use these buckets to take air samples when experiencing adverse health effects (e.g., eye, nose, and throat irritation; headaches; skin rashes). The pump sucks air into a bag inside the airtight bucket. The air sample is then analyzed by a laboratory to evaluate the danger posed by release of industrial pollutants. SWOP has compiled information to better inform the neighborhoods most at risk from Intel's pollution. They use an online "scorecard" published by

Environmental Defense on its Web site to see how Intel's Rio Rancho Fabrication Plant compares to other facilities in New Mexico.

Web sites: SWOP - www.swop.net
Environmental Defense - www.environmentaldefense.org

San Francisco-based **Communities for a Better Environment** (CBE) and citizens in Contra Costa County, California are also employing a bucket brigade as part of a federally funded program to let community members help measure pollution from oil refineries and other industries lining the county's shore. The student science club also samples the air so it can be tested for dozens of toxic materials. About 30 of the buckets have been distributed by the county health department using funds from an EPA grant, and air samples are delivered to the county health department for analysis. **Web sites:** www.cbecal.org/ and www.bucketbrigade.org/

The **Louisiana Bucket Brigade** (LABB) is an environmental organization led by communities that neighbor the state's oil refineries and chemical plants. The LABB was created to arm community members that are directly affected by pollution with buckets, cameras, and video cameras so that they can gather evidence to expose the potential health risks of industrial pollution and broadcast that information immediately. The information gathered by the citizens is being used in campaigns to pressure state and federal regulators, to research and expose operations at targeted facilities, and to alert communities and the general public about the hazards of industrial emissions. **Web site:** www.labucketbrigade.org/

In Johannesburg, South Africa, a local community organization, **groundWork**, collaborated with two United States-based counterparts to introduce community-based "bucket brigade" air pollution monitoring systems in neighborhoods that are located near industrial sites (including oil refinery plants). Community members used a log-in system to record and track pollution incidents that were published once the laboratory tests results were released. A citizen's committee kept track of pollution incidents in the area. The group publishes monthly reports on air pollution and toxic releases in local papers to inform the community on the health threats. **Web site:** www.groundwork.org.za/

The **Global Ozone Passive Monitoring Project**, a global-scale ozone air monitoring network, was designed based on the use of ozone passive air monitoring devices. Volunteers at more than 500 locations around the world assisted with this two-part study in 1999. The group used an ozone passive badge monitor with a porous Teflon wind screen through which ambient ozone diffuses. The ozone diffuses across an air gap inside the sampler and then encounters a layer of indigo carmine dye that reacts with ozone, producing a color change that is proportional to the ozone concentration to which the sampler is exposed, times the duration of exposure. A spectrophotometer was then used to measure the color of each ozone detection layer. Monitoring network volunteers placed the passive ozone sampler outdoors at their site for approximately one month and then mailed it back to California for analysis. The sampler itself is very small (4 x 5 x 1 cm) and was simply taken out of a sealed plastic bag, hung outside for one month, retrieved, and returned via mail. It was designed to be small enough to fit in an inconspicuous padded envelope for mailing. Experiments were conducted worldwide during two test periods: March 1999, and August 1999. March represents the end of the winter in the northern hemisphere, a period of possible stratospheric ozone intrusion, as well as the end of the summer photochemical smog season in the southern hemisphere. Results of the studies are available online. **Web site:** www.thesalmons.org/ozone/

The **Passive Ozone Network of Dallas** (POND) is a regional community network of thirty O_3 monitoring sites that used simple passive devices (the Ogawa Passive Sampler, PS-100). The EPA conducted a study of ambient O_3 concentrations in the Dallas, Texas area in 1998. Results of the study are available online. **Web site:** www.ogawausa.com/Article/page1.htm

The **Southern California Environmental Health Sciences Center** (SCEHSC), in collaboration with the community group **Boyle Heights Mejoramiento,** is investigating airborne particles in the Boyle Heights neighborhood in downtown Los Angeles. This group is using the handheld P-Trak ultrafine particle counter from TSI, Inc. The SCEHSC is developing a 3-week traffic and public health unit for high school students that will allow them to compare the air pollution threats in their neighborhoods. **Web site:** www.usc.edu/schools/medicine/academic_departments/preventive_med/occ_environmental/scehsc/sotoinit.html

8.0 Conclusions and Recommendations

There have been a number of recent developments in air pollution monitoring. Much of the new system development has focused on the measurement of PM mass and constituents. Difficult questions about the loss of semivolatile components from $PM_{2.5}$ remain.

The FRM is the basis for determination for attainment of the NAAQS, but it does not necessarily provide an accurate estimate of the airborne particle mass. There are a variety of continuous monitoring designs that are being tested, including the differential TEOM, the FDMS, and the CAMM. At this time, there needs to be further testing and refinement, but this is a need for further development, rather than additional research or other new concepts. It is the responsibility of the vendors to provide a better-defined measurement method to the measurement community.

At this time, there are adequate ambient monitoring systems to measure particulate and gaseous nitrate, although they are neither portable or inexpensive. The speciation network samplers use annular denuders to separate the gaseous HNO_3 from the particulate nitrate. By capturing the particles on a base-impregnated fiber filter or a Nylasorb® filter, the nitrate is retained on the filter until it is leached from it for analysis. It is labor-intensive to collect and analyze the filters from this system, and it provides only multihour (typically 24-hour) data.

Given the nature of emissions that are likely to arise from DG facilities, there is a need for new systems to measure NO_2 and gaseous NO_y, fine particles, and carbon. There are research methods for NO_2 and NO_y measurement, but they are complex and difficult to use. The current standard network monitors for NO_2 suffer from significant interference from NO_y, and new systems are needed for making the measurements necessary to manage ozone concentrations.

Currently, it is possible to measure particle size distributions effectively, but at high cost and with a complex measurement system. However, with the increasing interest in particle number as a potential indicator for exposure—particularly with respect to the health effects of ultrafine particles—there is a need for smaller, less expensive particle counters, especially if size information can also be obtained.

There are still many uncertainties with respect to the measurement of particulate carbon species. It is expensive to collect and analyze a large number of samples for the identification and quantification of specific organic compounds. In order to use current methods, it is necessary to collect a large mass of material, which increases the difficulty of making indoor or personal measurements. Therefore, other aspects of the carbonaceous aerosol are measured in order to provide information on the possible origins of the particles. There have recently been monitors which purport to measure "diesel," PAH, or ETS. The value of UV light absorption or photoionization for specific identification of diesel emissions or ETS is not yet clear, and more work on the value of these methods is needed. New, portable OC/EC measurement systems are available, but expensive. There is a need for better personal and indoor measurements of exposure to carbonaceous particles. However, a major part of this problem is that the discussion has been framed by what the current carbon techniques measure, rather than by defining what information might be useful to air quality managers in terms of decision making.

Sufficient attention has not been paid to the measurement of VOCs at concentrations typically encountered in home or office environments. Passive adsorptive badges are available for personal or indoor measurements at the high concentrations typically encountered in industrial workspaces. However, there is not yet an adequate capability to provide comparable monitoring in home and commercial spaces, unless the measurements are made over an extended time period. Because temporal information is often useful in identification of sources and exposure patterns, improved measurement methods are needed.

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10.0 Glossary

ATOFMS	Aerosol Time of Flight Mass Spectrometer
BAM	Beta Attenuation Monitor
BC	Black Carbon
CAMM	Continuous Aerosol Mass Monitor
CNC	Condensation Nuclei Counter
DMA	Differential Mobility Analyzer
EAD	Electrical Aerosol Detector
EC	Elemental Carbon
ELPI	Electrical Low Pressure Impactor
ETS	Environmental Tobacco Smoke
FDMS	Filter Dynamics Measurement System
FEM	Federal Equivalent Method
FRM	Federal Reference Method
MSHA	Mine Safety and Health Administration
NAMS	National Air Monitoring Station
OC	Organic Carbon
PAH	Polycyclic Aromatic Hydrocarbon
PAMS	Photochemical Assessment Monitoring Station
PCIS	Personal Cascade Impactor Sampler
PEM	Personal Environmental Monitor
PILS	Particle into Liquid System
PMASS	Personal Micro-Environmental Aerosol Speciation Sampler
RAMS	Real-time Ambient Monitoring System
SCC	Sharp-Cut Cyclone
SEAS	Semi-continuous Elements in Aerosol System
SEM	Scanning Electron Microscope
SES	Sample Equilibration System
SLAMS	State and Local Air Monitoring Station
SMPS	Scanning Mobility Particle Sizer
TEOM	Tapered Element Oscillating Microbalance
WINS	Well Impactor Ninety-Six

Appendix I

List of Vendors for Sampling Equipment

Appendix I

List of Vendors for Sampling Equipment

Vendor	Address	Web Address
Aerosol Dynamics Inc.	2329 Fourth Street Berkeley, CA 94710	n/a
AFC International, Inc.	PO Box 894 DeMotte, IN 46310	www.afcintl.com/
Aircuity, Inc.	55 Chapel St. Newton, MA 02458	www.aircuity.com
Assay Technology	1252 Quarry Lane, Pleasanton, CA 94566	www.assaytech.com/
BGI Inc.	58 Guinan Street Waltham, MA 02451	www.bgiusa.com/
EcoChem Analytics	202 Reynolds League City, TX 77573	www.ecochem.biz
GC Industries	2991 Corvin Drive Santa Clara, CA 95051	www.gcind.com
General Oceanics, Inc.	295 N.W. 163rd Street Miami, FL 33169	www.generaloceanics.com
K & M Environmental, Inc.	2421 Bowland Pkwy # 102 Virginia Beach, VA 23454	www.kandmenvironmental.com
Met One Instruments	1600 Washington Blvd Grants Pass, OR 97526	www.metone.com/
Mine Safety Appliances Company	1420 Mars-Evans City Rd. Evans City, PA 16033	www.msanet.com/
MSP Corporation	5910 Rice Creek Parkway Suite 300 Shoreview, MN 55126	www.mspcorporation.com/
Neutronics, Inc.	456 Creamery Way Exton, PA 19341	www.neutronicsinc.com
Ogawa & Company, USA, Inc.	1230 S.E. 7th Avenue Pompano Beach, FL 33060	www.ogawausa.com
Opsis AB	Box 244 SE-244 02 Furulund Sweden	www.opsis.se

Vendor	Address	Web Address
Pacific Scientific Instruments	481 California Avenue Grants Pass, OR 97526	www.particle.com/
Particle Measuring Systems	5475 Airport Blvd Boulder, CO 80301	www.pmeasuring.com/
PAX Analytics, Inc.	227 West Leyden Rd. Colrain, MA 01340	www.paxana.com
Quest Technologies, Inc.	1060 Corporate Center Drive Oconomowoc WI, 53066	www.quest-technologies.com
RKI Instruments, Inc.	1855 Whipple Rd. Hayward, CA 94544	www.rkiinstruments.com
Rupprecht & Patashnick, Inc.	25 Corporate Circle Albany, NY 12203	www.rpco.com/
SKC Inc.	863 Valley View Road Eighty Four, PA 15330	www.skcinc.com/
Tekran Inc.	132 Railside Road, Unit 1 Toronto, Ontario M3A 1A3 Canada	216.36.224.163/
Thermo Andersen	500 Technology Court Smyrna, GA 30082	www.thermoandersen.com/
Thermo Environmental Instruments Inc.	8 West Forge Parkway Franklin, MA 02038	www.thermoei.com/
Transducer Technology Inc.	2243 Comstock Lane Naperville, IL 60564-4337	www.transducertech.com/
TSI, Inc.	P.O. Box 64394 St. Paul, MN 55164	www.tsi.com
URG Corporation	116 S. Merritt Mill Road Chapel Hill, NC 27516	www.urgcorp.com/

Appendix II

Summary of Monitoring Instruments

Fixed Site, Integrated Particle Samplers

Fixed Site, Continuous Particle Monitors

Personal Integrated Particle Monitors

Continuous Personal Particle Monitors

Particle Number Monitors

Monitors for Gaseous Species

Appendix II

Summary of Monitoring Instruments

The following sheets describe a number of air quality monitoring systems. In order to provide some relative information on the nature of these instruments, this Appendix includes information on cost, portability, whether or not the equipment is capable of producing results on-site, and the degree of complexity of the instrument's QA procedures.

Cost (I, M, E)	I	Inexpensive (<$1000 each)
	M	Moderate cost ($1000 to < $10,000 each)
	M/E	Cost around $10,000 each
	E	Expensive (>$10,000 each)
	VE	Very Expensive (>$50,000)
Portability	L	Light (can be easily carried as a personal monitor)
	M	Moderate (can be carried by a normal healthy worker)
	H	Heavy (may need multiple people or special equipment to move)
Off-Site Work?	Y	Instrument produces a sample that requires additional analysis away from the sampling site
	N	Produces results on-site
QA Complexity	C	Complex (requires multiple steps for calibration and/or complicated procedures to provide adequate quality assurance)
	S	Simple (relatively easy process to assure the quality of the results)

Fixed Site, Integrated Particle Samplers

Instrument Type	Manufacturer	Model	Description	Cost (I,M,E)	Portability (L, M, H)	Off-Site Work?	QA Complexity (C or S)
Mass, Integrated							
	Rupprecht & Patashnick	2000	Manual FRM sampler for either PM_{10} or $PM_{2.5}$	M	M	Y	S
	Rupprecht & Patashnick	2025	Sequential FRM sampler for either PM_{10} or $PM_{2.5}$	M	M	Y	S
	Rupprecht & Patashnick	Partisol-Plus	Dichotomous Sequential Air Sampler	M	M	Y	S
	Rupprecht & Patashnick	2300	Sequential Speciation Sampler	E	M	Y	S
	Rupprecht & Patashnick	2400	High Volume Cascade Impactor Stage 1: large particles (>10 µm diameter); Stage 2: coarse particles (2.5 to 10 µm diameter); Stage 3: fine particles (1 to 2.5 µm diameter); Stage 4: accumulation mode (0.1 to 1 µm diameter)	M	M	Y	S
	Thermo Andersen	RAAS2.5 100	Manual FRM sampler for $PM_{2.5}$	M	M	Y	S
	Thermo Andersen	RAAS2.5 300	Sequential FRM sampler for $PM_{2.5}$	M	M	Y	S
	BGI, Inc.	PQ100	Manual sampler for FRM PM_{10} or TSP sampling	M	M	Y	S
	BGI, Inc.	PQ2000	Manual FRM sampler for $PM_{2.5}$	M	M	Y	S

Chemical Constituents, Integrated							
	Met One	SASS	Five channel speciation network sampler	E	M	Y	S
	Rupprecht & Patashnick	2300	Sequential 4 or 12 channel speciation network sampler, In its 4-channel configuration, the sampler is usually set up to operate all four flow paths during a single interval. It can also be operated as a sequential sampler with 2 groups of 2 channels or 4 groups of 1 channel. The 12-channel configuration provides additional sequential sampling capabilities with its expanded number of channels. Its 12 flow channels can be grouped as of 3 groups of 4 channels, 3 groups of 3 channels, 6 groups of 2 channels, or 12 groups of 1 channel.	E	M	Y	S
	Thermo Andersen	RAAS2.5 400	Six-channel speciation network sampler	E	M	Y	S

URG Corporation	Versatile Air Pollutant Sampler (VAPS)	Dual channel, three flows, collects two fine particle samples simultaneously and one coarse particle sample	E	M	Y	S
URG Corporation	URG-2000-01J	Weekly Air Particulate Sampler, 8 channels, capable of viewing and programming eight on/off settings for different sampling time periods; System can be left unattended for up to eight sampling periods; Internals are interchangeable (filter packs, annular denuders and poly-urethane foams (PUFs)	E	M	Y	S
URG Corporation	URG-2000-01K	Dual Sequential Fine Particle Sampler, manual 4-channel speciation network sampler	E	M	Y	S
URG Corporation	URG-3000DB	Manual sampler that measures the gas phase semi-volatile organic and condensed phase organic compounds; Provides the true phase distribution of the semi-voltaic organic compounds	E	M	Y	S

Fixed Site, Continuous Particle Monitors

Instrument Type	Manufacturer	Model	Description	Cost (I,M,E)	Portability (L, M, H)	Off-Site Work?	QA Complexity (C or S)
Continuous Mass							
	Rupprecht & Patashnick	1400a	Tapered Element Oscillating Microbalance (TEOM) monitor, $PM_{2.5}$ or PM_{10}; normally operated at 50ºC	E	M	N	S
	Rupprecht & Patashnick	SES	TEOM with drier in the inlet stream to remove water and permit 30ºC operation	E	M	N	S
	Rupprecht & Patashnick	8500	Differential system using a cooled filter to provide estimate of volatile and non-volatile portions of the ambient aerosol.	E	M	N	S
	Thermo Andersen	CAMM	Pressure-drop-based monitor, $PM_{2.5}$	E	M	N	S
	Thermo Andersen	BETA Y2K	Continuous Ambient Particulate Monitors using beta gauge principle; TSP, PM_{10}, $PM_{2.5}$ and $PM_{1.0}$; Measurement range from 0 to 5000μg/m^3	E	M	N	S
	Met One	BAM1020	Beta Attenuation Monitor, $PM_{2.5}$	E	M	N	S
	TSI, Inc	3935	Electrical Low-Pressure impactor, 30 nm to 10 mm, 12 stages	E	M	N	S
	Opsis	SM200	Beta Attenuation Monitor for TSP, PM_{10} or $PM_{2.5}$	E	M	N	S

Continuous Size							
	TSI Inc	3935	Electrical Low-Pressure Impactor (ELPI). 30 nm to 10 mm, 12 stages. ELPI combines the accuracy of impactor size classification and rapidity of electrical detection for the same device. A precisely known charge given to the particles in the charger is measured in real time with very sensitive multichannel electrometers as the particle impacts the collection plate.	E	M	N	S
Nephelometers							
	Radiance Research	908	1 wavelength, integrating nephelometer	M	M	N	S
	TSI	3551	1 wavelength, integrating nephelometer	M	M	N	S
	TSI	3563	3 wavelength, integrating nephelometer	E	M	N	S
	TSI	8520	Portable nephelometer; 0.001 to 100 mg/m^3; 0.1 to approximately 10 µm	M	M	N	S
	Rupprecht & Patashnick	3020	Foam cartridges available for the unit make it easy to perform size-selective sampling. These cartridges, installed in the inlet of the monitor, allow for sampling of the thoracic fraction (PM$_{10}$), ISO respirable (4.5 µm diameter), and fine (PM$_{2.5}$) particles.	M	M	N	S

	Grimm	Dust Monitor 1.107	PM$_{10}$, PM$_{2.5}$, and PM$_1$; 0.3 to 25 µm size range; 1 to 6500 mg/m^3 with 0.1 mg/m^3 resolution; reads out in mass units.	E	M	N	S
	Ecochem Analytics	DC 2000CE	Detects particulate-matter surface area through diffusion charging; hand-held unit	E	M	N	S
	Ecochem Analytics	LQI-DC	Detects particulate-matter surface area through diffusion charging	E	M	N	S
Continuous Constituents							
	Rupprecht & Patashnick	5900	Continuous OC/EC monitor, one OC temperature; one EC temperature, collection on impaction stage, no pyrolysis correction	E	M	N	C
	Rupprecht & Patashnick	8400N	Continuous nitrate, impaction, flash volatilization	E	M	N	C
	Rupprecht & Patashnick	8400S	Continuous sulfate, impaction, flash volatilization	E	M	N	C
	Sunset Laboratory		Continuous OC/EC monitor, partial NIOSH 5040 method, with TOT correction	E	M	N	C
	Thermo Andersen	RTA8	880 nm Aethalometer; measures “black carbon”	E	M	N	S
	Thermo Andersen	RTA9	880 nm and 350 nm Aethalometer, claims to detect “diesel” using the 350 nm absorption	E	M	N	S

Thermo Andersen	RTA10	Seven "channels," from 350 nm to 950 nm Aethalometer	E	M	N	S
BGI, Inc	TM-1	Two-channel light absorption, tuned to detect ETS using 620 nm and 370 nm light	E	M	N	S
Tekran, Inc	1135	Particulate mercury analyzer; Model 1135 Particulate Mercury Unit is used together with the Model 1130 Speciation Unit and the Model 2537A Mercury Analyzer to simultaneously monitor particulate bound mercury (HgP), elemental mercury (Hg0) and reactive gaseous mercury (RGM) in ambient air.	E	M	N	C
Ecochem Analytics	PAS2000	The Photoelectric Aerosol Sensor (PAS) works on the principle of photoionization of particle-bound PAH. Using an Excimer lamp, the aerosol flow is exposed to UV radiation. The Excimer lamp offers a high-intensity, narrow band source of UV radiation. The wavelength of the light is chosen such that only the PAH-coated aerosols are ionized, while gas molecules and non-carbon aerosols remain neutral.	E	M	N	S
Ecochem Analytics	PAS2000CE	Hand-held version of PAS2000	M	M	N	S

URG Corp.		Steam-injection collection of hygroscopically grown particles with analysis of ions in the field by ion chromatography	E	M	N	C
University of Maryland	SEAS	Steam-injection collection of hygroscopically grown particles subsequently analyzed for elemental concentrations	E	H	N	C
Georgia Inst. Tech.	PILS	Steam-injection collection of hygroscopically grown particles with analysis of ions in the field by ion chromatography	E	H	N	C

Personal Integrated Particle Monitors

Instrument Type	Manufacturer	Model	Description	Cost (I,M,E)	Portability (L, M, H)	Off-Site Work?	QA Complexity (C or S)
PM mass and/or chemical species							
	MSP Corp	200	Small, lightweight personal samplers (PEM) consist of a single-stage impactor followed by a filter to collect airborne particles for mass or chemical analysis. Aerosol is sampled through the impactor to remove coarse particles larger than the impactor cut-point. Cut-point diameters of 2.5 and 10 µm are available for personal $PM_{2.5}$ or PM_{10} sampling. Sampling flow rates of 2, 4, and 10 liters per minute are available.	I	L	Y	S
	MSP Corporation	PMASS	A 2.5 µm cut-point cyclone inlet with dual channels for simultaneous collection on two filter trains and includes provision for denuders in either, or both, channels	M?[1]	L	Y	C
	BGI, Inc	AFC-123	Simple small filter holder and pump; BGI offers several flow rates and particle size selective inlets for integrated particle sampling for PM_1, $PM_{2.5}$, or PM_{10}	I	L	Y	S

SKC	Various	Primarily industrial hygiene personal monitors with sampler inlets designed to meet various IH definitions of respirable particles. They do not make a $PM_{2.5}$ or PM_{10}, but sell the MSP PEM.	I	L	Y	S
HSPH	Multipollutant Sampler	Two impaction-based samplers for $PM_{2.5}$ and PM_{10} attached to a single elutriator. Two mini $PM_{2.5}$ samplers are also attached to the elutriator for organic carbon (OC), elemental carbon (EC), sulfate, and nitrate measurements. For the collection of nitrate and sulfate, the mini-sampler includes a miniaturized honeycomb glass denuder that is placed upstream of the filter to remove nitric acid and sulfur dioxide and to minimize artifacts. Two passive samplers can also be attached to the elutriator for measurements of gaseous co-pollutants such as O_3, SO_2, and NO_2.	M?[1]	L	Y	C

USC	PCIS	The Personal Cascade Impactor Sampler (PCIS) is a miniaturized cascade impactor, consisting of four impaction stages, followed by an after-filter. Particles are separated in the following aerodynamic particle diameter ranges: <0.25, 0.25–0.5, 0.5 –1.0, 1.0 –2.5, and 2.5–10 µm. The PCIS operates at a flow rate of 9 lpm, using a very high efficiency, battery-operated, lightweight pump at 15 a pressure drop of 11 in. H_2O (2:7 kPa).	M?[1]	L	Y	S
UNC	Passive Sampler	Particles travel through a protective, stainless-steel mesh and deposit on a smooth collection surface by gravity, inertia, and diffusion. For particle concentrations found outdoors, in the home, or in other nonindustrial environments, the appropriate sampling time is about one week. After use, the sampler is capped and analyzed by scanning electron microscopy (SEM).	I	L	Y	S

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[1] This is an estimate of the likely cost based on the complexity of the machining needed to make the sampling head plus the cost of the pump. Price has not yet been set.

Continuous Personal Particle Monitors

Instrument Type	Vendor	Model	Description	Cost (I,M,E)	Portability (L, M, H)	Off-Site Work?	QA Complexity (C or S)
Optical Particle Counter							
	Particle Measurement Systems	HandiLaz 310	0.3–5.0 µm; Sample flow rate of 0.1 cfm / 2.8 lpm; Size channels: 0.3, 0.5, 1.0, 5.0 µm; <10^6 ft^3	M	M	N	S
	Thermo Andersen	personal DataRAM	0.1 to 10 µm; measurement range from 0.001 to 400 mg/m^3; personal exposure	M	M	N	S
	Thermo Andersen	pDR-1200	1.0 to 10 µm; personal exposure measurements	M	M	N	S
	Royco	HH200A/200B	Handheld; HH200A ch1 0.5 µm; ch2 selectable — 0.7, 1.0, 3.0, or 5.0 µm and HH200B ch1 0.3 µm; ch2 selectable—0.5, 1.0, 3.0, or 5.0 µm	M	M	N	S
Condensation Nuclei Counter							
	TSI, Inc	P-TRAK	Handheld Ultrafine Particle Counter (UPC); 0 to 5 H 10^5 particles/cm^3; 0.02 to greater than 1 µm	M	M	N	S
Mass Monitors							
	Ecochem Analytics	DC 2000CE	Detects particulate-matter surface area through diffusion charging; hand-held unit	M	M	N	S

	Rupprecht & Patashnick, Inc	Not yet assigned	Small, portable metal TEOM, developed for MSHA	M?	L	N	S
Species Monitors							
	Ecochem Analytics	PAS2000CE	Handheld Photoelectric Aerosol Sensor (PAS) uses the principle of photoionization of particle-bound PAH. An Excimer lamp exposes the aerosol flow to UV radiation. The Excimer lamp is a high-intensity, narrow band source of UV radiation. The wavelength is chosen such that only the PAH-coated aerosols are ionized, while gas molecules and non-carbon aerosols remain neutral.	M	M	N	S

Particle Number Monitors

Instrument Type	Manufacturer	Model	Description	Cost (I,M,E)	Portability (L, M, H)	Off-Site Work?	QA Complexity (C or S)
Condensation Nuclei Counter							
	TSI, Inc	3022A	Condensation nuclei counter, 7 nm lower limit, 0 to 9.99 H 10^6 particles/cm^3	E	M[1]	N	S
	TSI, Inc	3025A	Condensation nuclei counter, 3 nm lower limit, 0 to 9.99 H 10^4 particles/cm^3	E	M[1]	N	S
	TSI, Inc	3010	Condensation nuclei counter, 10 nm lower limit, <10,000 particles/cm^3	E	M[1]	N	S
	TSI, Inc	3760/3762	Condensation nuclei counter, 11 nm lower limit, 0 to 10,000 particles/cm^3/0 to 5,000 particles/cm^3	M	M[1]	N	S
	TSI, Inc	3007	Condensation nuclei counter, 10 nm lower limit, 0 to 100,000 particles/cm^3	M	M[1]	N	S
	TSI, Inc	3070A	Electrical Aerosol Detector, 10 nm to >1 µm, measures total aerosol length	M	M	N	S
	TSI, Inc	P-TRAK	Handheld Ultrafine Particle Counter (UPC); 0 to 5 H 10^5 particles/cm^3; 0.02 to greater than 1 µm	M	M	N	S
	Grimm	5.401	Minimum size: >5 nm; Max. counts: 10^5 /l;	E	M[1]	N	S
	Grimm	5.402	Minimum size: >5 nm; Max. counts: 10^7 /l;	E	M[1]	N	S
	Grimm	5.403	Minimum size: >5 nm; Max. counts: 10^{10} /l;	E	M[1]	N	S

Particle Measuring Systems 7625	Minimum size 20 nm, max counts: 1,000,000 ft^{-3}	M	M[1]	N	S
Particle Measuring Systems 7650	Minimum size 14 nm, max counts: 1,000,000 ft^{-3}	M	M[1]	N	S

[1] Although the CNC is not hard for one person to carry, it is important to drain the working fluid reservoir and thus, it is not a portable instrument.

Optical Particle Counters

Climet	CI-500	0.3 to 20 mm particles, 1 CFM flow	E	M	N	S
Climet	Ultimate 100	0.1 mm sensitivity; Sensitivity as low as 0.065 µm is possible.	E	M	N	S
Climet	CI-200	0.2 µm 1.0 CFM particle counter	E	M	N	S
Climet	MicroPro 400	Choice of sizes: 0.5/5.0 µm or 0.3/0.5 µm	E	M	N	S
Particle Measurement Systems	LASAIR® II	0.3 - 25.0 µm; 0.3, 0.5, 1.0, 5.0, 10.0, 25.0 µm channels; <425000 ft^3	E	M	N	S
Particle Measurement Systems	Micro LPC	0.05, 0.07 and 0.1µm sensitivities; clean room environments	E	M	N	S
Particle Measurement Systems	HandiLaz 310	0.3–5.0 µm; Sample flow rate of 0.1 cfm/2.8 lpm; Size channels: 0.3, 0.5, 1.0, 5.0 µm; <10^6 ft^3	M	M	N	S
Thermo Andersen	personal DataRAM	0.1 to 10 µm; measurement range from 0.001 to 400 mg/m^3; personal exposure	M	M	N	S
Thermo Andersen	pDR-1200	1.0 to 10 µm; personal exposure measurements	M	M	N	S
Thermo Andersen	DataRAM	0.1 to 10 µm; 0.1 to 999.9 µg/m^3(resolution: 0.1µg/m^3); 1.00 to 39.99 µg/m^3 (resolution: 0.01mg/m^3); 40.0 to 399.9 mg/m^3 (resolution: 0.1mg/m^3)	M	M	N	S
Royco	100A/150B	100A 0.5 and larger or 150B 0.3 and larger; counts the number of particles in 0.1 cubic foot (2.83 lpm) of air.	M/E	M	N	S

Royco	MA100/MA200	MA100 6 ch 0.1, 0.2, 0.3, 0.5, 0.7, 1.0 or MA200 6 ch 0.2, 0.3, 0.5, 0.7, 1.0, 3.0, 5.0; Total counts, counts/ft^3, counts/m^3	M/E	M	N	S
Royco	HH200A/200B	Handheld; HH200A ch1 0.5 µm; ch2 selectable—0.7, 1.0, 3.0, or 5.0 µm and HH200B ch1 0.3 µm; ch2 selectable—0.5, 1.0, 3.0, or 5.0 µm	M/E	M	N	S
Royco	MA300B/300	300B 2 ch 0.3, 0.5 µm; 4 ch 0.3, 0.5, 1.0, 5.0 µm; 5 ch 0.3, 0.5, 1.0, 5.0, 10.0 µm; 6 ch 0.3, 0.5, 1.0, 3.0, 5.0, 10.0 µm; 300 2 ch 0.5, 5.0 µm; 4 ch 0.5, 1.0, 5.0, 10.0 µm; 5 ch 0.5, 1.0, 2.0, 5.0, 10.0 µm; 6 ch 0.5, 1.0, 2.0, 3.0, 5.0, 10.0 µm; coincidence loss <5% at 400,000 counts/ft^3	M/E	M	N	S
Royco	323/325	323 0.3, 0.5, 1.0, 3.0, 5.0, 10.0 µm; 325 0.5, 1.0, 2.0, 3.0, 5.0, 10.0 µm	M/E	M	N	S
Royco	330A/330B	330A 2 ch 0.5, 5.0 µm;4 ch 0.5, 0.7, 1.0, 5.0 µm; 5 ch 0.5, 0.7, 1.0, 2.0, 5.0 µm; 6 ch 0.5, 0.7, 1.0, 2.0, 3.0, 5.0 µm; 330B 2 ch 0.3, 0.5 µm; 4 ch 0.3, 0.5, 1.0, 5.0 µm; 5 ch 0.3, 0.5, 0.7, 1.0, 5.0 µm; 6 ch 0.3, 0.5, 0.7, 1.0, 2.0, 5.0 µm	M/E	M	N	S

Royco	5230/5250A	8 channels; 5230 User-selectable, starting at 0.30 µm; 5250A User- selectable, starting at 0.50	M/E	M	N	S
Royco	R8801/R8901	2 channels (standard), 4 or 5 channels (optional); Particle Size Ranges (µm) 2-channel 0.1, 0.3 µm; 4-channel 0.1, 0.2, 0.3, 0.5 µm; 5-channel 0.1, 0.2, 0.3, 0.4, 0.5 µm	M/E	M	N	S
Grimm	Dust Monitor 1.107	PM_{10}, $PM_{2.5}$, and PM_1; 0.3 to 25 µm size range; 1 to 6500 mg/m^3 with 0.1 mg/m^3 resolution; reads out in mass units.	E	M	N	S
Grimm	DUSTcheck IAQ 1.101	Reads in either counts or estimated mass concentrations; Generally measures in the range of 0.35 to 20 µm; has backup filter for gravimetric comparisons; counts up to 2 x 10^6 per liter; mass estimation to 100 mg/m^3	E	M	N	S

Size Measurement Systems, Aerodynamic Sizing							
	TSI, Inc	3220	The Aerosizer spectrometer uses a time-of-flight, cross-correlation technique to provide high-resolution measurements similar to single-particle-counting instruments. The Aerosizer DSP spectrometer detects particles in the range from 0.6 to 200 µm, in concentrations up to 5,000 particles per cm^3. It provides usable particle size data in concentrations up to 100,000 particles per cm^3.	VE	M	N	S
	TSI, Inc	3321	The Aerodynamic Particle Sizer (APS) uses time-of-flight and relative light scattering intensity to detect particles in the size range of 0.37 µm to 20 µm.	VE	M	N	S
Size Measurement Systems, Electrical Mobility							
	TSI, Inc	3936	Scanning Mobility Particle Sizer; multiple ranges depending on choice of DMA and CNC. With 2025A CNC and short DMA, 2 to 150 nm to several configurations with range of 10 to 1000 nm; 20 x 10^7 particles/cm^3. Can also be used as a DMPS.	VE	M[1]	N	S

Grimm	Sequential Mobility Particle Sizer and Counter	Uses a differential mobility analyzer similar to the TSI and a CNC to provide a DMPS.	VE	M[1]	N	S
MSP	WRAC	The Wide Range Aerosol Counter is a flexible combination of a DMA, CNC, and laser particle counter. Price depends on just what is included, but top of the line system does SMPS, DMPS, plus LAS. Not yet available. Proposed first delivery at the end of the first quarter of 2003.	VE	M[1]	N	S

Monitors for Gaseous Species

Instrument Type	Manufacturer	Model	Description	Cost (I,M,E)	Portability (L, M, H)	Off-Site Work?	QA Complexity (C or S)
VOCs, including Gaseous HAPs other than Hg							
	Assay Technology	ChemScout	Wide range of VOCs, as given in Table 5 of the report using passive adsorption badges.	I	L	Y	S[1]
	3M	3500/3520	Wide range of VOCs, as given in Table 5 of the report using passive adsorption badges.	I	L	Y	S[1]
	SKC	575	Wide range of VOCs, as given in Table 5 of the report using passive adsorption badges.	I	L	Y	S[1]
	K&M Environmental, Inc	TraceAir 380000-005	Wide range of VOCs, as given in Table 5 of the report using passive adsorption badges.	I	L	Y	S[1]
	RKI Instruments.	EAGLE; GX-2001; GP-82; GX-82A / GX-86A; GX-94; GasWatch; CO-94	Wide variety of gases, but typically at occupational exposure levels; electrochemical detection	I	L	Y	S[1]
	General Oceanics, Inc	PAQS	300 ml canister with capillary flow control	I	L	Y	C

	Drager	Grab Sample Detection Tubes	Color indicating, survey instrument for a very wide variety of gases beyond those listed in Table 5 of the report; uses a pump to pull a specific air volume through the tube.	I	L	N	S
	Drager	Chip Measurement System	Uses chemical-specific chips and a digital reader to provide measurement of 34 different gases and vapors; several chips cover different ranges of the same gas.	I	L	N	S
	Drager	Color Diffusion Tubes	Color indicating, survey instrument for a limited number of species. Based on diffusion into the tube and a resulting color reaction to provide a direct indication of the presence of and concentration of the specific gas of interest.	I	L	N	S
Criteria Gases							
	Rupprecht & Patashnick	3300	Ogawa Passive Sampling System provides a cost-effective means of determining the concentrations of NO, NO_2, NO_x, SO_2, and O_3.	I	L	N	S

Ogawa & Company	3300	Ogawa Passive Sampling System provides a cost-effective means of determining the concentrations of NO, NO_2, NO_x, SO_2, and O_3.	I	L	N	S
Transducer Technology	PH2S1000	H2S, < 1 ppm; electrochemical detector	M	M	N	C
Transducer Technology	PCO1000	CO, < 1 ppm; electrochemical detector	M	M	N	C
Transducer Technology	PNO21000	NO_2, < 0.002 ppm; electrochemical detector	M	M	N	C
TSI, Inc.	8552 Q-Trak	Non-dispersive infrared (NDIR) for CO_2; temperature (T) and relative humidity (RH)	M	M	N	C
TSI, Inc.	8554 Q-TRAK Plus	Electro-chemical CO; Non-dispersive infrared (NDIR) for CO_2; T and RH	M	M	N	C
K&M Environmental, Inc.	ChromAir ozone badges 380010-10	Color indicating passive ozone badge; ChromAir badges have six levels and can be used with the ChromAir color comparator for higher resolution and accuracy.	I	L	N	S
K&M Environmental, Inc.	ChromAir carbon monoxide badges 380008-10	Color indicating passive CO badge; ChromAir badges have six levels and can be used with the ChromAir color comparator for higher resolution and accuracy.	I	L	N	S

K&M Environmental, Inc.	ChromAir nitrogen dioxide badges 380006-10	Color indicating passive NO_2 badge; ChromAir badges have six levels and can be used with the ChromAir color comparator for higher resolution and accuracy.	I	L	N	S
K&M Environmental, Inc.	ChromAir sulfur dioxide badges 380005-10	Color indicating passive SO_2 badge, ChromAir badges have six levels and can be used with the ChromAir color comparator for higher resolution and accuracy.	I	L	N	S
K&M Environmental, Inc.	SafeAir carbon monoxide badges 382012-50	Color indicating CO badges; when used with the SafeAir color comparator, the system offers up to 11 levels of quantification	I	L	N	S
K&M Environmental, Inc.	SafeAir nitrogen dioxide badges 382013-50	Color indicating NO_2 badges; when used with the SafeAir color comparator, the system offers up to 11 levels of quantification	I	L	N	S
K&M Environmental, Inc.	SafeAir ozone badges 382004-50	Color indicating O_3 badges; when used with the SafeAir color comparator, the system offers up to 11 levels of quantification	I	L	N	S
K&M Environmental, Inc.	SafeAir sulfur dioxide badges382014-50	Color indicating SO_2 badges; when used with the SafeAir color comparator, the system offers up to 11 levels of quantification	I	L	N	S

PAX Analytics, Inc.	ACCESS Environmental Monitoring Systems	ACCESS combines the use of physical sensors for CO, CO_2, hydrocarbons, NO, NO_2, O_2, O_3, SO_2, meteorological variables, solar irradiance, UV, ELF, and ionizing	E	H	N	C
Aircuity, Inc.	IAQ Evaluation System	System has multiple sensors for CO_2, CO, particle counts with an OPC in two size bins (<2.5 and >2.5 mm, T, RH, pressure, total VOCs, O_3, and radon	E	H	N	C
GC Industries	various	Units Monitor Single Gases Including: Oxygen (Models GC501 & GC502), Carbon Monoxide (Model GC401), Hydrogen Sulfide (Model GC701), Sulfur Dioxide (Model GC801), Nitric Oxide (Model GC901) and Nitrogen Dioxide (Model GC952). All are for concentrations in the ppm range with precisions of +/-2 ppm.	M	M	N	C
Quest Technologies	aq-5000/aq-5001	CO, CO_2, hydrocarbons, NO, NO_2, O_2, O_3, H_2S, HCN; third party support for respirable particles and VOCs	M	M	N	C

[1.] Simple if the vendor's laboratory is used for the analysis of the sample. It is possible to analyze the samples, but the analyses are complex, as is the QA for the measurements.

Hg(0)

	Brooks-Rand	AF-03	Manual mercury (0) monitor using gold wire traps; thermal desorption and cold vapor atomic fluorescence	M	M	Y	C
	Texran	2537	Automatic gaseous mercury (0) sampler/analyzer	E	M	N	C
	K&M Environmental, Inc	ChromAir mercury badge 380018-10	Color indicating mercury badges; ChromAir badges have six levels and can be used with the ChromAir color comparator for higher resolution and accuracy.	I	L	Y	S
	K&M Environmental, Inc	SafeAir mercury badges 382005-50	Color indicating mercury badges; when used with the SafeAir color comparator, the system offers up to 11 levels of quantification.	I	L	Y	S
	Drager	Chip Measurement System	CO, NO_2, SO_2 chips available for use with a digital readout device.	M	L	N	S
	Ecochem Analytics	HG-MONITOR 3000	The measuring principle used in the HG-MONITOR 3000 is based on the resonance absorption of mercury atoms at a wavelength of 253.7 nm. Measurement range of 0.1 to 3000 $\mu g/m^3$.	M	M	N	C

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A SURVEY OF MONITORING INSTRUMENTS FOR MEASUREMENT OF AIRBORNE POLLUTANTS

FINAL REPORT 03-05

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