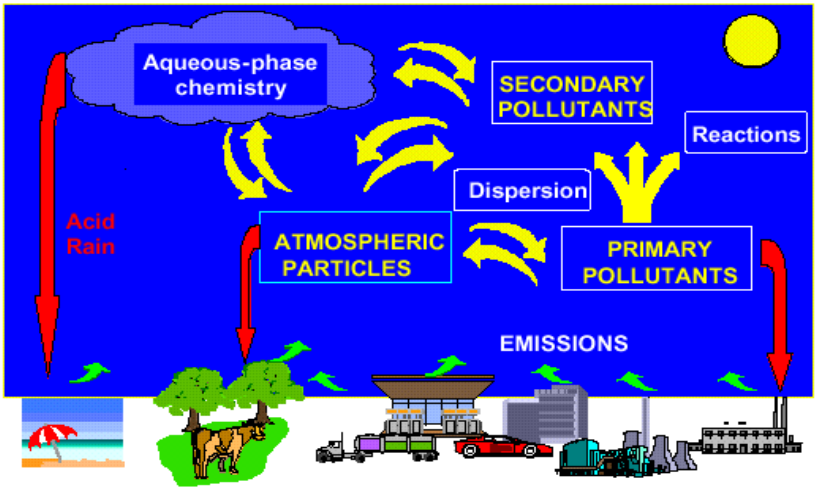
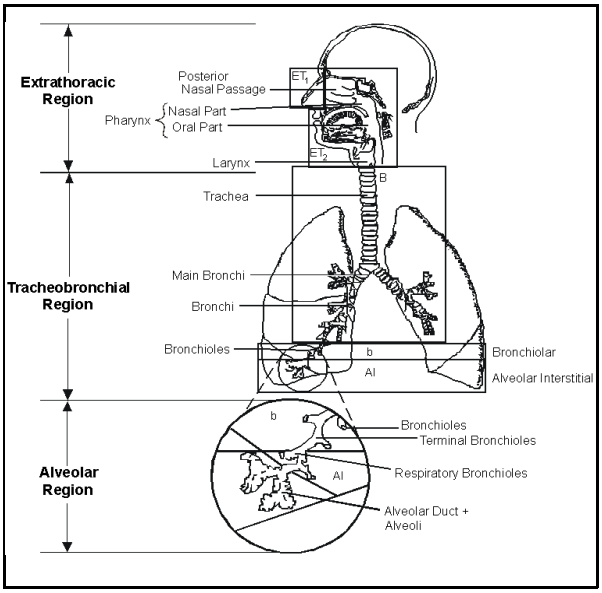
Strategic Research Plan for Particulate Matter





Air Quality Research Subcommittee
of the
Committee on Environment and Natural Resources (CENR)

December, 2002

STRATEGIC RESEARCH PLAN FOR PARTICULATE MATTER

Cover Figure: Depiction of the atmospheric processes of particulate matter and their contribution to human exposure with resulting deposition in the human air passageway and regions of the lung on the cover of this document signify the emphasis being placed on linkage between human health, human exposure and atmospheric sciences in this strategic plan. It is also descriptive of the relationship between particulate matter size and its level of lung penetration and deposition. While fine ($\leq$2.5μm) and coarse fraction (2.5 – 10μm) particles deposit to about the same extent in the trachea and upper bronchi, a distinctly higher percent of fine mass deposits in the alveolar region.

During the seven month period of November, 2001 through May, 2002, meetings of the Air Quality Research Subcommittee of the Committee on Environment and Natural Resources (CENR) and its Particulate Matter (PM) Research Coordination Working Group focused on a strategic plan for federal research on the health and environmental effects, exposures, atmospheric processes, source characterization and control of fine airborne PM. This document describes the broad elements of an interagency research plan to focus the resources of member agencies addressing the most pressing needs of this public health and welfare issue. The report lays out a conceptual framework that integrates discipline specific research in a risk assessment - risk management context. It summarizes current understanding, highlights recent accomplishments, and identifies some of the key information gaps in science to support public policy on PM. It highlights a set of policy relevant science questions and the intended impacts of ongoing Federal research to answer these questions. Science on this subject is rapidly evolving and periodic updates of this working document are anticipated.

Particulate Matter Research Coordination Working Group
Air Quality Research Subcommittee
Committee on Environment and Natural Resources

Copies of this research plan are available from:
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List of Acronyms

ACE	Aerosol Characterization Experiment
AERONET	Aerosol Robotic Network
AIRMoN	Atmospheric Integrated Research Monitoring Network
AL&WS	Air, Land, and Water Sciences (TVA)
AQRS	Air Quality Research Subcommittee
ARM	Atmospheric Radiation Measurement
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATSD	Agency for Toxic Substances and Disease Registry
AVHRR	Advanced Very High Resolution Radiometer
BRAVO	Big Bend Regional Aerosol and Visibility Study
BSRN	Baseline Surface Radiation Network
CASTNET	Clean Air Status and Trends Network
CDC	Centers for Disease Control and Prevention
CENR	Committee on Environment and Natural Resources
CERES	Clouds and the Earth's Radiant Energy System
CMAQ	Community Multiscale Air Quality [model]
CSREES	Cooperative State Research, Education, and Extension Service
DOD	Department of Defense
DOE-EE	Department of Energy – [Office of] Energy Efficiency
DOE-FE	Department of Energy – [Office of] Fossil Energy
DOE-SC	Department of Energy – [Office of] Science
EPA	Environmental Protection Agency
ESE	Earth Science Enterprise
FHWA	Federal Highway Administration
FRM	federal reference method
ESP	electrostatic precipitators
FSR&	Forest Service Research and Development
HEPA	high efficiency particulate air [filters]
IMPROVE	Interagency Monitoring of Protected Visual Environments
INDOEX	Indian Ocean Experiment
Landsat	NASA satellites providing continuous global land surface images
μm	micrometer, 10^{-6} meters
MISR	Multiangle Imaging SpectroRadiometer
MODIS	Moderate Resolution Imaging Spectroradiometer
NAAQS	National Ambient Air Quality Standard
NAPAP	National Acid Precipitation Assessment Program

NASA	National Aeronautics and Space Administration
NCEH	National Center for Environmental Health
NHLBI	National Heart, Lung, and Blood Institute
NIAID	National Institute of Allergy and Infectious Diseases
NIEHS	National Institute of Environmental Health Sciences
NIH	National Institutes of Health
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NMMAPS	National Morbidity, Mortality, and Air Pollution Study
NOAA	National Oceanic and Atmospheric Administration
NO_X	nitrogen oxides (nitric oxide and nitrogen dioxide)
NPS	National Park Service
NSF	National Science Foundation
OAR	Office of Air and Radiation (EPA)
ORD	Office of Research and Development (EPA)
PM	particulate matter
$PM_{2.5}$	particulate matter with an aerodynamic diameter less than 2.5 micrometers
PM_{10}	particulate matter with an aerodynamic diameter less than 10 micrometers
$PM_{10-2.5}$	particulate matter with an aerodynamic diameter between 10 and 2.5micrometers
PMF	Positive Matrix Factorization
PSD	prevention of significant deterioration
SCR	selective catalytic reduction
SeaWIFS	Sea-viewing Wide Field-of-view Sensor
SO_2	sulfur dioxide
SOS	Southern Oxidants Study
SRD	standard reference data
SRM	standard reference material
TVA	Tennessee Valley Authority
TOMS	Total Ozone Mapping Spectrometer
USDA	US Department of Agriculture
USFS	US Forest Service
USGS	US Geological Survey
UVB	ultraviolet-B

INTRODUCTION

Airborne particles of fine(<2.5μm) and coarse (2.5μm–10μm) size ranges are linked to widespread health effects and to visibility impairment of scenic vistas. Additionally, these particles and their component elements interact in ways that contribute to elevated concentrations of other air pollutants, ecosystem stress, and global climate change. The means by which particulate matter (PM for short) causes or contributes to these health and environmental issues is uncertain and is the subject of an integrated Federal research program. This strategy describes how agencies of the Federal government will coordinate and integrate research among atmospheric, exposure and health sciences to provide the information needed by policy makers.

Goal: Enhance the scientific information base for public policy that protects the public health (of primary importance) and the environment from harmful effects due to airborne particulate matter.

Objectives: Integrate health, exposure, ecology, atmospheric process, and source characterization research pertaining to particulate matter. Coordinate efforts among US Federal agencies and, as feasible, the private sector. Address the highest priority research needs first, to inform public policy choices for standard setting and air quality management.

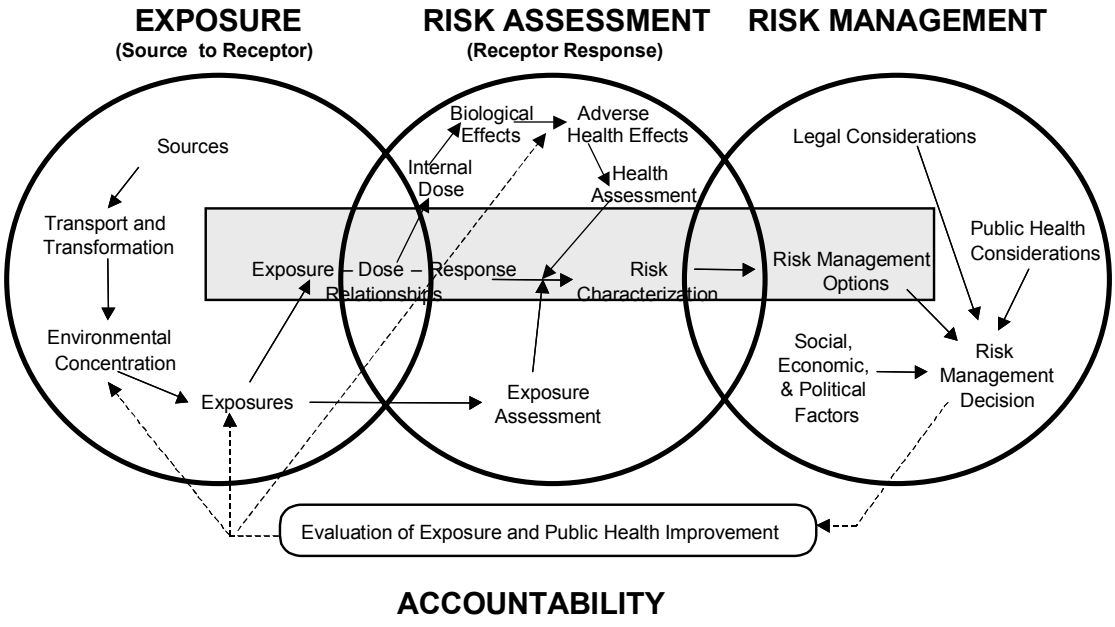
Approach: In 1997, the President called for a partnership of Federal agencies to develop a greatly expanded, coordinated, interagency PM research program. The program was to contribute new science associated with particulate matter health effects, cost-effective mitigation strategies, and improved air quality monitoring. In response, the Air Quality Research Subcommittee of the Committee on Environment and Natural Resources (CENR) formed the PM Research Coordination Working Group to support interagency strategic planning and coordination of all PM-related research. The Working Group has developed this overall federal PM research strategy, and several agencies have developed agency-specific PM research strategies to guide their internal and external programs.

The Federal PM research strategy is based on a conceptual paradigm for PM that integrates research across the exposure-risk assessment-risk management continuum (see Figure 1). Discipline specific research will provide key insights to explain the source-to-receptor relationships of exposure, the exposure-dose-response relationships of health effects and risk assessment, and the source control - exposure reduction relationships of risk management. Post management decision attention to evaluating improvements in PM exposure and corresponding improvement in human and environmental health is an additional feature of the paradigm. A central tenet of this strategy, as depicted by the overlapping and closed loop of the paradigm, is that all federal research be coordinated and fully integrated across this paradigm, such that all aspects are appropriately addressed to meet national statutory needs in setting and achieving air quality standards to protect the public health and environment.

Areas of PM research being coordinated under this strategy include: human health effects, ecological effects, exposure, air measurements, atmospheric processes, and source emissions characterization. Each is briefly described following the outline of the strategic actions to be taken by the PM Research Coordination Working Group in carrying out this strategy.

Figure 1.

Paradigm for Federal Research on Particulate Matter



STRATEGIC ACTION PLAN

Key actions necessary to meet plan objectives and goal include:

Establish a Conceptual Model for PM and for Complementary and Collaborative Research

A model linking emissions, atmospheric fate and transport, human exposure, health and environmental effects, risk assessment and control is used to support discipline-oriented teamwork within an interdisciplinary strategy. The complementary missions of participating agencies provide a basis for collaborative research. A conceptual model is developed that integrates these factors and ties them to the national standard setting, air quality management, assessment and review process. (See PARADIGM AND RESEARCH OVERLAY, Fig. 2)

Define Priority Questions

Protecting the public health and the environment requires research methods, models and data to address questions of policy relevance. As policies are established, the value of new information evolves and requires continual evaluation. A necessary first step to strategic coordination is to identify the critical, policy-relevant science questions embedded in the PM conceptual model that affect policy choices. (See Key Questions, pp. 18-23)

Evaluate Activities to Address Questions

Efforts are underway in the U.S. and abroad to address questions through both fundamental and applied research. To efficiently target, coordinate, and leverage atmospheric, exposure, and health research, we are comprehensively assessing ongoing efforts through a web-based PM research inventory, www.pmra.org, which is being maintained by the Health Effects Institute. (Work ongoing)

Prioritize Research Needs

The National Research Council, NARSTO (A North American Consortium for Atmospheric Research in Support of Air-Quality Management), and others have identified priority needs to support PM policy development. We embrace these evaluations and are applying an outcome-based approach to guide interagency research directions. (Work ongoing)

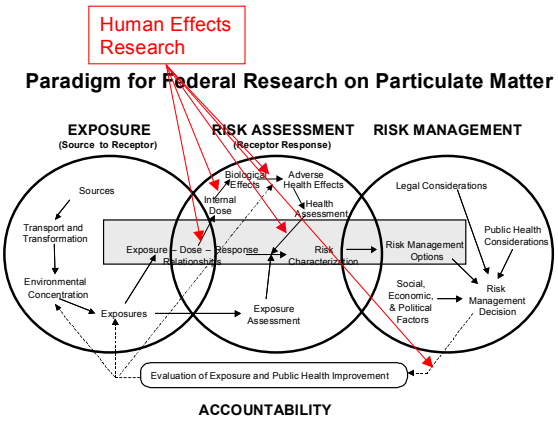
Support Effective Decision Making and Public Awareness

Application of research results informs policy making and aids review and redirection of research and monitoring efforts. Formal and informal communication methods ensure that data users, the public, and other stakeholders are informed of accomplishments and outcomes. Annual symposiums and workshops, meetings of national organizations, specialty workshops, and the web will be used for this purpose (Work ongoing)

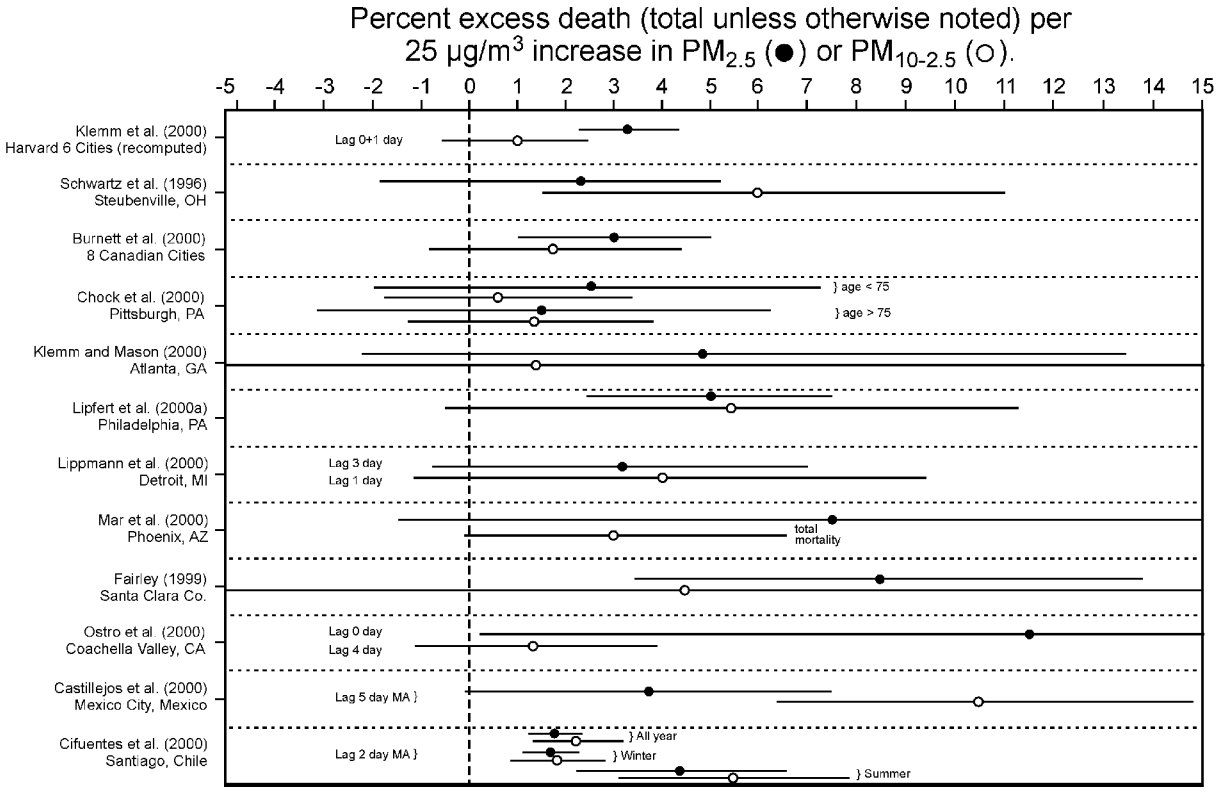
Each of these actions is important to carrying out this strategic plan as is an appreciation of the major areas of PM research and the interactions between them. What follows are summary descriptions for each major area of PM research profiling our current understanding, select recent accomplishments, and key information gaps. These descriptions provide initial guidance on pressing research needs.

RESEARCH COMPONENTS AND FOCUS ISSUES

A) Human Health Effects



Current Understanding: Particulate matter has been linked to a range of serious respiratory and cardiovascular health problems. Scientific studies suggest a likely causal role of ambient particulate matter in contributing to these health effects. The key acute effects associated with ambient particulate matter include premature mortality (see figure below), aggravation of respiratory and cardiovascular disease (as indicated by increased hospital admissions and emergency room visits, school absences, work loss days, and restricted activity days), aggravated asthma, acute respiratory symptoms (including aggravated coughing and difficult or painful breathing), chronic bronchitis, and decreased lung function that can be experienced as shortness of breath. The health effects of these exposures are difficult to accurately assess, but it has been estimated that exposures to PM may result in tens of thousands of excess deaths per year and many more cases of illness among the U.S. population. These risk estimates indicate the important public health need to adequately understand and address air pollution concerns.

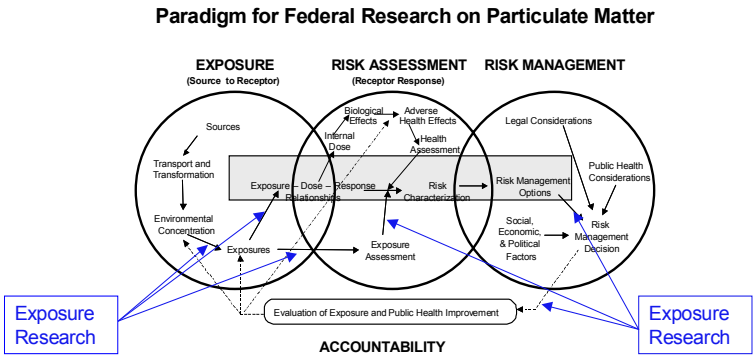


Percent excess risks estimated per 25 µg/m^3 increase in $PM_{2.5}$ or $PM_{10-2.5}$ from new studies evaluating both $PM_{2.5}$ and $PM_{10-2.5}$ data for multiple years, based on single pollutant (PM only) models. All lags = 1 day, unless indicated otherwise (See Section 8.4.2 for same studies shown here that found different risk estimates in MP models with both fine and coarse particles included). From EPA 2002.

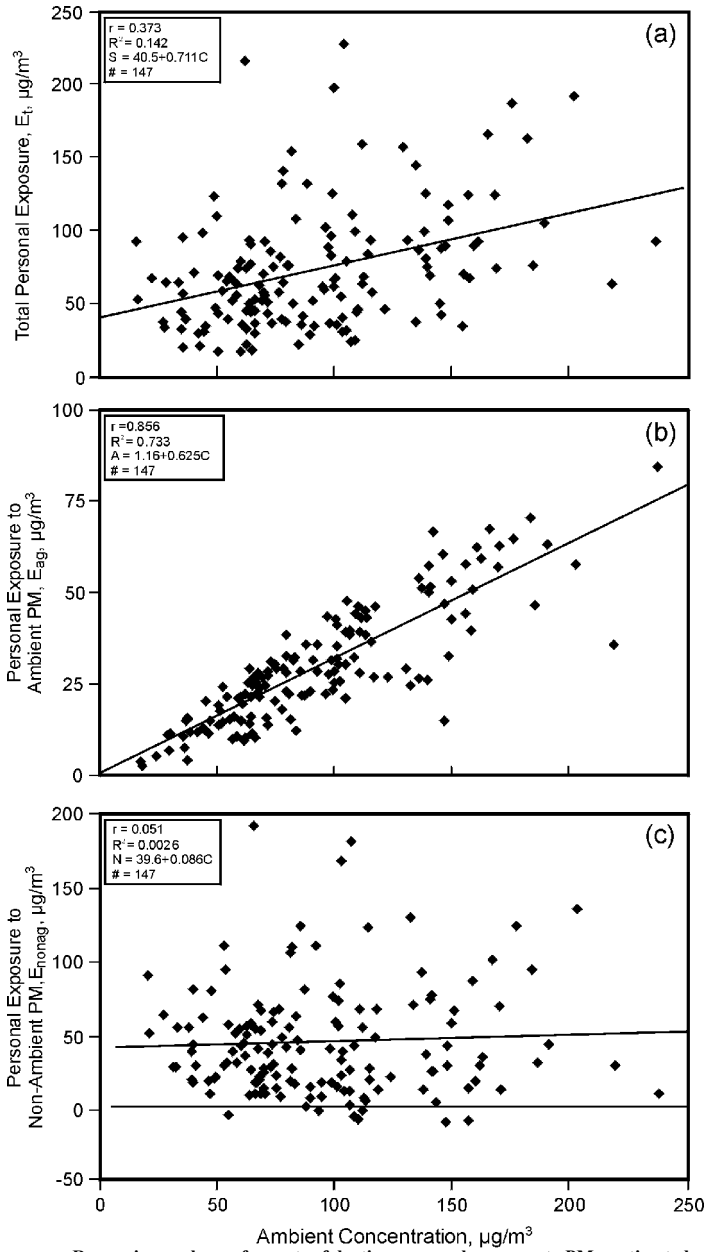
Selected Recent Accomplishments: The National Morbidity, Mortality and Air Pollution Study (NMMAPS) has assessed epidemiology findings from 90 U.S. cities and generally confirmed the key findings of the 1996 Air Quality Criteria Document for PM concerning associations between PM and acute mortality/morbidity. Similarly, the re-analysis of the Harvard Six Cities Study and the American Cancer Society Study have confirmed the original findings linking chronic PM exposure to shortened life span. A series of recent panel studies have shown associations between PM and altered autonomic control of the heart. Controlled exposure of humans and animals to concentrated ambient air particles have confirmed and extended the findings of the panel studies, as well as reported PM-induced increases in blood factors involved in clotting and coagulation. Together, these findings provide a plausible biological mechanism to explain PM-induced mortality, but may not explain which components of PM are responsible for these effects.

Key Information Gaps: The first and most important priority is a better assessment of the long term effects of PM. Additional priority needs include: 2) further identifying the components of PM responsible for its adverse health effects, 3) elucidating plausible biological mechanisms by which PM elicits its effects, 4) better definition of those sub-populations most susceptible to PM, and 5) better understanding of the contribution of gaseous co-pollutants PM effects.

B) Exposure Relationships



Current Understanding: Personal exposure to PM can result from exposure to ambient PM while outdoors, ambient PM penetrating indoors and into other microenvironments, or to PM generated indoors by their activities. Exposures to PM of non-ambient origin are driven by indoor sources and personal activities that generate PM. Human exposure data and models provide the critical link between ambient monitoring data, inhalation models, and studies of adverse health effects. Studies presenting correlations (see figure below) between personal exposure and outdoor PM concentrations show considerable variation among different studies, and within each study between the study subjects. Several studies have shown that, for individuals with little exposure to non-ambient sources, correlations between personal exposure and ambient PM are high. Still, even for these studies, correlations varied by individual depending upon their activities and the microenvironments they occupied. These variations may lead to exposure misclassification errors in certain types of PM health effects studies. Although exposure measurement errors for fine particles are not expected to influence the interpretation of findings from either the community time-series or the long-term, cross-sectional epidemiologic studies that have used ambient concentration data, they may underestimate the strength of the impact. Sufficient data are not available to evaluate the impact of exposure measurement error for PM species or size fractions.



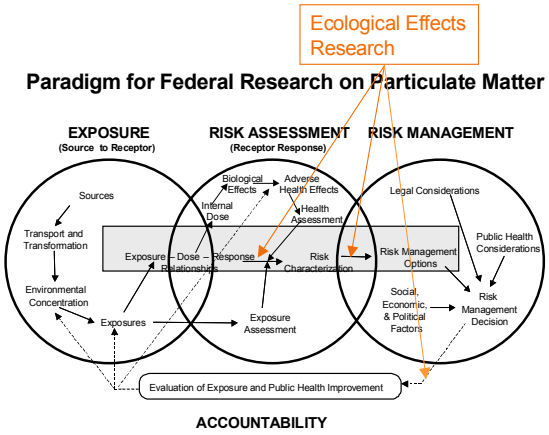
Regression analyses of aspects of daytime personal exposure to PM_{10} estimated using data from the PTEAM study. (a) Total personal exposure to PM, E_t, regressed on ambient concentration, C_a. (b) Personal exposure to ambient PM, E_{ag} regressed on C_a. (c) Personal exposure to nonambient PM, E_{nonag} regressed on C_a. Source: Data taken from Clayton et al. (1993).

Selected Recent Accomplishments: Recent longitudinal panel studies of elderly participants in Baltimore, MD and Fresno, CA, and studies of chronic obstructive pulmonary disease patients in Boston have shown that individual personal PM exposures may vary by season, residential and geographical setting, and subject groupings. Building type and ventilation characteristics strongly influence exposures to ambient PM as well as the

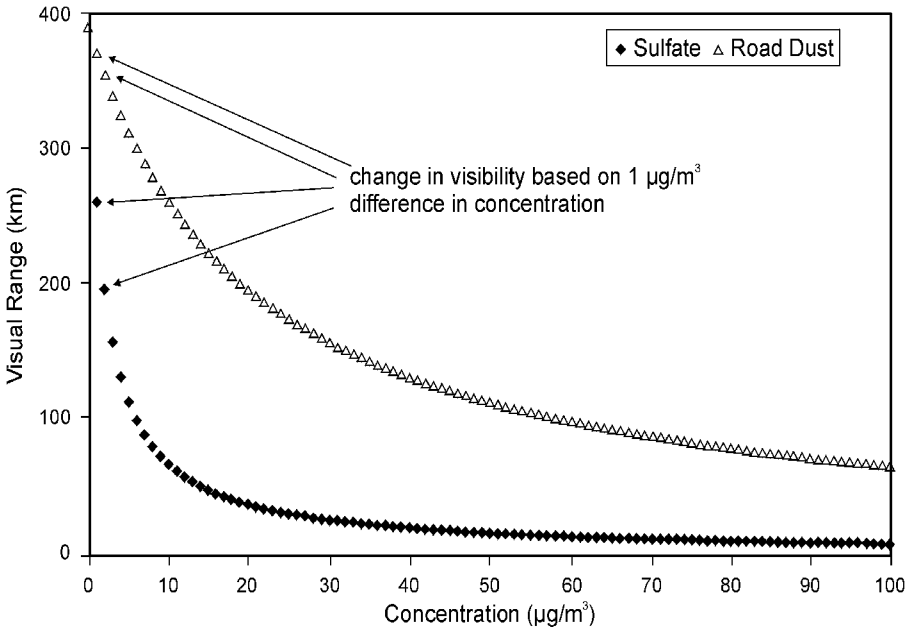
relationship between personal exposure and ambient concentrations. Although correlations between indoor and outdoor concentrations for $PM_{2.5}$ and fine particle sulfates are generally high, ultrafine particles give poor correlations. Finally, multi-pollutant exposure studies suggest that ambient concentrations of gaseous co-pollutants are surrogates of personal exposure rather than confounders.

Key Information Gaps: Priority needs include: 1) Linkage of human exposure models with inhalation/dose models and source/receptor and air quality models, 2) more reliable exposure models and estimates of personal and population exposures to PM of outdoor and indoor origin to reduce potential exposure misclassification errors in future PM epidemiology studies, and 3) a better understanding of exposures to PM species from all sources to accurately define the relationship between PM exposure and health outcomes.

C) Ecological Effects



Current Understanding: Secondary PM NAAQS standards are set to protect public welfare, visibility, ecosystems, climate change, and UVB radiation. Fine PM is a major contributor to visibility impairment in many parts of the U.S. (see figure below). The physical and chemical processes through which fine PM contributes to visibility impairment are fairly well understood and documented. With fine PM made up mostly of sulfate, elemental or organic carbon, and nitrate, it is these components most policy makers are targeting to improve area visibility. Sulfate and nitrate components of PM are also significant contributors to wet and dry deposition to watersheds, thereby playing a role in their acidification and nitrification. Acidic deposition and its effects on watersheds, surface waters, and fish and plant species have been well documented by the National Acid Precipitation Assessment Program (NAPAP). The light scattering and absorbing properties of fine PM, and the role it plays in cloud formation, have implications for global climate change and ultraviolet radiation penetration. While not nearly as well understood as visibility impairment, it is clear that there are off-setting processes at work. PM can contribute both positively and negatively to climate change, and can play a role both in absorbing harmful UVB radiation and in increasing UVB radiation near the ground. The quantification of these phenomena is complex due to the high variability of PM mass and number over time and space, and the differences in PM absorption and scattering properties.



Reduction in visual range as a function of increasing fine (sulfate) and coarse (dust) particle concentrations. Source: Watson and Chow (1994).

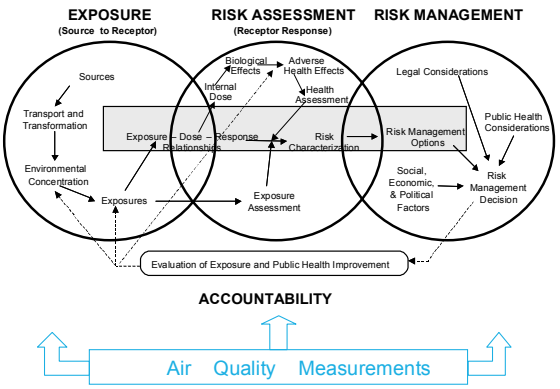
Selected Recent Accomplishments: The Big Bend Regional Aerosol and Visibility Observational (BRAVO) study, by the NPS and others, characterizing aerosol and visibility in the vicinity of Big Bend National Park, has used source tracers and modeling of source regions in Texas and Mexico to attribute impairment over this area. The NSF/NOAA supported field campaigns over the waters surrounding Southeast Asia, the Aerosol Characterization Experiments (ACE-1, ACE-2, and ACE-ASIA), are providing confidence in our ability to measure aerosol properties in the marine atmosphere. EPA's regional particulate component of its Models-3/CMAQ air quality model has been shown to produce estimates of visual range consistent with visibility observations and has been evaluated against data for a summer

season in eastern North America. Avian toxicology studies conducted by Pacific Northwest National Laboratories for DOD investigated the effects of military fog oil and graphite on surrogates of endangered avian species such as the Red-Cockaded Woodpecker with effects showing no significant impacts as compared to controls.

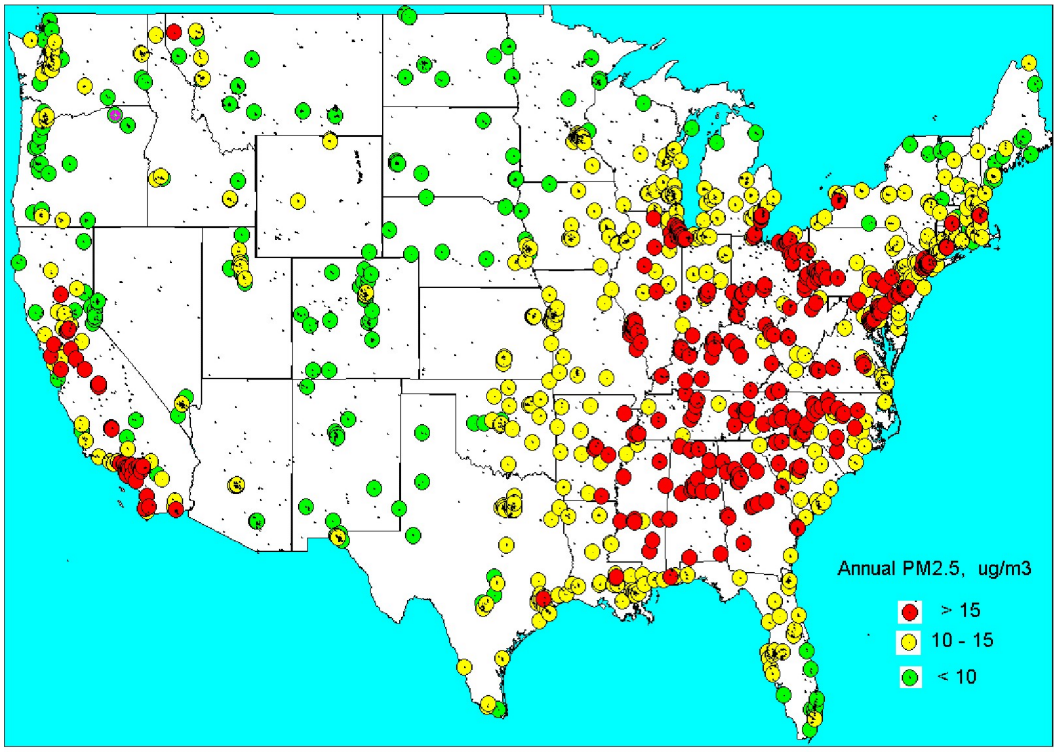
Key Information Gaps: Priority needs include: 1) transferring our understanding of PM related visibility impairment for rural regions to urban areas, 2) modeling secondary organic aerosol processes for their role in visibility impairment, 3) fully describing the role of nitrogen compounds from emissions, to secondary PM formation, to deposition, to effects, and 4) spatially and temporally resolving information on the atmospheric burden and radiative properties of aerosols.

D) Air Measurements

Paradigm for Federal Research on Particulate Matter



Current Understanding: PM measurements are needed to determine compliance with the PM NAAQS, identify contributing sources for attainment planning, and to determine health, ecological and radiative effects. Federal Reference Methods for $PM_{2.5}$ and PM_{10} that measure total mass integrated over 24 hours are used for NAAQS compliance and have precision in the ± 10% range. It is not currently possible to fully characterize the material that exists as a particle in the atmosphere as desired for other purposes due to complexities, such as semi-volatile material and particle bound water. Therefore, the approach used is to analyze for major PM constituents with methods developed based on first principles and field tested by the scientific community for their comparability. In order to serve all needs, the nation's current PM monitoring program consists of a multi-organizational, tiered network (see The Role of Monitoring Networks in the Management of the Nation's Air Quality, AQRS, 1999). EPA and the States run the 3-tier PM monitoring program (see figure below) with 900 FRM sites collecting total mass every third or sixth day, 185 sites measuring PM mass every day, 250 speciation sites analyzing PM for its principal constituents, and 7 super sites using the very latest in experimental techniques to come as close to full characterization as possible. In addition, the 135-site IMPROVE network run by the NPS monitors light extinction, or visibility, in National Parks and analyzes filter material for 5 major classes of material. EPA and NOAA run the nation's wet and dry deposition networks, the 55-site CASTNET program of EPA and the 12-site AirMON program of NOAA.



Average annual PM2.5 mass concentrations, 1995-2000. Source: http://capita.wustl.edu

Selected Recent Accomplishments:

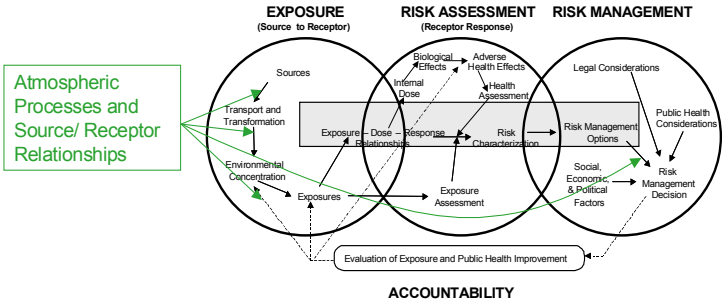
A number of techniques have been developed to measure PM $_{2.5}$ and/or PM_{10} mass on time scales from a

few minutes to an hour. Comparisons with traditional filter-based measurements suggest that these techniques provide comparable results in most instances. Instruments are now available to quantify the major components of ambient aerosols (sulfate, nitrate, ammonium, organic carbon, black carbon). Analysis times as short as a couple of minutes have been demonstrated. A number of single-particle mass spectrometer systems have been developed to probe the chemical composition of individual particles. Many of these emerging technologies were compared against each other and against conventional filter-based techniques at the Southern Oxidants Study's Atlanta Supersite. Initial results are very encouraging and these, and other similar techniques, are playing a major role at other EPA Supersites and in PM monitoring and research being conducted throughout the U.S.

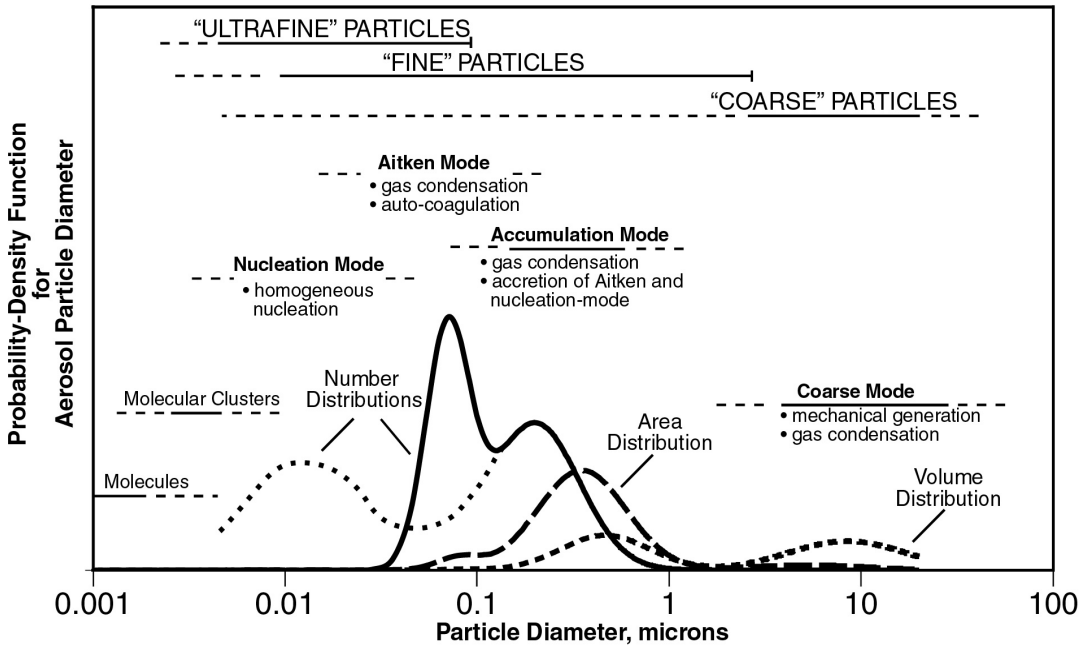
Key Information Gaps: Priority needs include: 1) precise (inter-comparable) methods for the nitrate and organic carbon fractions of PM, 2) comparison of continuous measurement methods for PM mass and determination of the relationship between what is measured and what is present in the atmosphere, and 3) reference standards to test the accuracy and comparability of methods.

E) Atmospheric Processes and Modeling

Paradigm for Federal Research on Particulate Matter



Current Understanding: Airborne particulate matter originates from a variety of sources and possesses a range of chemical, physical, and thermodynamic properties. It can be generally characterized as discrete particles spanning several orders of magnitude in size (see figure below), with several size fractions currently representing the focus of regulatory concern: PM_{10} (generally defined as all particles equal to and less than 10 microns in aerodynamic diameter); $PM_{2.5}$, also known as fine fraction particles (generally defined as those particles with an aerodynamic diameter of 2.5 microns or less), and $PM_{10-2.5}$, also known as coarse fraction particles (generally defined as those particles with an aerodynamic diameter greater than 2.5 microns, but equal to or less than 10 microns). Another fraction of interest to health scientists is the ultrafine fraction of particles, those less than 0.1microns. These divisions generally relate to the modes of particles that seem to occur naturally due to fundamental processes. The major constituents of atmospheric PM are sulfate, elemental carbon, nitrate, ammonium, particle-bound water, a great variety of organic compounds, and crustal material. Much of PM is referred to as secondary PM in that it is the result of interactions of gaseous pollutants after emission into the atmosphere (e.g., ammonium sulfate and ammonium nitrate). The emission sources, formation processes, chemical composition, atmospheric residence times, transport distances and other parameters of fine and coarse particles are distinct. Fine particles can remain in the atmosphere for days and up to weeks and can travel through the atmosphere hundreds to thousands of kilometers, while coarse particles usually deposit to the earth within minutes and hours and within tens of kilometers from the emission source. Meteorological conditions and processes, such as relative humidity, cloud cover, temperature, wind speed and direction play an important role in particle transformation, transport and fate.



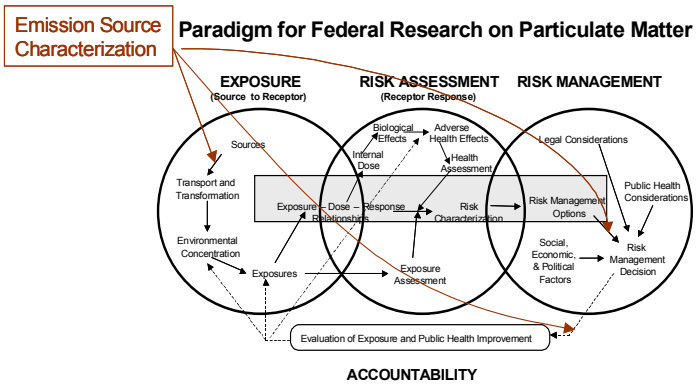
Schematic of terminology, including area and volume distributions of suspended particulate matter. Source: NARSTO, 2001

Selected Recent Accomplishments: EPA has completed development of a first version regional air quality model, Models-3/CMAQ, which simulates the chemical and meteorological processes contributing to fine particle levels in the atmosphere. EPA is in the process of evaluating the model against observed PM levels

taken from regional monitoring and intensive field campaigns. A recent intensive field study of the interaction of nitrogen oxides and humidity in the Atlanta, GA area has shed new light on the formation of particulate nitrates in the southeastern U.S.. Several studies in the southeastern U.S. have indicated primary and secondary particulate organic carbon is present year-round in amounts of the order of that for sulfate.

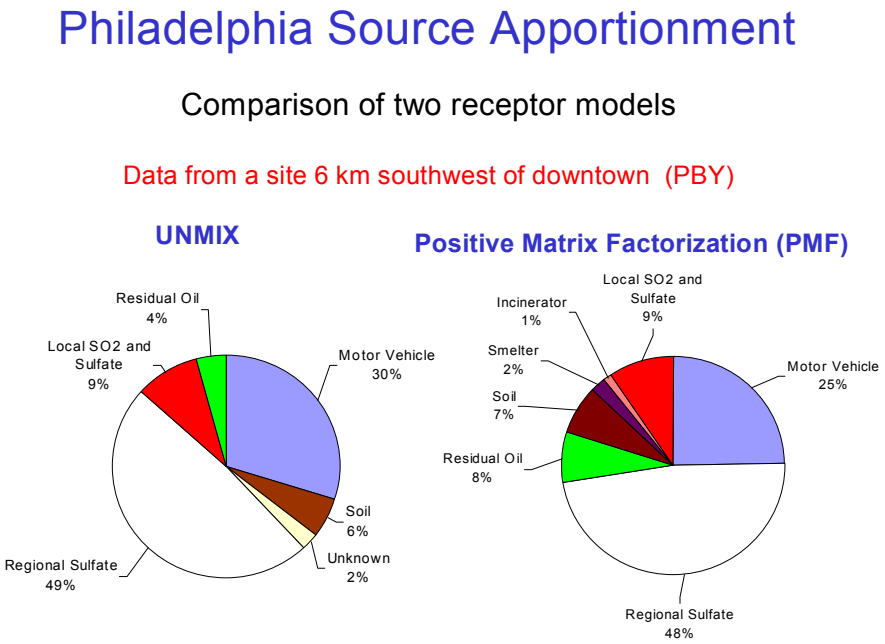
Key Information Gaps: The highest priority need is for sufficient time and spatially resolved speciated ambient data to evaluate the regional air quality models to be used for policy making. Additional priority needs include: knowledge of and model representations for the uptake of reactive or condensible materials by existing particles, chemical reactions involving particles in clear air and clouds, hygroscopic growth, phase transitions, and their removal by deposition.

F) Source Characterization



Current Understanding: The vast majority of fine particles over the U.S. are either directly emitted from combustion sources or are formed secondarily from gaseous precursors, such as sulfur dioxide, nitrogen oxides, and organic compounds (see figure below). In some regions, a small fraction can be due to crustal materials. Combustion of coal, oil, diesel, gasoline, and wood (by nature and man), as well as high temperature process sources, such as smelters and steel mills, all produce emissions that contribute to fine particle formation. In contrast, coarse particles are typically mechanically generated by crushing or grinding and are often dominated by resuspended dusts and crustal material from paved or unpaved roads or from construction, farming, and mining activities.

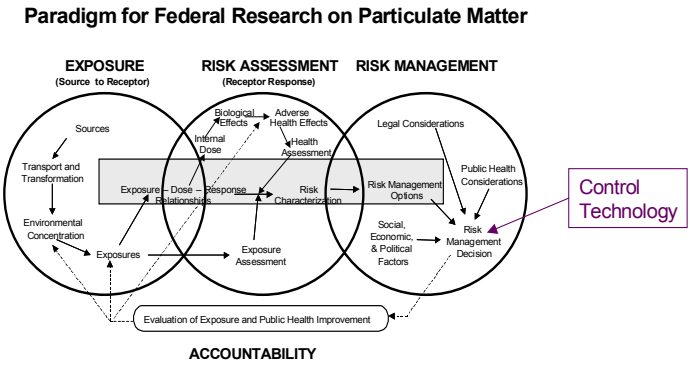
Selected Recent Accomplishments: Improvements continue to be made in the ability of receptor models to allocate ambient PM to source categories. These models, which have historically been used to allocate primary PM concentrations, are now being improved to allocate secondary PM as well. Recently developed techniques, such as positive matrix factorization, allow quantitative determinations of contributions from different source categories based on ambient data alone. Recent source attribution studies on the east and west coast of the U.S. have offered quantification of seasonal Saharan and Gobi dust reaching the U.S. and showing up in fine fraction PM.



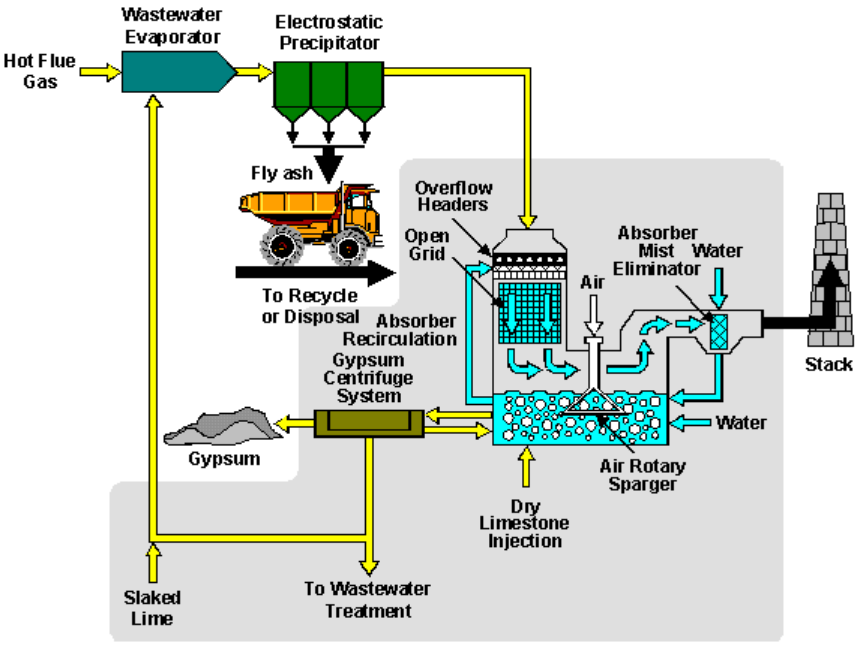
Reconstructed apportionment of PM2.5 mass for 3 year period of 1992-1995 using surrogate secondary sources. Source EPA (2000)

Key Information Gaps: Priority needs include: 1) characterization of emissions from non-road transportation sources, including construction, farm equipment, aircraft, marine vessels, and small-powered vehicles, 2) source apportionment work to distinguish diesel PM (on-highway and non-road) from ambient PM, and 3) characterization of ammonia emission sources, both natural and man-made.

G) Control Technology



Current Understanding: Controlling both primary and secondary particulate matter at their source is important to decrease adverse effects. Primary PM generated by combustion may be controlled through fuel modifications, altering combustion chambers to improve efficiency, and introducing post-combustion filters. For large combustion sources such as coal-fired power plants, electrostatic precipitators (ESPs) and fabric filters (baghouses) can achieve primary particulate collection efficiencies of over 99% for PM_{10} and 95% for $PM_{2.5}$. For smaller combustion sources, High Efficiency Particulate Air (HEPA) filters are commonly used in many applications which filter particles at sizes down to .3 microns with 95%–99.97% efficiency. Ceramic and composite material filters are used in advanced systems. Combustion sources can also control the emissions of gaseous precursors to secondary PM by employing wet scrubbing systems (see figure below) to remove sulfur dioxide, and selective catalytic reduction (SCR) to remove nitrogen oxides, at efficiencies that can exceed 95% and 90%, respectively. Primary emissions generated by mechanical forces are chiefly comprised of dust generated by disturbing soils, crushing rocks or natural erosion. Most soils form a natural barrier when fine particles are lofted, leaving heavier particles, pebbles and rocks. This crust protects the underlying soil from further degradation. Soil structure may be stabilized through modification of road construction, application of dust palliatives and by limiting disturbances to the natural crust. Fine particles may be deposited on the crust surface by hydrological events. Source term controls to prevent this type deposition are difficult because of expansive mitigation areas. Modified vegetative cover assists control of these source terms, as well as decreasing windblown erosion.

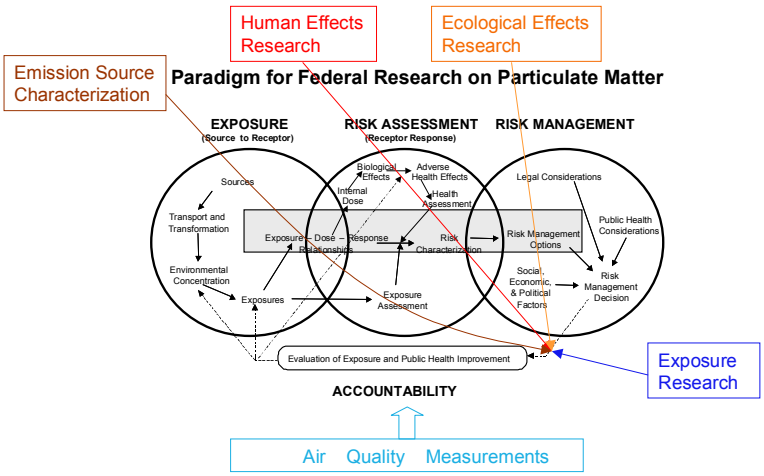


Control systems for primary PM (electrostatic precipitator) and secondary PM precursors (sulfur dioxide scrubber) at coal-fired power plants (Courtesy of US DOE Office of Fossil Energy)

Selected Recent Accomplishments: Recent control developments include highly compact, ceramic-membrane-coated silicon carbide (SiC) monolith filters, that can be coated with non-selective catalysts to achieve simultaneous removal of particulate matter while oxidizing vapor-phase volatile organic compounds and carbon monoxide. A separate oxidation catalyst also can be deposited on the filtration surface area that will result in "passive" regeneration of soot to allow extended continuous operation. Newly-developed technologies for coal-fired power plants that combine the best features of ESPs and baghouses have the potential to achieve primary particulate removal efficiencies of over 99.99%.

Key Information Gaps: The highest priority need is for technology that will improve the efficiency and cost-effectiveness of systems that control gaseous precursors to secondary particulate matter.

H) Accountability



Current Understanding: Measuring progress toward the goals of clean air and protection of public health and welfare can be accomplished through a multi-tiered approach. Our ability to track emissions reductions, Tier 1, varies by source type and pollutant of interest. Many of the country's largest combustion sources have continuous emissions monitoring for SO_2 and NO_x, making direct tracking over the course of months and years possible. Many other intermediate sized sources estimate their annual emissions through a combination of source testing, process parameter monitoring, and emissions factor modeling. It is particularly difficult to track transportation sources and open sources; the former depends on fleet age and maintenance, and the latter depends on meteorological conditions, as well as surface treatment.

Our ability to track air quality improvements and changes in exposures, Tier 2, is influenced by several factors. One is the need to separate pollution change signals from changes due simply to meteorology. This need can be met by having a sufficient baseline, estimated at 3–5 years, and data record, estimated at 5–10 years depending on how rapidly emissions fall and the level of confidence required for reported information. The Federal Reference Method and the U.S. PM mass monitoring network are specifically designed to track air quality progress against the PM NAAQS. It is much more difficult to track changes in PM constituents where questions of both method and deployment come into play. Routine methods are available for some constituents such as sulfate, but others such as nitrates and semi-volatile organic material require highly specialized techniques and personnel to operate them and are typically limited to intensive field studies over short periods of time. A set of newly instituted PM Speciation Sites will begin to address the desire to track changes in PM species. Ongoing exposure studies are identifying metrics relating changes in ambient air quality to changes in human exposures.

Tier 3 encompasses improvements in health and welfare effects including clearing visibility and ecosystem recovery. Of these, we are in the best shape to monitor changes in regional haze. Many aspects of an appropriate approach are now or soon will be in place including an agreed upon measurement and analysis method, a sufficiently representative network, and defined criteria of success. Monitoring changes in ecosystem health due to changes in sulfate and nitrate deposition are routinely monitored in certain sensitive watersheds with reports on progress issued every two years by NAPAP. Monitoring improvements in human health as PM exposure diminishes will continue using current and developing methods and models relating health effect indicators with associated PM levels. In the near term, changes in morbidity and morbidity indicators will be monitored in relation to changes in PM mass levels over a large sampling of cities. Tier 3 health monitoring will incorporate more sensitive health indicators and new scientific information about specific PM components and co-pollutants as they become available.

Selected Recent Accomplishments: The National Acid Precipitation Assessment Program's Biennial Report to Congress: An Integrated Assessment, May 1998. The EPA's National Air Quality and Emissions Trends Report, 1998 (June, 2000 available at www.epa.gov/oar/aqtrnd98).

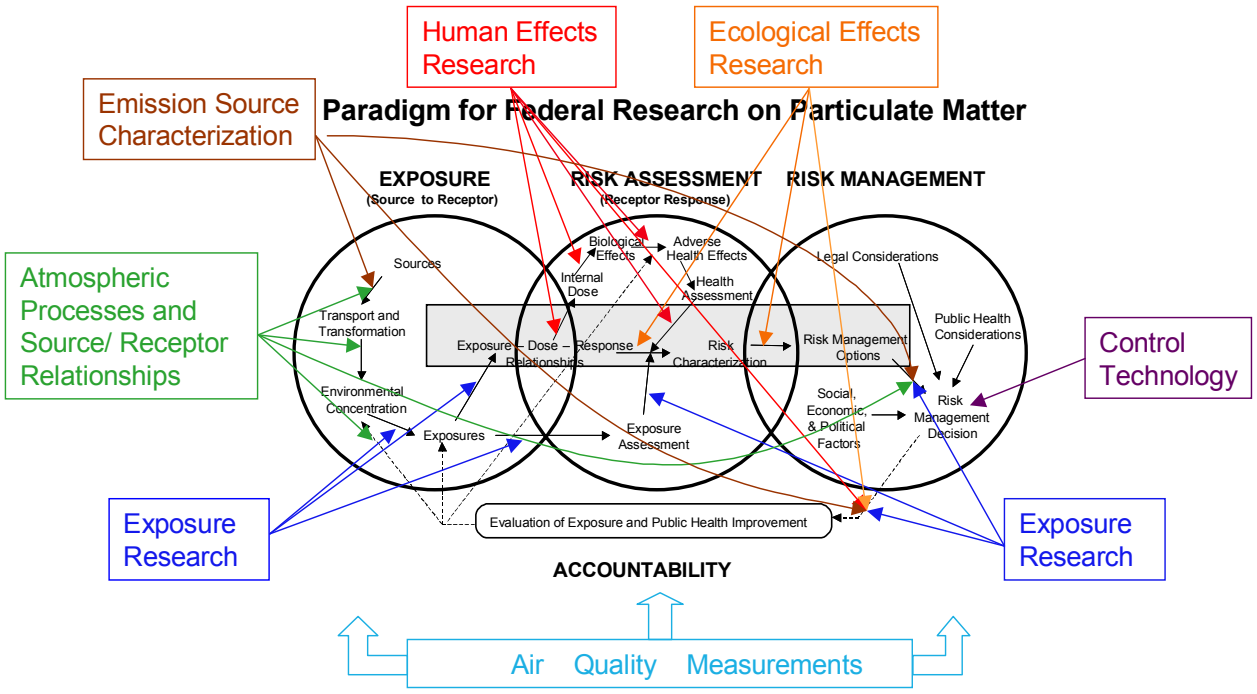
Key Information Gaps: An over-riding need within this strategy is development of a PM Accountability Design Plan, identifying the sources of data and protocols to be used within and between each tier of the program. The plan should specifically address approaches for quantifying changes and drawing scientifically defensible associations between changes in emissions, ambient PM concentrations and components, human exposures, and health effects. The plan should provide the identification of appropriate metric(s) for PM most closely tied to health effects. In particular, the plan should include a

review of new methods for the evaluation of health effects.

PARADIGM AND RESEARCH OVERLAY: KEY QUESTIONS AND IMPACTS

Figure 2 highlights the primary impact points for the discipline specific research described above in relation to the exposure-risk assessment-risk management continuum which must be understood to fully address the PM problem. Several aspects of this depiction are worth noting. Research in a given area will be important to multiple parts of the PM problem. For instance, health effects research will contribute crucial information to understanding delivered doses, biological mechanisms of effects, and adverse effect levels important to setting national air standards, in addition to ultimately identifying the full set of health indications used to assess progress protecting public health. Simultaneous research in multiple areas is important to understanding some parts of the problem. For example, both exposure research and health effects research are important to the assessments upon which risk characterization is based; emissions source characterization, ecological effects, health effects, and exposure research are all important to demonstrating improvement under program accountability. Air quality measurements and the methods they rely on, while not research strictly speaking, are important for nearly all parts of the PM problem.

Figure 2. Overlay of research components on PM research paradigm showing primary impact points.



Aspects such as those described above reinforce the view of interdependent discipline specific research and the need for its full integration to inform national policy formulation. An additional means of integrating research and assuring its policy relevance is to align its intended outcomes, particularly its intended impacts, with the policy related science questions it will help answer. Ten key questions fundamental to solving the PM problem have been identified and are listed below along with examples of the federal research meant to inform answers through the intended impacts of agency projects and programs.

Key Research Questions and Example Impacts of Agency Research:
(From NRC Research Priorities for Airborne Particulate Matter, Report II, 1999)

Exposure Relationships

1. What are the quantitative relationships between concentrations of PM and gaseous copollutants measured at stationary outdoor air monitoring sites, and what are the contributions of these concentrations to actual personal exposures, especially for susceptible subpopulations?

2. What are the exposures to the most biologically important constituents and characteristics of PM that cause responses in potentially susceptible subpopulations and the general population?

Projected impacts of agency research:

CDC/NIOSH - Research addresses a wide-range of particulate exposures such as: beryllium, bioaerosols, coal mine dusts, cotton dust, diesel exhaust emissions, organic agricultural dusts, and other mixed dust exposures, as well as laboratory studies of particle characteristics and toxic mechanisms, and risk assessment using both toxicologic and epidemiologic data. Impacts include: the identification of exposures that cause or may cause occupational asthma and chronic obstructive pulmonary disease; the measurement and control of mining-related PM such as the long-term health effects of uranium milling that may allow identification of exposed workers at risk for lung and renal diseases; the determination of the personal beryllium dose that produces beryllium sensitization and chronic beryllium disease in beryllium machinists influencing prevention by providing data on which to base a new beryllium exposure standard and help direct engineering and industrial hygiene practices to reduce exposure; and the evaluation of variables that affect concentrations and characteristics of bioaerosols during commercial airline flight segments.

EPA - Provide data and models that characterize and predict human exposure to PM and gaseous copollutants of ambient origin. Characterizing concentrations from stationary monitors and their relation to actual human exposures, thereby enhancing understanding of this key element in PM risk assessment, enhancing exposure assessments, and informing the design of new prospective epidemiologic studies. The results will inform choices of measured indicators used to show progress in reducing exposure and protecting health, and help identify critical indicator species for targeting cost-effective strategies to protect high risk populations.

Characterization of Emissions Sources

3. What are the size-distribution, chemical composition, and mass-emission rates of particulate matter emitted from the collection of primary-particle sources in the United States, and what are the emissions of reactive gasses that lead to secondary particle formation through atmospheric chemical reactions?

Projected impacts of agency research:

DOD - Research will characterize primary PM emissions generated by unique military activities or materials. Source emission sampling techniques for remote and extreme environments will be compared to federal methods documenting their reliability. Work will be preformed with the involvement of multiple agencies. Successful methods and equipment could augment data collection methods and potentially increase the number and location of monitoring sites at military installations to improve emissions inventories for this source where relevant to SIP planning.

DOE-FE - The complete characterization of primary PM emissions from energy-production sources, along with a thorough understanding of the types and rates of chemical reactions governing the formation of secondary PM in the downwind plumes of these sources, will help identify the relative contribution of these sources to ambient fine-particle mass concentrations. This knowledge will assist in the development of strategies and technologies for reducing emissions of specific PM components.

EPA - The research planned will reduce uncertainties in emissions estimates used to support state implementation planning. Improved emissions data for mobile, stationary and fugitive sources will be used as inputs to air quality simulation models and increase the likelihood that the output from these models will result in strategies that will achieve the emissions reductions required to comply with the NAAQS. The data on chemical composition (source profiles) will significantly improve the capability of federal and state officials to accurately link sources with data on ambient PM levels now being collected at thousands of monitors across the country.

FHWA - Working with other organizations, define the sources and characteristics of particulate matter generated by mobile sources. Projects will include determining and updating source profile information using speciation monitor data, dynamometer studies of diesel and gasoline vehicles to understand the emissions from various vehicles fleets and gross emitters, fugitive dust and the regional transported PM component. The goal of these projects is to gain an understanding of the transportation component of PM pollution and making this information available to policy makers considering attainment options.

TVA - Results from studies of point and area source plume chemistry and dynamics have contributed to the understanding of particle formation and growth, as well as ozone formation in these plumes. This research is expected to influence the development and testing of more effective control strategies for secondary PM.

Air Quality-Model Development and Testing (including atmospheric processes)

4. What are the advanced mathematical, modeling and monitoring tools needed to represent source-response relationships more accurately? To the extent biologically important components of PM are identified, how can the analytical tools be applied to link those components to their sources to provide effective and efficient air quality management to protect human?

Projected impacts of agency research:

DOD - Research is ongoing on the development of a near real-time, high spatial resolution air quality modeling system for field use during military training exercises. This system will utilize historic and real time meteorological data to model concentrations and dispersal patterns to assist compliance assurance and provide a planning tool for military training schedulers. Such systems may be of benefit to future air quality compliance efforts.

DOE-FE - Application of the most up-to-date air quality models will enable predictions to be made of PM mass and composition resulting from various emission reduction strategies for energy production sources. Differences between model predictions and measured ambient fine-particle concentrations and compositions will identify specific areas where model improvements are needed. An accurate assessment of the effects of emission reduction strategies for energy production

facilities is critical to the development of sound, cost-effective emission management strategies for all other industry sectors.

DOE-SC - Research will result in an improved understanding of the atmospheric processes that control the transport, transformation, and fate of energy-related particulates and convey this understanding in a form that is useful to those designing and implementing our nation's energy strategy and air quality management. Research will include the development and testing of predictive models of the coupled physical and chemical processes, with emphasis on the processes controlling the mass loading, geographic distribution, and microphysical properties of tropospheric aerosols. Numerical models will be used to develop methods of estimating aerosol composition and spatial distribution over regional and urban scales. Research in atmospheric chemistry will include the emission, secondary formation, transformation, and fate of fine particles in the atmosphere. Research will evaluate the causes of spatial and temporal variations in the chemical composition and concentrations of tropospheric aerosols.

EPA - Reduced uncertainties in atmospheric fate and transport models, and source-apportionment methods will increase the likelihood that strategies in state implementation plans will achieve the emissions reductions required to comply with the NAAQS. Improved understanding of the processes and sources affecting ambient concentrations and their part in personal exposures to PM of ambient origin contributes both to standards related risk assessments and the development of effective and efficient air-quality management strategies. The results would support control strategies targeted to potential biologically relevant PM components that may be identified by improving understanding of the relationships among sources, ambient concentrations, and human exposures.

FHWA - Research will evaluate of how well air quality models calculate emissions from vehicles. This includes emission factors and dispersion models, such as the new MOBILE-6, the current PART5 model, and any new fugitive dust model developed by EPA. The existing dispersion model, CAL3QHC, and emerging models will also be analyzed to understand how well they forecast PM emissions and concentrations. Results will lead to model improvements and information on model confidence levels for application in policy formulation.

NOAA - Multi-faceted PM research aims to build a better predictive understanding, which includes: 1) laboratory studies of fundamental physical and chemical processes responsible for particle formation and growth; 2) intensive field campaigns designed to quantify the composition, morphology, formation, and growth of ambient particles; 3) monitoring programs to document spatial and temporal trends; and 4) modeling studies to evaluate the skill of current air quality models to replicate field observations. At the core of this research is an improved understanding of the processes through the use of state of the art tools and techniques and a communication of these results to those responsible for developing and implementing environmental policies.

NSF - Research will lead to a better understanding of the processes that affect the formation of aerosols in the atmosphere, as well as a better characterization of the physical, chemical and radiative properties of aerosols and their transport and transformation in the atmosphere. Additionally, research will produce a better understanding of how atmospheric aerosol particles affect the Earth's radiative balance directly by scattering or absorbing light, and indirectly by acting as cloud condensation nuclei, thereby influencing the reflectivity, life-time, spatial extent and precipitation of clouds. Research will also identify the composition, sources, seasonality and trends for gases and aerosols in the background air transported to North America. Other contributions

include modeling studies and laboratory experiments to help unravel much of the complex chemistry and physics underlying secondary organic aerosol formation in the atmosphere and to characterize and quantify important heterogeneous processes that take place on particle surfaces, in addition to the design and fabrication of novel instrumentation for studying atmospheric aerosols. Outcomes of this fundamental research will feed into applied science, such as modeling studies guiding source reduction choices, and analysis of impacts multiple problem issues, such as aerosols, haze, and climate change.

TVA - conducts major research in the development of advanced modeling tools for predicting the effects of emission changes on ambient levels of particulate matter and other secondary pollutants. Current testing and validation of Models 3 and its components using comparisons with observational data is a major component of this research. Development and application of improved continuous measurement tools for $PM_{2.5}$ constituents is also having a major impact in this research area. New methods for deducing source-receptor relationships are being explored, with particular emphasis on evaluating potential control strategies for carbonaceous aerosol mass on both regional and local (urban) levels.

PM Components

1. What is the role of biological, chemical and physical characteristics of PM in eliciting adverse health effects?

Projected impacts of agency research:

EPA - Identifying specific components of PM responsible for adverse health effects, and linking those components to specific sources, will enable the EPA and the states to better target those sources responsible for emitting the most harmful air pollutants. A better understanding of how different combustion processes affect the toxicological characteristics of PM will provide insights on how to better control combustion emissions of public health concern.

Mechanisms of Injury

2. What are the underlying mechanisms (pulmonary and systemic) that can explain the epidemiology findings of mortality/morbidity associated with exposure to ambient PM?

Projected impacts of agency research:

EPA - Understanding the pathophysiological processes by which PM causes death and disease in humans will provide biological plausibility to the epidemiology studies, further strengthening the basis for the PM standard. EPA will use an integrated approach to understand the mechanisms responsible for PM-induced pulmonary and cardiovascular injury, including cutting edge molecular biology and genomic approaches, in vitro toxicology, and use of transgenic animals.

NIH/NIEHS - A variety of *in vivo* and *in vitro* models will be used to identify mechanisms of PM-induced disease identified in human population studies, including the investigation of the mechanisms of PM-related asthma and other inflammatory lung diseases, cardiovascular disease, immunity-related disorders, and adverse effects on fetal and post-natal growth and maturation of the lung. Controlled exposure experiments of human subjects will help bridge the knowledge gap between population-based studies and *in vivo* and *in vitro* studies. In addition, studies will be conducted to identify the toxic effects of specific components of PM using *in vitro* and *in vivo* models, combined with newer technologies such as gene and protein expression. Further, epidemiologic and human panel studies will be conducted to identify adverse health outcomes, most

notably cardiopulmonary outcomes, but also including adverse birth outcomes, such as low birth weight, that are associated with exposure to PM. These studies will add to the scientific basis of the NAAQS, and potentially identify health endpoints to demonstrate future benefits from reduced exposure to PM.

Dosimetry and Fate

3. What are the deposition patterns and fate of particles in the respiratory tract of individuals belonging to presumed susceptible subpopulations?

Projected impacts of agency research:

EPA - Deposition models link ambient concentrations to tissue doses of biologically important PM constituents in normal and diseased individuals, helping to understand the mechanisms of toxicity and susceptibility and to create exposure-dose-response models of susceptible subpopulations

NIH/NIEHS - Determine patterns of pulmonary and nasal deposition and retention of inhaled particulate matter using animal models and human exposure studies. The use of newer computer technology and mathematical modeling should help identify areas of higher deposition and cellular injury.

Co-Pollutant Interactions

4. How can the effects of PM be disentangled from the effects of other pollutants? How can the effects of long-term exposure to PM and other pollutants be better understood?

Projected impacts of agency research:

EPA - A better understanding of the effects of mixtures of air pollutants on human health results in the most effective targeting of risk management actions and improved estimation of the consequences of air pollutants in their entirety and the role of long-term exposures on health.

NIH/NIEHS - Determine the contribution of non-particulate pollutants (such as ozone) to those health effects related to PM inhalation using co-exposure studies in experimental animal models adding to the ability to separate PM from other air pollution induced effects leading to optimized standard setting and risk management planning.

Susceptibility

5. What subpopulations are at increased risk of adverse health outcomes from PM?

Projected impacts of agency research:

CDC/NIOSH - More fully characterize the asphalt exposures of road pavers with characterization of the particle size distribution--including sub-micrometer--of asphalt particulate and the chemical composition of the particulate.

EPA - Improve basis for NAAQS by providing information about the effects of PM on sensitive subpopulations, the shape of the PM dose-response curve for PM of various characteristics.

NIH/NIEHS - Determine how differences in genetics, age, race, and socioeconomic status might make certain populations more sensitive to PM effects. This work will potentially identify sub-populations that should be specifically considered in risk assessments and risk management policy choices. Further molecular epidemiology studies and genetic studies in experimental animals, using newer technologies, such as transgenic animals and gene expression methods, should help identify factors that predispose to PM-related disease.

Exposure Misclassification

6. To what extent does the choice of statistical models in the analysis of data from epidemiological studies influence estimates of health risks from exposures to PM? Can existing methods be improved? What is the effect of measurement error and misclassification on estimates of the association between air pollution and health?

Projected impacts of agency research:

EPA - Improved understanding of errors in measurement of PM mass and composition, relationships between ambient concentrations and personal or community average exposure to particles of ambient origin, and effects of such errors on statistical models will improve design and implementation of prospective epidemiological and exposure studies.

Cross-cutting Topics

7. What important research areas cross-cut or underpin the preceding questions?

Projected impacts of agency research:

DOD - Particulate matter impacts on endangered species concern multiple agencies. Effects of graphite and mineral oil aerosols on avian species were investigated and found to be negative. Future studies comparing avian respiratory systems with human health study surrogates may provide additional insights into human health effects. Also under development and field-testing is the Mobile Dust Mapper which quantifies localized "hot spots" of increased PM emissions on unpaved or dust palliative treated roads. The Mapper can optimize dust suppression treatment schedules and document efficacy of current dust palliatives. DOD emits fugitive dust as part of military training and is developing and testing non-aqueous dust suppression techniques. Formulas pertaining to each technique's cost and effectiveness in various climates, soil types and land use may provide an effective tool for estimating cost and effectiveness of various dust suppression strategies.

EPA - Ambient air measurement methods research, developing and evaluating improved instruments and methods, is fundamental to fully characterizing ambient PM. The ability to measure currently unidentified fractions of PM is important to standard setting, determining attainment, and producing the data needed to develop and test models for implementation planning. New Federal Reference Methods (FRMs), such as for the new defined PM_{coarse} fraction, underpin the NAAQS standard setting process. Risk assessment research that periodically reviews the state of science on PM, its character, exposures and effects and that produces the Criteria Documents, is the basis of the NAAQS for PM.

FHWA - Research is trying to determine the best programs to be used to reduce or eliminate the emission of particles. It is clear that some programs have greater success in improving air quality and that some, although not providing large reductions in emissions, do provide marginal benefits with very low costs. An understanding of the programs and their associated benefits and costs will assist FHWA in providing input strategies into State Implementation Plans designed to improve air quality.

NIST - Fundamental research and metrology products (definitive analytical methods, Standard Reference Materials (SRMs), Standard Reference Data (SRD), and Calibration Services) will be developed to support critical PM measurements performed by U.S. industry and government. This will improve the accuracy, reliability, and traceability of aerosol monitoring, particle size and

morphology measurements, PM speciation measurements, and source apportionment models. NIST contributions will allow informed business and regulatory decisions by U.S. industry and government to be based upon a sound technical foundation, and will help document emission controls and reduction of public health concerns.

NOAA - An improved understanding of key processes will result in improved models leading to better environmental policies and strategies. The understanding of these processes can be used to explain the observed differences in PM composition in various regions of the country. A comparison of measured atmospheric transformation rates with model-predicted values will allow an objective evaluation of model uncertainty and skill. A particle-by-particle composition profile will provide important information on the source of primary particles and the precursors of secondary particles resulting in more effective emission management strategies. The composition of individual particles will also provide important information to guide the study of health effects of PM exposure.

TVA - Research addresses the measurement of PM constituents and their relationship to gaseous co-pollutants of anthropogenic (stationary and mobile) and biogenic origin at background, rural and urban sites in the Tennessee Valley. Specific outcomes address the diurnal and seasonal variability in these relationships and the impact this variability has on estimates of human exposure to PM.

INTEGRATING RESEARCH STRATEGY

Three dimensions are central to the interagency research strategy:

1) Interdisciplinary collaborations

Actions:

- Sponsorship of workshop bringing together atmospheric scientists, exposure researchers, health effects community (Chapel Hill, NC)
  Outcome: identification of 11 characteristics of PM that merit hypothesis-based testing to identify mechanisms of toxicity
- Interagency agreements to leverage resources: NIEHS/NIAID/EPA, NIST/EPA, DOD/DOE/EPA
  Outcome: large incremental knowledge gain on indoor/outdoor exposure through the Inner-city Air Pollution Study of pediatric asthma severity; leveraging NIST and EPA resources to standardize analytical methods and samples; and development of source apportionment approaches under the SERDP program.
- Interdisciplinary collaborations during large field campaigns:
  Outcome: SOS, TEXAQS 2000, coordination /collaboration between EPA's PM health Centers and Supersites

2) Inter-organizational planning and coordination

Actions:

- Interagency coordination, workgroups, and joint research activities
- Collaborative programs, particularly those involving the private sector
- Periodic updates to cross-agency, and agency specific research strategies

3) Integrated science assessment and communication

Actions:

- Periodic progress and status reports for policy makers (in context of conceptual PM model)
- Periodic public information documents
- Decision support systems development, and value of information studies

MEMBER AGENCY PM RESEARCH PROGRAM DESCRIPTIONS

ATSDR — The **Agency for Toxic Substances and Disease Registry** (ATSDR) is the Federal public health agency responsible for providing the public with information to prevent harmful exposures and disease related to toxic substances. ATSDR conducts research on PM through evaluating human health risks from toxic waste sites and releases and by conducting timely and responsive public health actions. Most of this work is site-specific, and exposures vary widely by community. Some of the recent investigations and assessments have examined exposures to PM related toxic substances generated by asphalt facilities, cement facilities, demolition/reclamation activities, ordnance burning or detonation activities, phosphate processing plants, and metal refineries and metals handling facilities. The agency also conducts or supports health studies to determine the relationship between exposures to toxic substances and disease, often in cooperation with state health departments or universities. A few recent studies have looked at the association between exposure to PM and other toxic air contaminants and the exacerbation of asthma in specific communities. Additional information about the work of the agency is available at http://www.atsdr.cdc.gov/.

CDC/NCEH — The **Centers for Disease Control and Prevention** (CDC) **National Center for Environmental Health** (NCEH) is involved in several different projects examining the effects of particulate air pollution on human health. Pollutants and sources of interest include: ambient particulate matter, forest-fire smoke, environmental tobacco smoke, and indoor air pollution from biomass smoke sources. NCEH's current projects focus on evaluating the effects of outdoor air pollution on heart rate variability in Mexico City, evaluating health effects related to forest fires in both the U.S. and in Malaysia, and evaluating the effect of environmental tobacco smoke exposure on outcomes, such as lung function in children, lead levels in children, and folate levels in adults. NCEH, through its laboratory, is developing potential biomarkers for smoke exposure which could be used in its future forest fire work. In addition, NCEH is involved in building an infrastructure at state and local levels to improve surveillance for respiratory diseases, such as chronic obstructive pulmonary disease and asthma. Improved surveillance may enhance the ability to quickly and efficiently link poor air quality data to human health effects such as these. More information on NCEH projects can be found at http://www.cdc.gov/nceh/programs.htm.

CDC/NIOSH — The **Centers for Disease Control and Prevention** (CDC) **National Institute for Occupational Safety and Health** (NIOSH) is the Federal agency responsible for conducting research and making recommendations for the prevention of work-related disease and injury. Research on PM exposures in the Institute addresses a wide range of particulate exposures such as: beryllium, bioaerosols, coal mine dusts, cotton dust, diesel exhaust emissions, organic agricultural dusts, and other mixed dust exposures, as well as laboratory studies of particle characteristics and toxic mechanisms, and risk assessment using both toxicologic and epidemiologic data.. CDC/NIOSH is also actively involved in addressing issues of how exposure can and should be measured in terms of metrics, such as particle number and surface area concentration, and plans to investigate exposure against these metrics in a number of scenarios. Through the National Occupational Research Agenda (NORA), NIOSH describes a research strategy that addresses PM exposures that cause or may cause occupational asthma and chronic obstructive pulmonary disease (COPD). More information about the NORA Asthma and COPD program is available at http://www.cdc.gov/niosh/. Additionally, the NIOSH Mining Safety and Health Research program conducts a very active program in the measurement and control of mining-related PM. Additional information on the mining related PM projects is available at: http://www.cdc.gov/niosh/mining/projects.

DOD — Each of the **Department of Defense's** (DOD) three services (Army, Navy, and Air Force) has a medical command that emphasizes health protection. During overseas deployments these commands monitor local air quality for toxicity and human exposure. Each service also has unique research and development (R&D) groups that are responsible for examining broad service-wide concerns. Investigative

areas include toxicity, exposure minimization, source characterization, emission reduction technology, and atmospheric dispersion and trajectory modeling at resolutions from meso- to micro-scale. Each shipyard, base, and installation, both inside and outside the continental United States, has an associated environmental office that resolves local issues with applied research methods or special investigations. Local studies may include endangered species, health impacts, source apportionment, customization of emission factors, and emission mitigation. When local environmental offices identify research needs that extend beyond local concerns, the most critical are funded and sent to R&D groups for investigation. In addition, DOD partners with other federal agencies to capitalize on research expertise and resources. The most well known is the DOD/DOE/EPA partnering that occurs through the Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program. Current projects may be viewed at http://www.serdp.org and http://www.estcp.org respectively. To facilitate cross-service R&D solutions the Clean Air Act Tri-Services Steering Committee coordinates information exchange, develops analyses, and proposes research applications for all aspects of the Clean Air Act. For additional information contact rochelle.williams@us.army.mil, or see http://www.denx.osd.mil.

DOE — The **Department of Energy** (DOE) conducts PM research through its Office of Energy Efficiency and Renewable Energy (EE), Office of Fossil Energy (FE), and Office of Science (SC). DOE-EE manages the Environmental Science and Health Effects Program concerned with the atmospheric impacts and potential health effects that may be caused by the use of petroleum-based fuels and alternative transportation fuels. DOE-FE manages the Airborne Fine Particulate Matter (PM) Research Program concerned with atmospheric emissions from energy-production sources and their effect on PM at ambient receptors. This program is described fully in FE's Five Year Research Plan on Fine Particulate Matter in the Atmosphere (DOE, 2000). For more information on this program go to www.netl.doe.gov/coalpower/environment. DOE-SC manages the Atmospheric Science Program, including more basic research on atmospheric processes in atmospheric chemistry, environmental meteorology, and tropospheric aerosols linked to energy-related pollutants. Office of Science also manages the Research Aircraft Facility which provides a fully-instrumented airborne measurement platform in support of DOE and multi-agency programs. Office of Science's programs are described in its Atmospheric Science Program Strategic Plan (DOE, 2001) and Tropospheric Aerosol Program Plan (DOE, 2001). For more information on these programs go to www.er.doe.gov/production/ober/GC/atsi.html.

DOI/USGS — The **US Geological Survey** (USGS) has several research efforts relating to PM including those on: Eolian dust deposition in the Southwestern US, deposition of African dust in the Caribbean, and volcanic ash and aircraft hazards. Eolian dust topics addressed in ongoing USGS research include: 1) dust generation as a direct result of aridification, 2) the role of dust in soil formation and geomorphic processes, and 3) estimations of paleoclimate from soil properties. USGS research is underway to validate the hypothesis that many coral reef events, algal infestation, white band and black band disease, sea fan disease, sea urchin die-off, and possibly mass coral bleaching are related to dust deposition originating from North Africa. As the result over the past 14 years of there having been 23 incidents involving aircraft that have inadvertently encountered volcanic eruption plumes, the USGS's Volcano Hazards Program, particularly those at the Alaska Volcano Observatory, are working with officials of the Federal Aviation Administration (FAA) to develop automatic early warning systems for large ash clouds and to streamline communication for eruptions of U.S. volcanoes that might impact aircraft. For more on USGS air pollution related science programs go to http://www.usgs.gov/.

DOT/FHWA — The Department of Transportation and the **Federal Highway Administration** (FHWA) have been active in an effort to understand and assess the contribution to particulate matter (PM) pollution from mobile sources (cars, trucks, buses, etc.). FHWA's strategy consists of 14 individual projects in five broad areas that cover the emissions of PM from mobile sources. Most of the Department's

research focus will be concentrated in three areas, including source measurements (sources, monitoring, characterization) of PM emissions, air quality analysis and modeling methods, and air pollution mitigation strategies. The FHWA program seeks to determine what areas will be in non-attainment because of mobile source emissions, where PM is a local or regional atmospheric problem, what analysis tools are available for estimating the mobile source component and what mitigation strategies are available to reduce emissions. Department research is moving through the workplan strategy phase to selecting projects and locations where research projects will be conducted with the current effort involving collection and analysis of emissions and traffic data at certain locations across the country. The FHWA plan covers many years and will be available for review on FHWA's Environmental Website in the near future.

EPA — The **Environmental Protection Agency** (EPA) accomplishes its fundamental and applied particulate matter research through the intramural and extramural programs of its Offices of Research and Development (ORD). EPA's research spans the risk continuum, from human health effects and ecological effects research to human exposure, air quality measurement methods, atmospheric processes, source-to-receptor modeling, source emissions characterization, to control technology and accountability. For program, project, and task level descriptions go to http://www.epa.gov/ord/replans/. EPA's Office of Air and Radiation (OAR), together with state and local air pollution agencies, maintains the national air quality monitoring network and the national emissions inventory. In addition, OAR's Office of Transportation Air Quality coordinates the verification process on new PM retrofit control technologies for heavy duty diesel vehicles. Tabular information and summaries for emissions of PM and its precursors from stationary and mobile sources are available at http://www.epa.gov/air/data/sources.html. The national air quality monitoring program includes a tiered PM network having 1100 PM mass monitoring stations, 55 speciation sites and 7 super sites. For more information go to http://www.epa.gov/ttn/amtic. EPA's PM research program is fully described in its Airborne Particulate Matter Research Strategy (EPA, 2001). Its Ecological Research Strategy (EPA, 1998a) and the draft Global Change Research Strategy (EPA, 2000c) complement this PM strategy.

NASA — The **National Aeronautics and Space Administration** (NASA) conducts particulate matter (aerosol) observations and research as part of its Earth Science Enterprise (ESE). This research includes observations and analysis under its atmospheric chemistry and radiation science programs to characterize, understand, and predict the role of particulate matter as a global atmospheric constituent. Observations are archived in the NASA Data Active Archive Centers for widespread use. NASA's Earth Observing System supports the AERONET ground based monitoring network in federation with other institutions. NASA also participates in the NOAA BSRN and DOE ARM programs. NASA conducts field expeditions around the world with highly instrumented aircraft, which document detailed chemical and transport processes and validate measurements from space. NASA's space-based satellite observations provide global context and long term records of the principal sources of aerosols and their impact on climate. The space-based TOMS, SeaWIFS, MISR, ASTER, MODIS, CERES, Landsat, and AVHRR investigations have characterized aerosol types and developed general ideas about the amount of aerosol to be found in different seasons and locations. These observations inform and validate NASA-sponsored climate and chemistry models that are a basis for assessing the impacts of human activities on the Earth system under the U.S. Global Change Research Program. A description of NASA's research program can be found in Understanding Earth System Change, the Research Strategy for 2000–2010 (http://www.earth.nasa.gov/visions/researchstrat/index.htm). NASA's ESE also develops advanced technologies and supports applications of remote sensing to serve national priorities in partnership with other government agencies and the private sector.

NIH/NHLBI — The **National Heart, Lung and Blood Institute** (NHLBI) of the National Institutes of Health (NIH) provides leadership for a national program in diseases of the heart, blood vessels, lungs, and blood; blood resources; and sleep disorders. The Institute plans, conducts, fosters, and supports an integrated and coordinated program of basic research, clinical investigations and trials, observational studies, and demonstration and education projects. Research is related to the causes, prevention, diagnosis, and treatment of heart, blood vessel, lung, and blood diseases, and sleep disorders. Included are research projects dealing with the pathophysiological effects of a variety of airborne agents that induce injury to the lungs or modulate the development or manifestations of pulmonary diseases such as asthma. NHLBI-supported studies of environmental pollutants such as ozone or particulate matter are typically focused on the cellular and molecular mechanisms involved in their lung health effects. Current investigations examine the roles of specific inflammatory, oxidant, and cellular pathways in mediating the effects of inhaled substances. For more information on NHLBI air pollution related projects and programs see http://www.nhlbi.nih.gov/health/public/lung/.

NIH/NIAID — The **National Institute of Allergy and Infectious Diseases** (NIAID) supports an asthma research program through investigator-initiated projects and a national network of research centers. Supported research has begun to elucidate the role of immune dysfunction in asthma, and a major goal of the NIAID asthma research program is to translate this knowledge into novel therapies and strategies to prevent disease onset. The NIAID Asthma and Allergic Diseases Research Centers program, a network of 12 extramural centers, is the foundation of the NIAID portfolio on the pathobiology of asthma. Two of the centers are co-funded by the National Institute of Environmental Health Sciences (NIEHS) and focus on environmental aspects of asthma and allergy, including the role of indoor allergens and mechanisms by which polyaromatic hydrocarbons from diesel exhaust particulates induce health responses. In 1991, the NIAID established a nationwide network of inner-city pediatric asthma research centers to directly address the disproportionate impact of asthma on inner-city children. From its inception, the major objectives of the program have been to identify factors that contribute to the prevalence and severity of asthma in inner-city children and to translate that new knowledge into interventions that will reduce morbidity and, eventually, achieve prevention. The current Inner City Asthma Study, funded jointly by the NIAID and the NIEHS, was launched in FY 1996. Seven inner-city centers are evaluating an intervention that includes aggressive environmental controls and a novel physician feedback module. In addition, through support from the Environmental Protection Agency, another arm of the study is evaluating the effects of indoor and outdoor air pollutants, including particulate matter, on asthma morbidity. More information on NIAID's inner city asthma study can be found at http://www.niaid.nih.gov/research/dait.htm.

NIH/NIEHS — The **National Institute of Environmental Health Sciences** (NIEHS) is the major Institute of the NIH that supports research in environmental health sciences. A comprehensive portfolio of research programs is designed to understand the fundamental biological mechanisms by which environmental pollutants adversely affect human health. These programs include basic scientific studies at the molecular and cellular level, population-based studies of children and adult cohorts, and translational studies to extrapolate from the fundamental sciences to the human disease processes. Health effects of environmental mixtures, gene expression technology, proteomonics, and gene-environmental interactions are high priority research issues at the NIEHS. Five of eight Centers for Children's Environmental Health and Disease Prevention recently established by NIEHS and EPA focus on environmental factors and children's lung disease. The NIEHS also supports 21 Research Centers and five Marine Research Centers, many of which have research focused on the basic mechanisms of air pollutant toxicity. The NIEHS and the NIAID (National Institute of Allergy and Infectious Diseases) co-support the National Cooperative Inner-City Asthma Study. The U.S. EPA supports an extension of this study to evaluate the effects of indoor and outdoor air pollution on pediatric asthma severity (the Inner-City Air Pollution Study). More information can be obtained at www.niehs.nih.gov.

NIST — The **National Institute of Standards and Technology** (NIST) is an non-regulatory agency within the U.S. Department of Commerce. NIST strengthens the U.S. economy and improves the quality of life by working with industry to identify difficult measurement issues, then addressing these issues by developing and applying technology, advanced measurements, and standards. Factors that drive the need for advanced measurements and standards include increasing world trade, growing reliance on laboratory accreditation as a means to ensure confidence in calibration and test reports, and, in some technology and environmental areas, a proliferation of regulations. For more information go to www.nist.gov. Measurements related to airborne particulate matter (PM) are critical to many U.S. industries, since accurate and precise PM measurements are the basis of effective business and regulatory decisions. NIST has programs in PM metrology involving particle-size calibration, morphological and compositional mapping, Standard Reference Material (SRM) development and certification for organic and inorganic compounds, metals, black carbon, and isotopic species.

NOAA — The **National Oceanic and Atmospheric Administration** (NOAA) forecasts and predicts the future state of the atmosphere, focusing its air quality research on gaining a fundamental understanding of the atmospheric processes that must be characterized for credible and useful predictions. The National Weather Service (NWS) and the Office of Oceanic and Atmosphere Research (OAR) are involved in monitoring atmospheric particles and studying the processes responsible for their formation and distribution in the atmosphere. Weekly particle composition data are combined with meteorological data using an "inferential model" to estimate the contribution of particles to dry deposition of acidic substances for the Atmospheric Integrated Research Monitoring Network (AIRMoN) sites located throughout the U.S. The NWS, in cooperation with the Federal Aviation Administration (FAA) and Department of Defense (DOD), operates the Automated Surface Observing Systems (ASOS) with more than 900 stations located at civilian and military airfields throughout the country, providing information on visibility and a host of meteorological parameters. NOAA conducts basic process-oriented laboratory and field studies and develops models to build a better predictive understanding of the formation, composition, optical properties, and ultimate fate of atmospheric particles. Research is also directed toward the development of innovative technologies to characterize the composition and morphology of individual particles in near-real time. For more information on NOAA air quality research go to http://www.oar.noaa.gov/atmosphere/.

DOI/NPS — The **National Park Service** (NPS) conducts its atmospheric aerosol research through its Air Resource Division (ARD) (http://www2.nature.nps.gov/ard/). This research is directed at understanding and remedying the degradation of visibility in Class I areas due to anthropogenic haze. NPS/ARD conducts most of its research as part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) program. This regional haze monitoring program measures PM_{10}, speciated fine mass, and light scattering and extinction at most visibility-protected federal Class I areas. These data are used to establish current visibility and aerosol conditions, identify the chemical species and emission source regions for visibility impairment, and document long-term trends in aerosol and visibility conditions. Periodically, NPS/ARD participates in special intensive monitoring studies, such as the current Big Bend Regional Aerosol and Visibility Observational Study (BRAVO) study in southwest Texas, along the U.S.-Mexico border (http://vista.cira.colostate.edu/improve/Studies/BRAVO/). These studies are designed to more fully characterize atmospheric aerosols and their optical properties, as well as to identify the major contributing sources to a particular Class I area's haze. In addition, special research activities are pursued that currently include characterizing species-dependent aerosol hygroscopicity, identifying the contribution of smoke to organic and sulfur aerosols, and characterizing coarse particle optical properties. For more information, see the IMPROVE website at: http://vista.cira.colostate.edu/improve/.

NSF — The **National Science Foundation** (NSF) supports basic research on atmospheric aerosols. This includes research to better understand the processes that affect the formation of aerosols in the atmosphere, as well as research to characterize the physical, chemical and radiative properties of aerosols

and their transport and transformation in the atmosphere. NSF recently has supported a number of major field programs, such as the Aerosol Characterization Experiments (ACE) and the Indian Ocean Experiment (INDOEX). These projects focus on how atmospheric aerosol particles affect the Earth's radiative balance directly by scattering or absorbing light, and indirectly by acting as cloud condensation nuclei, thereby influencing the reflectivity, lifetime, spatial extent and precipitation of clouds. Another project, the Photochemical Ozone Budget of the Eastern North Pacific Atmosphere (PHOBEA) project was developed to understand the composition, sources, seasonality and trends for gases and aerosols in the background air transported to North America. NSF also supports a significant amount of modeling studies as well as laboratory experiments to help unravel much of the complex chemistry and physics underlying secondary organic aerosol formation in the atmosphere and to characterize and quantify important heterogeneous processes that take place on particle surfaces. Other funding supports the design and fabrication of novel instrumentation for studying atmospheric aerosols. More information on NSF projects can be found at http://www.geo.nsf.gov/atm/atmfocus.htm.

TVA — The **Tennessee Valley Authority** (TVA) conducts monitoring of particulate matter as part of its obligations under the Prevention of Significant Deterioration (PSD) regulations. TVA also conducts research on particulate matter, its mass and composition, and its sources in projects managed by staff at the Environmental Research Center and the Public Power Institute, conducted in large part by the Air, Land, and Water Sciences (AL&WS) Department. This work includes operation of a network for the measurement of fine particulate matter in the TVA region with the cooperation of state and local air management staff, as well as studies of the chemical composition of particulate matter and studies of the sources of primary and secondary particulate matter affecting both urban and rural areas in the valley. Airborne studies of TVA point source plumes have included interpretation of the effect of reductions in emissions from these sources (achieved as a result of Clean Air Act provisions) on secondary pollutant levels in the region. For more information on TVA's environment and air programs go to http://www.tva.gov/environment/air/.

USDA/CSREES — The **Cooperative State Research, Education and Extension Service** (CSREES) is the Federal Agency responsible for the USDA's principal entree into the university system of the United States for the purpose of conducting agricultural research and education programs as authorized by the Hatch Act of 1887, the Cooperative Forestry Research Act of 1962, Public Law 89-106, the National Agricultural Research, Extension, and Teaching Act of 1977, the Equity in Educational Land-Grant Status Act of 1994, and the Agricultural Research, Extension and Education Reform Act of 1998. Through these authorities, the USDA participates with State and other cooperators to encourage and assist the State institutions in the conduct of agricultural research and education through State Agricultural Experiment Stations of the 50 States and territories, approved Schools of Forestry, 1890 Land-Grant Institutions and Tuskegee University, Colleges of Veterinary Medicine, and other eligible institutions. The funds appropriated under the authorities listed above provide Federal support for research and education programs at these institutions. Research on PM is related primarily to reducing the contribution of agricultural practices to emission sources and monitoring of background levels in rural areas of the United States. More on CSREES programs can be found at http://www.reeusda.gov/1700/programs/programs.htm.

USDA/USFS — U.S. Forest Service Research and Development (FSR&D) is the primary science agency for natural resources management in regards to fire in the United States. As such, FSR&D has developed the particulate emissions factors used by all federal agencies, state agencies, and the private sector for particulate emissions from forest and rangeland fires. Additionally, the FSR&D has been the major developer of dispersion models used for permitting of individual burns by states as they manage particulate emissions and visibility. At the present time, FSR&D is actively involved in developing new systems to predict fire behavior, fuel consumption, and emissions from fires – all issues directly related to

particulate emissions. FSR&D is also working with sister agencies (e.g., EPA, NOAA, NASA, and DOD) on remote sensing of aerosols and particulate from fires. In FY2001, under the National Fire Plan, FSR&D launched an initiative to provide better science for fire management. Due to the focus of the National Fire Plan on reducing fuels and returning fuel loadings to a more natural ecological state, the Forest Service will increase the use of prescribed fire as a fuel reduction treatment. As part of its program, FSR&D will develop new tools for modeling fire meteorology, fire severity, and smoke. Also under development are new techniques for measuring particulate emissions directly on fire sites, understanding their potential for impacting firefighter health, and inventorying the total amount of particulate emitted from fires across the nation. For more information on FSR&D go to http://www.fs.fed.us/research.

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Committee on Environment and Natural Resources (CENR)
Air Quality Research Subcommittee (AQRS)

The CENR is charged with improving coordination among Federal agencies involved in environmental and natural resources research and development, establishing a strong information-transfer link between science and policy, and developing a Federal environmental and natural resources research and development strategy that responds to national and international issues. There are five research subcommittees under the CENR:

- Air Quality
- Ecological Systems
- Global Change
- Natural Disaster Reduction
- Toxics and Risk

The Air Quality Research Subcommittee has articulated two major goals in its Strategic Plan:

- to enhance the effectiveness and productivity of U.S. air quality research, and
- to improve information exchange between research and policy on air quality issues, including the scientific knowledge base for air quality standards and assessing compliance

Dr. Daniel L. Albritton of NOAA chairs the Subcommittee, which includes representatives from the following departments and agencies:

Department of Agriculture - Agricultural Research Service
Department of Agriculture - Cooperative State Research, Education, and Extension Service
Department of Agriculture - Natural Resources Conservation Service
Department of Agriculture - U.S. Forest Service
Department of Commerce - National Institute of Standards and Technology
Department of Commerce - National Oceanic and Atmospheric Administration
Department of Defense
Department of Energy
Department of Health and Human Services - Center for Disease Control and Prevention
Department of Health and Human Services - National Institutes of Health
Department of Housing and Urban Development
Department of State
Department of the Interior - National Park Service
Department of the Interior - U.S. Geological Survey
Department of Transportation - Federal Aviation Administration
Department of Transportation - Federal Highway Administration
Environmental Protection Agency
National Aeronautics and Space Administration
National Science Foundation
Office of Management and Budget
Office of Science and Technology Policy
Tennessee Valley Authority