

A Multiyear Federal Research Plan for Particulate Matter

Within the Context of the NRC's Committee on Research Priorities for Airborne Particulate Matter's Report IV

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

April 2007

EXECUTIVE OFFICE OF THE PRESIDENT
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL
WASHINGTON, D.C. 20502

April 3, 2007

Dear Colleagues:

I am pleased to transmit the report "A Multiyear Federal Research Plan for Particulate Matter Within the Context of the NRC's Committee on Research Priorities for Airborne Particulate Matter's Report IV." This report was prepared by the Air Quality Research Subcommittee (AQRS) of the National Science and Technology Council's Committee on Environment and Natural Resources (CENR).

In this report, the AQRS evaluates particulate matter (PM) research being conducted or planned across the federal government against the findings and recommendations of the National Research Council (NRC) report, *Research Priorities for Airborne Particulate Matter: IV*, published in 2004. In addition, this document describes the organizational role of the AQRS for ensuring that the many PM related research projects conducted or supported by the government address the priorities, issues, and challenges identified in the NRC report. It profiles agency research being done under each of the ten topic areas identified in the NRC report, establishes research milestones for major agency-specific research contributions, establishes a process for periodic progress review and refinement, and identifies organizational roles and responsibilities in coordinating cross-agency research.

In describing ongoing and planned research, the report provides a description of the broad scope of federal research related to this important issue and identifies areas where additional research attention will be beneficial.



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About the Committee on Environment and Natural Resources (CENR)

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 seven research subcommittees and two interagency working groups under the CENR:

- Air Quality Research Subcommittee
- Ecological Systems Subcommittee
- Global Change Research Subcommittee
- Interagency Working Group on Dioxins
- Interagency Working Group on Earth Observations
- Natural Disaster Reduction Subcommittee
- Oceans Subcommittee
- Toxics and Risk Assessment Subcommittee
- Water Availability and Quality Subcommittee

About the Air Quality Research Subcommittee (AQRS) of the CENR

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.

Air Quality Research Subcommittee of the CENR

Member Departments and Agencies

Department of Agriculture
Department of Commerce
Department of Defense
Department of Energy
Department of Health and Human Services
Department of Housing and Urban Development
Department of State
Department of the Interior
Department of Transportation
Environmental Protection Agency
National Aeronautics and Space Administration
National Science Foundation
Tennessee Valley Authority

Other Participating Agencies

Office of Management and Budget
Office of Science and Technology Policy
Council on Environmental Quality



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Introduction

Airborne particulate matter (PM*) is widely recognized as a serious environmental and public health concern at levels typical of some U.S. metropolitan areas. EPA estimates that current regulations to reduce air pollution can prevent tens of thousands of premature deaths per year and prevent perhaps hundreds of thousands of annual hospitalizations for cardiovascular and respiratory illnesses. PM obscures scenic vistas in our National Parks and Wilderness Areas, and has an impact on global climate change by perturbing the Earth's radiation balance. The science that governs the atmospheric formation, distribution, and impacts of PM is complex. A broad-based, multi-disciplinary research program is needed to improve the basis for effective policy development and implementation. Such an approach calls for high levels of cooperation, collaboration, and integration among those responsible for and/or engaged in research on atmospheric PM (emissions, transport, formation, growth, deposition, etc.) and its impacts (human health effects, visibility, radiation balance, etc.).

In this document, we evaluate the PM research that is being implemented across all federal agencies against recommendations and findings of the National Research Council's (NRC) Committee on Research Priorities for Airborne Particulate Matter[1]. Specifically, this multiyear plan:

- presents ongoing and planned future research by federal agencies in the context of the research priorities laid out in the NRC Committee's most recent report[1], focusing on the 10 priority research topics identified by the Committee,
- identifies potential gaps within the context of these 10 research topics,
- identifies a course of action to fill gaps,
- presents ongoing and planned federal activities, both joint and agency-specific, within the context of the NRC recommendations on developing a broader multi-agency research program and improving tools for science tracking and synthesis, and
- identifies a plan of action to promote further improvements in coordination and cooperation among the federal agencies.

Federal Research and Coordination on Airborne Particulate Matter. Federal research on particulate matter spans many different agencies and is conducted for many different missions. Research emphases of the federal agencies involved in PM research, described in Table 1, can range from human exposure and health for informing regulation to atmospheric chemistry for understanding climate change. As is often the case in research, findings in one area can benefit other areas. Indeed, the last decade has seen an increasing recognition of the need for a broad-based PM research program that is integrated across the agencies.

In 1997, for example, the President called for a partnership of federal agencies to develop a greatly expanded, coordinated, interagency PM research program that would contribute new science associated with PM health effects, cost-effective mitigation strategies, and improved air quality monitoring. This partnership, the

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* A list of acronyms used in this report can be found on page 43.

1 NRC, *Research Priorities for Airborne Particulate Matter: IV. Continuing Research Progress*, National Academy Press, Washington, D.C., 2004.

Particulate Matter Research Coordination Working Group or simply, the PM Working Group, was established in 1998 under the Air Quality Research Subcommittee (AQRS) of the National Science and Technology Council's Committee on Environment and Natural Resources (CENR). The PM Working Group focuses on issues related to the integration of PM research throughout the federal research enterprise, with a specific emphasis on improving communication and collaboration between the atmospheric sciences and human health research communities. In 2002, the PM Working Group published a *Strategic Research Plan for Particulate Matter*[2] that summarizes current understanding, highlights and accomplishments, and identifies key information gaps in science to support public policy on PM.

The 2002 *Strategic Research Plan for Particulate Matter* is based on a conceptual paradigm for PM that integrates research across the exposure/risk assessment/risk management continuum (see Figure 1). In this paradigm, 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 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 coordi-

Table 1. Federal Agencies Engaged in Particulate Matter Research.

Agency/ Department*	Human Health Effects	Human Exposure	Ecological Effects	Air Measure-ments	Atmospheric Processes & Modeling	Source Characteri-zation	Control Technologies
CDC	√	√					
CSREES			√	√	√		
DOE	√	√		√	√	√	√
EPA	√	√	√	√	√	√	√
FHWA						√	√
NASA				√	√		
NIEHS	√	√					
NIOSH	√	√		√			√
NPS			√	√	√		
NSF					√		
NOAA			√	√	√	√	
NIST				√			
TVA				√	√	√	
USFA				√	√	√	
USGS				√			

* A list of acronyms used in this report can be found on page 43.

[2] AQRS, *Air Quality Research Subcommittee, Strategic Research Plan for Particulate Matter*, http://www.esrl.noaa.gov/csd/AQRS/reports/srppm.html, December 2002.

nated under this strategy include human health effects, ecological effects, exposure, air measurements, atmospheric processes, and source emissions characterization, as described in Table 1. In addition to this multi-agency plan, several agencies have developed agency-specific PM research strategies to guide their internal and external programs.

Role of the National Research Council in Planning for Federal Research on Particulate Matter. During this same period, Congress and the EPA began a multi-million dollar research effort to better understand the sources and nature of these airborne particles, their exposures to people, and the ways that these particles cause disease.

To provide independent guidance to the EPA, Congress asked the National Research Council (NRC) to study the relevant issues. The result was a series of four reports, published between 1998 and 2004, on the particulate matter research program. The first two books offered a conceptual framework for a national research program, identified the 10 most critical research needs (Table 2), and described the recommended timing and estimated costs of such research. The third volume began the task of assessing initial progress made in implementing the research program. The fourth and final volume, *Research Priorities for Airborne Particulate Matter: IV. Continuing Research Progress*[1], gauged research progress made over a 5-year period on each of the 10 research topics and identified needed future research, overarching science challenges, and steps for sustained research management. The National Research Council concluded that particulate matter research has led to a better understanding of the health effects caused by tiny airborne particles.

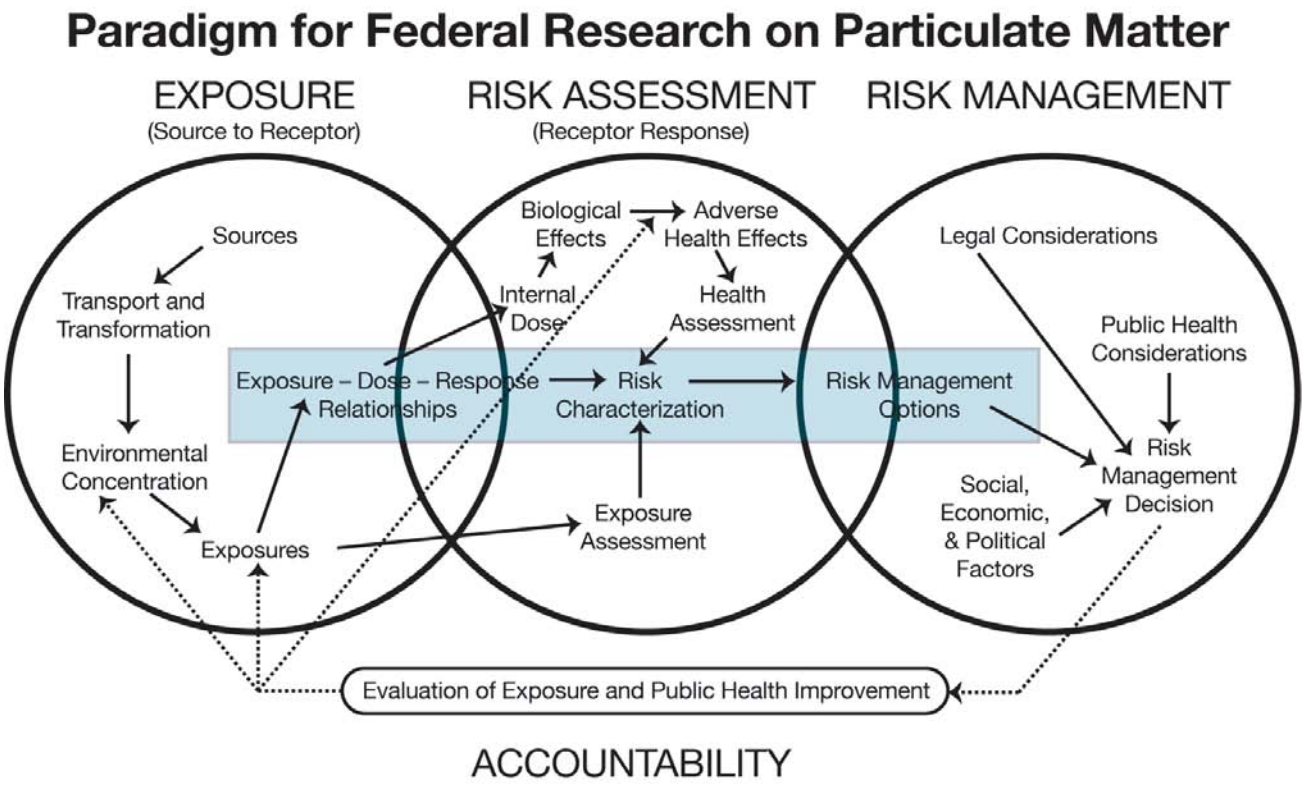


Figure 1. Paradigm for Federal Research on Particulate Matter. Reproduced from page 2, Strategic Research Plan for Particulate Matter, AQRS, CENR, December 2002.

Table 2. Airborne Particulate Matter Priority Research Topics identified by the NRC Committee*.

Research Topic 1. Outdoor Measures Versus Actual Human Exposures
What are the quantitative relationships between concentrations of particulate matter and gaseous co pollutants measured at stationary outdoor air monitoring sites and the contributions of these concentrations to actual personal exposures, especially for subpopulations and individuals?

Research Topic 2. Exposures of Susceptible Subpopulations to Toxic Particulate Matter Components
What are the exposures to biologically important constituents and specific characteristics of particulate matter that cause responses in potentially susceptible subpopulations and the general population?

Research Topic 3. Characterization of Emission Sources
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 gases that lead to secondary formation through atmospheric chemical reactions?

Research Topic 4. Air Quality Model Development and Testing
What are the linkages between emission sources and ambient concentrations of the biologically important components of particulate matter?

Research Topic 5. Assessment of Hazardous Particulate Matter Components
What is the role of physiochemical characteristics of particulate matter in eliciting adverse health effects?

Research Topic 6. Dosimetry: Deposition and Fate of Particles in the Respiratory Tract
What are the deposition patterns and fate of particles in the respiratory tract of individuals belonging to presumed susceptible subpopulations?

Research Topic 7. Combined Effects of Particulate Matter and Gaseous Pollutants
How can the effects of particulate matter be disentangled from the effects of other pollutants? How can the effects of long-term exposure to particulate matter and other pollutants be better understood?

Research Topic 8. Susceptible Subpopulations
What subpopulations are at increased risk of adverse health outcomes from particulate matter?

Research Topic 9. Mechanisms of Injury
What are the underlying mechanisms (local pulmonary and systemic) that can explain the epidemiological findings of mortality and morbidity associated with exposure to ambient particulate matter?

Research Topic 10. Analysis and Measurement
To what extent does the choice of statistical methods in the analysis of data from epidemiological studies influence estimates of health risks from exposures to particulate matter? Can existing methods be improved? What is the effect of measurement error and misclassification on estimates of the association between air pollution and health?

* Reproduced from Box S-1, page 5, of *Research Priorities for Airborne Particulate Matter: IV. Continuing Research Progress* (Reference #1).

They further concluded, however, that the EPA, in concert with other agencies, should continue research to reduce further uncertainties and inform long-term decisions.

The NRC work focused on research to improve the scientific basis for establishing and implementing health based standards in contrast to the broader focus of the AQRS 2002 strategic plan outlined above.

This Report: *A Multiuear Federal Resaerch Plan for Particulate Matter*. In the following sections, the AQRS PM Working Group evaluates PM research that is being implemented across all agencies against the recommendations and findings of the NRC Committee. The plan describes the role of the AQRS in ensuring that the many PM-related research projects across the government address the priorities, issues, and challenges identified by the NRC. It profiles agency research being done under each of the ten NRC topic areas, establishes research milestones for major agency-specific research contributions, establishes a process of periodic progress review and refinement, and identifies organizational roles and responsibilities in coordinating cross-agency research. It is designed to encourage research integration to address multi-disciplinary research questions and includes both intramural and extramural research, both policy-driven projects and those more fundamental to addressing underlying physical, chemical, and biological relationships.

Eight years have passed since the NRC committee and the AQRS PM Working Group were first established. Thus, a careful and comprehensive review of progress and plans related to PM research is timely, providing a context that member agencies can use to identify and interpret their roles in implementing the NRC findings. It is important to remember that while the NRC study focuses primarily on research to clarify human exposures to PM and attendant health effects, the AQRS research portfolio goes well beyond this scope to address a variety of environmental research (e.g., climate and public and ecosystem health). This being the case, AQRS has benefited from a number of other research assessments in addition to this NRC study[3,4,5,6,7,8]. Likewise, this plan considers a significant amount of relevant research that is designed to address additional drivers in addition to research that is aimed directly at the NRC recommendations. Finally, member agencies receive external guidance on research needs and priorities from Federal Advisory Committee Act (FACA) committees such as: USDA's Agricultural Air Quality Task Force, EPA's Clean Air Science Advisory Committee and its Board of Scientific Counselors, and the Department of Energy's (DOE's) Biological and Environmental Research Advisory Committee.

KEY CONCLUSIONS

In Part I of this plan, the NRC findings and recommendations for each of the 10 Research Topic Areas are described and discussed. In

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3 AQRS, *The Role of Monitoring Networks in the Management of the Nation's Air Quality*, http://www.esrl.noaa.gov/csd/AQRS/reports/monitoring.html, March 1999.

4 National Academy of Sciences, *Air Quality Management in the United States*, National Academies Press, Washington, D.C., 2004.

5 NARSTO *Particulate Matter Assessment for Policy Makers: A NARSTO Assessment*, P. McMurry, M. Shepherd, and J. Vickery, eds. Cambridge University Press, Cambridge, England. ISBN 0 52 184287 5, 2004. Available on the web at http://www.narsto.org/section.src?SID=6.

6 CENR, *Strategic Plan for the U.S. Climate Change Science Program*, A Report by the Climate Change Science Program and the CENR Subcommittee on Global Change Research, Washington, D.C., July 2003.

7 Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2001 – The Scientific Basis*, Cambridge University Press, United Kingdom, 2001.

8 National Academy of Sciences, *Air Emissions from Animal Feeding Operations: Current Knowledge, Future Needs*, National Academies Press, Washington, D.C., 2003.

reviewing the findings and recommendations of the NRC Committee in the context of ongoing and planned federal research, the PM Working Group of the AQRS has drawn a number of conclusions that are discussed more fully in the body of the Part I. Several of these are repeated here, including:

- The AQRS agrees with the general NRC assessment that there has been substantial progress answering the research questions related to the topic of personal exposure (see discussion of Research Topics 1 and 2, pages 7-10). The AQRS notes, however, that the data collected are not yet sufficient to develop a national perspective on personal exposures, especially for susceptible individuals.
- The AQRS views assessment of hazardous particulate matter components (see discussion of Research Topic 5, pages 17-19) as the highest priority area of research. This work requires a collaborative, multi-disciplinary effort by the atmospheric science and health effects research communities. The AQRS also acknowledges that there is a clear interactive linkage between research to determine the hazardous PM components, and research to determine factors of susceptibility and biological mechanisms that elicit health effects.
- The AQRS endorses the recommendations of the 2005 NARSTO Emissions Inventory Assessment[9], which independently identified the same needs found by the NRC within its own eight recommendations and initial action plan to implement them (see discussion of Research Topic 3, pages 10-12). AQRS members will focus their emissions research on the objectives underlying the recommendations and be guided by priorities developed through "...systematically continuing to improve emission inventories by applying sensitivity and uncertainty analyses and by comparing them to independent sources of measured data" (Chapter 9, page 245 of Reference #3).
- The AQRS recognizes the fundamental importance of air monitoring and finds that new technologies and programs have been instituted to strengthen this capability over the past six years (see discussion of Research Topic 4, pages 12-16). However, important but poorly characterized components remain, notably carbonaceous PM species, and measurements for these must be developed and incorporated in routine monitoring. The AQRS will update the 1999 report 4 on the nation's collective air monitoring, incorporating the described changes in networks, including future plans for methods development and network adoption, describing their operation, and providing a means of coordination.
- The AQRS acknowledges that the research related to the combined effects of particulate matter and gaseous pollutants is in its infancy and calls for more effort in this area (see discussion of Research Topic 7, pages 20-21). Also, collaborative efforts between atmospheric scientists, exposure scientists, epidemiologists, and toxicologists are needed to address the difficult issue of combined effects in human populations.

[9] NARSTO, *Improving Emission Inventories for Effective Air Quality Management Across North America*, April 2005.

Part I: Research Recommendations by Topic Area

In this section, the AQRS* addresses the observations and recommendations made in Chapters 3, 4, and 5 of the NRC report.[1] In Chapter 3, the NRC reviewed progress under each of its ten Research Topics originally identified in the 1998 *Research Priorities for Airborne Particulate Matter: I. Immediate Priorities and a Long-Range Research Portfolio*.[10] The discussion responds to the two key questions raised by the NRC in its review: "What has been learned?" and "What remains to be done?" In the following pages, the AQRS discusses the NRC's comments and recommendations with regard to its ten Research Topics (see Table 2, page 4) and provides descriptions of research efforts undertaken by the member agencies to address remaining research needs.

Following the Research Topic discussion, an overview is presented (see Tables 4 and 5, pages 26 and 27) relating the work being done by AQRS member agencies and Departments under the ten topic areas and the crosscutting themes identified by the NRC in Chapter 4 ("Looking Across the Research Topics") and the seven overarching challenges identified in Chapter 5 ("Challenges Ahead for Particulate Matter Research").

NRC PORTFOLIO RESEARCH TOPIC #1: OUTDOOR MEASURES VERSUS ACTUAL HUMAN EXPOSURE

GUIDANCE FROM THE NRC REPORT

- Describe the quantitative relationships between outdoor measures and actual personal exposures to PM.
- Evaluate existing exposure models.

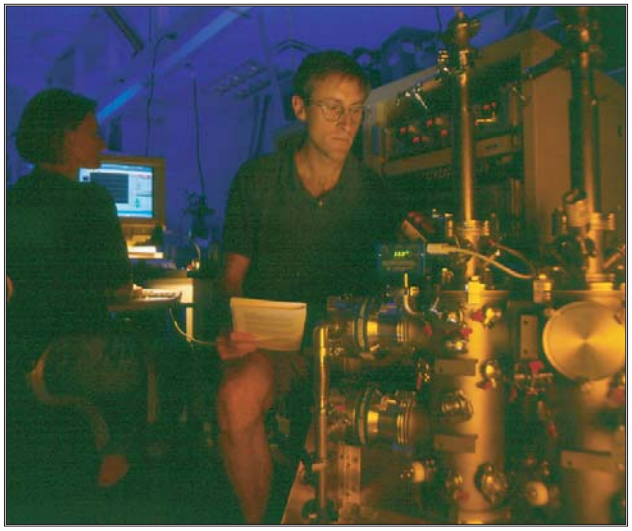
AQRS Approach

The AQRS agrees with the NRC assessment that there has been substantial progress answering the research questions related to this topic. A large number of studies have been completed, substantial data have been gathered, and results are being published. Data from these and supplemental studies by the EPA, National Institute of Environmental Health Science (NIEHS), and DOE are being used in the further development and evaluation of human exposure models, notably EPA's Stochastic Human Exposure and Dose Simulation (SHEDS) model and its comparison to other exposure models being used in assessments of air quality impacts. The AQRS notes that the

* A list of acronyms used in this report can be found on page 43.

10 NRC, *Research Priorities for Airborne Particulate Matter: I. Immediate Priorities and a Long-Range Research Portfolio*, National Academy Press, Washington, D.C., 1998.

data collected are not yet sufficient to develop a national perspective on personal exposures, especially for susceptible individuals.



Agency Current and Planned Research

EPA:

Research is currently ongoing to analyze data from eight panel studies and to put data into the Human Exposure Database System (HEDS). Work is continuing on development and evaluation of human exposure modeling approaches, including the SHEDS model. The Detroit Exposure and Aerosol Research Study (DEARS) was initiated in FY 04. This study is evaluating relationships between central site, outdoor, indoor, and personal measurements of air pollutants (PM, PM components, and air toxics) and how specific sources impact these measurements and relationships.

DOE/National Energy Technology Laboratory (NETL):

The Steubenville Comprehensive Air Monitoring Program (SCAMP), co-funded by DOE, EPA, the Ohio Air Quality Development Authority, and industry, is evaluating exposure of individuals in Steubenville, Ohio, to $PM_{2.5}$, $PM_{2.5}$ components, and gaseous co-pollutants using centralized monitoring, in-home monitors, and personal monitors.

Department of Health and Human Services (DHHS)/National Institute of Environmental Health Science (NIEHS):

Investigator-initiated grants, and grants through the Environmental Health Science Centers program, use personal monitoring to assess individual exposure that is then correlated with disease endpoints, such as asthma. These grants investigate differences between personal and centralized exposures, including how indoor as well as outdoor air exposures affect total personal exposures, and also provide funding to develop better personal monitors.

DHHS/National Institute for Occupational Safety and Health (NIOSH):

NIOSH's basic practice is to perform personal exposure measurements when feasible. NIOSH also has considerable history in comparing area versus personal exposure in occupational settings. For instance, a personal direct reading monitor based on Tapered Element Oscillating Microbalance (TEOM) technology has been developed for personal exposure measurement in coal mines, and could potentially be adapted for use in non-occupational settings. This technology has been extensively tested in coal mines and agrees quite well with traditional respirable sampler/gravimetric or chemical analysis.

NRC PORTFOLIO RESEARCH TOPIC #2: EXPOSURES OF SUSCEPTIBLE SUBPOPULATIONS TO TOXIC PM COMPONENTS

GUIDANCE FROM THE NRC REPORT

- Develop additional exposure measurement methods for PM components.
- Design future exposure studies for hazardous components.

AQRS Approach

The NRC's assessment considered that work in this area should be "implemented only after the work under topic 5 sufficiently advances understanding of particle characteristics that determine their toxicity." We feel that research has advanced our understanding sufficiently to begin interdisciplinary work on this topic through integrated exposure and health effects studies aimed at characterizing exposures to and effects of PM components. Integrated research efforts can facilitate and accelerate systematic efforts to determine hazardous components. This is consistent with the NRC-recognized need for an integrated approach across the atmospheric science, exposure, and health effects research spectrum in addressing the hazardous components issue. Exposure studies are being conducted as an integral part of the ongoing search for the biologically relevant components of PM.



Agency Current and Planned Research

EPA:

As described above, the Office of Research and Development (ORD) is conducting the Detroit Exposure and Aerosol Research Study (See Research Topic #1). As part of this study, ORD is improving measurement and analysis of PM components, particularly organic PM. Specifically, ORD is improving analytical techniques to lower detection limits for organic PM species, thus allowing measurement and analysis of personal exposure to these species.

DOE/NETL:

The Steubenville Comprehensive Air Monitoring Program (SCAMP) evaluated 32 non-smoking senior adults using electrocardiogram measurements and relating these to central monitoring station daily concentrations of fine particles and gases. Sulfate is being used as a marker of regional, non-traffic pollution. SCAMP is also studying the air pollution exposures of panels of 12 to 16 children (9-13 years of age) using personal, indoor, and outdoor fine particle and gas measurements. Information was also obtained on activities and time spent in various microenvironments using activity diaries and housing characteristic questionnaires. (Also see Research Topic #1 above.)

DHHS/NIEHS:

NIEHS continues to fund grants through its Environmental Justice and Community-Based Research Program, which evaluates exposures among individuals with increased health risk due to their ethnicity, socioeconomic status, etc. Research on the adverse effects of air pollutants on susceptible laboratory animals (e.g., aged or with pre-existing disease) is supported through the joint NIEHS-EPA Request for Applications (RFA), "The Role of Air Pollutants in Cardiovascular Disease."

USDA/CSREES:

The Cooperative State Research, Education, and Extension Service (CSREES) program

of the USDA is currently funding studies on the exposures of animals to ambient air pollution, which may have value as surrogates for human exposures.

NRC PORTFOLIO RESEARCH TOPIC #3: CHARACTERIZATION OF EMISSIONS SOURCES

GUIDANCE FROM THE NRC REPORT

- Develop a master list and plan for a comprehensive national emissions inventory.
- Develop and apply additional test methods and testing for sources such as wildfires, non-road engines, and residential wood burning.
- Estimate the uncertainties in emissions inventories.



AQRS Approach

The NARSTO organization, which includes many who are also AQRS members, has developed a plan for future emissions inventory development across the United States, Canada, and Mexico. The NARSTO effort independently identified the same needs the NRC found and thus its interagency plan can be used to achieve the goals laid out by the NRC. The NARSTO Emissions Inventory Assessment (2005)[9] makes eight recommendations to improve North American emission inventories and puts forward an initial action plan for the three countries to follow in implementing these recommendations:

1. Reduce uncertainties associated with emissions from key under-characterized sources. Further discussion and a listing are presented in Table 3 (corresponds to NRC guidance calling for a master list and plan).
2. Improve speciation estimates.
3. Improve existing and develop new emission inventory tools (corresponds to NRC guidance on new test methods).
4. Quantify and report uncertainty (corresponds to NRC guidance on uncertainties).
5. Increase inventory compatibility and comparability.
6. Improve user accessibility.
7. Improve timeliness.
8. Assess and improve emissions projections.

AQRS members endorse these recommendations and will focus their emissions research on these objectives, guided by priorities developed through the further recommended action to "systematically continue to improve emission inventories by applying sensitivity and uncertainty analyses and by comparing them to independent sources of measured data" (2005 NARSTO Emissions Inventory Assessment, Reference #9, page 245). AQRS members recognize that resources must be targeted to reduce the greatest sources of uncertainty and focused on those source categories whose control will be most effective, from both a cost and a health-risk reduction perspective, in achieving air-quality management goals. Various expert panels have proposed lists of priority emission inventory development needs along these lines. The preceding list (see Table 3), which has been consolidated from these recommendations and produced in the NARSTO assessment, is viewed as containing the top-priority needs for improving emission inventories.

Future periodic program reviews, as discussed in Part II below, will focus on assessing progress in this area by the member organizations, and future recommendations concerning priority areas will be provided.

Table 3. Highest Priority Emission Inventory Needs *

- Size-segregated, speciated emissions of fine particles and their precursors, including black and organic carbon emissions
- Toxic and hazardous air pollutants
- Emissions from the on-road vehicle fleet
- Emissions of ammonia from agricultural and other area sources
- Speciated, spatially, and temporally resolved organic emissions from biogenic sources
- Emissions of volatile organic compounds (VOCs) and organic hazardous air pollutants (HAPs) from petrochemical and other industrial facilities
- Emissions from off-road mobile sources including farm and construction equipment, aircraft and airport ground equipment, commercial marine facilities, and locomotives
- Emissions from open biomass burning, including agricultural and forest prescribed burning, wildfires, and residential backyard burning
- Residential wood combustion, including woodstoves and fireplaces
- Paved and unpaved road dust

* As identified by the 2005 NARSTO Emissions Inventory Assessment (Reference #9).

Agency Current and Planned Research

DOE/NETL:

The Carnegie Mellon University-Pittsburgh air quality study is using advanced PM characterization methods to evaluate emissions from coal plants, coke plants, steel mills, road dust, and vehicles. Under the Office of Fossil Energy's University Coal Research and Small Business Innovative Research, DOE/NETL is also sponsoring several projects to develop advanced methods for characterizing the emissions from coal-fired utility boilers.



DOE/Office of Science (SC):

The DOE Office of Science anticipates funding one or two proposals associated with field campaigns in Mexico City that would address emission sources contributing to aerosol loadings.

Department of Commerce (DOC)/National Oceanic and Atmospheric Administration (NOAA):

Ambient measurements from surface sites and aircraft are being used to evaluate existing emission estimates; the 2004 focus was on the Northeast. NOAA participated in the preparation of NARSTO's assessment of emission inventories. They will continue evaluations using ambient data. A study was conducted in 2006 in east Texas, including the Houston and Galveston areas, which provided an opportunity to evaluate techniques for emission characterization using remote sensing techniques.

USDA/CSREES:

Emissions are being characterized for several species of animal production, wild fire and controlled burns, and fugitive dust

from agricultural production practices. Research has been solicited on all aspects of production agriculture through USDA's National Research Initiative.



DHHS/Agency for Toxic Substances and Disease Registry (ATSDR):

PM and other emissions from asphalt production sites are being evaluated. Seven sites have been sampled to date. Data from those sites are being evaluated, along with data from NIOSH's five sites and the EPA's AP42 and other site-specific data.

EPA:

Through its work on NARSTO's assessment of emissions inventories[9], EPA will identify an approach to meet the requirement for a systematic source testing and inventory plan. The Office of Research and Development (ORD) and the Office of Air and Radiation (OAR) are actively working on new emission test methods, including those using dilution, for identified key sources. ORD and others have extensive research underway to upgrade source profiles. ORD is also working with OAR to update the Repository of Total Organic Compounds and Particulate Matter (SPECIATE database, which is a repository of information on total organic compounds (TOC) and PM. Work incorporating Geographical Information Systems (GIS) into some emissions models is also ongoing. In addition, ORD is working to identify source marker compounds for use in source apportionment analyses. This work includes improved analytical methods for organic speciation and for detection of trace level inorganic compounds. These efforts will enhance source apportionment used to develop and evaluate emission inventories.

DOC/National Institute of Standards and Technology (NIST):

Databases and reference materials are being developed to provide for improved quantitative measurement of emissions. A structure is being developed for the organization of kinetics databases for particle formation models from the combustion of transportation fuels.

NRC PORTFOLIO RESEARCH TOPIC #4: AIR QUALITY MODEL DEVELOPMENT AND TESTING (AND MEASUREMENT)

GUIDANCE FROM THE NRC REPORT

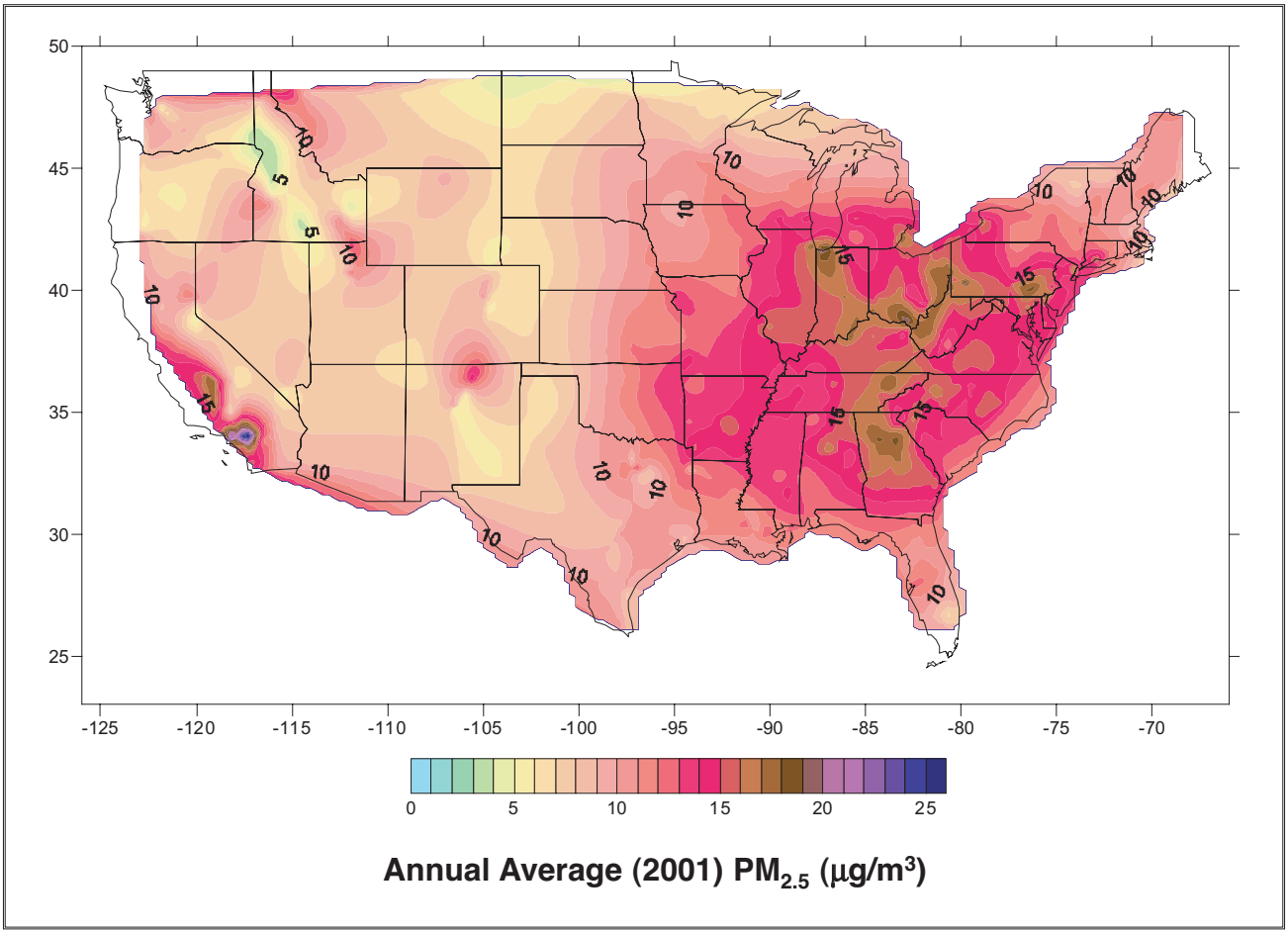
- Produce integrated, well-tested aerosol models, both source and receptor based, for local air quality management.
- Develop and implement a plan for continuing comparisons that systematically test emissions data, source and receptor models, and ambient data against one another.
- Account for substantial sampling and analytical uncertainties in the measurement of major particle species, most critically organic material.

AQRS Approach

The primary subject of this research topic in the NRC portfolio is the development and testing of

models to be used in air quality management planning. Several AQRS members conduct research and development of aerosol models and this activity is profiled below (see agency-specific activity descriptions that follow and agency websites found in Part II and Table 6 for full descriptions of agency models). Taken collectively, member research results in ongoing model evaluation and improvement called for by the NRC. In addition, periodic intensive field programs by AQRS members under the coordinating leadership of one or more members, e.g., the New England Air Quality Study directed by NOAA, are specifically designed to test the suite of available aerosol models against one another and against all available ambient data. AQRS members commit to this ongoing practice as part of the next generation of model development.

A secondary theme under this topic is the development, evaluation, and deployment of air quality monitors. This subject was last reviewed by the AQRS in its 1999 report on *The Role of Monitoring Networks in the Management of the Nation's Air Quality*.[3] At the time, it profiled the major ground-based air quality and deposition monitoring networks in the U.S., including IMPROVE, NAMS/SLAMS, PAMS, NADP/NTN, NADP/MDN, CASTNet, AIRMoN, and the GPMP programs (see list of acronyms, page 43). The report went on to discuss the importance of monitoring infrastructure and described the AQRS role in encouraging sustained operation of critical baseline programs, promoting research to improve capabilities for emerging issues, and coordinating network intercomparisons, sampling equipment collocations, quality assurance, and design of new networks.



Annual Average (2001) $PM_{2.5}$ ($\mu g/m^3$)

In the seven years since the 1999 report[3], substantial improvements and changes to the nation's collective air monitoring network have occurred. New remote monitoring capability has emerged, new monitoring programs have been instituted, and a new monitoring strategy has been prepared for the nation's air quality compliance network. The Interagency Monitoring of Protected Visual Environments (IMPROVE) network has doubled in size. A new national fine particle network has been added (including measurements of PM mass via Federal Reference Method (FRM) and continuous methods and measurements of PM species in the Speciation Trends Network (STN)), and specialty programs have been instituted for intensive study of fine particle formation (the Supersites program) and screening of urban air toxics. New methods for poorly characterized PM components, notably carbonaceous species, have been and continue to be the focus of intensive methods development research. Large intensive field studies, such as Supersites and the International Consortium for Atmospheric Research on Transport and Transformation (ICARTT) programs, have demonstrated the value of new LIDAR (Light Detection and Ranging), tethered, aircraft-based and satellite technology for upper-air measurements crucial for understanding the all-important transport phenomena affecting local air quality. The EPA, working with its state/local/tribal partners and AQRS members, is putting a new National Air Monitoring Strategy in place, overhauling the national compliance and air quality management network (National Air Monitoring Stations (NAMS) / State and Local Air Monitoring Stations (SLAMS), and Photochemical Assessment Monitoring Stations (PAMS)). Coordination of the country's compliance networks with the nation's infrastructure science monitoring programs is a key feature of the EPA strategy. The multi-agency nature of the nation's air quality monitoring, taken in whole, emphasizes the importance of this coordination. The AQRS will update the 1999 report[3], incorporating the described changes in networks, including future plans for methods development and network adoption, describing their operation, and providing a means of coordination.



Agency Current and Planned Research

USDA/CSREES:

Research into dispersion models, primarily for application in cattle feed-yards, is ongoing. Effort is underway to evaluate the use of the Federal Reference Method for estimating PM from agricultural sources. New emphasis is being placed on process-based models that use a mass balance approach. New methods that accurately estimate emissions from rural areas using improved particle size distributions are also being developed.

DOE/NETL:

The Carnegie Mellon University-Pittsburgh air quality study is using advanced sulfur processing methods in the Comprehensive Air Quality Model with Extensions (CAMx) to predict PM concentrations and composition in the Eastern U.S. Ohio University is refining the CMAQ (Community Multi-scale Air Quality) model to evaluate regional/local deposition of mercury in the Ohio River valley.

DOE/SC:

Research is ongoing in aerosol modeling for air quality purposes. Funding for a number of proposals for modeling of aerosol processes relating both to air quality and climate is anticipated. For instance, the Atmospheric Science Program (ASP) Megacity Aerosol Experiment – Mexico City (MAX-Mex) study aims to "obtain a process level understanding of the concentration, composition, size distribution, hygroscopicity, and optical properties of ambient aerosol, and their evolution in the Mexico City plume, in the context of Mexico City urban emissions; gather a comprehensive meteorological and chemical data set suitable for use in regional and global-scale model validation; and determine the direct radiative effect of aerosols in the Mexico City plume as a function of time, location, and processing conditions."

DOC/NOAA:

The following activities are underway: comprehensive, intensive studies of aerosol formation and growth; use of comprehensive datasets from regional air quality intensives to evaluate existing PM models; laboratory experiments on fundamental processes related to aerosol formation and growth; development of techniques to improve estimates of aerosol deposition; quantification of fundamental kinetic and thermodynamic parameters for aerosol formation and growth; development of new techniques to quantify aerosol properties and composition; measurement of deposition rates for different aerosol compositions under different land use; development of new models for PM; and development of a nationwide PM forecast capability.

EPA:

ORD is providing air quality modeling tools (CMAQ and Chemical Mass Balance (CMB), UNMIX source-receptor model, and Positive Matrix Factorization, PMF) and information (Supersites results) to support state implementation plan (SIP) development. CMAQ is being run for periods up to a full year for the continental U.S. and is being tested against all available field monitoring datasets. A comparison of CMAQ to REMSAD (Regional Modeling System for Aerosols and Deposition) for PM and CAMx (1c) for ozone is being conducted. A modeling center (Community Modeling and Analysis System, CMAS) was created for CMAQ user support, training, and distribution. Work continues on improvements to CMAQ's sub-grid processes. ORD is also working to improve receptor modeling tools such as PMF and UNMIX. New versions of these models have recently been developed and will soon be released for use by air quality managers. ORD will be providing guidance and training in the use of these receptor models and is now working with several states and EPA regional offices to apply them.

ORD is also conducting in-house ambient measurement methods research focused primarily on Federal Reference Method (FRM) development and testing. Beyond that, ORD activities include efforts to improve analytical methods for organic speciation and to address organic PM sampling artifacts. OAR is promoting the NCore network as part of the new National Ambient Air Monitoring Strategy, with Level 2 sites for research and Level 3 sites for compliance; Level 1 (post-Supersites equivalent) are under consideration. In addition, ORD's extramural Science To Achieve Results (STAR) grants program is supplementing methods development and modeling research in the areas of carbonaceous PM, PM source apportionment, and continuous PM measurement.

ORD is conducting in-house methods development focused on the FRM air sampling method. The extramural STAR grants program is supplementing methods development, especially for carbonaceous PM.

The Council for Regulatory Environmental Modeling (CREM) oversees the Agency's models knowledge base for all aerosol and other models used in program and policy analysis, e.g., CMAQ, REMSAD, and CMB. Models in this inventory must meet guidelines covering peer review history, documentation and availability, best management practices for application, and steps for continuous improvement. A record of EPA's actions in response to NRC modeling recommendations will be maintained in this public database (see the website at http://www.cfpub.epa.gov/crem/).

DOC/NIST:

A program is now underway to develop engineered PM materials reproducibly and with traceability to a well-characterized aerosol generation facility. Method optimization for carbonaceous constituents in $PM_{2.5}$ is being developed as part of a NIST/EPA interagency agreement (IAG), as well as inter-laboratory quality assurance exercises and the development of reference materials. Method optimization focuses on measurement accuracy for elemental carbon in ambient air that is heavily influenced by distinctive PM sources. New measurement techniques and databases are being developed to address measurement issues. A laser-based thermal heating technique is under development to provide thermophysical, optical, and chemical kinetics information on PM. The technique can be used to investigate potentially spurious effects of heating a soot-bearing surface, such as found with thermal optical analyzers. Inter-laboratory quality assurance exercises and development of reference materials for organic constituents of $PM_{2.5}$ are underway as part of a NIST/EPA IAG, in addition to uncertainty assessment for elemental carbon. Inter-laboratory comparison exercises assess measurement variability for various organic constituents including polycyclic aromatic hydrocarbons (PAHs) and substituted PAHs. Reference materials include ambient $PM_{2.5}$ and methods calibration solutions with assigned values for carbonaceous components that include various toxic organic compounds and emission source markers.

Department of the Interior (DOI)/National Park Service (NPS):

Research is ongoing to characterize organic aerosols, nitrate aerosols, aerosol acidity, filter artifacts and losses, and aerosol optical properties. Organic aerosol research includes distinguishing sources using various organic molecular markers and carbon isotope ratios, identifying organic aerosol optical properties and hygroscopicity, as well as investigating the variations in organic size distributions from biomass burning as a function of age of the smoke. New methods for cost-effective identification of organic molecular markers for wood smoke (levoglucosan and related sugar and anydro-sugar compounds) are being explored. Characterization of nitrate and other ions in aerosol particles in the IMPROVE network include the examination of: aerosol acidity and its neutralization during post-sampling handling of IMPROVE filters; the form and size distribution of nitrate; the efficiency of aqueous extraction of nylon filters; the losses of ammonium from particles collected on nylon filters; the temporal variability of fine particle ion concentrations; and the efficiency of IMPROVE denuders for the collection of nitric acid. Receptor and deterministic models are used to identify contributing source regions to aerosol concentrations. Techniques have been developed and applied to reconcile measured sulfate concentrations with model results from both REMSAD and CMAQ, to yield a more reliable estimate of source-area contributions.

NRC PORTFOLIO RESEARCH TOPIC #5: ASSESSMENT OF HAZARDOUS PARTICULATE MATTER COMPONENTS

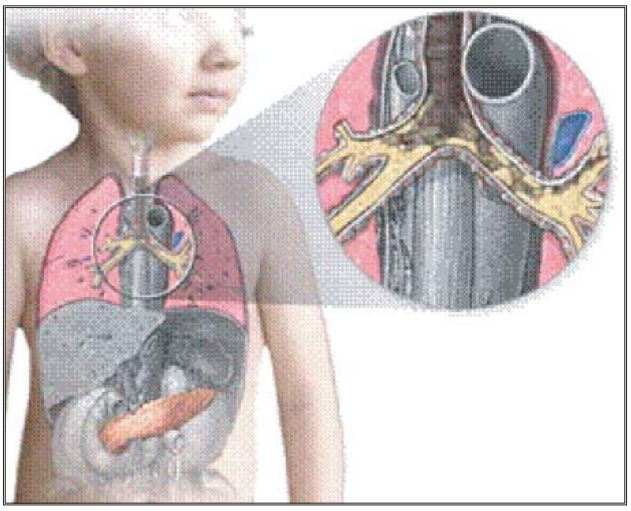
GUIDANCE FROM THE NRC REPORT

- Better integrate toxicological and epidemiological studies to ensure complementary findings.
- Undertake a systematic, multi-disciplinary approach to assessing the comparative toxicity, including exposure-dose-response relationships of particles of differing characteristics and from different sources.
- Extend toxicological investigations from single-particle characteristics to include: 1) addressing characteristics that have received little attention; 2) defining exposure-dose response relationships, at realistic exposures; 3) making direct comparisons between PM with different characteristics using identical protocols; and 4) evaluating the importance and role of the characteristic in question as it exists as a component of realistically complex exposures.

AQRS Approach

The AQRS considers this its most complex and highest priority area of research. The toxicological database has provided considerable evidence to support the hypothesis that certain physicochemical attributes of particles can be causally linked with regard to the observed health effects of ambient PM. A single causal attribute may not be found, but may contribute to a complex mechanism driven by the nature of a given PM and its contributing sources. The multiple interactions that may elicit a response in a host may make it difficult to identify any single causal component and may also account for the fact that mass, as the most basic metric, shows the relationships to health outcomes that it does.

Research in this area is moving toward source-based linkages with hazardous components and their contributions to PM adverse health effects. This new source-based approach will make use



of two techniques, source-specific studies and source-region studies. In source-region studies, concentrated atmospheric particles (CAPs) from urban areas and regions across the country will be used in coordinated epidemiological and toxicological studies of health effects, their mechanisms, and relative toxicity. Maximum use will be made of toxicological studies with identical protocols. Source identification will be accomplished through atmospheric sciences techniques of receptor and source-based modeling and analysis. Source types amenable to study in this way include: utilities producing regional sulfates, gasoline and/or diesel fuel burning engines, wild and agricultural fires, and metal and other select industries. The strategy's second approach, source-specific studies, will make use of emissions samples collected from representative sources in extended toxicological studies of associated health effects. Some of the source categories to be studied in this way include diesel engines, coal combustion emissions, wood smoke, and road dust. Both approaches will make use of integrated exposure studies to ensure that realistic PM composition and concentrations are used and are part

of the exposure-dose-response relationships produced as the final product of this work.

Agency Current and Planned Research

DHHS/NIEHS:

Research to study the toxicity of particulate matter components, using laboratory-generated PM (including diesel exhaust particles) as well as real-world PM, is being supported through the extramural division. *In vitro* and *in vivo* models, as well as human exposure models and epidemiologic studies, are being used. For instance, research is being supported to use statistical methods (such as Principal Component Analysis and Rolling Factor Analysis) to relate composition of concentrated air particulates (CAPs) to their toxic effects. Most of this research is supported through investigator-initiated grants; however, research is also being supported through a joint EPA-NIEHS Request For Applications (RFA) to specifically study the role of PM in cardiovascular disease. Work through program projects and Environmental Health Science Centers is trying to integrate exposure assessment, toxicology, and epidemiology research.

DOE/NETL:

The Toxicological Evaluation of Realistic Emissions of Source Aerosols (TERESA) program is assessing the toxicity of coal combustion emissions by exposing laboratory animals to actual plant emissions that have been "aged" and converted to reaction products. Two projects to evaluate human health effects resulting from realistic exposures to primary and secondary $PM_{2.5}$ from coal-fired power plant emissions were initiated in FY 05. One project evaluated the health effects of coal plant emissions and emissions from other sources (e.g., wood smoke, vehicle engines, road dust) by generating these emissions in a controlled laboratory setting and evaluating their relative toxicity via a series of animal exposure experiments. The second project utilized a mobile animal exposure laboratory and particle concentrator in three different ambient environments – one dominated by vehicle emissions, one dominated by secondary PM from coal combustion, and one containing a mixture of vehicle emissions, secondary PM from coal plants, and emissions from various local industrial and residential sources.

EPA:

Steering committees have been formed and workshops will be held on systematic approaches for hazardous component investigation. In-house and STAR grant programs are supporting clinical, epidemiologic, animal, and *in vitro* studies for the following purposes:

- To link components and attributes of PM effects, in healthy and susceptible populations, for coarse, fine, ultrafine, CAPs, surrogates, and diesel emissions.
- To investigate thresholds and how variations in duration, concentration, and make-up impact PM effects.
- To characterize the relationship between the dose an individual is exposed to and the dose delivered to the target organs, as well as to identify a dose metric.
- To determine the plausibility and mechanisms for effect endpoints, including cardiac, pulmonary, immunologic, and vascular endpoints, covering short-term and long-term effects.
- To do source apportionment and factor analysis using multi-pollutant/multi-city epidemiologic studies, including traffic studies.
- To conduct controlled human, animal, and *in vitro* exposure studies that link components and/or sources to effects and determine source potency by endpoint, including coarse, fine, and ultrafine CAPs, and diesel, coal, oil, gaso-

line, and wood combustion emissions. This includes research conducted by the EPA intramural research program, research under the new EPA-NIEHS cardiovascular disease RFA, and Phase 2 of the EPA PM Centers program.

DHHS/NIOSH:

Projects are underway to investigate several multi-component aerosols including asphalt fumes, welding fumes, diesel fumes, and allergens.

NRC PORTFOLIO RESEARCH TOPIC #6: DOSIMETRY: DEPOSITION AND FATE OF PARTICLES IN THE RESPIRATORY TRACT

GUIDANCE FROM THE NRC REPORT

- Identify differences in the fractional and regional deposition associated with aging.
- Relate clearance and the effects of gender, age, and respiratory abnormalities.
- Further characterize the translocation from the lung to other organs.
- Produce more information on the dosimetry in animal models of human diseases.

AQRS Approach

Given the wide range of sizes and surface characteristics of ambient particles, the AQRS agrees that it is important to determine the sites of deposition in the airways and alveoli and the mechanisms of clearance from the lung. This has been an active area of research for many years, and data collected so far have increased our understanding of how particles deposit in the lung. Further information is needed to increase our understanding of particle clearance and how particle size and composition impacts distribution to other parts of the body (e.g., to cardiovascular and neurological systems). The growing recognition of the potentially unique toxicological properties of soluble and ultrafine particles requires that new methodologies for generating these particles and better models for determining the deposition patterns continue to be developed. Likewise, the availability of faster computers and more sophisticated statistical and modeling methods should facilitate these efforts. Collaborations with researchers in the growing fields of nanoparticle toxicity and aerosol drug delivery, including those in the private sector, should also be encouraged.



Agency Current and Planned Research

DHHS/NIEHS:

Investigator-initiated grants are supported through the regular project grant program to use computer models to evaluate the deposition of air pollutants, including PM, in respiratory tracts. Research to determine the extent of distribution of the toxic components out of the lung and into the systemic circulation is also supported. Research supported by the NIH's National Health, Lung, and Blood Institute (NHLBI) is also looking at modeling of particle deposition and at the dosimetry of inhaled therapeutic aerosols.

EPA:

Current plans call for limited dosimetry studies of animal-to-human extrapolation and the conduct of modeling studies that will address fractional and regional deposition. These studies will also address dosimetry in animal models. Efforts are also planned to examine the translocation from lungs to other organs.

DOC/NIST:

A project has been initiated to develop a measurement approach to obtain spatially resolved species composition of multiphase aerosols generated from drug delivery/inhalation devices. Included is development of a reference aerosol generator for calibration of inhalation devices.

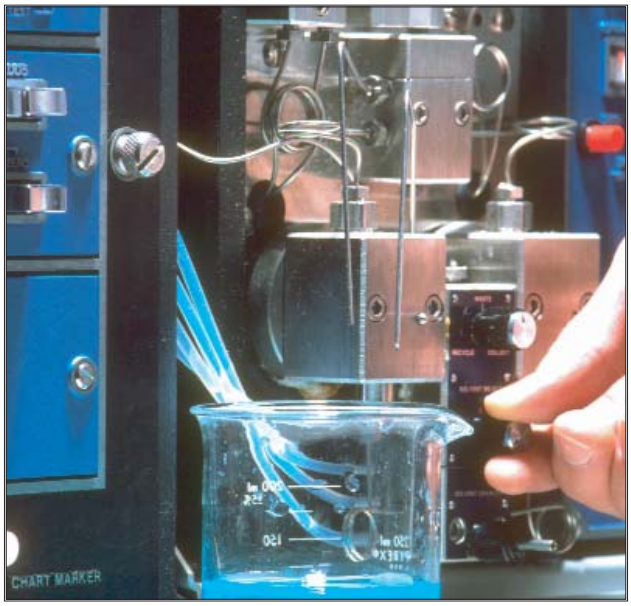
NRC PORTFOLIO RESEARCH TOPIC #7: COMBINED EFFECTS OF PARTICULATE MATTER AND GASEOUS POLLUTANTS

GUIDANCE FROM THE NRC REPORT

- Conduct further studies to disentangle the effects of PM from other pollutants and determine whether PM effects vary with concentrations of other major pollutants in ambient air.
- Produce a better understanding of why some mixtures and potentially those from different sources have different effects in different diseases.

AQRS Approach

The simultaneous exposure of individuals to multiple pollutants causes two challenges for PM research: determining the potential confounding role of gaseous pollutants, and determining if exposure to multiple pollutants results in a modified biological response, e.g., whether the effects are additive or synergistic. Collaborative efforts between atmospheric and exposure scientists, epidemiologists, and toxicologists are needed to address the difficult issue of combined effects in human populations. Likewise, while laboratory studies of combined exposures are ongoing, this area of research is still in its infancy and more efforts in this area are needed.



Agency Current and Planned Research

DOE/NETL:

A project was initiated in FY 05 to assess the feasibility of a retrospective epidemiology study of $PM_{2.5}$ and co-pollutants in the area of Pittsburgh, Pennsylvania, using air quality data from 1999-2003. All exposure and health effects projects sponsored by DOE/NETL include the examination of the combined effects of PM and gaseous pollutants.

DHHS/NIEHS:

Epidemiologic and clinical studies, such as the Inner City Air Pollution study (co-funded by EPA) and research at the Environmental Health Science Centers, are looking at associations between air pollution and a number of health endpoints, including cardiovascular and respiratory disease and risk of adverse birth outcomes. In addition, NIEHS is participating with EPA, Centers for Disease Control and Prevention (CDC), and the National Institute of Child Health and

Human Development (NICHD) in the Children's Health Study. These studies try to factor in elements such as correlations between pollutant levels that might result in erroneous conclusions.

EPA:

In-house epidemiological studies of long-term health effects and traffic emissions in El Paso and Detroit are being conducted, and STAR grants for the California Children's Health Study and the 24-city study are being supported. In-house and STAR grant studies on reproductive and developmental effects are also being conducted. In-house clinical human studies are being done on the toxicity of diesel emissions and CAPs and gases. Animal studies of diesel and coal emissions, CAPs, gases, and VOCs are also being conducted. Data from the Detroit exposure studies are producing relationships between ambient PM, PM attributes, and PM sources. Models of personal exposure to PM, leading to predicted exposure gradients, are being developed and applied.

DOC/NIST:

A passage for aerosol particle treatment and sampling is to be appended to the aerosol generation facility (see NIST contribution in Research Topic #3) to study aerosol particle interactions with other independently introduced gaseous and solid additives. Conditions such as temperature and humidity will be controlled throughout the passage to simulate atmospheric conditions of interest.



NRC PORTFOLIO RESEARCH TOPIC #8: SUSCEPTIBLE SUBPOPULATIONS

GUIDANCE FROM THE NRC REPORT

- Conduct more research on the different scales of exposure, characteristics of exposure, cellular and molecular mechanisms, range of potential adverse effects, and potential effect modifiers.
- Investigate whether chronic PM exposures relate to the development of disease and organ dysfunction.
- Validate animal models and demonstrate relevance of these models, especially for mimicking compromised organ functions found in susceptible individuals.

AQRS Approach

The AQRS PM Working Group believes that this is a high priority area. Data show that age and health status clearly influence susceptibility to the adverse health effects of PM. Race and socioeconomics have also been implicated as susceptibility factors. Genetic background is a likely influence, as it is in many other disease processes, although this area has been much less studied in relation to air pollution. Support for controlled human exposure and epidemiologic studies will continue, with emphasis on identifying susceptibility factors and susceptible populations. Given the potential expense and effort-intensive nature of these types of studies, researchers will be encouraged to mine existing datasets (using, for instance, meta-analysis) to try to tease out information on this topic, and to try to exploit existing long-term cohorts, such as through the National Health and Nutrition Examination Survey (NHANES) study. Likewise, further experimental human exposure studies on individuals having specific risk factors, and studies using animals that model human risk factors, will be encouraged.

The Toxics and Risk Assessment Subcommittee's mission is to coordinate interagency research on problems associated with exposures to toxic materials resulting from releases to all environmental media. This broad mission potentially encompasses human exposures to toxic air pollutants found in PM. The Subcommittee collaborations to date have focused on key toxics and risk-related issues of endocrine disruptors, methylmercury, and human exposure. Each of these is potentially connected to the needs identified here for a better understanding of the different scales and characteristics of exposure and human susceptibility associated with PM and its components. The AQRS and the Toxics and Risk Assessment Subcommittee will work through their leadership to insure that activities are properly coordinated and that potential mutual benefits are explored.

Agency Current and Planned Research

DHHS/NIEHS:

Grants are supported through the investigator-initiated grant program, and the Environmental Justice, Community-Based Research, and Health Disparities Programs, as well as the joint NIEHS-EPA cardiovascular disease RFA, to assess the burden of exposure in populations at greater health risk, e.g., by virtue of their race, socioeconomic status, pre-existing disease, etc. These projects use epidemiologic methods, community-based research, animal models, and controlled human exposure studies to assess susceptibility.

EPA:

Through in-house research, the STAR grant program, and Phase 2 of the PM Centers program, studies are being conducted to assess the relationship between CAPs; coarse, fine, ultrafine, and diesel PM; and gaseous pollutants and adverse health outcomes. These studies include epidemiologic panel studies of asthmatics and diabetics and elderly individuals, as well as clinical studies of asthmatics and individuals with unspecified risk factors. Research projects through this program also address animal models of asthma, cardiovascular disease, and diabetes in relation to exposures to diesel exhaust and coal emissions, CAPs, pollutant gases, and VOCs.



DHHS/CDC:

The Public Health Air Surveillance Evaluation (PHASE) project supports the mutual efforts of the CDC, EPA, and state/local partners to systematically and routinely link and analyze air quality characterization data and public health surveillance data. It is designed to evaluate methods for generating ozone and particulate matter data that can be linked to health outcomes data, to develop a standard method for linking the data, to assess potential methods for analyzing the linked data, and to provide methods that will enhance the national effort to build an environmental public health tracking network. The CDC was given the mandate to develop a National Environmental Public Health Tracking Network (NEPHTN) and is working collaboratively with the EPA, state, and academic partners in this endeavor. An important concept of NEPHTN is that data will be available in the state networks for a core set of high priority health and environ-

mental measures that would be similar enough across states to be aggregated at a regional or national level. As part of the national effort to build the NEPHTN, CDC, EPA, and three states (Maine, New York, and Wisconsin) have been working since February 2004 to develop and evaluate strategies to link air quality data with cardiovascular and respiratory health data. The sources of the air characterization data under evaluation include ambient air monitors, the EPA/NOAA Community Multi-scale Air Quality Model, NASA Satellite Aerosol Optical Depth data, and statistically interpolated and combined sources. The health effects measured include hospital discharge, emergency department, and mortality data for cardiovascular disease, asthma, and other respiratory effects. A final recommendation on the most appropriate methods for generating, linking, and analyzing the air and health data is now available.

NRC PORTFOLIO RESEARCH TOPIC #9: MECHANISMS OF INJURY

GUIDANCE FROM THE NRC REPORT

- Extend physiological and cellular mechanism studies to molecular mechanisms.
- Understand the relationship between the mechanisms responsible for acute versus chronic effects.
- Understand the dose dependency for mechanisms underlying exposure-response relationships.

AQRS Approach

There is a clear interactive linkage between research to determine the hazardous PM components, and research to determine factors of susceptibility and biological mechanisms that elicit health effects. Although the epidemiologic data linking PM to adverse health effects continues to strengthen, experimental research is required to establish the cause-and-effect relationship. This type of research is needed to identify cellular and molecular targets, identify susceptibility factors, and determine possible intervention strategies. Experimental research (*in vitro* and *in vivo*) should be informed by the human studies, in terms of potential health endpoints and PM types. Therefore, work will continue in this area, with emphasis being placed on using epidemiologic data to develop appropriate hypotheses and on encouraging interdisciplinary collaboration to assure that environmentally relevant PM materials and appropriate doses are used in the protocols.

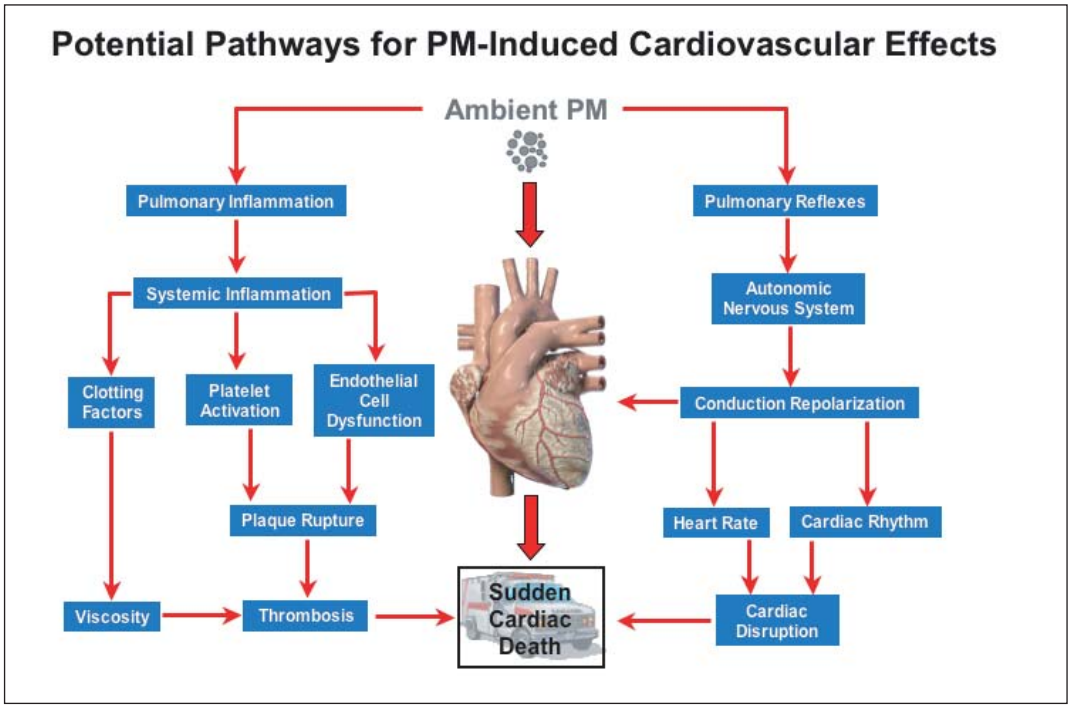
Agency Current and Planned Research

DHHS/NIEHS:

Research in this area is supported both in the extramural and intramural components. This includes *in vitro*, *in vivo*, and controlled human exposure studies, and panel studies. Studies examine the cellular responses to CAPs, diesel exhaust, and artificially produced particulate material. Studies using animal models, including dogs and wild type and genetically manipulated rodent models, examine the effects in the context of the whole organism. Experimental human studies evaluate the mechanisms of pulmonary and cardiovascular responses to PM in carefully controlled situations.

EPA:

Clinical and animal studies are conducted to link the effects of components and attributes of PM to mechanisms of action. This is done for healthy versus susceptible subpopulations, using coarse, fine, and ultrafine PM and components from CAPs and surrogates. In addition, toxicology, *in vitro*, and molecular studies of plausibility and mechanisms-of-effect endpoints, including cardiac, pulmonary, immunologic, and vascular endpoints, are conducted. Mechanisms of long-



term and short-term effects are contrasted. This work is supported by the EPA-NIEHS cardiovascular RFA and the first phase of PM Centers Programs.

DHHS/NIOSH:

Several projects are ongoing to investigate mechanisms of respiratory system response to several types of particles including silica, fibers, titanium dioxide, carbon nanotubes, and other nanoparticles.

NRC PORTFOLIO RESEARCH TOPIC #10: ANALYSIS AND MEASUREMENT

GUIDANCE FROM THE NRC REPORT

- Develop a more complete understanding of the impacts of modeling approaches in time-series studies.
- Further investigate the issue of harvesting or mortality displacement.

AQRS Approach

Epidemiologic studies that employ a variety of designs, including prospective, time-series, case-control, and case-crossover studies, need to continue to be supported. One goal of these studies will be to evaluate the effect of study design and modeling approach on the results. As mentioned above, inclusion of experts in exposure and atmospheric sciences will enhance this effort.

Agency Current and Planned Research

DHHS/NIEHS:

Through the investigator-initiated grant program, epidemiologic studies are supported to assess the link between PM and disease endpoints. These studies include research to optimize experimental design and to develop innovative statistical methods.

DOE/NETL:

An ongoing project, begun in FY05, is assessing the feasibility of alternative statistical modeling approaches for conducting a retrospective epidemiology study of $PM_{2.5}$ and co-pollutants in the Pittsburgh, Pennsylvania, area using air quality data from 1999-2003.

EPA:

These considerations are inherent in ongoing in-house and STAR grant epidemiology stud-

ies, including both the Detroit children's health study and the recently awarded 10-year multi-city epidemiologic study.

DOC/NIST:

Product performance is measured with respect to criteria air pollutants, including particles, based on translating their cradle-to-grave releases of these pollutants into disability-adjusted life years that represent health losses from air pollution. A new measurement approach to determine soot volume fraction has been developed for fires. Aerosol measurements and standards are being developed for asbestos.



CROSS-CUTTING RESEARCH ISSUES AND OVERARCHING CHALLENGES

The NRC report[1] in Chapter 4 ("Looking Across the Research Topics") discusses five cross-cutting issues that provide additional insight into the work to be done under each of the ten research topics and allows for alternative mechanisms to gauge overall progress in addressing the PM issue as a whole:

- The increasing number of health outcomes associated with PM
- Particle toxicity of PM characteristics and emission source types
- Increased emphasis on exposure-dose-response relationships
- Considering PM health effects in the context of other pollutants
- Considering the implications of setting and implementing the PM National Ambient Air Quality Standards (NAAQS)

Table 4 shows the relationship between these cross-cutting topics and the 10 research priority areas also identified by the NRC. Viewing these research priorities in this alternative framework highlights an important role for the AQRS. Specifically, the multidisciplinary perspective and complementary nature of the various agency missions that constitute the AQRS facilitate the integration of information gained through this federal effort.

Similarly, the NRC in Chapter 5 ("Challenges Ahead for Particulate Matter Research") discusses seven overarching challenges it sees that must be faced in addressing the full complement of research under its portfolio and gauging its progress by alternative means:

- Completing PM emissions inventories and models necessary for NAAQS implementation
- Developing a synergistic program to assess component and mixture toxicity
- Enhancing air quality monitoring for research
- Investigating long-term health effects
- Improving toxicological approaches
- Transitioning to a multi-pollutant program
- Integrating across disciplines

Table 5 crosswalks these challenges with the work being done by the AQRS associated with each of the 10 priority research topics. Meeting each of these challenges will take the combined synergy of the federal air research community. Once again the AQRS is optimally positioned to facilitate meeting these challenges within the context of implementing its coordinated research strategy.

Table 4. Relationship Among the NRC's Crossing-cutting Issues and Their Research Topics.

Cross-cutting Issue (From Chapter 4 of the NRC Report [1])	Description of Issue (Paraphrase of NRC Description)	Research Topic(s)
An increasing number of adverse health outcomes associated with PM and the related susceptible subpopulations	Research on the health effects of air pollution, including particulate matter, initially emphasized the development and exacerbation of lung diseases. However, in more recent years, studies have shown a strong association between exposure to PM and non-pulmonary diseases, most notably cardiovascular disease, but also including adverse birth outcomes. Along with this came the recognition that certain individuals and populations are more at risk for the adverse effects of PM exposure, by virtue of a pre-existing disease,age, race, etc.	#8 and #9
Particle toxicity in relation to different particle characteristics and emission-source types	Current air quality rules treat all particles of a given size as equally toxic and having the same dose-response relationship. It is becoming clear that some particles are more toxic than others, though which types or combinations are most toxic is unclear. Although acknowledged as a very difficult problem, a better understanding of the relative toxicities of particles and their mixtures with different physical and chemical characteristics and from different sources, will be important to effective reduction of PM-induced health effects.	#5
Increasing emphasis on exposure-dose-response relationships	Research in the past has focused mostly on the identification of hazardous pollutants. As more is learned about the hazardous components of PM, a shift in emphasis needs to take place toward characterizing the form of the quantitative relationship between exposure and risk to most effectively reduce PM-related risk.	#2, #5, and #9
Consideration of PM health effects within the broader context of the other pollutants	Most research results have come from experiments that use single- or two-pollutant exposures. Research is beginning to show that the health effects of exposures to multiple air pollutants more representative of a mixed atmosphere can have a synergistic effect. Since many pollutants work through similar pathophysiologic mechanisms, it is likely that simultaneous exposure to gases would influence the body's response to particulate matter. Further research using multiple pollutant exposures and focusing on synergistic responses is needed.	#7
Consideration of the implications for setting and implementing the PM NAAQS	For NAAQS implementation purposes sources that should have priority need to be identified. Those will be sources emitting PM components in locations and during periods that most directly contribute to local PM levels above national standards. The NAAQS has four elements: an indicator, averaging time, numeric level, and statistical form that historically have been set relying primarily on epidemiological data relating a PM metric to health endpoints. In the future, a greater emphasis on understanding PM components and their sources with an enhanced understanding of mechanism of effects could usefully guide the setting of the NAAQS indicator and averaging time, and lead to most effective implementation.	#3, #4, and #9

Table 5. Relationship Among the NRC's Overarching Challenges and Their Research Topics.

Overarching Challenge (From Chapter 5 of the NRC Report [1])	Description of Challenge (Paraphrase of NRC Description)	Research Topic(s)
Completing the PM Emissions Inventory and PM Air Quality Models necessary for NAAQS implementation and informing health research	The report calls for faster progress to ensure that state implementation plans are based on the best information available by promoting iterative improvements in emission inventories, monitoring networks, and air quality models.	#3 and #4
Developing a systematic program to assess the toxicity of different components of the PM mixture	Results from previous studies have given us data that are not "convergent" enough to allow strong conclusions to be drawn. The report recommends a new paradigm for research on the health effects of PM components that would be more systematic and would involve better integration across toxicology and epidemiologic areas.	#5
Enhancing air quality monitoring for research	Air quality monitoring activities should begin to move away from solely assessing NAAQS compliance to providing data that are useful for health effects research. Redesign of these monitoring programs should get input from health and atmospheric scientists to assure these needs will be met.	#4
Investigating the health effects of long-term exposure to air pollution	Estimates of disease burden associated with exposure to PM are needed and research should continue to develop on the basis of existing and new cohorts. Although long-term epidemiology studies are difficult and expensive, these kinds of studies are needed for quantitative risk assessment and cost-benefit analysis. Long-term animal studies are also needed, although the problems with finding animals and designs that can model human disease are recognized.	#5, #7, #8, and #9
Improved toxicologic approaches	Toxicologic studies are needed that employ appropriate animal models and that use inhalation as the primary route of exposure and involve concentrations more representative of real world exposures. Endpoints other than respiratory and cardiovascular ones should be included in the experiments. In addition, well-characterized particle samples should be used.	#9
From a particulate matter research program to a multipollutant research program	Most research to date has focused on one or a few pollutants, and a new multipollutant experimental paradigm is needed. This shift in focus should acknowledge that real-world exposures involve complex mixtures of hundreds of air contaminants of several physical-chemical classes.	#7
Integrating across the disciplines	In order to address these large research issues, an integrative approach involving epidemiologists, toxicologists, exposure assessment experts, and atmospheric scientists is essential, and collaboration among the specialties needs to begin early in the experimental design process. There are several obstacles to this type of approach, but some researchers have begun to use it.	#1 – #10

Part II: Improving Program Coordination

The NRC report[1] addresses the improvement of PM research management and the gathering and synthesis of information. Specifically, it addresses: (a) the need for enhancing and sustaining research management across the broader research enterprise, and (b) the tools needed for enhancing the tracking and synthesis of science going forward. This part of the report discusses how the AQRS addresses these NRC recommendations.

DEVELOPING A BROADER MULTI-AGENCY RESEARCH PROGRAM

The NRC Subcommittee made five recommendations to enhance cross-federal management of PM research:

1. Establish multi-agency and agency-wide research goals and measures for determining the degree of success in meeting national goals.
2. Prepare a multiyear plan for PM research across agencies, transitioning to a multi-pollutant approach, and incorporating state and private activities.
3. Obtain periodic independent reviews of the multiyear plan.
4. Define the specific roles and responsibilities of individual research funding agencies.
5. Incorporate other non-federal PM research funding organization inputs and expand the transparency of the federal PM research planning process.

Each of these recommendations has been acted upon by the AQRS with the response being provided below.

NRC RECOMMENDATION #1

Establish multi-agency and agency-wide research goals and measures for determining the degree of success in meeting national goals.

Response:

- **The AQRS Strategic Research Plan for Particulate Matter [2] (December 2002) sets out the multi-agency and national goal, objectives, and approach for PM research.** The goal, objectives, and approach of the AQRS strategic plan (see box) provide the foundation for the more detailed plan called for by the NRC.
- **Agency research plans contain agency-wide goals and measures.** Member agencies all have multiyear research planning processes that set goals and measures of progress in achieving their respective science mission. Some agency research missions are broad and go to the general reduction of scientific

PM Research: Goals, Objectives, and Approach from the AQRS *Strategic Research Plan for Particulate Matter*

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 U.S. 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:
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 loops 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.

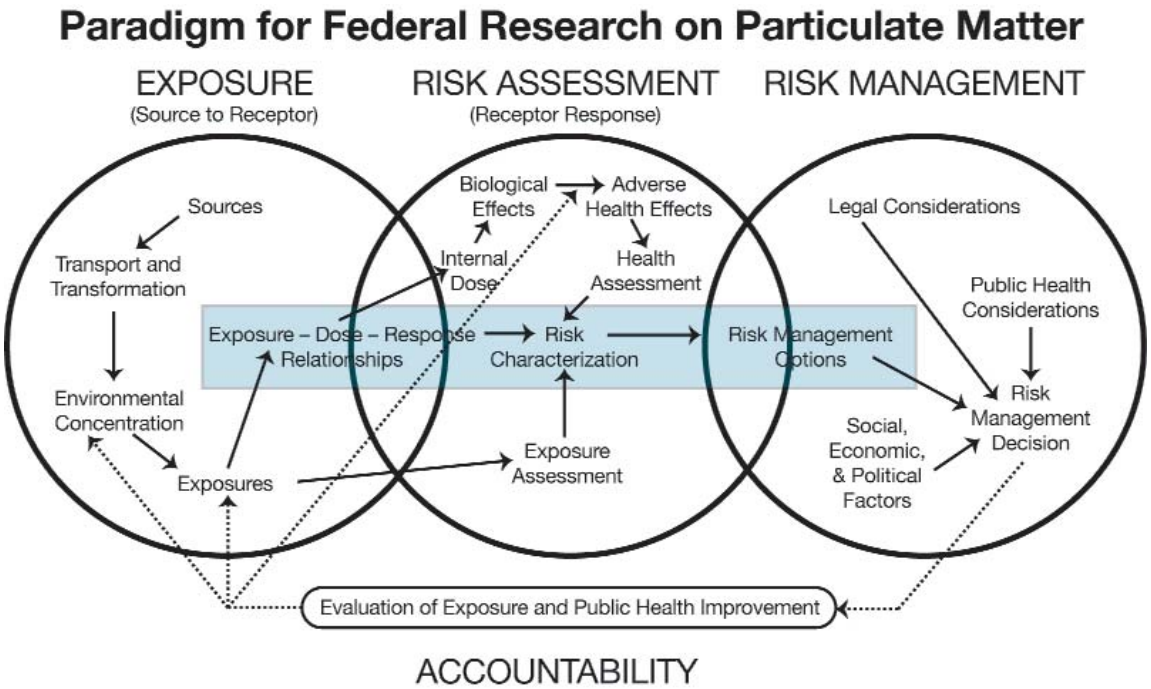


Figure 1. Paradigm for Federal Research on Particulate Matter. Reproduced from page 2, Strategic Research Plan for Particulate Matter, AQRS, CENR, December 2002.

uncertainty or to advancing the state of scientific knowledge, for example to support basic research on atmospheric aerosols, or to understand the fundamental biological mechanisms by which environmental pollutants affect human health. Other science missions are problem driven and directly inform public policy or programs, for example providing the underlying science needed to set national standards to protect the public health from the harmful effects of air pollution, or preparing the scientific foundation to help remedy the degradation of visibility in Class I areas due to haze. In both instances the research being done contributes to the goals and objectives of the AQRS *Strategic Research Plan for Particulate Matter* [2], even though some aspects are driven primarily by the PM research agenda while some are not. Some research may be investigator initiated and fall under broad areas of agency interest. Other research may be highly prescribed to meet specific agency needs. Table 6 presents the major parts of agency program objectives and measures that contribute directly or indirectly to the research needs identified by the NRC. The activities and milestones presented in Table 6 reflect past federal research investments, those made prior to 2006 that will produce results into 2010, and current and planned investments under base research programs. Collectively these objectives and measures form the central components of a combined federal multiyear research plan for particulate matter.

Table 6. Research & Development Activity: Current and Planned Investments *

USDA/CSREES RESEARCH MILESTONES	2006	2007	2008	2009	2010
By 2007, generate comprehensive PM emission inventory for production agriculture					
Research on characterizing and estimating agricultural emissions	■	■			
Update inventory of agricultural emissions		■			
By 2007, generate best practices for reducing agricultural PM emissions					
Research on developing best practices to reduce agricultural emissions	■	■			
Complete document of recommended best practices		■			
By 2010, have a better understanding of the fate and transport of agricultural PM					
Research on fate and transport of PM on component farm processes such as corrals, buildings, etc.	■	■			
Research on fate and transport of PM for whole farm enterprises and development of process-based models	■	■	■	■	■
By 2010, evaluate implementation of best practices and create PM emission reduction targets					
Transfer technologies to producers to mitigate emissions		■	■	■	■
Develop emission reduction targets					■

* A list of acronyms used in this report can be found on page 43.

Table 6, continued. Research & Development Activity: Current and Planned Investments.

DOC/NOAA PM RESEARCH MILESTONES	2006	2007	2008	2009	2010
Quantification of aerosol formation, growth, transport and deposition					
Provide kinetic parameters for secondary organic aerosols (SOA) derived from biogenic precursors (ESRL)					
Quantify role of petrochemical emissions in SOA formation and growth (ESRL)					
Develop and test improved modules for SOA predictive models (ESRL)					
Provide improved estimates of sulfate aerosol deposition rates (ARL)					
Quantify relationship between nighttime chemistry and ambient aerosol levels (ESRL)					
Quantification of aerosol optical properties					
Quantify relationship between light scattering and composition for the Northeast (PMEL)					
Quantify relationship between light scattering and composition for Texas (PMEL)					
Provide improved characterization of aerosol hygroscopic growth (ESRL)					
Development of instrumentation for aerosol detection and characterization					
Develop fast-response instrumentation for quantification of aerosol composition (ESRL)					
Develop instrumentation for remote sensing of aerosol size distribution (ESRL)					
Develop fast-response instrumentation for quantification of aerosol extinction (ESRL)					
Development and deployment of PM forecast capability					
Compare PM forecast models (ARL, ESRL)					
Develop and evaluate smoke models for AQ forecasts (ARL, ESRL, NESDIS, NWS)					
Produce prototype operational $PM_{2.5}$ model (ARL, ESRL)					

DOI/NPS PM RESEARCH MILESTONES	2006	2007	2008	2009	2010
By 2008, air quality in 70 percent of reporting park areas has remained stable or has improved					
New methods for cost effectively identifying organic molecular markers for wood smoke					
Characterization of nitrate and other ions in aerosol particles in the IMPROVE network					
Receptor/deterministic models used to identify contributing source regions to aerosol concentrations					

Table 6, continued. Research & Development Activity: Current and Planned Investments.

EPA PM RESEARCH MILESTONES *	2006	2007	2008	2009	2010
By 2012, develop and transfer data and tools to attain PM NAAQS and refine health risks					
Deliver updated air quality model, and improved emissions and ambient data (NERL, NRMRL)	■				
Transfer information on performance, cost-effectiveness, applicability of control technologies (NRMRL)	■				
Update and enhance tools to model, measure, and reduce PM mass (NERL, NRMRL, NCER)	■	■	■	■	■
Produce measurements and models of carbonaceous PM source to fate (NERL, NRMRL, NCER)	■	■	■	■	
Transfer data/tools to predict and measure residual non-attainment impacts (NERL, NRMRL, NCER)	■	■	■	■	■
By 2009, develop and transfer new epidemiology, toxicology, and clinical data on health risks to general and susceptible subpopulations from short-term exposures					
Identify the factors of susceptibility for acute PM exposures in susceptible subpopulations (NHEERL, NCER)	■				
Characterize effects of PM and co-pollutants on healthy animals and humans (NHEERL, NCER)	■	■			
Identify and link effects/mechanisms of toxicity for constituents/sources (NHEERL, NRMRL, NCER)	■	■	■		
Determine the critical factors influencing short-term exposure (NERL, NCER)	■				
Characterize exposure and exposure factors for general and susceptible subpopulations (NERL)		■	■		
Produce a refined and evaluated exposure model (NERL)	■	■			
By 2014, produce new exposure, epidemiology, toxicology, and clinical data on health risks for susceptible subpopulations from long-term PM exposures					
Characterize long-term cardiopulmonary effects of PM and co-pollutants (NHEERL, NCER)		■			
Characterize long-term respiratory health effects of PM in children (NHEERL, NCER)	■	■		■	
Develop accurate surrogates of long-term exposure for PM constituents and co-pollutants (NERL)			■	■	■
Assess the exposure-response relationship for PM and source-based components (NHEERL, NCER)	■	■			
Characterize the combined effects of PM and co-pollutants in susceptible subpopulations (NHEERL, NCER)	■	■		■	■
Describe mechanism of acute effects; link to PM components in susceptibles (NHEERL, NCER)	■	■	■	■	■
Identify and contrast factors of susceptibility for acute, subchronic, and chronic exposures to PM and co-pollutants (NHEERL, NCER)					■

* *For more information see EPA's Particulate Matter Research Program Multi-year Plan - 2003 (updated in 2006) at http://www.epa.gov/osp/myp.htm.*

Table 6, continued. Research & Development Activity: Current and Planned Investments.

	2006	2007	2008	2009	2010
By 2006, complete ambient monitoring and analysis in Ohio Valley region					
Final Report, Pittsburgh Air Quality Study (Pittsburgh PM Supersite)	■				
By 2006, complete predictive modeling and evaluation of coal plant emission charges					
Analyze effects of power plant emission control strategies on PM in Pittsburgh region using PMCAMx+	■				
By 2009, evaluate health effects of PM from coal power plants					
Assess short-term toxicity of PM from coal combustion emissions by exposing animals to actual plant emissions that have been "aged" and converted to reaction products	■				
Develop a strategy to better define the public health implications of PM emissions from coal-fired power plants in the Pittsburgh region, using retrospective epidemiological study methods	■				
Conduct laboratory animal study of selected respiratory and cardiac health hazards from repeated inhalation exposure to PM from "simulated downwind" coal combustion emissions	■	■	■		
Use mobile animal exposure laboratory and particle concentrator in ambient environments to evaluate adverse cardiopulmonary effects from exposure to coal-fired power plant and traffic-related PM	■	■	■	■	

* *For more information see DOE/NETL's DOE-NETL Air Quality Research Program: Overview at http://www.netl.doe.gov/coal/E&WR/air_q/.*

** *From 1998 - 2004, DOE's Office of Fossil Energy conducted an Air Quality Research program through its National Energy Technology Laboratory (NETL). Phase out of this program began in 2005. No new initiatives have begun since that time; however, projects that were funded prior to 2005 are proceeding toward their scheduled completion and are reflected in Table 6 milestones.*

DOT/FHWA PM RESEARCH MILESTONES *	2006	2007	2008	2009	2010
Develop and transfer data and tools to attain PM NAAQS and refine health risks					
Support development of updated air quality analysis methods and improved emissions data	■	■	■		
Transfer information on performance, cost-effectiveness, applicability of control technologies		■	■	■	
Determine PM emission contributions from light duty (gasoline) vehicles	■				
Determine PM emission contributions from heavy duty (diesel) vehicles	■				
Determine spatial distribution of PM emissions and concentration (proximity studies)	■	■			
Determine nature of PM2.5 emissions (regional versus local)	■	■	■		
Determine cost-effective mobile source mitigation strategies	■	■	■		

* *For more information see FHWA's Strategic Workplan for Particulate Matter Research: 2000 to 2004 at http://www.fhwa.dot.gov/environmental/pm/index.htm.*

Table 6, continued. Research & Development Activity: Current and Planned Investments.

DHHS/NIEHS PM RESEARCH MILESTONES	2006	2007	2008	2009	2010
By 2009, develop better understanding of role of PM in cardiovascular disease (CVD)					
Evaluate results on mechanisms of PM-induced cardiovascular disease from joint grants with EPA under "Role of Air Pollutants in Cardiovascular Disease" RFA	■	■	■	■	
Evaluate results from epidemiologic studies on air pollution and CVD	■	■	■		
By 2008, develop better understanding of effects of PM on exacerbation of asthma symptoms					
Evaluate results of epidemiologic studies from Children's Center and investigator-initiated grants	■	■	■		
Evaluate results from basic studies on the effect of diesel and other PM on immune function in the lung	■	■	■		
By 2008, develop better understanding of effect of PM exposure on prenatal development					
Evaluate results of epidemiologic studies on risk of birth defects	■	■			
Evaluate results from Fetal Basis of Adult Disease RFA that deal with prenatal PM exposure and adolescent and adult lung and cardiovascular disease	■	■			
By 2008, develop better understanding of differential effects of PM exposure on different populations					
Evaluate results from Environmental Justice, Community-Based Participatory Research, and Health Disparities programs that deal with location of residence and risk of adverse effects of PM exposure	■	■	■		

TVA PM RESEARCH MILESTONES	2006	2007	2008	2009	2010
By 2006, further modeling and measurement studies on composition, sources, and variability of PM in the Tennessee Valley region					
Evaluate role of hourly PM composition measurements in determining variability of exposures to PM in the southeast region of the U.S.	■				
Report on project on source apportionment of organic aerosols in TVA region; continue cooperative study of organic aerosol source apportionment in southeast U.S. jointly through the VISTAS RPO	■				
Continue work on model treatment of clouds and sulfur	■				
By 2010, model and measure effect of emissions reductions on air quality in Tennessee Valley region					
Project to examine ability of models to simulate climatological variability in PM	■	■	■	■	
Trends analysis of ozone and PM data for urban and rural/background sites in the region		■		■	■

NRC RECOMMENDATION #2
Prepare a multiyear plan for PM research across agencies, transitioning to a multi-pollutant approach, and incorporate state and private activities.

Response:

- **The AQRS PM Research Strategy will be updated and will become a multiyear plan for PM research.** The PM Research Coordination Working Group will hold a series of reviews comparing the combined set of agency program objectives and timelines listed in Table 6 with the research needs identified by the NRC in Part I above. Convening a series of reviews under its organizing research areas and in each of the NRC priority areas will facilitate the exchange of project progress, thereby maximizing cross-government collaboration in furthering our understanding of PM within the context of federal government priorities. These reviews will be led by designated research area co-leads and will encourage a more fully integrated approach to ensuring that the government's research provides the science necessary for developing sound federal policies. Following these reviews, the AQRS will update its *Stategic Research Plan for Particulate Matter* [2] to address key information and research gaps. The resulting updated strategy document will serve as the interagency multiyear plan for PM research called for by the NRC. Once drafted by the AQRS, this multiyear plan will be forwarded to the CENR for its review and approval.

- **Member agencies participate in other cross-organizational research planning and coordination.** In addition to the AQRS and PM Research Coordination Working Group, two other organizations, NARSTO and the Health Effects Institute (HEI), facilitate cross-organizational research planning and coordination. NARSTO (http://www.narsto.org) was chartered in 1995 as a public/private consortium of the major sponsors of atmospheric sciences research in the U.S., Canada, and Mexico. Its membership includes state and private organizations and many members of the AQRS. NARSTO coordinates research on air measurements, atmospheric processes and modeling, and source characterization. It is guided by a PM Research Plan, set to strategic execution plans, periodic assessments, and regular meetings. NARSTO provides a direct opportunity to interact with states and the private sector and to address multi-pollutant issues. For example NARSTO is expanding its role to include climate aspects of aerosol pollution. HEI (http://www.healtheffects.org) is an independent, nonprofit corporation chartered in 1980 to provide high-quality, impartial, and relevant science on the health effects of pollutants from motor vehicles and from other sources in the environment. It is supported jointly by the EPA and industry. HEI's priorities for research and special reviews are guided by the five-year HEI Strategic Plan, which is reviewed and updated annually after consultations with HEI sponsors and other interested parties.

- **Agency research plans, programs, and projects are increasingly multi-pollutant in nature.** The Combined Effects of PM and Gaseous Pollutants research topic (see NRC Research Topic #7 above) is leading member agency research agendas to be increasingly multi-pollutant in character. For example, our work on PM requires us to consider the synergistic effects of combined sulfate, nitrate, and carbonaceous material, and also to consider their collective impacts on ozone and air toxic issues through the sources and processes they have in common.

Further, the science information and tools that PM research is developing have multi-pollutant features. New air quality models and source receptor models have multi-pollutant capabilities. Source characterization profiles are multi-pollutant. Exposure studies report on co-pollutant results, and health effects studies are more and more focused on air quality and source emission mixtures. Most agencies are routinely taking multi-pollutant objectives into consideration during their multiyear planning (Table 7) and preparations for individual studies and field campaigns. The future update of the AQRS *Stategic Research Plan for Particulate Matter* [2] and expansion to a multiyear plan will include a multi-pollutant approach that builds on these common goals, tools, and science outcomes.

NRC RECOMMENDATION #3
Obtain periodic independent reviews of the AQRS multi-year plan and the agency-specific plans it incorporates.

Response:

- **Agencies have their multiyear research plans and major program plans and related goals, measures, strategies, and priorities reviewed by independent advisory committees.** Agency-specific multiyear research plans and major research program plans now regularly go through external peer review. For example, EPA's PM Multi-Year Plan has been reviewed in the past by the NRC PM Research Panel and in the future will be reviewed by a comparable panel periodically convened for this purpose. Beyond this program-wide review, all of EPA's program research plans are routinely externally reviewed by its Science Advisory Board and its Board of Scientific Counselors. Further, EPA's laboratory and center cross-cutting research programs are put through external

Table 7. Agency Co-leads for PM Research Coordination, and Contributing Research Organizations.

PM RESEARCH AREA	LEAD COORDINATING AGENCIES	OTHER AGENCIES CONTRIBUTING
Human Health Effects	NIEHS and EPA	CDC, NIOSH, DOE/NETL
Human Exposure	EPA and NIOSH	CDC, NIOSH, DOE/NETL
Ecological Effects	NPS and NOAA	EPA, USDA/CSREES
Air Measurements	EPA and NOAA	NPS, USGS, NASA, DOE/FE TVA, NIST, USDA/CSREES, NIOSH
Atmospheric Processes and Modeling	NOAA and EPA	NSF, DOE/SC, TVA, USDA/CSREES
Source Characterization	EPA and USDA/CREES	FHWA, DOE/FE, TVA, NIOSH, NOAA
Control Technologies	EPA and DOE/NETL	FHWA, NIOSH, USDA/CSREES

peer review every three years. NOAA's overall research plans are similarly reviewed by an independent Science Advisory Board. Individual NOAA laboratory research programs and projects are periodically reviewed by an independent expert panel. The DOE Atmospheric Science Program was recently reviewed by an independent Federal Advisory Committee. The review included briefings on aerosol research supported by both other AQRS agencies as well as agencies that contribute to the U.S. Climate Change Science Program (CCSP). The review was conducted in accordance with the Federal Advisory Committee Act. Agencies also perform an external review function for one another. For example, EPA personnel performed technical merit reviews that guided the selection of three DOE/NETL projects in FY 05 to examine the relationship between coal power plant emissions and human health.

- **The AQRS PM multiyear plan will use a tiered approach to external peer review.** The first tier of external review will continue to be the ongoing reviews of individual agency plans that form the foundation of the AQRS multiyear plan. A second tier of review will be provided by the AQRS parent Committee on Environment and Natural Resources member agencies and their science experts. This review will precede CENR sign-off on the AQRS PM multiyear plan before it is released to the public. A third tier of review will take place in the context of EPA's role as co-lead for overall interagency coordination. EPA's PM Multi-Year Plan,[11] including its description of interagency research, is periodically put through external peer review by its standing Board of Scientific Counselors and specially convened panels such as the NRC.

NRC RECOMMENDATION #4
Define the specific roles and responsibilities of individual research funding agencies**.**

Response:

- **The PM Research Coordination Working Group has identified the principal roles and responsibilities for funding agencies.** Two different types of research are conducted by member agencies: problem-driven research directly supporting regulatory policies and programs, and fundamental or basic research contributing to the body of science that generally informs public policy. The roles and responsibilities of member organizations tend to be characterized by one of these two types of research. EPA, for example, has regulatory and standard-setting missions, and its research programs are largely problem driven. Therefore EPA's principal role is to see that sound science is available for its programs as needed, producing it themselves or through cooperating with other research organizations to fill information gaps. Other agencies such as NIEHS, NOAA, and NSF have research missions that contribute to the reduction of uncertainties in areas of general societal interest such as public health, weather, atmospheric processes, and climate change. Their roles are to advance the body of knowledge in those areas, working in combination with others.

  PM research by member agencies can also be characterized as falling into one or more of the broad research areas of the AQRS *Strategic Research Plan for Particulate Matter* [2]: human health effects, human exposure, ecological effects, air measurement, atmospheric processes and modeling, source

[11] EPA, *Particulate Matter Research Program Multi-year Plan-2003*, updated 2006, www.epa.gov/osp/myp.htm.

characterization, and control technology. It is by means of research in these areas that the research needs under the topics identified by the NRC are addressed. The primary topic-specific research contributions by member agencies are discussed in Part I above and their planned outcomes are profiled in Table 6. To improve the coordination of this multi-disciplinary, multi-purpose research, the PM Research Coordination Working Group has identified lead agencies that will further coordinate and review progress under each of these major research areas. Lead and contributing agencies for future PM research are designated in Table 7.

NRC RECOMMENDATION #5

Incorporate other non-federal PM research funding organization inputs and expand the transparency of the federal PM research planning process.

Response:

- **Agency-specific research plans are multi-year and multi-pollutant in scope and incorporate coordination with state, private, and other federal organizations.** All member agencies prepare multiyear research plans in one form or another. Some plans are prepared as part of the agency's annual budget process and some are prepared as stand-alone planning documents. In both cases these plans lay out the agency's future research direction, goals, objectives, and measures. They also include multi-pollutant approaches and provide for collaboration with state, private, and other federal research organizations. Examples of stand-alone multiyear documents include: EPA's *Particulate Matter Research Program Multi-year Plan* - 2003, http://epa.gov/osp/myp.htm; DOT/FHWA's *Strategic Workplan for Particulate Matter Research: 2000 to 2004* (being updated), http://www.fhwa.dot.gov/environment/pm/index.htm; DOE/NETL's *DOE-NETL Air Quality Research Program: Overview*, http://www.netl.doe.gov/coal/E&WR/air_q/; and DOE/SC's *A Reconfigured Atmospheric Science Program*, http://www.asp.bnl.gov/.

- **State and private activities are additionally incorporated though large-scale, multi-organizational research projects.** In addition to broad multi-organizational research planning and coordination under NARSTO and HEI, specific field campaigns and research centers incorporate state and private involvement. Field studies focused on air quality characterization and processes are typical of the partnerships formed. Recent examples include the New England Air Quality Study (NEAQS-2002 and 2004), the Texas Air Quality Study (TexAQS 2000 and TexAQSII 2005-2006), and DOE/NETL's Steubenville, Ohio exposure study. Similar studies are now being planned for future years. The ongoing EPA Detroit Exposure and Atmospheric Research Study (DEARS) is another good example of a research study incorporating state and private involvement. As for health effects studies, EPA has sponsored five PM Health and Exposure Research Centers across the country over the 2000-2005 five-year period and has renewed its centers programs for another five years beginning in 2006. The centers have drawn investment and participation of both industry and their home states.

IMPROVED TOOLS FOR SCIENCE TRACKING AND SYNTHESIS

The NRC Subcommittee makes two recommendations in producing the tools needed for enhanced tracking and synthesis of science going forward:

1. Develop and maintain an inventory of PM research and publications.
2. Improve information synthesis.

Both of these recommendations have been acted upon by the AQRS with the response being provided below.

NRC RECOMMENDATION #1
Develop and maintain an inventory of PM research and publications.

Response:

- **The AQRS is considering several alternative approaches and will include its preferred approach in the update of its *Stategic Research Plan for Particulate Matter*[2].** In recognition of the widely ranging options and potential public expense of such an inventory, the PM Working Group Co-chairs appointed EPA to lead the preparation of a set of options for consideration. EPA is to examine a set of options for a master database to be put on the web and be publicly accessible. Options will cover alternative levels of scope (e.g., program and project descriptions with updates, recent journal articles and reports, links to other databases, and points of contact in searchable form), resource levels, and agency involvement in development and maintenance. One option to be explicitly discussed is building on the Particulate Matter Research Activities (PMRA) database instituted in 2000 to catalogue multi-agency PM research projects, recognizing that this site would need to be significantly redesigned to add desirable features such as status, outcomes, and publications. The PM Working Group will review the options presented by EPA and endorse an approach to be used and supported by member agencies prior to updating its *Stategic Research Plan for Particulate Matter*.

- **Member agencies maintain active web-based inventories of research and publications coming out of their work.** A second source of current information on PM research progress is available through agency databases. In addition to access to agency research progress available through their planning websites (see Table 6), new information systems are also being made available. These include the EPA's Environmental Information Management System with its Science Inventory database and Technical Information Management System newly coming on line (http://www.epa.gov/eims/systems.html). The expansion of the CSREES Current Research Information System (CRIS) at http://cris.csrees.usda.gov/ is being planned to include all extension/outreach projects such as the indoor air quality Healthy Homes program. CSREES also has the Research, Education, & Economics Information System (REEIS; http://www.reeis.usda.gov/) that currently captures research information across all of USDA and synthesizes reports by year, funding, and performing agency. Information on aerosol research funded by the Atmospheric Sciences Program in DOE's Office of Science can be accessed at http://www.asp.bnl.gov/, and lists of publications coming from that research can be accessed at http//www.asp.bnl.gov/asp_pubs.html. NIH maintains the Computer Retrieval of Information on Scientific Projects (CRISP) database, which contains abstracts and information on all currently funded NIH projects (http://crisp.cit.nih.gov). In addition the NSF maintains descriptions of its many sponsored atmospheric science laboratory and field studies at http://www.nsf.gov/div/index.jsp?div=ATM.

NRC RECOMMENDATION #2
Improve information synthesis.

Response:

- **The AQRS will hold periodic specialty meetings on progress.** As one means of tracking research progress and improving information synthesis, the AQRS, beginning in March 2006, will hold periodic specialty meetings on progress under individual Research Topic areas of this report (see Part I). Meetings will review progress by member agencies and their state and private counterparts, and will highlight recent developments. Special progress reports will be issued from time to time where noteworthy advances have been made and/or where decisions have been made leading to new directions or priorities. In addition, members will proactively use the AQRS email list to inform one another of any recent developments and transmit summaries and notices of availability of major project reports.

- **Member organizations will hold specialty conferences and workshops.** Member organizations have commonly held periodic reviews of science progress assessing recent advances by their organizations and affiliated programs and identifying future needs to fill key information gaps. This practice will be continued and extended in two ways. There will be a greater emphasis on information synthesis, and participation will be broadened to build interdisciplinary integration and interagency coordination. The National Agricultural Air Quality Workshop held in 2006 is an example of this new approach. USDA held a workshop on June 5-8, 2006, to address all aspects of agricultural air quality, including PM emissions. The two primary work products of the workshop will be an updated emission inventory and a best-practices document for mitigating agricultural emissions. These two documents will then be reviewed by the National Academy of Sciences.

- **The AQRS endorses an update of the NARSTO PM Assessment in 2008.** EPA released its most recent update of the PM Air Quality Criteria document [12] (AQCD) in October 2004. This update encompasses a review of the advances in exposure and PM health science since the 1996 version underpinning decisions on the National Ambient Air Quality Standard for PM. It is a complete example of a compilation and synthesis product of science and research results on PM exposure and health effects. The next update of the PM Criteria Document is scheduled for three years from now (October 2009). While the PM AQCD includes a review and summary of atmospheric sciences (Chapters 2 and 3), the NARSTO PM Science Assessment[5] (February 2004) provides a more comprehensive review of PM atmospheric sciences as a complement to the Criteria Document. Specifically, the NARSTO PM Science Assessment reviews and synthesizes the atmospheric science used by policy makers in the U.S., Canada, and Mexico to implement national standards such as the PM NAAQS. It encompasses air measurements, atmospheric processes and modeling, and source characterization science. The next update of the NARSTO synthesis by its own recommendation is the end of 2008. This timing would fit well with the scheduled update of health and exposure science. It would also fit well with U.S. plans to institute environmental progress tracking to evaluate the success of implementation strategies required in 2008 to meet PM and ozone NAAQS.

[12] U.S. EPA, *Air Quality Criteria for Particulate Matter*, U.S. Environmental Protection Agency, Washington, D.C., EPA 600/P-99/002aF-bF, 2004.

List of Acronyms

Agencies and Organizations

DHHS	Department of Health and Human Services
ATSDR	Agency for Toxic Substances and Disease Registry
CDC	Centers for Disease Control and Prevention
NIOSH	National Institute for Occupational Safety and Health
NIH	National Institutes of Health
NHLBI	National Heart, Lung, and Blood Institute
NICHD	National Institute of Child Health and Development
NIEHS	National Institute of Environmental Health Science
DOC	Department of Commerce
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
ARL	Air Resources Laboratory
ESRL	Earth System Research Laboratory
NESDIS	National Environmental Satellite, Data, and Information Service
NWS	National Weather Service
PMEL	Pacific Marine Environmental Laboratory
DOE	Department of Energy
FE	Fossil Energy Program
NETL	National Energy Technology Laboratory
SC	Office of Science
DOI	Department of the Interior
NPS	National Park Service
USGS	United States Geological Survey
DOT	Department of Transportation
FHWA	Federal Highway Administration
EPA	Environmental Protection Agency
NCER	National Center for Environmental Research
NERL	National Exposure Research Laboratory
NHEERL	National Health and Environment Effects Research Laboratory
NRMRL	National Risk Management Research Laboratory
OAR	Office of Air and Radiation
ORD	Office of Research and Development
HEI	Health Effects Institute
NARSTO	Originally, North American Research Strategy for Tropospheric Ozone

NASA	National Aeronautics and Space Administration
NRC	National Research Council
NSF	National Science Foundation
TVA	Tennessee Valley Authority
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture
CSREES	Cooperative State Research, Education, and Extension Service
USFS	USDA Forest Service
WMO	World Meteorological Organization

Federal Government Committees

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

Monitoring Networks and Programs

AIRMoN	Atmospheric Integrated Research Monitoring Network
CASTNet	Clean Air Status and Trends Network
GPMP	Gaseous Pollutant Monitoring Program
IMPROVE	Interagency Monitoring of Protected Visual Environments
NADP/NTN	National Atmospheric Deposition Program/National Trends Network
NADP/MDN	National Atmospheric Deposition Program/Mercury Deposition Network
NAMS	National Air Monitoring Stations
NCore	National Core air monitoring program
NEPHTN	National Environmental Public Health Tracking Network
PAMS	Photochemical Assessment Monitoring Stations
RPO	Regional Planning Organizations (TVA)
SCAMP	Steubenville Comprehensive Air Monitoring Program (DOE/NETL)
SLAMS	State and Local Air Monitoring Stations
STN	Speciation Trends Network ambient PM monitoring program
VISTAS	Visibility Improvement State and Tribal Association of the Southeast

Methodology and Modeling-related Systems

CAMx	Comprehensive Air Quality Model with Extensions
CMAQ	Community Multi-scale Air Quality model
CMAS	Community Modeling and Analysis System model clearinghouse
CMB	Chemical Mass Balance receptor model
CREM	Council for Regulatory Environmental Modeling
FRM	Federal Reference Method for ambient air measurements

LIDAR	Light Detection and Ranging
PMF	Positive Matrix Factorization receptor modeling approach
REMSAD	Regional Modeling System for Aerosols and Deposition
SHEDS	Stochastic Human Exposure and Dose Simulation
TEOM	Tapered Element Oscillating Microbalance
TERESA	Toxicological Evaluation of Realistic Emissions of Source Aerosols
UNMIX	Source Receptor Model

Other Acronyms

AQCD	Air Quality Criteria Document
CAPs	Concentrated air particulates
CCSP	United States Climate Change Science Program
CMU	Carnegie Mellon University
CRIS	Current Research Information System (CSREES)
CRISP	Computer Retrieval of Information on Scientific Projects (NIH Database)
CVD	Cardiovascular Disease
DEARS	Detroit Exposure and Aerosol Research Study
FACA	Federal Advisory Committee Act
GIS	Geographical Information Systems
HAPs	Hazardous Air Pollutants
HEDS	Human Exposure Database System
IAG	Interagency Agreement
ICARTT	International Consortium for Atmospheric Research on Transport and Transformation
IPCC	Intergovernmental Panel on Climate Change
MAX-Mex	Megacity Aerosol Experiment - Mexico City
NAAQS	National Ambient Air Quality Standards
NHANES	National Health and Nutrition Examination Survey
PAHs	Polycyclic Aromatic Hydrocarbons
PHASE	Public Health Air Surveillance Evaluation
PM	Particulate matter
$PM_{2.5}$	Particulate matter with an average atmospheric diameter of less than 2.5 micrometers
PM_{10}	Particulate matter with an average atmospheric diameter of less than 10 micrometers
PMRA	Particulate Matter Research Activities
RFA	Request for Applications
SIP	State Implementation Plan
SOA	Secondary Organic Aerosol
SPECIATE	Repository of Total Organic Compounds and Particulate Matter
STAR	Science To Achieve Results Grants Program (EPA)
TOC	Total Organic Compounds
VOCs	Volatile Organic Compounds



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