Preliminary Particulate Matter Mass Concentrations Associated With Longitudinal Panel Studies:

Assessing Human Exposures of High Risk Subpopulations to Particulate Matter

R. Williams, L. Wallace, J. Suggs, G. Evans, J. Creason, R. Highsmith, L. Sheldon, A. Rea, A. Vette, R. Zweidinger, K. Leovic, G. Norris, M. Landis, C. Stevens, C. Howard-Reed, and T. Conner
U.S. Environmental Protection Agency, Research Triangle Park, NC, USA

C. Rodes, P. Lawless, and J. Thornburg
Research Triangle Institute, Research Triangle Park, NC USA

L.-J. S. Liu, D. Kalman, J. Kaufman, J. Koenig, T. Larson, T. Lumley, and L. Sheppard
University of Washington, Seattle, WA, USA

K. Brown, H. Suh, A. Wheeler, D. Gold, and P. Koutrakis
Harvard School of Public Health, Boston, MA, USA

M. Lippmann
New York University, New York, NY, USA

Project Officers
R. Williams and L. Wallace
Human Exposure Analysis Branch
National Exposure Research Laboratory
Research Triangle Park, NC 27711, USA

Office of Research and Development
National Exposure Research Laboratory
Human Exposure and Atmospheric Sciences Division
Research Triangle Park, NC 27711, USA

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Disclaimer

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Abstract

A series of longitudinal human exposure particulate matter (PM) panel studies were conducted from 1997 through 2001 in a number of U.S. cities. These studies were conducted by the U.S. EPA' s Office of Research and Development (ORD) or by organizations sponsored through the National Exposure Research Laboratory (NERL). A primary goal of this research was to determine the relationships between personal exposures to particles and associated gases relative to stationary outdoor monitor concentrations in high-risk subpopulations as defined by the National Research Council's PM research priorities. Validated data from this effort will be used to assess the contribution of ambient pollution to personal exposure and to identify human activity patterns that might contribute to personal exposure. Common features of the studies included use of a single survey questionnaire to assess human activity patterns and repeated use of a PM monitoring approach that would permit comparison of the data among the investigators. The investigators varied their study locations, monitoring seasons, and study populations so that an in-depth characterization of PM exposures among potentially sensitive subpopulations could be performed.

The panel studies monitored voluntary participants over the course of 7 to 28 day periods. Each study was defined by the study panel, monitoring season, and locality. The number of participants in each study ranged from 5 to 63. Susceptible subpopulations of interest included Chronic Obstructive Pulmonary Disease (COPD) patients, individuals with cardiovascular disease, the elderly, asthmatics, and African-Americans having hypertension. Panels of healthy individuals were also included in the assessment. The elderly have been identified as one of the most sensitive subpopulations in the U.S. to health effects associated with PM exposures; consequently, while subject age in each study varied, the majority of subjects were over age 65.

The exposure assessment included integrated (24-h) and/or real-time monitoring of PM size fractions of $PM_{2.5}$, PM_{10} and $PM_{10\text{-}2.5}$. The subscripts represent the particle size sampled; for instance, $PM_{2.5}$ represents 50% collection of particles of 2.5 μm in diameter. Personal, residential indoor, residential outdoor, and community-based PM air monitoring was performed using a variety of instrumentation. PM-related toxic gases of nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and ozone (O_3) also were measured. Monitoring took place in Baltimore, MD (2 studies); Fresno, CA (2 studies); Atlanta, GA (2 studies); Boston, MA (2 studies); Los Angeles, CA (2 studies); Seattle, WA (2 studies); New York, NY (1 study); and Research Triangle Park, NC (2 studies).

This report describes the completion of field measurements associated with the various studies and their progress to date. Individual study designs and future recommendations are also reported. In excess of 15,000 personal, residential, and community-based PM mass concentration measurements have been performed. Combined, these studies have monitored over 200 individuals and represent over 4000 total monitoring days during the 4-year period (1998-2001). References to peer-reviewed summaries and presentation abstract titles of data findings are also included.

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INTRODUCTION

In July 1997, the US Environmental Protection Agency's (EPA) Administrator issued a new Particulate Matter (PM) National Ambient Air Quality Standard (NAAQS) for $PM_{2.5}$ which was based largely on epidemiological investigations that indicated increased risks of mortality and morbidity were associated with concentrations of ambient particles. At the same time, Congress established a major research initiative to reevaluate the NAAQS, as mandated by the Clean Air Act. As part of this initiative, the National Research Council (NRC) conducted an independent study to identify the most important research priorities and to develop a conceptual plan for PM research related to the new $PM_{2.5}$ NAAQS (Research Priorities for Airborne Particulate Matter I: Immediate Priorities and a Long-Range Research Portfolio, NRC, 1998). A high priority in the first three years was gaining a better understanding of outdoor measures versus actual human exposures (NRC Research Topic 1):

> *"What are the quantitative relationships between concentrations of particulate-matter and gaseous co-pollutants measured at stationary outdoor air-monitoring sites, and [what are] the contributions of these concentrations to actual personal exposures, especially for potentially susceptible subpopulations and individuals?"*

Additionally, the council directed researchers to gather more information on the toxicological mechanisms and actual human exposures to PM of ambient origin.

This document fulfills the mandate of the NERL to *". . .Complete the field monitoring component of a series of longitudinal panel studies and report upon the preliminary PM mass exposure data resulting from these efforts"* and thus meets the annual performance measure (APM#1) established in response to the Goverment Performance and Results Act (GPRA). As a summary report, data are reported on a preliminary basis and are not discussed in depth. (Appendix D contains tabular summaries of PM mass concentration data from the completed studies.) Data summaries associated with the exposure assessment of co-related gases, time activity patterns, source apportionment, associated health effects, and other databases developed (or currently being developed) from the field studies will be reported separately.

This report indicates that ORD has fully completed its 2001 fiscal year goal to conduct PM human exposure field measurements in response to NRC Research Topic #1. This goal has been accomplished in both a timely and cost-effective manner. Fourteen peer-reviewed journal articles summarizing results from studies conducted during 1997-1999 have already been published, and additional articles are in development for the later-phase (1999-2001) studies. Peer-reviewed journal article titles that summarize findings to date, as well as presentations at national or international scientific symposia in support of this effort, are reported in Appendix A and Appendix B. This effort has resulted in the collection of a diverse and in-depth database for characterizing personal exposures to PM in potentially susceptible subpopulations. This database will permit an extensive analysis of the quantitative relationships between personal exposures to PM of ambient origin and related co-pollutants and the factors that influence these exposures. The NERL anticipates that this pooled database will be publically available during 2003.

Report Overview

During the period of 1997-present, NERL's PM Exposure Research Program focused specifically on NRC Research Topic 1 with the direct support of $6.0 million provided by EPA's ORD. Approximately $4.7 million supported research conducted by a series of university research teams (cooperative agreements), while approximately $1.3 million supported NERL-designed research plans. Longitudinal panel exposure studies were conducted to characterize temporal variation of personal exposure to PM, including that of PM measured at ambient sites. These studies were fundamental to increasing scientists' understanding of the associations between personal exposure to PM, PM measured at ambient sites, and health effects, especially for susceptible subpopulations.

Susceptible subpopulations of interest included Chronic Obstructive Pulmonary Disease (COPD) patients, individuals with cardiovascular disease, the elderly, asthmatics, and African-Americans having hypertension. Collaborative efforts between the NERL and the National Health and Environmental Effects Research Laboratory (NHEERL) permitted an integrated approach between exposure assessment and health effects research in the panel studies performed by these institutions. The Research Triangle Institute (RTI) contributed significantly to the field data collection for the studies performed by these laboratories. Cooperative agreements were awarded to three University consortia: Harvard University School of Public Health, New York University School of Medicine, and the University of Washington Department of Environmental Health. The panel studies were designed to evaluate different susceptible subpopulations, geographical regions, seasons, and housing conditions. Study designs from each research group were compared so that duplication or non-duplication of effort was performed to more completely satisfy the overall goal of the research.

Common approaches used by each research group included measurements of personal exposure using personal monitors as well as measurements of ambient, outdoor residential, and indoor residential concentrations using stationary monitors. In addition, based on recommendations by the NRC, a concerted effort was made to measure exposures to a number of gases including SO_2, NO_2, CO, and O_3. For each participant, information on housing characteristics, time/activity patterns and potential sources of PM exposure was collected using diaries and questionnaires. The Office of Management and Budget (OMB) approved a time-activity pattern diary and questionnaire for the panel studies in 1999. All of the involved institutions adopted these survey instruments for the studies conducted during the 1999-2001 time period. (Copies of the questionnaires and diary used to investigate time activity patterns and sources of PM exposure are provided in Appendix C.) Multiple participants in each respective panel were monitored over 7-28 days to investigate both longitudinal and cross-sectional correlations between personal, indoor, outdoor, and ambient measurements. Data from over 15,000 individual PM mass concentration measurements involving more than 200 individuals and their residences were collected in these studies.

The overall goal of all the longitudinal panel studies was to characterize inter-personal and intra-personal variability in exposure to PM and to describe the relationship between personal exposures to PM of ambient origin and ambient concentration measurement based on central-site monitoring for susceptible subpopulations. Specific objectives that were developed to meet this goal are the following:

- To quantify personal exposures and indoor air concentrations for PM/gases for potentially sensitive individuals (cross sectional, inter- and intrapersonal).

- To describe (magnitude and variability) the relationships between personal exposure, and indoor, outdoor and ambient air concentrations for PM/gases for different sensitive cohorts. These cohorts represent subjects of opportunity and relationships established will not be used to extrapolate to the general population.

- To examine the inter- and intrapersonal variability in the relationship between personal exposures, and indoor, outdoor, and ambient air concentrations for PM/gases for sensitive individuals.

- To identify and model the factors that contribute to the inter- and intrapersonal variability in the relationships between personal exposures and indoor, outdoor, and ambient air concentrations for PM/gases.

- To determine the contribution of ambient concentrations to indoor air/personal exposures for PM/gases.

- To examine the effects of air shed (location, season), population demographics, and residential setting (apartment vs stand-alone homes) on the relationship between personal exposure and indoor, outdoor, and ambient air concentrations for PM/gases.

This report provides a detailed description of the individual studies conducted in support of this goal. Data are provided detailing the range of PM mass concentrations observed during the studies in relation to specific geographical locations, seasons, sensitive subpopulations, and particle size fraction. The following is a summary of some of the highlighted results from the studies:

- Data collection was completed in 8 major exposure studies. These were performed in various east coast and west coast U. S. cities to investigate potential differences in aerosol properties due to geographical setting. Monitoring took place between 1998 and 2001. These studies involved multiple season/subpopulation/location variables (total of 14).

- More than 200 people were recruited to participate in the exposure studies from Boston, MA; Los Angeles, CA; Baltimore, MD; Research Triangle Park, NC; Seattle, WA; Fresno, CA; New York, NY; and Atlanta, GA. The majority of these individuals had a range of underlying disease states or other factors (cardiovascular, pulmonary, aged, etc.) that were postulated as increasing their potential for experiencing adverse health effects from PM exposures.

- In excess of 15,000 filter samples were collected and analyzed for integrated (24-h) PM mass concentrations. Collocated $PM_{2.5}$, PM_{10} samples were typically collected at the community and residential locations. $PM_{10\text{-}2.5}$ was collected or determined by mass differential in many of the studies.

- More than 4000 sampling days of individual human exposure to PM were included in these studies. In addition to the $PM_{2.5}$ and/or PM_{10} human exposure data, an equivalent amount of time-activity pattern and PM source data were collected.

- Techniques were established, validated, and improved in the recruitment, retention, and participation of sensitive subpopulations for human exposure assessments. In some instances, this involved populations with an average age well over 65. This was accomplished by improved recruitment and retention strategies that involved integrating community concerns about participant involvement in the study, improvements in personal monitoring equipment that reduced participant burden, and development of mutually beneficial relationships with private institutions (such as retirement facilities). Combined, these practices combined available resources and helped in achieving the study objectives.

- Numerous peer-reviewed journal articles have been published based on the exposure studies. References are provided in Appendix A. These articles provided integral information used in the March 31, 2001 draft version of ORD's Ambient Air Quality Criteria Document for Particulate Matter (2001 PM AAQCD) and summarized some of the personal, residential, and ambient PM mass concentration findings from specific longitudinal panel studies. In addition, over 50 abstracts describing the preliminary results from all of the panel studies have been presented or accepted for presentation at national and international scientific conferences (Appendix B).

EXPERIMENTAL DESIGN OF PARTICULATE MATTER HUMAN EXPOSURE LONGITUDINAL PANEL STUDIES

PM exposure panel studies were performed by NERL/NHEERL/RTI scientists and scientists at three university consortia (Harvard University School of Public Health, New York University School of Medicine, and the University of Washington Department of Environmental Health). The Harvard consortium included Rutgers University, the Environmental and Occupational Health and Safety Institute (EOHSI), and Emory University. The study designs of each research group were fundamentally similar although the studies were conducted by different researchers in cities throughout the U.S. The rationale for similar study approaches was to produce the largest PM exposure database possible by combining the data from several exposure studies conducted independently in various geographic regions using panels with differing characteristics.

The common approach used in each study included measurements of personal PM exposure and ambient (community), outdoor residential, and indoor residential PM concentrations. In addition, exposures to SO_2, NO_2, CO, and O_3 were measured at the recommendation of the NRC. For each participant, questionnaires and diaries were used to collect information on time/activity patterns and potential sources of PM exposure. Multiple participants in each respective panel were monitored over time (7-28 days) to investigate both longitudinal and cross-sectional correlations between personal, indoor, outdoor, and ambient measurements. Although each research group employed the same basic study design, slightly different exposure monitoring instruments, study populations, and locations were selected. In addition to the exposure measurements, study-specific health effect monitoring was performed in the Baltimore, Fresno, Atlanta, New York, and Seattle studies to help relate certain physiological responses to personal, indoor, and/or outdoor concentrations of particles and associated gases. Tables 1 and 2 show a summary of the study designs and the measurements made in all of the exposure studies. Information concerning the types of PM mass monitors used in the various studies are summarized in Table 3.

Time activity information, data on housing characteristics, and source usage were collected using a diary and questionnaires that were developed and reviewed by all consortia and submitted approved by OMB. Copies of the survey forms are provided in Appendix C. Approval for these studies was obtained in July 1999, and all studies performed after this date used these common survey forms to collect time activity pattern and environmental factors data. OMB approval of the questionnaires and diary were contingent upon their use only for characterizing the participants involved (non-transferrable to the general or specific subpopulations). Therefore, data associated with the panel studies should be viewed as representing unique participant pools as defined by each panel's study design. Volunteers involved in the studies were participants of opportunity and where not selected based upon a statistical survey design. Individual quality assurance project plans (QAPPs) were developed for each panel study, and data quality objectives for the collected data were validated versus these standards. It was requested that all QAPPS follow EPA quality assurance guidelines (EPA-QA/G5). More detailed descriptions of the study designs used in each study are provided below.

Table 1. Summary of PM exposure panel study designs conducted by the NERL/NHEERL/RTI Research Group

Study City	Baltimore-2	Fresno-1	Fresno-2	RTP-1	RTP-2
Panel Description	Retirement facility, elderly	Retirement facility, elderly	Retirement facility, elderly	Low SES neighborhoods, minorities with controlled hypertension	Cardiac Defibrillators,
Number of Participants	20	60 residential 5 personal	60 residential 16 personal	35	8
Seasons (Days/Season)	Summer (28)	Winter (12)	Spring (12)	Spring (7), Summer (7), Fall (7), Winter (7)	Spring (7), Summer (7), Fall (7), Winter (7)
PM 2.5 Mass	P, I, IF, O, A	P, I, IF, O, A	P, I, IF, O, A	P, I, O, A	P, I,O, A
PM 10 Mass	I, IF, O, A	I, IF, O, A	P, I, IF, O, A	I, O, A	I, O, A
PM Nephelometer	P, I	—	P	P, I	P, I
PM Number Count	IF, O	IF, O	IF, O	I, O select homes	I, O select homes
EC-OC	IF, O, A	IF, O, A	IF, O, A	P, I, O, A	P, I, O, A
NO_2	IF, O, A	IF, O, A	IF, O, A	I, A	I, A
O_3	IF, O, A	IF, O, A	IF, O, A	P, A	P, A
CO	IF, O, A	IF, O, A	IF, O, A	I, O, A	I, O, A
Speciation Monitoring (VAPs)	IF, O, A	IF, I, O, A	IF, I, O, A	—	—
Elements (SO_4)	P, I, IF, O, A	P, I, IF, O, A	P, I, IF, O, A	P, I, O, A	P, I,O, A
Size Distribution	—	—	I,O	I, O (select homes)	—
Air Exchange	—	—	PFT	PFT	PFT
Health Measures	Primary HRV	Primary HRV	Primary HRV	PEF, FEV, pulse, 0_2 sat.	PEF, FEV, pulse, 0_2 sat.

SES = Socioeconomic status, P = Personal, I = Indoor residential, IF = Indoor facility, O = Outdoor residential, A= ambient, EC-OC = elemental and organiccarbon, PFT = perfluorotracer method, HRV = Heart rate variability, BP = Blood pressure, PEF = Peak expiratory flow, FEV = Forced expiratory volume
O_2 sa t= blood oxygen saturation, pulse = heart rate pulse

Table 2. Summary of PM exposure panel study designs conducted under cooperative agreement with the NERL

	Harvard School of Public Health			New York University	University of Washington
Study City	Atlanta	Boston	Los Angeles	N.Y.C.	Seattle
Panel Description	COPD, MI	COPD, MI, Spouses	COPD	Lung Disease	COPD, Healthy, MI
Number of Participants	15 + 9[a]	30	15	16	107 (57+50[b])
Seasons (Days/Season)	Fall (7), Spring (7)	Winter (7), Summer (7)	Winter (7), Summer (7)	Winter (12), Summer (12)	Fall (10), Winter (10), Spring (10)
PM 2.5 Mass	P, I, O, A	P, I, O, A	P, I, O, A	I, O, A	P, I, O, A U
PM 10 Mass	I,O, A (Spring) P,I,O.A (Fall)	I, O, A	P, I, O, A	P, I, O, A	I, O, A
PM Nephelometer	-	-	-	P, I, O, A	P, I, O[b], A
PM Number Count	-	-	-	-	I, O[b], A
EC-OC	P, I, O, A	P, I, O, A	P, I, O, A	P, I, O, A	P, I, O[b], A
NO_2	P, I, O, A	P, I, O, A	P, I, O, A	P, I, O	P, I, O, A
SO_2	P, I, O, A	P, I, O, A	P, I, O, A	-	P, I, O, A
O_3	P, I, O, A	P, I, O, A	P, I, O, A	-	-
VOCs	-	-	-	-	P, I, O, U, A
CO	I, O	B, I, O, A	I, O	-	B, I, A
Trace Elements	P, I, O, A	P, I, O, A	P, I, O, A	P, I, O	P, I, O, A
Sulfate	P, I, O, A	P, I, O, A	-	P, I, O	-
Nitrate	-	-	P, I, O, A	P, I, O	-
Air Exchange Rate	PFT	PFT	PFT	CO_2	PFT, CO_2
Health Measures	HRV, BP, O_2 Sat.,PEF/FEV_1	-	-	PEF/FEV_1, pulse, symptoms	Pulse, O_2 Sat., PEF/FEV_1, HRV, BP, urine biomarkers[d]

COPD = Chronic obstructive pulmonary disease, MI = Miocardial infarction
B = Breath, P = Personal, I = Indoor, O = Outdoor, A = Ambient, U-Urine samples, O_2 sa t= blood oxygen saturation, pulse = heart rate pulse
PFT = Perfluorotracer method, HRV = Heart rate variability, BP = Blood pressure, PEF = Peak expiratory flow, FEV = Forced expiratory volume
[a] EPRI-API Funding; [b] PM Center Grant; [c] CARB Funding; [d]NHEERL Funding

Table 3. Summary of PM mass measurement methods used in panel studies

Institution	Personal	Residential Indoor	Residental Outdoor	Ambient	PM Size Fraction (µm)	Monitors or Inlets Compared
NERL/NHEERL/RTI	PEM and nephelometer	PEM or HI and nephemoleter	PEM and FRM TEOM, VAPS, or HI	PEM, FRM, and combinations of TEOM, VAPS, HI, DFPSS or Dichot	$PM_{2.5}$ and/or PM_{10}	PEM, TEOM, VAPS, FRM, cyclone; FRM, DFPSS, TEOM; PEM, HI, TEOM DICHOT,
Harvard University	HPEM, PEM	HPEM, PEM	HPEM, PEM	HI, FRM	$PM_{2.5}$ and/or PM_{10}	HI, FRM; PEM, HI; HPEM, HI; HPEM, PEM
University of Washington	HPEM and nephelometer	HI, nephelometer	HI, nephelometer	HI, HPEM, FRM, nephelometer	PM_1(nephelometer), $PM_{2.5}$ and/or PM_{10}	HI, HPEM, FRM
New York University	PEM and nephelometer	HI	HI	HI, FRM	PM_{10}	HPEM, nephelometer

PEM=Personal Exposure Monitor® (impactor, 2-4 lpm), HPEM=Harvard Pesonal Exposure Monitor® (dual impactor, 4 lpm), HI=Harvard Impactor (impactor, 10 or 20 lpm), FRM =Federal Reference Monitor (impactor, 16.6 lpm), TEOM=Tapered Element Oscillating Microbalance® (impactor, 16.6 lpm), VAPS=Versatile Air Pollutant Sampler® (impactor, 15 to 3 lpm), DFPSS=Dual Fine Particle Sampling System® (impactor, 16.6 lpm), Dichot=Dichotomous sampler (impactor, 16.6 lpm), nephelometer (eg., MIE® model pDR-1000 or Radiance Reflectance).

Baltimore Summer 1998 Study (NERL/NHEERL/RTI)

This study took place in July-August, 1998, and included measurements of personal, apartment, indoor residential, outdoor residential, and outdoor central site ambient concentrations over a 28-day period. This study sought to build upon earlier findings from a 1997 pilot study conducted in Baltimore using a similar study design. The 1998 study involved 21 ambulatory elderly (65+) residents of a single 18-story building. The study site was within 3 km of the retirement facility studied in the initial 1997 pilot study (Williams et al., 2000a). The facility used in the 1998 study was selected primarily because it met specific exposure monitoring and epidemiological study requirements (i.e., an adequate population size for subject recruitment, minimum number of known indoor, outdoor, or local PM sources, and administrative cooperation). The all-brick facility was built in 1994 and used a centralized roof-mounted HVAC system for common and administrative areas of the building (such as hallways). Private apartments had their own independent thermostats and smaller, self-contained HVAC systems. All of the apartments within the facility had exterior windows and balconies. Based upon the 1997 study and data from the U.S. EPA's AIRS database, populations living near this location were expected to be exposed primarily to regional, rather than locally- generated, outdoor $PM_{2.5}$ sources. This was a basic requirement of subject selection for the epidemiological component of the study which focused on the day-to-day variability of PM concentrations and observed human health effects.

The participants were recruited from multiple floors of the facility to determine the spatial variation of personal and apartment PM mass concentrations. A subgroup of 15 primary participants were selected for near-daily monitoring (n = 23 days). The remainder of the study participants were used as replacements when needed. Personal monitoring was performed using a $PM_{2.5}$ Personal Environmental Monitor® (PEM; MSP Inc.; Minneapolis, MN) located near the individuals' breathing zone and secured to a lightweight cloth vest worn by the individuals. Personal monitors were operated concurrently with all of the stationary measures beginning at approximately 8:00 a.m. (± 15 min) each day. Environmental surveys were collected from the subjects each analysis day to gather information concerning time activity patterns and conditions within the facility.

The sampling approach used in the 1998 Baltimore study is outlined in Table 1 (Baltimore 2). Personal and indoor monitoring focused primarily on fine particles; however, some indoor PM_{10} samples were also collected every other day. In addition to measurements of PM mass, supplemental measurements were made to better characterize PM including particle nephelometry, number count, and chemical speciation (EC-OC, elements, SO_4, etc.). Continuous monitoring of criteria pollutants was conducted inside the retirement facility, outside the facility, and at a central community monitoring site. The additional instrumentation used to characterize PM included real-time microbalances (TEOMs®), $PM_{2.5}$ prototype Federal Reference Method (FRM) monitors, endotoxin collection, personal and stationary nephelometers, and versatile air pollution samplers (VAPS®). The TEOMs were used so that real-time mass concentrations were available for the epidemiologic investigation. Locating multiple instruments at the same location allowed comparison of indoor and outdoor PM mass concentration sampling methodologies and collection of samples for PM speciation (e.g., individual particle characterization, elemental analysis).

Repetitive $PM_{2.5}$ (n = 15) and PM_{10} (n = 5) monitoring was planned for the apartment of each subject who participated in personal $PM_{2.5}$ monitoring on at least an every-other-day schedule following an initial every-day measure (day 1-3). The sampling schedule was maintained over 28 days and was projected to yield approximately 225 $PM_{2.5}$ and 75 PM_{10} apartment samples. Residential indoor, residential outdoor, and ambient $PM_{2.5}$ and PM_{10} samples (n = 28 days) were collected daily and operated concurrently with the personal and apartment monitors (8:00 a.m. to 8:00 a.m.). These measurements were critical to the epidemiological component of the study based on findings from the pilot study which indicated associations between indoor/outdoor fine PM mass concentrations and some cardiovascular health effects (Liao et al., 1999). Residential indoor measurements were performed at a central site within the facility in a 5th floor apartment while residential outdoor monitoring occurred on the facility's rooftop. Ambient samples were collected at a community monitoring platform located 11 km south-southeast of the residential facility where ambient monitoring had been performed during the 1997 pilot study (Williams et al., 2000a).

A new real-time personal nephelometer (MIE pDR® personalDataRAM, MIE, Inc.; Bedford, MA) was used to characterize personal PM exposures for a select number of participants (n= 5). A total of 41 participant monitoring days was performed. The nephelometer was worn adjacent to the gravimetric PM mass monitor on the vest for comparative purposes. The data collected using the nephelometers provided some of the first continuous personal exposure measurements (1-minute averaging time) collected on a high-risk subpopulation (Howard-Reed et al., 2000; Rea et al., 2001).

All of the PM mass concentration data from this study have been validated and a full database of this information has been developed. Very low PM mass concentration limits of detection were established after improved gravimetric analysis techniques were developed by RTI (Lawless and Rodes, 1999). Based upon 24-h sampling periods and 2.8 m^3 of collected air volume, detection limits of approximately 2 $\mu g/m^3$ were established for the nearly 900 low-volume (personal, residential and ambient) samples collected over the 28 days of the study. Method performance data are summarized in Table D-1. A large number of other filter-based and real-time PM mass measurements were also performed (Williams et al., 2000b,c). Creason et al. (2001) have recently reported upon potential health findings from this study.

Data indicates that a relatively low coefficient of variation (<48%) existed between individual personal exposures on a day-to-day basis in this communal setting. $PM_{2.5}$ mass concentrations for this variable were also relatively low (typically less than 48 $\mu g/m^3$). It is believed that human activity patterns (low known incidences of exposures to indoor PM sources such as cooking aerosols) and little time spent outdoors greatly influenced these results. Both Howard-Reed et al., (2000) and Rea et al., (2001) have reported upon these activity patterns and the use of a personal nephelometer that permitted real-time assessment of these influences upon potential human exposures. Landis et al., (2001) have characterized the relationships between particles of ambient origin to those observed during personal exposure monitoring in this subject population. Summaries of PM mass concentrations relative to $PM_{2.5}$, PM_{10} and $PM_{10\text{-}2.5}$ size distributions across various spatial boundaries (personal, apartment, residential indoor, residential outdoor, and ambient locations) are reported in Tables D-3 through D-6. Numerous peer-reviewed journal articles of this effort not sited here have also been published (Williams et al., 2000d; Conner et al., 2001; Rodes et al., 2001).

Speciation of the PM mass, source apportionment, and investigation of the relationships between PM mass and gas-phase co-pollutant concentrations determined during the study have been performed. Results of these findings have been presented in over 10 presentation abstracts at national or international symposia. Preparation of peer-reviewed journal articles concerning these topics is currently being performed. It is anticipated that publication of the majority of these articles will occur during the 2001-2002 calendar years.

Fresno Winter and Spring 1999 Studies (NERL/NHEERL/RTI)

A residential retirement facility in Fresno, California was selected for these PM exposure and health studies. The facility consisted of single-story apartment living units (duplexes and quadruplexes) spread across a relatively large campus area. The 1999 Fresno studies were performed to contrast geography (west coast versus east coast), season, housing, and other factors to the aforementioned Baltimore study. The location of the retirement facility in Fresno provided ambient and personal PM measurements in a western area of the U.S. typically characterized by high nitrate concentrations. The demographics of the participants' underlying health status was similar to that of the participants in the Baltimore study; however, the participants in the Fresno study were more active as indicated by a preliminary assessment of their activity patterns. This, as well as housing and other factors, are believed to have affected both their personal as well as their indoor (apartment) $PM_{2.5}$,$_{10}$ mass concentrations (higher exposure potential).

A monitoring platform located about two miles south of the selected retirement facility was used to collect ambient data. Data from the platform provided regional-scale community monitoring information to compare with outdoor measurements made on the grounds of the retirement facility. Outdoor monitoring was performed at a single location on the premises of the retirement facility. $PM_{2.5}$ was the primary targeted PM species although special measurements were made of particles in the $PM_{1.0}$ to $PM_{0.01}$ size range outside of one residence using a a Laser Aerosol Spectrometer (LAS-X®) and a Scanning Mobility Particle Sizer® (SMPS; TSI, Inc. St Paul MN).

An empty apartment on the retirement campus was used as an onsite central indoor monitoring site. The outdoor monitoring site was located in a grassy area between several buildings. Both the apartment and its adjoining courtyard were equipped with instrumentation to monitor particle mass ($PM_{2.5}$ and PM_{10}), CO, and O_3. In addition to using Marple PEMs for $PM_{2.5}$ and PM_{10}, supplemental instrumentation was used to characterize indoor and outdoor particle concentrations and characteristics. The additional monitoring equipment included TEOMs, $PM_{2.5}$ FRM samplers and Dual Fine Particulate Sampling Systems (DFPSS®) for $PM_{2.5}$; a LAS-X and a SMPS particle counter for ultra-fine particles (< 0.1 µm). These samplers were used to provide continuous data on particle mass concentration, reference measurements, samples for subsequent chemical speciation (e.g., analyses for elements, elemental and organic carbon), and ultrafine particle count data for indoor/outdoor comparisons. A total of 60 residences participated, and a subgroup of 16 participants was monitored for personal PM exposure. Daily personal exposures of $PM_{2.5}$ and PM_{10} were alternately measured during the spring study. In addition, air exchange measurements were made inside each residence during the spring study.

Winter Study

The winter Fresno study was conducted over a 28-day period from February 1-28, 1999 (Table 1) with the participation of approximately 60 residents of the retirement facility. Sampling consisted of both integrated and real-time measurements. Twenty-four hour integrated personal air sampling was conducted on 5 participants using a personal sampling system attached to $PM_{2.5}$ PEM sampling units. The pump and data logger were placed in the pockets of a short-waist coat with inlets located near the breathing zone. Integrated monitoring inside the residence was conducted daily, except Sundays, in about 60 apartments for $PM_{2.5}$. PM_{10} samples were collected in a subset of 12 of these apartments using PEMs. The sampling location within each residence was standardized to be about 1.5 meters above the floor (the approximate breathing zone of an average adult), not adjacent to a wall or other flow-obstructing object, and not immediately adjacent to a potential source such as a stove or heat vent. All integrated samples, including personal and in-residence samples, were collected over a 24-hour period beginning at or near 8:00 a.m. each day. A baseline questionnaire was administered to all participants at the beginning of the study to gather information about their individual residences and their personal activities. Also, daily personal activity diaries were kept by each participant wearing a personal monitor. Gas-phase co-pollutants, PM mass speciation, and PM size distribution measurements were performed in this study with additional reports summarizing these findings expected to be developed and published during the 2002-2003 calendar years. Evans et al., (2000), Rea et al., (2001), Vette et al., (2001) and Rodes et al., (2001) have reported upon the PM mass concentration findings associated with the first study.

Summer Study

The second phase of the Fresno study was conducted during a 28-day period from April 19 to May 16, 1999 (Table 1). The main objective of Fresno 2 was to determine the seasonal variation in personal PM exposures and PM concentrations between winter and spring. Historical data collected in Fresno indicated that the coarse fraction of PM_{10} was higher in the spring than in the winter. In order to determine if exposures to PM_{10} were higher in spring, a PEM sampling unit equipped with a PM_{10} inlet was added to the daily in-residence monitoring program for all residences included in the study. Also, the personal monitoring component for Fresno 2 was increased to include 16 residents, with 24-hour integrated measurements of personal exposures to $PM_{2.5}$ and PM_{10} collected on alternate days. Fine and coarse particle mass samples were collected using a dichotomous sampler each day at the outdoor central site and every third day at the platform site. Twelve participants carried MIE personal nephelometers on alternate days for two weeks to provide some real-time data on personal exposures to relate with time activity pattern. Air exchange rates were estimated for each participating residence using a perfluorocarbon tracer (PFT) method (Dietz, 1982). Special studies were also performed to characterize PM removal efficiency by residential heating and cooling systems (Rodes et al., 2001) as well as the role of season, particle size, and meteorology upon aerosol concentrations (Lawless et al., 2001). PM mass concentration findings from this study have been reported (Evans et al., 2000; Howard-Reed et al, 2000; Rea et al., 2001; Vette et al., 2001 and Rodes et al., 2001).

Summary of Fresno Studies

Validated databases for all of the PM mass concentration measurements have been developed. Data provided in Tables D-7 though D-9 summarize statistics associated with some of the PM mass concentrations from the two Fresno studies. Evans et al., (2000), Howard-Reed et al., (2000), and Rea et al., (2001) have reported upon the preliminary PM mass concentration findings associated with the two studies. The expected change in $PM_{2.5}/PM_{10}$ ratio did occur with ambient $PM_{2.5}$ mass concentrations falling significantly between the first (winter) and second (spring) seasons. Preliminary investigation of the human activity data associated with the participants in the two studies suggest that they were significantly more active than elderly residents of the 1998 Baltimore Study (Howard-Reed et al., 2000; Rea et al., 2001). Personal exposures of $PM_{2.5}$ or PM_{10}, which were at or above mass concentrations found indoors or in comparison to ambient measurements, might have been influenced by this higher activity level. Other factors could also be responsible. Reduction of data from the PM mass speciation, gas-phase co-pollutant, human activity pattern and health effects variable measurements is currently underway. The human and environmental factors that influenced these results are still being investigated with additional reporting anticipated for the 2002-2003 calendar year.

Research Triangle Park 2000-2001 Studies (NERL/NHEERL/RTI)

The Research Triangle Park (RTP) studies were conducted to extend and enhance the data set generated in the Baltimore and Fresno studies. The studies addressed the effect of housing conditions (e.g., construction type, ventilation status) and investigated how personal time activity patterns and indoor PM sources might affect the relationship between personal PM exposures and ambient concentrations. The RTP studies greatly expanded monitoring personal exposure across both the number of participants, as well as the overall period of measurement (one calendar year). Additionally, individual homes, rather than a communal apartment building or communal campus, were monitored for PM mass concentrations across a wide geographical setting (RTP area, North Carolina).

Table 2 also indicates the variety and depth of the study design with the inclusion of measurements for elemental-organic carbon, personal nephelometry (real-time PM mass exposure measurements) for each participant on a daily basis, as well as air exchange and other measurements for each residence. These represent significant enhancements of the overall data collection potential in comparison to the earlier studies. It is believed that the real-time personal exposure monitoring combined with the daily activity diary across multiple residences and variety of participant characteristics will permit a unique investigation of potential PM sources (personal, indoor, and ambient) with respect to individual human exposures.

The studies were comprised of two distinct susceptible subpopulations which were distinct from earlier panels; earlier NERL panel participants were much older and had a much wider variety of health deficits (respiratory, cardiovascular, healthy, etc). These panels included an African-American panel (n= 28) with controlled hypertension living in a low socioeconomic status (SES) neighborhood and a mixed race cardiovascular disease panel (n= 8) who had implanted cardiac defibrillators (Table 1).

These studies, identified as RTP 1 and RTP 2 in Table 2, were conducted at the same time and had exactly the same study design with the exception of the panel inclusion criteria described above. The 35 participants were non-smoking, 50+ years of age, and living in their own homes. The participants were monitored for 7 consecutive days during each season over one calendar year (Summer 2000, Fall 2000, Winter 2001, Spring 2001) for a total of 28 days. Over 80% of the participants were monitored during all four seasons. The number of participants was restricted due to the equipment and staffing needed to perform exposure monitoring upon individual participants living in residences distributed across a relatively large geographical area. Over 70 km separates the low-moderate SES-classified neighborhood in southeast Raleigh, NC where the African-American panel lived from the Chapel Hill area where the majority of the cardiac defibrillator panel lived. However, data indicate that, with only minor exception, there was very little difference between the two panels in their overall mean personal exposure patterns regardless of geographical area or season.

Subject recruitment and retention were identified as areas in need of special attention, especially for African Americans. Procedures were developed that had a very positive influence upon both recruitment and retention of subjects in both RTP panels. Over 80% of the subjects initially recruited into the first season of the two studies were retained over the entire course of one calendar year. Collaborations with institutions having established ties to the African American community (such as Shaw University, Raleigh, NC) helped to establish trust between this subpopulation and the research team. A systematic communication plan between the participants and their primary study contacts (NERL/RTI research group) was highly effective in establishing rapport and maintaining the interest of the subjects over the study period. The procedures used to permit this response for recruitment and retention are currently being summarized, and peer review of these results is expected in the 2002 calendar year.

Twenty-four hour personal exposure measurements of $PM_{2.5}$ mass, $PM_{2.5}$ EC-OC, and O_3 were collected for all study participants (Table 1). Teflon® filter media was used in the collection of PM mass while quartz media was used to collect samples for EC-OC determinations. The $PM_{2.5}$ PEM inlets were operated at ~ 2 Lpm/channel to collect the PM mass and EC-OC samples. PEM measurements for PM_{10} mass were collected at the ambient site (located from 5 - 70 km from the residences), outdoor residential, and indoor residential locations over the same time periods. In addition, daily $PM_{2.5}$ samples were collected using inertial impactor samplers operated at 20 lpm at the indoor residential, outdoor residential, and ambient sites. Select trace elements (e.g., S, K, Fe, Ca, Zn) will be measured on the $PM_{2.5}$ filter samples using X-ray fluorescence (XRF). Sulfate concentrations will be estimated using the sulfur concentrations measured by XRF. Ogawa® badges were used to collect twenty-four hour integrated NO_2 samples in each residence and at the ambient site. Similar badges were used to measure personal exposures to O_3. Continuous measurements of CO and O_3 were made at the ambient site, and CO was measured continuously indoors at each residence.

A $PM_{2.5}$ FRM and a dichotomous sampler were operated at the ambient site. The $PM_{2.5}$ FRM was collocated with a $PM_{2.5}$ PEM and operated one out of every 10 collection days. This allowed for direct comparisons of both PM sampling methods to federal equivalency methods. TEOMs, operated by the State of North Carolina and located at the ambient site, were used to collect real-time mass measures of $PM_{2.5}$ and PM_{10} and provide data with which to evaluate temporal variability.

Nephelometers (MIE pDRs) were used to collect real-time $PM_{2.5}$ data concurrently with the personal and indoor monitors. Although these instruments did not provide accurate mass measurements, they provided valuable information on the personal and indoor sources of PM and on the influence that personal activities have on PM exposures. In selected homes, real-time particle counts in the fine and ultrafine size range (0.01 to 2.5 µm) were measured both indoors and outdoors using particle size characterization monitors (SMPS). This instrumentation provided data for evaluating the influence of temporal variability in particle counts at the residence. Data from these measurements will be used to estimate particle penetration rates, decay rates, and source strengths which can be applied to indoor air quality models.

For each participant, questionnaires and activity diaries were used to collect information on locations, activities, and potential sources of PM exposure. Information on housing structure, ventilation system, ventilation parameters, and potential indoor sources was also collected for each residence. Air exchange rates were measured daily in each residence during monitoring using a PFT methodology. These data will be used to evaluate the factors that influence exposure to PM and its relationship to ambient site measurements.

Simple health effect measurements which consisted of 5-minute real-time measures of pulse oxygen saturation and heart rate were taken for each participant on each of their monitoring days (n=28). Daily monitoring of two lung function variables, peak flow (1 sec) and peak volume was performed using a hand-held spirometer. All of the above health metrics were collected during the morning home visits concurrent with PM personal, residential, and ambient monitoring. The filter-based PM mass measurements associated with both studies is summarized in Tables D-10 through D-12 and typically represent the mean of between 3 and 6 participants and residences monitored on a given day These tables report the integrated $PM_{2.5}$, PM_{10}, and $PM_{10-2.5}$ mass concentrations pertaining to personal, residential indoor, residential outdoor and ambient (community) settings as appropriate. Data values are divided between the two panels, seasons, and PM size fractions.

This study is the last of the NERL/NHEERL/RTI performed panel studies in pursuit of the ORD goal. Field data collection was completed in late May 2001. All of the PM mass concentration data from all monitoring devices across all seasons and panels have been validated, and a database containing this information has been prepared. Analysis of the associated gaseous co-pollutants, human activity patterns, PM mass speciation and other components of the study design is underway. A number of preliminary findings from these studies have been submitted for presentation at national symposia. It is anticipated that articles summarizing results of both studies will be prepared and submitted for publication during the 2002 and 2003 calendar years.

Harvard University School of Public Health 1999-2000 Studies

The studies conducted by the Harvard School of Public Health (HSPH) took place in Atlanta, Boston, and Los Angeles from Fall 1999 through Summer 2000 (Table 2). All field data collection was completed by August 1, 2000. As part of the overall study objectives, the HSPH group developed and evaluated a multi-pollutant personal sampler used to measure exposure to PM (mass and chemical species) and criteria pollutant gases. The multi-pollutant sampler was used in each city and season to measure personal, indoor, and outdoor samples. The studies were conducted over 5 seven-day periods, during which 3 to 5 homes were monitored simultaneously. The Atlanta study was financially supplemented by the Electric Power Research Institute (EPRI) and the American Petroleum Institute (API) which allowed a total of 24 persons to be monitored compared to the 15 originally planned and funded through a cooperative agreement with the NERL.

Atlanta Fall 1999 Studies

Personal, indoor, and outdoor multi-pollutant sampling was conducted on a panel of 15 individuals (8 men and 7 women) with moderate to severe physician-diagnosed COPD and nine individuals (8 men and 1 woman) with incidences of MI within the previous three to twelve months. A total of 25 participants were recruited into the study, and 24 participated (Table 2). Each individual was monitored over a 24-hour period for exposures, as well as for heart rate and heart rate variability. Indoor and outdoor measurements were made for seven consecutive days at 24 homes for a total of 168 sample days. During each seven-day panel, five homes were measured simultaneously. PEMs were used for personal monitoring while multi-pollutant samplers with Harvard personal exposure monitors (HPEM) were used for indoor and outdoor samples (Sioutas et al., 1998). Sampling was conducted during September to November 1999.

Staff members conducted morning visits to measure heart rate and service the exposure monitoring equipment. Each morning a brief questionnaire was completed to document chest pain, doctor’s visits, hospital visits, medication changes, and medications taken that morning. Heart rate was measured using a thirty-minute protocol involving periods of rest, standing, walking, and slow breathing using a Holter monitor and was used to establish heart rate variability for each participant.

Atlanta Spring 2000 Studies

During the Spring 2000 study, 22 participants were successfully recruited out of a pool of 25. The study population included 4 men and 9 women with COPD and 7 men and 2 women with a recent MI (Table 2). A total of 9 COPD and 6 MI participants were repeats from the fall sampling period. Sampling was conducted during April and May 2000. Personal, indoor, and outdoor measurements were conducted for seven consecutive days at 22 homes for a total of 158 sample days during which

860 filter-based PM mass measurements were collected. During each seven-day panel, five homes were measured simultaneously. The spring sampling protocol differed slightly from that in the fall, as personal PM_{10} measurements were also collected and personal exposures were measured using the multi-pollutant samplers with HPEMs instead of the PEMs. Indoor and outdoor samples were collected using the same configuration as in the fall. Preliminary PM mass concentration data from the Atlanta studies are presented in Tables D-13 and D-14. These data summarize the overall PM mass concentrations from pooling results from both panel populations.

Boston Winter/Summer 1999-2000 Studies

HSPH staff conducted four seven-day panels in Boston during November 1999 and January 2000 (Table 2). Due to difficulties in recruiting participants having had recent episodes of MI, the study population was expanded to include individuals with heart disease or COPD. Individuals with heart disease were recruited into the study if they had an incidence of MI within the past five years or had by-pass surgery or angina treated by medication.

Eight couples and seven single individuals participated in the winter monitoring for a total of 161 personal sample days. The winter study population, included 5 individuals with a MI within the previous five years (4 male, 1 female); 1 male with conjunctive heart failure and a defibrillator; 4 individuals with COPD (2 male, 2 female); 3 males with a history of by-pass surgery; and 2 males with medication-treated angina. The Boston summer study was conducted from June 6 to July 25, 2000. A total of six couples participated in the summer sampling. This represented approximately one-third of those from the winter season.

During each season, indoor and outdoor samples were collected for seven consecutive days at 15 homes for a total of 105 sample days. Three or four homes were measured simultaneously during each seven-day period, and at least one couple was measured during each panel. Multi-pollutant samplers with PEMs were used for personal, indoor, and outdoor monitoring during both sampling seasons.

PM mass concentration data for the Boston studies is currently being validated. A summary of the data collected during the two seasons is presented in Table D-15.

Los Angeles Winter/Summer 1999-2000 Studies

The Los Angeles studies involved 15 participants with COPD who were monitored for seven days in each season (Table 2). In the summer there were 8 repeat participants from the winter sampling period. The participants were sampled in groups of three. Participants for the study had a history of respiratory disease (COPD) and lived in the Los Angeles area neighborhoods including El Segundo, Palos Verdes and Downey, CA.

Sampling for the winter Los Angeles study ran from February 8 through March 23, 2000. The summer Los Angeles sampling ran from June 12 through July 24, 2000. Unlike the Atlanta and Boston studies, the samples collected in the Los Angeles studies were analyzed for nitrate instead of sulfate, and measurements of personal PM_{10} were made in both seasons. Personal PM_{10} was measured only in the spring for Atlanta and in the summer for Boston, but indoor and outdoor PM_{10} were measured in all cities during both seasons. Otherwise, the sampling protocols were identical. Personal samples were collected using PEMs in the winter and HPEMs during the summer.

The HSPH and its collaborators have also completed all field efforts associated with two panel studies conducted in the Los Angeles area during the winter of 1999-2000 and the summer of 2000. A total of 630 personal, residential indoor, and residential outdoor (210 each) filter-based PM mass measurements were obtained in each season. Table D-16 summarizes the field data collections completed for the Los Angeles field study.

Summary of HSPH Studies

Field collection of all variables associated with the HSPH studies have been completed. Validation of PM mass concentration data from all monitors, seasons, and panels is currently underway. A database containing this information should be completed during the 2001 calendar year. The summary of ancillary data such as measured gaseous co-pollutants, human activity patterns, PM mass speciation and other components of the study design is ongoing. Initial findings from these studies have been submitted for presentation at national symposia during 2001. Summary journal articles are expected to be prepared and submitted for publication during the 2001 and 2002 calendar years.

University of Washington 1999-2001 Studies

Seattle 1999-2000

This study was conducted on one panel of 32 elderly COPD subjects and one panel of 31 healthy subjects living in group homes and individual residences recruited from the metropolitan Seattle area. Additional resources from an EPA grant establishing the University as a Particle Research Center of Excellence allowed for the addition of these 31 healthy control subjects to the original study population (Table 2). About 45% of the 63 subjects (13 COPD and 11 healthy subjects) were re-enrolled for monitoring in a second season and 5 COPD subjects were monitored in a third season within a year. All of the study participants were over 65 years old (85% between 71 and 90 years old), non-smoking living in non-smoking households, and spent more than 30 minutes outdoors each day. All COPD subjects had light to moderate COPD while healthy subjects were free of COPD, compromised lung function, and heart diseases. An equal number of subjects lived in group homes and private residences; only 7 subjects lived in private apartments. The studies were conducted over 13 monitoring sessions, including 6 high wood-smoke (fall) sessions and 7 low wood-smoke (spring/summer) sessions between October 1999 and August 2000. Each session consisted of 10 consecutive monitoring days starting at 4 PM (±2 h) on Tuesdays and ending at 4 PM (±2 h) on Fridays. Up to 9 subjects were monitored simultaneously during each session.

Seattle 2000-2001

This second year study was conducted on one panel of 25 elderly subjects with MI and one panel of 19 pediatric asthmatics. The addition of the 19 pediatric asthmatics was made possible through an EPA's Particle Research Center of Excellence grant. Approximately 55% of these 44 subjects (12 MI subjects and 13 asthmatics) were monitored in both high wood-smoke (fall/winter) and low wood-smoke (spring) seasons. All MI subjects were over 65 years old, except for one (56 years old); living in group homes (2), private apartments (15), or private homes (8). Pediatric asthmatic subjects were aged between 5 and 12 years, living in either private homes (18) or apartments (1). This study included 13 low and high wood-smoke sessions between September 2000 and May 2001. Each session consisted of 10 consecutive monitoring days, starting at 4 PM (±2 h) on Tuesdays and ending at 4 PM (±2 h) on Fridays. Up to 8 subjects were monitored simultaneously during each session. The total number of personal samples collected in both years represented 1660 subject days (not including fixed site samples).

Unique aspects of these studies included the collection of urine samples to be analyzed for biomarkers indicative of woodsmoke (methoxyphenols) and gasoline (polycylic aromatic hydrocarbons-PAHs) exposure. Personal exposures to $PM_{2.5}$ were measured using HPEMs. Downstream of the device, a polyurethane filter (PUF) sampler was used to collect the re-evaporated semi-volatile organic compounds (SVOCs) including wood smoke compounds. Each subject carried the personal monitors continuously for 24 hours (4 PM to 4 PM) in the breathing zone, except while sleeping, showering, or using the restroom. The monitor was attached to the shoulder strap of either a backpack or a fanny pack that contained the air pump. When the monitoring pack was not worn, it was placed at an elevation of 3-5 feet (e.g., on a table) close to the subjects. Subject compliance in operation of the monitor was checked using secondary electronic data loggers. Every subject wore an Ogawa passive sampler for 10 days as a means to determine NO_2 and SO_2 concentrations. In addition, a total of 30 subjects during the two-year studies also carried the MIE pDR nephelometer for up to 10 days. This was the same device that was used in the Baltimore, Fresno, and RTP-based studies. During the second year of the study, 8 subjects also carried personal HPEM EC-OC samplers.

At each subject's home, two nephelometers (Model M902 & M903, Radiance Research, Seattle, WA) were used to determine real-time PM_1 concentrations. Indoor and outdoor PM concentrations were measured with a Harvard Impactor (HI) (Air Diagnostics and Engineering, Inc., Naples, ME) for PM_{10} and $PM_{2.5}$. One $HI_{2.5}$ and one HI_{10} were collocated inside the home while one $HI_{2.5}$ and one HI_{10} were collocated outside the home. Only Teflon filters were used in the Year 1 study, while both Teflon and Quartz filters were used in the Year 2 study for weights, trace elements, and EC/OC analysis. All HIs were operated continuously for 24 hours (4 PM-4PM) at a flow rate of 10 Lpm. The indoor monitors were collocated in the main activity room where the subject spent the most time. In Year 2, Integrated Organic Gas and Particle Samplers (IOGAPS) were used at the central site and one home site per session for indoor and outdoor monitoring. Home site IOGAPS were operated on a 24 h schedule while the central site IOGAPS were operated on a 12 h monitoring basis (midnight to midnight).

Urine samples were collected from each subject for SVOC and wood smoke compound analysis. Exhaled breath samples were also collected for CO analysis. CO concentrations in exhaled breath were measured using an electrochemical sensor. Bag samples of indoor CO samples from each home were collected, transported back to the laboratory, and analyzed using an electrochemical sensor. In addition, a continuous electrochemical CO sensor was placed in one of the study subject's homes during each of the study sessions. For each participant, information on housing characteristics, time/activity patterns and potential sources of PM exposure was collected using diaries and questionnaires.

Indoor CO_2 concentrations at a central location of each home were measured as a real-time surrogate for air exchange rate. To verify the CO_2 method, a traditional tracer gas method was also employed during the first 6 sessions of the study. This method was based upon the PFT technique developed by Dietz et al., (1982). Continuous temperature and relative humidity inside the homes were also measured as part of the home environment characterization.

Health effect measures were collected from each subject in this study. A symptom diary was administered by technicians during their daily visit to obtain information on the severity of symptoms, including cold, phlegm, shortness of breath, wheeze, sore throat, runny/stuffy/blocked nose, itching/burning eyes, fever/chills, fatigue, headache, tightness in chest, and fear induced by asthma attacks as well as to record dosage of prescription medications. Quantitative health measures included peak expiratory flow rate (PEF) and forced expiratory volume in one second (FEV_1) using Airwatch® monitors (ENACT, Palo Alto, CA). Pulse rates and oxygen saturation rate were measured using a portable pulse oximeter (Nellcor Model N20), blood pressure with a digital monitor (Model HEM-705CP, Omron Health Inc.,Vernon Hills, Il), and electrocardiogram measurements with a portable Holter monitor (Delmar Co., Stockton, CA).

Summary of Seattle Results

A preliminary data base containing PM mass concentrations has been developed from this effort. Validation of gas-phase pollutant data, human activity patterns, and other collected data is expected to be completed during the 2001 calendar year. PM speciation efforts, involving laboratory analysis for select metals of filter-based samples are expected to begin during 2001 and will continue during 2002. Presentations of preliminary findings from the Seattle Year 1 study have been made in various national symposia, and manuscripts are being prepared and planned for submission for publications during the summer and fall of 2001. Summary journal articles for both years 1 and 2 findings are expected to be prepared and submitted for publication during the 2002 calendar year.

The Year 1 and 2 studies which monitored a total of 107 subjects in four panels during October 1999 and May 2001 have been completed. Summary of filter-based PM mass concentration data from personal, residential indoor, residential outdoor, and community (ambient) monitoring in the Year 1 study is summarized in Table D-17. The type and location of samples are summarized in Table D-18. A large number of personal $PM_{2.5}$ mass measurements were collected from nearly equal subpopulations of COPD and healthy panels (~ 880 total measurements). Numerous community-based measurements were performed from multiple locations. This study is significant because of its depth (nearly 900 filter-based data points were collected) and because it also focused heavily on assessing exposure to wood-smoke related semi-volatile organics. A future robust analysis of possible PM-related health effects relative to simultaneously collected epidemiological data will incorporate these results as well as other data (gas-phase variables, PM speciation, etc). Laboratory efforts are underway to analyze all collected samples and summarize the results.

New York University 2000 Studies

The New York City study involved 9 participants with moderate to severe cases of asthma and COPD who were monitored for 12 days in the summer and 12 days in the winter with either one or two subjects participating in each successive 12-day period. The participants lived in apartments in either Manhattan or nearby Brooklyn and, though ambulatory, were not employed outside of their apartments.

Each participant wore a battery-powered personal sampling pump collecting a 4 Lpm 24-hour personal exposure monitor (PEM) PM filter sample for PM_{10}. The monitors could be placed on a fixed mount adjacent to the subject's bed or chair while they were sedentary. Participants also wore MIE pDR personal nephelometers. Simultaneous $PM_{2.5}$ and PM_{10} HI samples were collected inside their apartment and directly outside their apartment. In addition, simultaneous $PM_{2.5}$ and PM_{10} samples were collected at a central air monitoring site. The samples will be analyzed for weight, elemental composition (by x-ray fluorescence), elemental and organic carbon (by white light and UV absorption), and ions (by ion chromatography).

The participants performed expiratory flow maneuvers twice each day to determine FEV_1 and peak flow rate using an Airwatch II® pneumotach. Each volunteer performed twice daily pulse oximetry measurements (Nellcor Model N20) to determine whether pulmonary and/or cardiac functions were related to their personal PM exposures.

The New York City sampling phase of the study ended in February 2001, laboratory analyses are continuing, and data validation is currently underway. It is anticipated that results from this study will be presented at professional society meetings in 2002. Additional new studies by this research team may be performed in Anaheim, CA and Seattle, WA. Data from the completed New York study and the proposed future studies are expected to be available by 2003.

SUMMARY

NERL's PM Exposure Research Program has focused on the NRC Research Topic 1: investigating the quantitative relationships between ambient PM and gaseous co-pollutants and identifying the contribution of these concentrations to measured personal exposures. This research has focused on potentially susceptible subpopulations, namely, COPD patients, people with cardiovascular disease, asthmatics, the elderly, African Americans with hypertension, and asthmatic children. In addition, each study focused on a particular geographical area, season(s) of the year, and housing conditions. Fifteen individual research studies have been carried out in a collaborative effort between NERL, NHEERL, RTI, and three University consortia: Harvard University School of Public Health, University of Washington Department of Environmental Health, and New York University School of Medicine. The data from all of these studies will be combined into one publicly accessible database.

This report documents completion of the field portion of these research efforts. Study designs from each panel have been summarized and preliminary PM mass data also have been included. Common approaches used by each research group included measurements of personal exposure using personal monitors as well as measurements of ambient, outdoor residential, and indoor residential concentrations using stationary monitors. In addition, a concerted effort was made to measure exposures of a number of gases including SO_2, NO_2, CO, and O_3, based on recommendations by the NRC. For each participant, information on time/activity patterns and potential sources of PM exposure was collected using questionnaires. Multiple participants in each respective panel were monitored over time (7-28 days) to investigate both longitudinal and cross-sectional correlations between personal, indoor, outdoor, and ambient measurements. Data from over 15,000 individual PM mass concentration measurements involving more than 200 individuals and their residences were collected in these studies. Research products based on this research including published peer-reviewed journal articles and presentations at scientific conferences are listed in Appendix A and Appendix B.

Recommendations for Future Work

- Complete the ongoing validation of all PM mass concentration data collected during each panel study and develop panel-specific databases containing this information.

- Complete the statistical analysis for each longitudinal study outlined in the peer-reviewed study designs using the validated databases for these analyses. This effort will include establishing the basic relationships between outdoor (ambient) PM mass concentrations and personal exposures. Likewise, PM mass concentration relationships between ambient, indoor residential, outdoor residential and personal exposures should be established for as many of the size fractions as possible.

- Quantify the relationship between ambient site PM-related mass concentrations and personal exposure to pollutants of ambient origin. This will include evaluating marker pollutants (eg., sulfate) as well as by developing new source apportionment models and characterization methodologies to differentiate personal exposures to pollutants of ambient origin.

- Characterize the relationships between time activity patterns and personal and residential PM mass concentrations for each susceptible subpopulation studied.

- Complete the chemical analyses of PM filter samples (e.g., elements, soluble metals, carbon species), validate the chemical speciation data, and enter it in panel-specific databases.

- Determine the relationships between PM mass, PM composition/speciation, and estimated source contributions with related co-pollutants (e.g., CO, O_3) for each panel study. Examine the influence of personal and environmental factors on these relationships.

- Develop a unified database (across all panel studies) containing validated PM mass concentrations, co-pollutant concentrations, and other variables collected during each panel study.

- Perform statistical analyses upon the unified database to investigate the relationships between season, geography, age, and health status of the panel on PM mass.

- Develop a database containing pooled data from all of the studies that is accessible to the general public and other researchers who may conduct additional analyses with the data.

- Develop more sophisticated (lower burden, greater utility) personal monitors and analytical tools to maximize PM measurement efforts and related co-pollutant source characterization. Based upon the experiences gained in the present work, PM monitors need to be made smaller, quieter, and less obtrusive. Analytical methods to speciate PM and related co-pollutants need refinement, and technological advances that will permit more timely and effective sample analysis should be developed. These efforts will require funding beyond the $6 million of original funding.

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APPENDIX A

Research Products: Manuscripts

Conner, T., Norris, G., Landis, M., and Williams, R. Individual particle analysis of indoor, outdoor, and personal samples from the 1998 Baltimore retirement home study. Atmospheric Environment, 35: 3935-3946 (2001).

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APPENDIX B

Research Products: Presentations

NERL/NHERL/RTI Research Group

Creason, J., Neas, L., Shy, C., Williams, R., Sheldon, L., Liao, D., and Walsh, D. Effects of particulate matter on the heart rate variability of elderly residents in an east coast retirement community: the Baltimore 1998 PM study. PM2000 Conference, Charleston, SC, January 25-28, 2000**.** NHEERL-RTP-HSD-AB-00-100.

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Sheldon, L., Rea, A., Vette, A., Howard-Reed, C., Williams, R., Highsmith, R., Rodes, C., and Lawlesss, O. The contribution of particle resuspension to indoor and personal air concentrations. ISEA 2000, Exposure Analysis in the 21st Century Integrating Science, Policy and Quality of Life. Monterey, California. October 26, 2000, 4F-03o. NERL-RTP-HEASD-00-107.

Shy, C., Creason, Liao, D., Williams, R., Zweidinger, R., Watts, R., Devlin, R., Hazucha, M.,and Nestor, J. Physiological responses of elderly persons to particulate air pollution. Presentation at the 14th Annual Conference on Air Pollution:Science and Regulation. Health Effects Institute Annual meeting, Boston, MA, April 5-7, 1998. NHEERL-RTP-HSD-AB-98-220.

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University of Washington Research Group-Research Abstracts

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Larson, T., Tuttle, T., and Liu, L.-J. S. Measurement of indoor and outdoor $PM_{2.5}$ andlight scattering coefficient at selected residences in Seattle, WA. 2000 PNWIS/AWMA 40thAnnual Conference, Victoria, BC, Canada, Nov 8-10, 2000.

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Harvard School of Public Health Research Group-Research Abstracts

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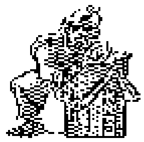
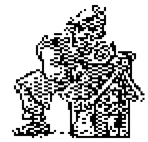
APPENDIX C

Residence Survey, Daily Follow Up Questionnaire, and Activity Pattern Diary



Residence Survey



1

Address:

Building Characteristics

1. Type of dwelling:

( ) Detached house | ( ) High rise apt. (>3 floors)
( ) Duplex/triplex | ( ) Trailer
( ) Row house | ( ) Other, please specify ______
( ) Low rise apt. (1-3 floors)

2. Approximate age of building (years): ☐

3. Is the dwelling located within 100 yards of a busy roadway? Y ( ) N ( )

4. Is there a dirt road located within 100 yards of the dwelling? Y ( ) N ( )

5. Are there any other sources of dust (construction, industry, commercial garage, etc.) located within 100 yards of the dwelling? Y ( ) N ( )

6. What type of garage, if any, is there in the dwelling?

( ) None, detached, or separate carport | ( ) Attached | ( ) Underneath

6. a. Is this garage used for:

( ) Parking one car | ( ) Parking two cars | ( ) Storage only

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Ventilation Characteristics

1. How many separate central AC or window/wall units are in the home?

☐ Central AC units | ☐ Window/wall AC units

2. What are the heating sources in the home?

( ) Radiators (steam or hot water) | ( ) Kerosene space heater
( ) Forced air | ( ) Wood burning stove
( ) Open stove | ( ) Fireplace
( ) Electric space heater | ( ) Other, please specify ______
( ) Gas space heater

00070

Residence Survey 2

Address:

Ventilation Characteristics (cont.)

3. Is there a whole-house or attic fan? Y N

4. What is the thermostat setting? (F)

5. Are there storm windows? Y N

6. How would you best describe the VENTILATION in this dwelling?

Well Ventilated — Very Stuffy

Cooking/Fuel Characteristics

1. What type of cooking fuel is used?
Gas Electric Other, please specify:

2. Is there a fan over the cooking stove, range, oven, or elsewhere in the kitchen area? Y N

3. How does this fan work?
Kitchen exhaust vented outside Other, please specify:
Recirculation of indoor air Don't know
Charcoal filter

4. Is there a pilot light on a:
Gas range Oven Clothes dryer

5. Is there a clothes dryer? Y N

5. a. Is the clothes dryer vented out of the dwelling? Y N

6. What type of filter bag is used in the vacuum cleaner?
Standard vacuum filter
High efficiency filter (HEPA)
Other, please specify:

50020

Residence Survey

3

Address:

Room Characteristics

Draw a floor plan of the space in the space provided below. Include windows, curtains/drapes, and location of ventilation system supplies and returns.

Residence Survey

4

Address:

	Room	% of floor covered by rug or carpet	Presence of molds, mildew, water damage: Y	Presence of molds, mildew, water damage: N	Dust factor for room: Clean … Dusty
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

Daily Follow-Up Questionnaire
(Technician Administered)

Participant ID   Start Date (yesterday's date)

A A B C D   MM / DD / YY

A=participant ID #
B=cohort
C=season
D=sampling location (P)

Survey Approved
OMB Control No. 2080-0058
Approval Expires 7/31/2002

This is an automated form. Please fill it out carefully, staying within the designated boxes. Please use military time.

1. How many people spent at least 4 hours in your home in the last 24 hours? [ ]

1a. Did you smoke cigarettes or cigars in the last 24 hours? [ ] Cigarettes [ ] Cigars

1b. How many people, including visitors, smoked cigarettes or cigars inside your home in the last 24 hours? [ ]

1c. About how many cigarettes were smoked? [ ] About how many cigars were smoked? [ ]

2. Were any meals cooked using the stove in your home in the last 24 hours? ○ Yes ○ No

2a. How many times did you use the stove in the last 24 hours? [ ]

2b. Did you use the stove for any of the following activities? About what time?

○ Frying   Time #1 [ ]:[ ]

○ Grilling   Time #2 [ ]:[ ]

○ Sauteeing   Time #3 [ ]:[ ]

○ Broiling

2c. Did you burn any food in the last 24 hours? (e.g., toast?) ○ Yes ○ No

2d. Was the exhaust fan used for any cooking activity? ○ Yes ○ No

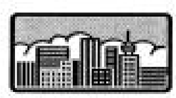
3. Did you use any of the following? About what time? How long?

Candles?	Time of day?	Duration of burning (minutes)?
○ Yes ○ No	[ ]:[ ]	[ ]
Incense?	**Time of day?**	**Duration of burning (minutes)?**
○ Yes ○ No	[ ]:[ ]	[ ]

4. Did you use an ultrasonic or 'cool mist' humidifier in your home in the last 24 hours? ○ Yes ○ No

4a. If so, what type of water did you use in the humidifer?

○ tap water
○ bottled, distilled, deionized water
○ other, please specify: ____________________



4b. About what time did you use a humidfier?

Turned humidifier on: [ ]:[ ]   Turned humidifier off: [ ]:[ ]

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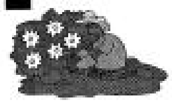
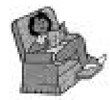
Daily Follow-Up Questionnaire
(Technician Administered)



Participant ID: ☐☐☐☐☐ (A A B C D)

Start Date (yesterday's date): ☐☐ / ☐☐ / ☐☐ (MM DD YY)

5. Did you have any windows open in the last 24 hours? ○ Yes ○ No



5a. How many windows were open in the last 24 hours? ☐☐

5b. About how many inches wide were they open?

Window #1	Window #2	Window #3	Window #4
☐☐	☐☐	☐☐	☐☐

5c. About how many hours were the windows open?

Window #1	Window #2	Window #3	Window #4
☐☐	☐☐	☐☐	☐☐

6. Did you use a gas or kerosene fired space heater or gas stove to heat your home? ○ Yes ○ No

6a. About how many hours did you use either of these? Heater? ☐☐ Stove? ☐☐

7. Did you or someone else clean in the last 24 hours? ○ Yes ○ No

7a. Did you or someone else do any of the following activities?

○ Vacuuming
○ Dusting
○ Sweeping

About what time of day?

Time vacuuming	Time dusting	Time sweeping
☐☐:☐☐	☐☐:☐☐	☐☐:☐☐

8. Did you use an air cleaner in the last 24 hours? ○ Yes ○ No

8a. If so, which of the following air cleaning device(s) did you use?

○ Ion generator
○ Electrostatic precipitator
○ Filter
○ Other, please specify: ______________________

8b. About what time did you use an air cleaner?

Time air cleaner turned on:	Time air cleaner turned off:
☐☐:☐☐	☐☐:☐☐

9. Were there any pets inside your home in the last 24 hours? ○ Yes ○ No

9a. If so, how many? ☐☐

28573

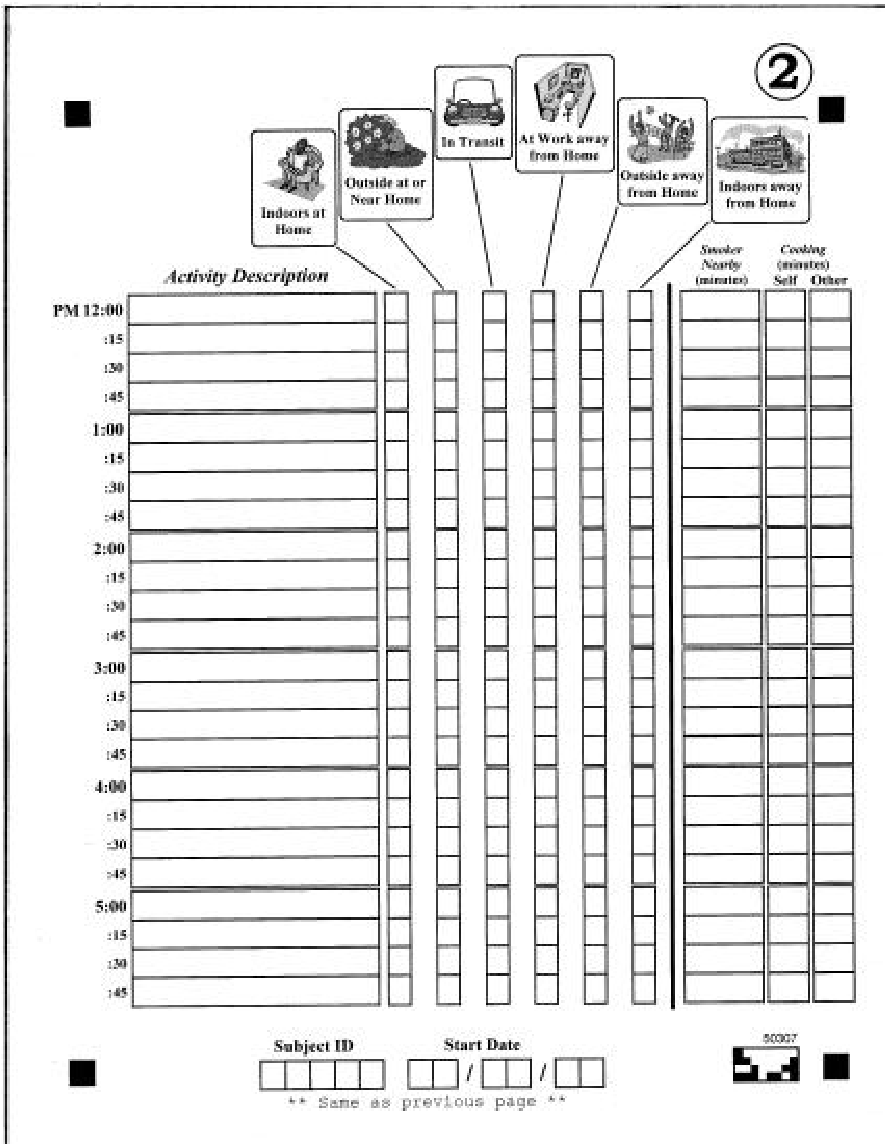
Survey Approved
OMB Control No. 2080-0058
Approval Expires 7/31/2002

①

	Activity Description	Indoors at Home	Outside at or Near Home	In Transit	At Work away from Home	Outside away from Home	Indoors away from Home	*Smoker Nearby* (minutes)	*Cooking* (minutes) Self	Other
AM 6:00										
:15										
:30										
:45										
7:00										
:15										
:30										
:45										
8:00										
:15										
:30										
:45										
9:00										
:15										
:30										
:45										
10:00										
:15										
:30										
:45										
11:00										
:15										
:30										
:45										

Tech. Init. ☐☐ **Subject ID** ☐☐☐☐☐ **Start Date** ☐☐ / ☐☐ / ☐☐
M M / D D / Y Y

50088



2

	Activity Description	Indoors at Home	Outside at or Near Home	In Transit	At Work away from Home	Outside away from Home	Indoors away from Home	Smoker Nearby (minutes)	Cooking (minutes) Self	Cooking (minutes) Other
PM 12:00										
:15										
:30										
:45										
1:00										
:15										
:30										
:45										
2:00										
:15										
:30										
:45										
3:00										
:15										
:30										
:45										
4:00										
:15										
:30										
:45										
5:00										
:15										
:30										
:45										

Subject ID ☐☐☐☐☐ Start Date ☐☐ / ☐☐ / ☐☐

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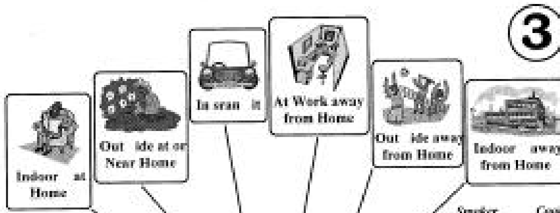

	Activity Description	Indoor at Home	Out ide at or Near Home	In sran it	At Work away from Home	Out ide away from Home	Indoor away from Home	*Smoker Nearby (minutes)*	*Cooking (minutes)* Self	Other
PM 6:00										
:15										
:30										
:45										
7:00										
:15										
:30										
:45										
8:00										
:15										
:30										
:45										
9:00										
:15										
:30										
:45										
10:00										
:15										
:30										
:45										
11:00										
:15										
:30										
:45										

Subject ID ☐☐☐☐☐ **Start Date** ☐☐ / ☐☐ / ☐☐

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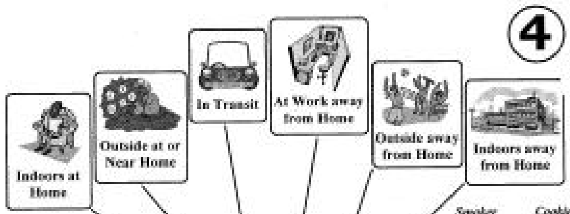
④



	Activity Description	Indoors at Home	Outside at or Near Home	In Transit	At Work away from Home	Outside away from Home	Indoors away from Home	Smoker Nearby (minutes)	Cooking (minutes) Self	Cooking (minutes) Other
AM 12:00										
1:00										
2:00										
3:00										
4:00										
5:00										

** Resume 15 min. intervals **

	Activity Description	Indoors at Home	Outside at or Near Home	In Transit	At Work away from Home	Outside away from Home	Indoors away from Home	Smoker Nearby (minutes)	Cooking (minutes) Self	Cooking (minutes) Other
6:00										
:15										
:30										
:45										
7:00										
:15										
:30										
:45										
8:00										
:15										
:30										
:45										
9:00										
:15										
:30										
:45										

Subject ID ☐☐☐☐☐ Start Date ☐☐ / ☐☐ / ☐☐

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APPENDIX D

PM Mass Concentration Data and Field Data Collection Summaries

Table D-1. Summary of Method Performance Data for $PM_{2.5}$ and PM_{10} PEM Samplers (1998 Baltimore Study)

Statistic	$PM_{2.5}$	PM_{10}
number of samples collected	719	170
% samples collected within flow rate specifications (± 20% of 2 lpm)	99	98
% of samples collected within total sampling parameters (meeting nominal flow rate and MDL)	97	98
Mean mass of field blanks	0.72 µg	0.72 µg
Precision of every 20th filter replicate	± 1.99	± 1.99
Estimated MDL (µg/m^3)	0.69	0.69
RMS differences of duplicate field samples (µg/m^3)	± 3.95	± 4.30
Estimated MQL (µg/m^3)	2.08	2.08
% of samples meeting MQL	100	100

MDL = method limit of detection, MQL = method limit of quantification, MQL = 3 X MDL. Values assume 2 lpm flowrate and 1440 minute sample collections.

Table D-2. Summary Statistics of Personal $PM_{2.5}$ Exposures by Date (1998 Baltimore Study)

Sample Day	N (subjects)	Mean	Min	Max	CV
1	12	14.0	9.6	19.4	22.4
2	13	15.9	9.5	30.5	39.7
3	14	24.8	14.2	47.8	33.4
4	0	—	—	—	—
5	13	19.0	14.4	26.1	18.3
6	14	14.5	10.3	20.4	20.1
7	13	6.8	3.0	10.9	35.9
8	0	—	—	—	—
9	14	11.6	8.2	20.2	28.6
10	13	18.3	8.6	26.1	24.2
11	13	11.3	7.4	17.7	28.8
12	11	11.5	7.1	14.8	26.9
13	14	10.7	5.8	16.7	33.5
14	13	11.3	7.5	14.8	19.3
15	0	—	—	—	—
16	11	9.1	5.0	13.6	29.8
17	14	12.4	7.5	19.3	29.0
18	13	14.6	8.8	21.9	29.0
19	13	11.8	7.8	17.1	26.2
20	13	10.0	7.2	15.0	26.1
21	14	9.4	6.2	12.9	21.4
22	0	—	—	—	—
23	13	11.0	7.0	16.4	23.3
24	14	15.0	11.1	19.3	16.1
25	13	8.1	2.4	11.5	38.1
26	14	9.5	4.2	22.6	47.2
27	13	18.1	8.7	33.7	38.0

N=number of successful personal exposure samples collected per day. Dates with no values represent scheduled non-sampling periods

Table D-3. Summary Statistics of $PM_{2.5}$ Mass Concentrations ($\mu g/m^3$) by Measure and Location (1998 Baltimore Study)

	PEM					FRM[1]	
Statistic	Personal	Apartment	Indoor	Outdoor	Ambient	Outdoor	Ambient
Sample size (days)	23	16	26	28	25	28	26
Arithmetic (Geometric) Means	13.0 (12.4)	10.5 (9.5)	9.4 (8.5)	22.0 (19.3)	22.0 (19.2)	19.7 (16.8)	20.4 (17.3)
Min	6.8	3.8	3.7	6.7	8.4	6.8	3.9
Max	24.8	20.5	19.2	51.6	59.3	49.6	55.3
CV	32.4	47.0	46.6	54.5	58.7	58.9	58.9
Ratio[2] to matched ambient PEM or FRM $PM_{2.5}$ monitor	0.70 (n=21)	0.49 (n=14)	0.49 (n=24)	1.03 (n=25)	—	1.05 (n=26)	—
Ratio[3] to co-located PM_{10} PEM	—	0.73 (n=15)	0.92 (n=26)	0.71 (n=28)	0.72 (n=25)	—	—

[1]Federal Reference Method Sampler for $PM_{2.5}$. Arith =arithmetic means, geo = geometric means. Descriptive statistics utlized arithmetic values.
[2]Ratio of matched instrument mass concentration relative to the ambient PEM or the ambient FRM $PM_{2.5}$ sampler. Values in () represent number of daily pairs compared.
[3]Ratio of $PM_{2.5}$ measure to that of a co-located PEM PM_{10} monitor. Values in () represent number of daily pairs compared.

Table D-4. Summary Statistics of PEM PM_{10} Mass Concentrations (µg/m^3) by Location (1998 Baltimore Study)

Statistic	Apartment	Indoor	Outdoor	Ambient
Sample size (days)	15	28	28	26
Arithmetic (Geometric) Means	13.5 (12.5)	11.0 (10.0)	30.0 (27.6)	29.9 (27.3)
Min	7.1	3.5	12.8	12.5
Max	29.8	23.2	65.6	73.6
CV	44.0	45.5	45.6	47.5
Ratio[1] to matched ambient PM_{10} monitor	0.48 (n=14)	0.39 (n=26)	1.05 (n=26)	—

[1]Ratio of mass concentration relative to the ambient PEM PM_{10} sampler. Values in ( ) represent number of daily pairs compared. Descriptive statistics represent arithmetic values.

Table D-5. Summary Statistics of PEM $PM_{10\text{-}2.5}$ Mass Concentrations by Location (1998 Baltimore Study)

Statistic	Apartment	Central Indoor	Outdoor	Ambient
Sample size (days)	15	26	28	25
Arithmetic (Geometric) Means (µg/m^3)	3.5 (3.0)	1.0 (1.7)	8.0 (7.7)	8.0 (6.7)
Min (µg/m^3)	1.3	-3.1	-2.0	0.6
Max (µg/m^3)	9.4	4.8	15.7	15.3
CV (%)	61.9	207.9	46.9	46.5
Ratio[1] to calculated ambient $PM_{10\text{-}2.5}$ variable	1.1 (n=13)	0.3 (n =24)	1.0 (n =25)	—

$PM_{10\text{-}2.5}$ is defined as the mass contained within the $PM_{2.5}$ to PM_{10} size fraction. [1]Ratio of mass concentration relative to the $PM_{10\text{-}2.5}$ value derived from the ambient $PM_{2.5}$ and PM_{10} PEMs. Values in ( ) represent number of daily pairs compared. Descriptive statistics (min, max, CV) represent arithmetic values. Apartment values were calculated from the means from each sample collection day.

Table D-6. Summary Statistics of $Pm_{2.5}$ Mass Concentrations ($\mu g/m^3$) by Sampling Location (Fresno 1)

Statistic	Personal	Apartment	Outdoor	Ambient[1]
Sample size (days)	24	24	28	13
Arithmetic (Geometric) Means ($\mu g/m^3$)	13.3 (11.4)	9.7 (9.1)	20.5 (16.7)	21.7 (18.7)
Min ($\mu g/m^3$)	0.4	3.8	3.8	6.1
Max ($\mu g/m^3$)	23.8	16.7	52.0	36.8
CV (%)	39.6	34.1	65.1	48.3
Ratio[2] to matched outdoor monitor	0.74 (n=23)	0.54 (n=23)	—	1.32 (n=13)
Ratio[3] to co-located PM_{10} monitor	—	0.64 (n =24)	0.73 (n =28)	0.65 (n=10)

Descriptive statistics (min, max, CV) represent arithmetic values. [1]Platform $PM_{2.5}$ measurements were made by an FRM instrument. [2]Ratio of matched instrument mass concentration relative to outdoor $PM_{2.5}$ PEM. Values in ( ) represent number of daily pairs compared. [3]Ratio of $PM_{2.5}$ measure to that of a collocated PM_{10} monitor. Values in ( ) represent number of daily pairs compared.

Table D-7. Summary Statistics of PM_{10} Mass Concentrations ($\mu g/m^3$) by Sampling Location (Fresno 1)

Statistic	Apartment	Outdoor	Ambient[1]
Sample size (days)	24	28	28
Arithmetic (Geometric) Means ($\mu g/m^3$)	15.1 (14.5)	28.2 (23.6)	34.1 (27.3)
Min ($\mu g/m^3$)	8.2	5.6	2.7
Max ($\mu g/m^3$)	22.8	62.7	76.1
CV (%)	27.8	56.2	54.4
Ratio[2] to matched outdoor monitor	0.62 (n=24)	–	1.09 (n=28)

Descriptive statistics (min, max, CV) represent arithmetic values. [1]Platform PM_{10} measurements were made by a continuous TEOM instrument. [2]Ratio of matched instrument mass concentration relative to outdoor PM_{10} PEM. Values in ( ) represent number of daily pairs compared. Apartment values were calculated from the means over each sample collection day.

Table D-8. Summary Statistics of $Pm_{2.5}$ Mass Concentrations (µg/m³) by Sampling Location (Fresno 2)

Statistic	Personal	Apartment	Outdoor	Ambient[1]
Sample size (days)	12	24	28	28
Arithmetic (Geometric) Means (µg/m³)	11.1 (10.8)	8.0 (7.8)	10.1 (9.6)	8.6 (8.2)
Min (µg/m³)	7.2	4.3	4.6	4.3
Max (µg/m³)	15.8	12.0	20.2	16.1
CV (%)	22.8	21.2	31.9	34.3
Ratio[2] to matched outdoor monitor	1.15 (n=12)	0.84 (n=24)	–	0.83 (n=28)
Ratio[3] to co-located PM_{10} monitor	–	0.47 (n =24)	0.36 (n =28)	0.41 (n=28)

Descriptive statistics (min, max, CV) represent arithmetic values. [1]Platform $PM_{2.5}$ measurements were made by a continuous TEOM instrument. [2]Ratio of matched instrument mass concentration relative to outdoor $PM_{2.5}$ PEM. Values in ( ) represent number of daily pairs compared. [3]Ratio of $PM_{2.5}$ measure to that of a collocated PM_{10} PEM monitor. Values in ( ) represent number of daily pairs compared.

Table D-9. Summary Statistics of PM_{10} Mass Concentrations (µg/m³) by Sampling Location (Fresno 2)

Statistic	Personal	Apartment	Outdoor	Ambient[1]
Sample size (days)	12	24	28	28
Arithmetic (Geometric) Means (µg/m³)	37.3 (36.7)	16.7 (16.5)	28.7 (28.0)	21.9 (21.0)
Min (µg/m³)	27.8	12	17.3	8.7
Max (µg/m³)	51.6	22.6	41.4	36.3
CV (%)	19.3	14.4	23.0	27.2

Ratio[2] to matched outdoor monitor	—	0.59 (n=24)	—	0.76 (n=28)

Descriptive statistics (min, max, CV) represent arithmetic values. [1]Platform PM_{10} measurements were made by a continuous TEOM instrument. [2]Ratio of matched instrument mass concentration relative to platform PM_{10} PEM. Values in ( ) represent number of daily pairs compared. Apartment values were calculated from the means over each sample collection day.

Table D-10. NERL/NHEERL/RTI RTP Panel Study $PM_{2.5}$ Mass Concentration Summary (2000-2001)

Summer 2000 Cardiac Defibrillator Panel

Variable	n(days)	mean	gmean	cv	min	max
ambient	21	22.7	21.9	27.3	14.5	35.0
indoor	21	22.8	20.1	57.1	7.0	64.9
outdoor	21	23.7	22.7	29.3	12.4	39.1
personal	21	28.4	26.0	46.6	14.9	74.9

Summer 2000 African-American Panel

Variable	n(days)	mean	gmean	cv	min	max
ambient	51	20.9	19.5	37.3	7.3	37.1
indoor	51	18.8	17.2	43.2	6.6	45.0
outdoor	51	23.0	21.3	36.5	6.4	39.9
personal	50	25.6	22.2	67.0	8.7	99.5

Fall 2000 Cardiac Defibrillator Panel

Variable	n(days)	mean	gmean	cv	min	max
ambient	20	19.5	17.2	47.3	6.0	41.0
indoor	21	24.2	20.0	69.2	7.7	80.0
outdoor	21	19.5	17.4	47.2	7.5	42.4
personal	21	26.8	24.5	40.1	9.0	48.2

Fall 2000 African-American Panel

Variable	n(days)	mean	gmean	cv	min	max

ambient	40	19.0	16.4	54.3	6.0	45.5
indoor	42	21.5	19.1	50.2	5.7	49.6
outdoor	42	19.2	16.9	50.9	5.9	46.9
personal	42	23.9	21.5	49.0	8.3	60.4

Table D-10 (cont'd). NERL/NHEERL/RTI RTP Panel Study $PM_{2.5}$ Mass Concentration Summary (2000-2001)

Winter 2000 Cardiac Defibrillator Panel

Variable	n(days)	mean	gmean	cv	min	max
ambient	20	15.2	14.0	40.5	5.0	26.5
indoor	21	16.0	12.9	70.1	4.1	49.2
outdoor	21	13.6	12.4	47.7	6.2	33.8
personal	21	26.0	21.0	76.3	7.8	85.9

Winter 2001 African-American Panel

Variable	n(days)	mean	gmean	cv	min	max
ambient	41	14.8	13.4	44.7	5.0	32.9
indoor	42	13.9	12.7	48.1	5.2	38.4
outdoor	42	16.1	14.9	38.6	5.2	31.6
personal	42	19.4	18.2	38.1	9.7	36.1

Spring 2001 Cardiac Defibrillator Panel

Variable	n(days)	mean	gmean	cv	min	max
ambient	21	15.9	14.9	31.9	5.8	25.0
indoor	20	23.9	20.6	58.3	8.7	51.1
outdoor	16	18.7	17.6	35.9	7.6	36.4
personal	19	29.3	27.4	36.4	13.3	48.1

Spring 2001 African-American Panel

Variable	n(days)	mean	gmean	cv	min	max
ambient	35	17	16.0	34.4	5.8	29.3
indoor	35	18.1	16.7	43.2	5.9	44.1
outdoor	30	19.5	18.4	33.0	7.8	31.9
personal	35	21.3	20.1	35.4	9.6	49.9

Table D-11. NERL/NHEERL/RTI RTP Panel Study PM_{10} Mass Concentration Summary (2000-2001)

Summer 2000 Cardiac Defibrillator Panel						
Variable	n(days)	mean	gmean	cv	min	max
ambient	21	30.5	29.7	22.9	16.8	46.4
indoor	21	28.0	25.2	49.2	8.5	71.9
outdoor	21	31.5	30.6	25.1	19.0	53.3

Summer 2000 African-American Panel						
Variable	n(days)	mean	gmean	cv	min	max
ambient	51	29.6	27.7	34.7	11.1	53.2
indoor	51	24.5	22.7	38.8	9.2	49.5
outdoor	51	31.8	29.9	34.1	10.4	61.4

Fall 2000 Cardiac Defibrillator Panel						
Variable	n(days)	mean	gmean	cv	min	max
ambient	21	34.2	30.2	46.8	8.1	74.9
indoor	21	30.4	27.5	44.7	12.5	51.8
outdoor	21	28.6	26.4	38.1	10.2	47.1

Fall 2000 African-American Panel						
Variable	n(days)	mean	gmean	cv	min	max
ambient	42	32.9	28.1	55.8	8.1	84.7
indoor	42	29.5	27.0	42.8	9.3	63.2
outdoor	42	29.1	26.3	45.6	9.1	67.5

Table D-11 (cont'd). NERL/NHEERL/RTI RTP Panel Study PM_{10} Mass Concentration Summary (2000-2001)

Winter 2001 Cardiac Defibrillator Panel

Variable	n(days)	mean	gmean	cv	min	max
ambient	21	22.7	20.9	37.0	4.8	38.7
indoor	20	34.5	25.8	91.1	6.5	147.8
outdoor	21	21.5	20.0	38.1	10.9	39.1

Winter 2001 African-American Panel

Variable	n(days)	mean	gmean	cv	min	max
ambient	41	23.6	21.8	37.3	4.8	42.7
indoor	42	24.1	22.8	36.7	12.4	48.8
outdoor	42	25.4	24.1	33.2	11.1	50.1

Spring 2001 Cardiac Defibrillator Panel

Variable	n(days)	mean	gmean	cv	min	max
ambient	19	47.8	42.1	52.0	14.7	105.0
indoor	20	36.8	32.6	48.4	10.2	71.8
outdoor	21	43.9	38.5	48.9	9.7	94.8

Spring 2001 African-American Panel

Variable	n(days)	mean	gmean	cv	min	max
ambient	33	42.6	38.8	47.6	14.7	105.0
indoor	35	29.4	28.0	33.2	12.6	58.5
outdoor	35	40.0	38.1	30.9	14.4	74.0

Table D-12. NERL/NHEERL/RTI RTP Panel Study $PM_{10-2.5}$ Mass Concentration Summary (2000-2001)

Summer 2001 Cardiac Defibrillator Panel

Variable	n(days)	mean	gmean	cv	min	max
ambient	6	6.9	7.8	15.6	5.3	8.4
indoor	21	5.5	5.8	54.0	1.5	11.4
outdoor	21	8.3	8.9	31.8	3.5	14.2

Summer 2000 African-American Panel

Variable	n(days)	mean	gmean	cv	min	max
ambient	13	7.5	8.3	28.8	4.5	11.4
indoor	51	5.8	5.6	77.7	0.1	19.8
outdoor	51	8.7	9.0	48.8	3.9	25.0

Fall 2000 Cardiac Defibrillator Panel

Variable	n(days)	mean	gmean	cv	min	max
ambient	6	14.0	14.0	46.9	8.4	26.3
indoor	21	8.5	8.3	45.8	-0.4	14.9
outdoor	21	9.3	9.0	55.0	1.3	20.5

Fall 2000 African-American Panel

Variable	n(days)	mean	gmean	cv	min	max
ambient	12	12.1	12.2	45.9	5.8	26.3
indoor	42	8.0	7.5	59.7	-0.8	20.9
outdoor	42	9.8	9.9	43.8	3.0	20.4

Table D-12 (cont'd). NERL/NHEERL/RTI RTP Panel Study $PM_{10-2.5}$ Mass Concentration Summary (2000-2001)

Winter 2001 Cardiac Defibrillator Panel						
Variable	n(days)	mean	gmean	cv	min	max
ambient	5	6.2	6.8	45.7	3.5	10.6
indoor	19	16.6	12.4	153.7	-1.1	116.6
outdoor	19	8.4	7.6	81.0	1.6	24.7

Winter 2001 African-American Panel						
Variable	n(days)	mean	gmean	cv	min	max
ambient	12	5.4	6.1	38.3	2.6	10.6
indoor	42	10.2	9.8	72.9	3.3	39.8
outdoor	42	9.7	9.1	65.8	1.6	30.0

Spring 2001 Cardiac Defibrillator Panel						
Variable	n(days)	mean	gmean	cv	min	max
ambient	4	19.1	18.3	51.4	8.8	32.1
indoor	13	12.5	12.3	37.4	3.6	22.7
outdoor	13	26.8	20.8	72.6	2.4	58.4

Spring 2001 African-American Panel						
Variable	n(days)	mean	gmean	cv	min	max
ambient	8	15.9	14.9	48.7	8.4	32.1
indoor	30	10.7	11.1	37.4	5.1	19.4
outdoor	30	19.2	18.4	49.6	5.8	47.8

Table D-13. $PM_{2.5}$ Mass Concentrations from the Atlanta HSPH Studies by Panel

Season	Panel	Sample Type	Mean	Median	Std. Dev.	Count	GSD	Geomean
Fall 1999	COPD	Personal	19.3	15.2	15.7	92	1.79	16.0
		Indoor	17.5	12.7	22.9	93	2.17	12.6
		Outdoor	18.0	14.5	21.8	81	1.96	13.9
	MI	Personal	15.5	12.3	8.5	56	1.76	13.3
		Indoor	14.4	12.2	9.4	56	1.71	12.4
		Outdoor	16.2	11.9	13.4	57	1.77	13.3
Spring 2000	COPD	Personal	15.3	13.5	8.2	87	1.76	13.3
		Indoor	18.1	14.6	13.8	82	2.04	14.3
		Outdoor	22.4	21.2	9.8	82	1.63	20.1
	MI	Personal	13.5	13.8	6.1	63	2.36	11.0
		Indoor	21.2	15.4	14.9	62	1.82	17.6
		Outdoor	22.9	20.4	11.3	55	1.94	19.5

GSD= geometric standard deviation. Count= number of independent filter-based samples collected.

Table D-14. $PM_{2.5}$ Mass Concentration Summary from the Atlanta HSPH Studies

	Fall 1999			Spring 2000		
	Personal	Indoor	Outdoor	Personal	Indoor	Outdoor
Mean	17.9	16.3	17.2	14.5	19.4	22.4
Median	14.7	12.5	13.8	13.6	14.9	20.8
SD	13.6	19.0	18.8	7.4	14.3	10.6
Count	148	149	138	150	144	138
GSD	1.8	2.0	1.9	2.1	2.0	1.8
Geomean	14.9	12.5	13.7	12.3	15.6	19.9

Table D-15. Collected Samples from the Winter 1999-2000 & Summer 2000 Boston Field Studies

Personal Winter n=105 Summer n= 105	2nd Personal Winter n=56 Summer n= 56	Indoor Winter n=105 Summer n=105	Outdoor Winter n=105 Summer n=98	Misc. n= 25
$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	Household questionnaire
PM_{10} (summer only)	PM_{10} (summer only)	PM_{10}	PM_{10}	Floor plan of home
EC-OC	EC-OC	EC-OC	EC-OC	—
Sulfate	Sulfate	Sulfate	Sulfate	—
Ozone	Ozone	Ozone	Ozone	—
SO_2	SO_2	SO_2	SO_2	—
NO_2	NO_2	NO_2	NO_2	—
Time activity diary	Time activity diary	Air exchange rate	Air exchange rate	—
Daily follow-up questionnaire	Daily follow-up questionnaire	Continuous temp. and RH	Continuous temp. and RH	—
Motion sensor	Motion sensor	Continuous CO	Continuous CO (only 1 location during summer)	—

Table D-16. Collected Samples from Each Season of the Winter 1999-2000 & Summer 2000 Los Angeles Field Study

Personal (n= 105)	Indoor (n=105)	Outdoor (n=105)	Misc. (n= 23)
$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	Household questionnaire
PM_{10}	PM_{10}	PM_{10}	Floor plan of home
EC-OC	EC-OC	EC-OC	—
Nitrate	Nitrate	Nitrate	—
Ozone	Ozone	Ozone	—
SO_2	SO_2	SO_2	—
NO_2	NO_2	NO_2	—
Time activity diary	Air exchange rate	Air exchange rate	—
Daily follow-up questionnaire	Continuous temp. and RH	Continuous temp. and RH	—
Motion sensor	Continuous CO	Continuous CO	—

Table D-17. Summary of PM Measurements from the 1999-2000 Seattle Panel Study

Location	Pollutant	Subjects	N	Mean	SD	Min	Max
Personal	$PM_{2.5}$ (µg/m^3)	COPD	458	13.9	11.7	-1.2	81.2
		Healthy	419	12.8	12.2	0.8	103.3
Indoor	$PM_{2.5}$ (µg/m^3)	COPD	458	8.2	5.2	1.0	49.9
		Healthy	419	7.6	4.4	0.4	38.0
	PM_{10} (µg/m^3)	COPD	458	13.4	6.5	2.5	38.6
		Healthy	419	12.5	6.6	1.6	62.2
Outdoor	$PM_{2.5}$ (µg/m^3)	COPD	458	8.7	4.7	1.6	25.7
		Healthy	419	9.3	4.9	1.4	24.6
	PM_{10} (µg/m^3)	COPD	458	13.8	6.7	2.9	54.9
		Healthy	419	14.5	6.8	2.9	54.9
Community site	$PM_{2.5}$ (µg/m^3)	All	880	8.5	4.5	1.4	22.4
	PM_{10} (µg/m^3)	All	880	14.5	8.2	2.7	46.3

Table D-18. Type and Location of Samples Collected in the Seattle Studies (1999-2001)

Measurements	Personal	Indoor	Outdoor	Central Site
PM_{10}	—	HI (10 lpm)	HI (10 lpm)	HI (10 lpm)
$PM_{2.5}$	HPEM (4 lpm)	HI (10 lpm)	HI (10 lpm)	HI (10 lpm)
PM_1	Personal nephelometer	Nephelometer	Nephelometer	Nephelometer
Aerosol number, size	—	DMA, CPCS, APC(1)	DMA, CPCS, APC(1)	DMA, CPCS, APC(1)
EC/OC (1)	HPEM	HI, IOGAPS(2)	HI, IOGAPS(2)	HI, IOGAPS(2)
Gasoline marker	Urine sample	HI/PUF	HI/PUF	HI/PUF & IOGAPS(2)
WS/SVOC(3)	HPEM/PUF	HI/PUF	HI/PUF	HI/PUF
WS biomarker	Urine sample	—	—	—
CO	Breath sample	Langan CO	—	TECO 48/Dasibi 3
NO_2/SO_2	Ogawa badge			
Air exchange rate	—	TelAir/PFT	TelAir	—
Continuous RH	—	Onset logger	—	—
Continuous temp	—	Onset logger	—	—
Compliance	Motor on/off	—	—	—
Time/activity and medication	Diaries	—	—	—
PEF/FEV_1	Airwatch monitor	—	—	—
Pulse rate/O_2	Pulse oximeter	—	—	—
HRV/BP	Holter monitor	—	—	—

(1) Differential mobility analyzer (DMA), condenstaion particle counter sensor (CPCS), and aerodynamic particle counter (APC) were deployed in the Year 2 study. (2) Integrated organic gas and particle samplers (IOGAPS) were deployed in Year 2. (3)WS/SVOC represents woodsmoke-semivolatile organic carbon.

Table D-19. Summary of Personal Samples Collected in the Seattle Studies (1999-2001)

	Panel	# of subjects	# of seasons	Total subject days
Year 1	COPD	15	1	150
		12	2	240
		5	3	150
	Healthy	20	1	200
		11	2	220
Year 2	Heart Diseased	13	1	130
		11	2	220
		1	3	30
	Asthmatics	6	1	60
		13	2	260
Total		107		1660