The Design and Field Implementation of the Detroit Exposure and Aerosol Research Study (DEARS)

Ron Williams[a,*], Anne Rea[b], Alan Vette[a], Carry Croghan[a], Donald Whitaker[a], Carvin Stevens[a], Steve McDow[a], Roy Fortmann[a], Linda Sheldon[a], Holly Wilson[b], Jonathan Thornburg[c], Michael Phillips[c], Phil Lawless[c], Charles Rodes,[c] and Hunter Daughtrey[d]

[a]*US Environmental Protection Agency, National Exposure Research Laboratory, RTP, NC 27711, USA*
[b]*US Environmental Protection Agency, Office of Air Quality Planning and Standards, RTP, NC 27711, USA*
[c]*RTI International, RTP, NC 27709, USA*
[d]*Alion Science and Technology, Durham,NC 27709*

Address all correspondence to Ron Williams, US Environmental Protection Agency, MD E-204-05, Research Triangle Park, NC 27711.
Tel.: +1-919-541-2957; Fax.: +1-919-541-0905.
E-mail: williams.ronald@epa.gov

Keywords: *particulate matter, DEARS, air toxics, personal monitoring, human exposures.*

Running head: The DEARS

Abstract

The US Environmental Protection Agency (US EPA) recently conducted the Detroit Exposure and Aerosol Research Study (DEARS). The study began in 2004 and involved community, residential, and personal-based measurements of air pollutants targeting 120 participants and their residences. The primary goal of the study was to evaluate and describe the relationship between air toxics, particulate matter (PM), PM constituents, and PM from specific sources measured at a central site monitor with those from the residential and personal locations. The impact of regional, local (point and mobile) and personal sources on pollutant concentrations and the role of physical and human factors that might influence these concentrations were investigated. A combination of active and passive sampling methodologies were employed in the collection of PM mass, criteria gases, semivolatile organics (SVOCs), and volatile organic compound (VOC) air pollutants among others. Monitoring was conducted in six selected neighborhoods along with one community site using a repeated measure design. Households from each of the selected communities were monitored for five consecutive days in the winter and and again in the summer. Household, participant and a variety of other surveys were utilized to better understand human and household factors that might affect the impact of ambient-based pollution sources upon personal and residential locations. \A randomized recruitment strategy was successful in enrolling nearly 140 participants over the course of the study. Over 36,000 daily-based environmental data points or records were ultimately collected. This paper fully describes the design of the DEARS and the approach used to implement this field monitoring study and reports select preliminary findings.

Introduction

The US EPA's Clean Air Goal is for the air in every community to be safe and healthy to breathe (US EPA 2004). An intensive five year research effort to further this goal was conducted beginning in 1998 using guidance from the National Research Council (NRC, 1998). One major component of this effort involved longitudinal human exposure panel studies in an effort to better understand the contribution of particulate matter (PM) of ambient origin to total personal exposures over time (Williams et al., 1999; Evans et al., 2000; Williams et al., 2000a,b,c,d; Williams et al., 2002; Williams et al., 2003a,b; Wallace and Williams, 2005; Wallace et al, 2006a,b; McBride et al., 2007). Results from these studies showed that for fine PM mass and sulfate, a central monitoring site could serve as an adequate surrogate for exposure in community-based epidemiological studies (US EPA, 2004). These studies did not attempt to investigate spatial differences across a metropolitan area relative to the composition of PM or the influence of local sources upon such differences. Fine particulate mass and sulfates are often spatially homogeneous with respect to mass concentration, and exposure and health effects using these metrics can be reasonably predicted from central site monitoring data. To ensure that EPA standards protect human health, we must be able to evaluate exposure and health effects for those PM species that will remain after particulate sulfates and other PM components are removed or greatly reduced as a result of reduced emissions. Data show that outdoor to indoor correlations are often poor for several species including ultrafines (Vette et al, 2001). Other studies have shown that outdoor concentrations of elemental carbon and several organic species are non-

homogenous across air sheds and are influenced by both mobile and stationary sources seasonality (Rogge et al., 1993; Li et al., 2005; Olson et al., 2008). For those species that show only weak associations between residential outdoor and central site concentrations or might have multiple localized sources of origin, it is uncertain whether epidemiological studies based on measurements at a central monitoring site will be adequate to evaluate potential individual or population-based health risks from a given source. For these species or sources, data and models will be needed to develop better exposure surrogates for epidemiological studies and risk assessments.

The US EPA's longitudinal PM studies discussed earlier did not attempt to address similar uncertainty issues associated with air toxics. Even so, the US EPA is directed to develop standards that address significant sources of pollutants like industrial and mobile sources and control urban air toxics by developing standards for the smaller area sources. Many of these standards will require a risk assessment, which involves an understanding of how human exposures are affected by specific sources of air toxics. Setting a standard that is defensible and protective of human health requires a comprehensive scientific understanding of exposure to ambient pollutants and the exposure-response relationship.

There have been some notable air toxics human exposure studies conducted in the past. These include the TEAM (Total Exposure Assessment Methodology) studies (Wallace et al.,1985) and the multi-city EXPOLIS (Exposure in Cities) study focusing upon a variety of air pollutants in numerous European cities (Koistinen et al., 1999; Helm et al., 2000; Jurvelin et al., 2000; Boudet et al., 2001; Edwards et al., 2001; Jurvelin et al., 2001; Rotko et al., 2001; Chow et al., 2002).

More recently the RIOPA study (Residential Indoor, Outdoor, and Personal Assessment) has investigated the impact of spatial locations upon multiple air pollutants (Kousa et al., 2002; Naumova et al., 2003; Reff et al., 2004; Meng et al 2005; Weisel et al., 2005; Kwon et al., 2006). The Genotox ER studies conducted in four European cities represent similar efforts to those above and also involved a multi-pollutant monitoring approach (Nerriere et al., 2005, 2006). The impact of spatial locations were included in all of the studies above but they were not specifically designed to aid in the development of human exposure models and had limitations relative to fully estimating the contribution of major line, point, and regional pollutant sources upon personal and residential locations. Linking specific sources with human exposures and their resulting health effects is likely to provide data that can be applied to regulatory policy more quickly, and can help support identification of biologically important characteristics and constituents as well (US EPA, 2004).

Source apportionment techniques are now being incorporated into exposure research in order to evaluate the ambient-personal exposure relationship for PM from various sources as well as for individual PM species (Landis et al., 2001; Hopke et al., 2003; Zhao et al., 2006; Meng et al., 2007; Olson, 2008). Some studies have started to link specific sources with observed human health effects (Riediker et al., 2004; Duvall et al., 2008). It is now recognized that the inclusion of organic marker components into source apportionment is needed to more adequately define source factors (Schauer et al., 1996; Schauer and Cass, 2000; Olson et al., 2008). These efforts have typically focused upon the use of particle-phase organics such as straight-chained hydrocarbons, polynuclear aromatic hydrocarbons, carboxylic acids, hopanes, and sugars as

source markers. More recently, the Multilinear Engine (ME) and Positive Matrix Factorization (PMF) have been used as statistical tools to model these chemical markers (Paatero et al., 1999; Hopke et al., 2003; Zhao et al., 2006). These approaches use a wide number of exposure variables in assigning source contributions and can easily incorporate data on elemental, organic concentrations, and a large number of other exposure variable data into their models. Only a few such studies have incorporated residential and especially personal-based measures in their analyses (Landis et al., 2001). The Detroit Exposure and Aerosol Research Study (DEARS) was designed to provide data that will be used in support of the needs discussed above. PM, semivolatile organics (SVOCs), and volatile organic compounds (VOCs), along with select inorganic and organic pollutant classes were collected to better understand differences in source contributions across a metropolitan area

Study objectives

The DEARS was designed to examine the spatial variability of $PM_{2.5}$ and $PM_{10-2.5}$ and their components as well as select air toxics to determine the suitability of conducting health outcome studies using a central site monitor in a metropolitan area having multiple source impacts. The six major approaches used to meet the primary goal of the study were:

(1) determine the associations between concentrations measured at central site monitors and outdoor residential, indoor residential and personal exposures for selected air toxics, PM constituents, and PM from specific sources,

(2) describe the physical and chemical factors that affect the relationship between central site monitors and outdoor residential and indoor residential concentrations, including those that affect

ambient source impacts,

(3) identify the human activity factors that influence indoor residential concentrations and personal exposures to selected PM constituents and air toxics,

(4) improve and evaluate models used to characterize and estimate residential concentrations of and human exposures to selected air toxics, PM constituents, and PM from specific sources,

(5) investigate and apply source apportionment models to evaluate the relationships for PM from specific sources and to determine the contribution of specific ambient sources to residential concentrations and personal exposures to PM constituents and air toxics, and

(6) determine the associations between ambient concentrations of criteria gases (O_3, NO_2, and SO_2) and personal exposures for these gases as well as personal exposures to air toxics, PM constituents, and PM from specific sources.

One of the primary hypotheses to be investigated involves determining the impact of local and regional sources upon community, neighborhood and potentially personal exposures to air pollutants and the role of various parameters influencing these relationships (e.g., housing stock, personal activities, and meteorology). A full description of the data analysis objectives of the DEARS is available online (www.epa.gov/dears). This paper describes the study design and the field implementation aspects of the DEARS along with some of the preliminary summary statistics of select measurements.

Methods

Selection of the Detroit Area

The Detroit area, specifically Wayne County, was selected for the DEARS because of its current and projected future non-attainment status for $PM_{2.5}$, the number of point and mobile source influences present, its geographic location, its meteorology, the presence of existing ambient monitoring networks, the potential for state and local collaboration, and community-based partnerships (NEI, 2002; Williams, 2005). This area has been reported to contain a large number of potential industrial point sources of PM and air toxics, including coke ovens, iron/steel manufacturing, coal-fired power plants, sewage sludge incineration, automotive industry, refineries, and chemical plants (Keeler et al., 2005; Hammond et al., 2008). The border crossing between Windsor, Canada and Detroit, MI, via the Ambassador Bridge provided a large potential diesel and automotive source from idling motor vehicles. An estimated 10,000 heavy diesel tractor trailers and 30,000 gasoline vehicles cross this bridge every day. There are four major interstates and many heavily traveled roadways in the area which served as potential line sources of vehicle emissions in Detroit and the surrounding Wayne County (Williams, 2008).

The Detroit Air Toxics Pilot Study (DATPS, 2004) involved the collection of PM and various gaseous co-pollutants. Results indicated a significant variability in local air mass concentrations of certain air toxics. In addition, they confirmed the presence of many industrial (point) sources and seasonal variability in the pollutants mass concentrations. This report strengthened our assessment that the Detroit area would be a viable location to field a study like the DEARS. This included the need for it to be a $PM_{2.5}$ non-attainment area and have a variety of neighborhoods impacted differently with respect to local sources (Williams, 2005).

Enumeration Monitoring Areas (EMAs)

A preliminary DEARS pilot study involving three days of environmental measurements was conducted in prospective neighborhoods of interest based upon the information above as well as census information on housing stock, population density, road traffic and other potential exposure variables (Williams, 2008). This monitoring relied on continuous (1-5 minute duration) measurements of carbon monoxide, particulate matter, and polycyclic aromatic hydrocarbons taken at a number of locations within the prospective neighborhoods and on multiple days. These measurements provided the means to determine the relative scale of pollutant concentrations observed across the Wayne County area. The pilot helped determine whether some of the suspected point and line sources (such as mobile source influences in neighborhoods in close proximity to roadways) had observable differences in concentrations that might distinguish them from the other neighborhoods. Data were used to establish those communities that would be targeted for participant recruitment.

The DEARS was designed to recruit approximately 120 participants (10 days each) resulting in a total of 1200 participant days. We attempted to enroll 40 individuals per sampling year (one summer followed by one winter season) and then repeating this process two additional times over the course of a three-year period with new sets of participants. Participants were only monitored during their year of recruitment and no cross-overs to the next monitoring cycle was allowed. The sampling schedule was arranged so that at least one participant from each EMA would be participating each week (total of six participants across all EMAs). This ensured that the environmental monitoring would have the necessary spatial spread.

EMAs 1, 3, 4, 6, and 7 (Figure 1) were involved in the first two seasons of the DEARS.

EMA #2 (Wyandotte) was originally considered for inclusion but ultimately its characteristics were believed to be similar to some of those already involved and therefore was never incorporated into the recruitment strategy. Following the first year, it was determined that EMA 7 had very low concentrations of most pollutants and that personal monitoring there might not be very informative. We therefore reallocated resources and performed only daily outdoor monitoring at a former residential site in EMA 6 during the remainder of the study. As a result, we were then able to perform full personal and residential monitoring for EMA 5 during the last four seasons of the DEARS. Prior to the last year of monitoring it was determined that there would not be a sufficient number of available homes in the EMA 3 area to potentially allow for successful recruiting. We therefore converted EMA 3 to an outdoor only monitoring situation just like that discussed previously for EMA 6 with the exception that we triangulated a series of outdoor monitoring locations around the Ambassador Bridge to further assist our investigations of this potential local source. We also enrolled a second person for one of the remaining EMAs each week to allow for investigations of intra-neighborhood variability.

Study Neighborhoods and Demographics

Residential neighborhoods (EMAs) were selected based on proximity to known or suspected point and line sources. Figure 1 provides a depiction of each EMA selected for inclusion in the DEARS with respect to surrounding areas. Data from the 2000 Census (Census, 2000) was used to estimate potential populations in each EMA, their demographics and their housing stock. Participants were monitored for five consecutive (24-hr) days in each of two consecutive seasons

(summer, winter). Table 1 gives a description of each area, the associated census tracts (Wayne County, MI) and the suggested a priori point and line source impacts. This table shows that a mix of mobile source impacted (diesel or gasoline vehicles) as well as various industrial source impacted areas were selected for inclusion. The various neighborhoods also provided the means examine the influence of housing stock, age, and similar factors. The non-smoking households were required to live in either single family dwellings, or live in duplex-like situations where they had their own heating and cooling systems and did not share any common hallways with other families. This was a requirement to limit the influence of potential PM and air toxic sources from neighbors that could not be documented.

A total of 137 participants enrolled in the DEARS. The over-enrollment (>120) was needed when a participant would complete their first season (summer) followed by self or study-withdrawal prior to their second and final monitoring period (winter). A new enrollee would then be inserted into that season of monitoring to complete the sampling schedule. Study withdrawal occurred when a participant was no longer available or deemed non-compliant with respect to acquiring their full cooperation (primarily availability for household monitoring or tobacco smoke exclusions). Only 18 of the 137 enrollees (13.1%) either removed themselves or were removed from the study.

Study Participant Selection and Recruitment

Selection criteria for participants were: (1) non-smoking, (2) living in a non-smoking household, (3) ambulatory, (4) expectations to live in the same dwelling for the next nine months, (5) living in a detached home, (6) being age 18 or older, and (7) being able to understand either English or

Spanish instructions. There were no health restrictions on enrollment other than being ambulatory. Likewise, there were no enrollment restrictions on occupation, socio-economic-status, sex or ethnicity. The DEARS was a purposeful, randomized household selection. The focus in recruitment was not the individual per se, but the location of the residence and its proximity to other monitoring locations. Volunteers were provided information concerning this observational study and their informed consent was documented. Spanish-speaking interpreters and translated study documents were provided for all participants who could not communicate in English. The observational human exposure research component of the DEARS was approved by an external Institutional Review Board (IRB) prior to the initiation of the study. Participant recruitment documents and the data collection instruments were approved by the RTI International's IRB, and the Office of Management and Budget, respectively. The daily participant burden relative to the personal and residential monitoring was estimated to be ~ 45 minutes/day.

Recruitment was based on the location of the selected EMAs and the households within each EMAs. Census tracts in the EMAs became candidates for the study based upon the local point and line sources, prevailing southwest wind direction, and density of the housing. Once the census tracts were selected, marketing lists with names, addresses, and phone numbers of occupied houses were obtained from Marketing Systems Group (Fort Washington, PA). Geographic coordinates for the addresses were obtained from Tele Atlas (Lebanon, NH) to ensure the residences were located within the target areas. Several stratified cluster samples were then selected for each EMA and a systematic approach was used to ensure geographic

representativeness and protect against selection bias. Recruitment started with the first randomly selected sample cluster for each EMA and continued in serial fashion down each such list until the roster for each EMA was complete. Recruiters worked as far into the list as necessary to get the needed respondents. Homes from new cluster samples were added when all homes available for contact on a previous list had been exhausted. Recruiters followed typical procedures for door-to-door household recruitment that included a lead letter followed by home visits. Respondents who completed all aspects of the study for two consecutive seasons received a maximum of $250 burden compensation as well as two $50 gift cards awarded by local community action groups for their participation.

Recruitment visits were conducted in cooperation with local community action groups. These groups included the Community Action Against Asthma (CAAA) and the Arab Community Center for Economic and Social Services (ACCESS). Working with these groups was an important component in the recruiting process due to their familiarity with the neighborhoods, and their ability to share the value of the DEARS with the local community. A community roll-out meeting was held in June 2004 where the goals and purposes of the DEARS were presented to local community action groups, city and state and regional environmental officials. A DEARS website (www.epa.gov/dears) was established where participants, local institutions and other interested parties could gain the latest information on the study as it progressed.

Participant retention strategy

The DEARS utilized a number of techniques to encourage retention. Participants were provided fact sheets, frequently asked questions, brochures, and a DEARS video explaining the study and

its purpose. In addition, they often received phone calls from the DEARS Principal Investigator following their monitoring to see if they had any additional questions or issues related to their involvement. Recruitment staff called participants between seasons to encourage their retention and inform them of the study schedule. Participants were able to "self-schedule" their monitoring periods for the upcoming seasons. They were provided two exposure monitoring debriefings with the Principal Investigator held between the summer and winter periods. The first was used to update the participants on the progress of the study and their role in making it a success. They were also provided examples the exposure monitoring data packets they would later receive. A second debriefing was held prior to their second season where each participant received their individual exposure data from the prior season. These packets contained summaries of their personal, residential indoor, residential outdoor and community-based concentrations of regulated criteria pollutants such as $PM_{2.5}$ and nitrogen dioxide. In addition, a debriefing with local community leaders was held in October 2007 to provide summaries of pollutant concentrations and preliminary data findings.

Study staffing

Field data collections were performed under contract with RTI International (Durham, NC). Staff familiarized themselves with the many operating procedures followed by two days of intensive hands-on training each season. This training was followed by performing three days of practice runs in a mock participant's home involving all of the study procedures. This training helped to ensure high rates of data collection and quality.

Measurement plan

The DEARS was designed to be conducted over a three year period. The decision to collect 1200 participant-days was established based upon observed historical inter-and intra-variability of $PM_{2.5}$ mass concentrations from previous studies (Williams, 2008). These calculations determined that approximately 800 participant-days (80 participants each monitored for 10 days) would be needed to ensure sufficient statistical power. However, no such historical data was available to establish the needed sampling population to investigate various PM mass components, gas phase or semi-volatile pollutants of interest. Therefore, a goal of 1200 total monitoring days was established for all measures to ensure sufficiency. This length of time was needed to allow for the extensive data collections of approximately 1200 participant monitoring days. Sample collections over such a long period also helped to alleviate any possible concerns of data collections during a single "rogue" season where meteorology might be quite different from normal. Data collections during the extremes of the seasonal calendar (summer and winter) were desired so that the effects of meteorology upon human and environmental factors could be examined. These seasons also offered the greatest potential of having fairly consistent conditions for the longest periods of the calendar year (Williams, 2008).

Daily sampling from Tuesday to Sunday morning was conducted during each monitoring season to evaluate expected daily variations in industrial source emissions, traffic volumes, and personal activities. This was determined to be the best schedule for the collection of five days of continuous measurements having a mixture of weekend and weekday events. Such a schedule

would collect data when a majority of the local industries were operating as well as a typical snapshot of weekly traffic patterns.

Monitoring took place across all of the study platforms starting at a nominal time of 9 am ± 2.5 hr, resulting in no more than a 10% disagreement in any potential site comparison time overlap. A total of six participant homes were involved each day. Figures 2a-d provide representations of the personal, residential indoor, residential outdoor and central community site monitoring platforms used in the study. The DEARS was designed so that in nearly every instance, consistent methodologies were used across the various platforms. Normally this would mean that the same sampler type would be used on all four monitoring locations. A number of passive sampling methodologies were deployed to meet this requirement and minimize participant burden.

Personal monitoring was conducted via a nylon vest (Figure 2a). Use of this vest has been previously reported (Williams et al., 2003a). The vest provided the means to distribute the 4-5 lbs of monitoring equipment on the participant's shoulders in a comfortable manner. It had low dander and was believed to have had low VOC and carbonyl emissions. Sampling inlets were situated in the breathing zone of the participant. A minimum of 5 cm spacing between the various monitor inlets was maintained to prevent pollutant "starvation" issues. The vest was to be worn outside of all clothing regardless of season. DEARS participants were asked to wear the vest at all times with the exception of sleeping, bathing, and clothing changes. There were some incidences where participants did remove their vest such as long periods of sitting on a couch, lying (not sleeping) in bed or similar events. When not worn, the vests were requested to be

suspended nearby on a hanger at the same height as the participant. In addition to monitoring equipment, the vest also contained electronic sensors that helped to determine the degree of participant compliance. Such a system has been previously described (Rodes et al., 2001). This compliance term reflects the percentage of time that the participant actually wore the vest during the planned monitoring period. This can be an important statistic relative to knowing how accurate the "personal" monitoring was. We will describe monitoring compliance in a separate report.

Residential indoor monitoring was performed using an aluminum luggage dolly (Figure 2b). The use of such systems has previously been described (Williams 2000a; Williams 2003a,b; Olson, 2008). Monitors placed on this platform were positioned approximately 1-1.5 m above the floor level and at least 12 inches from any wall surface. This was often in a living room or den. The cart was not placed near known influences like fireplaces, heating and air conditioning vents, direct sunlight, lamps, or in the way of foot traffic.

Residential outdoor monitoring was performed using an aluminum bluff body as well as other weather-shielded sampling inlets (Figure 2c). Inlet heights were at the 2 m level. These systems had low VOC and carbonyl emission features as well as the ability to withstand the Michigan winters. Heater systems were installed in the air pump storage cases. This was needed to prevent pump failures when temperatures often fell below freezing. It was also determined that gentle heating of the active filter-based monitor inlets would be needed to ensure that their inlets remained opened from ice or frost formation. This was accomplished by heating strips on the backs of the monitors warming them to approximately 5 ^{0}C, just enough to prevent inlet freeze-

over from occurring. Outdoor monitors were typically situated in the back yard of each home and if at all possible, fully open with respect to air movement. The preferred location was at least 3 m from any street/driveway or structure, away from the overhang of any tree or building, away from heating and cooling units, and away from bushes or other vegetation. Sampling stands were typically positioned with 2 meters separation from each other.

The central community monitoring site was located at Allen Park, MI (N42 11.808 W83 20.867). This site was kindly provided by the Michigan Department of Environmental Quality (MDEQ) and represented the best fit for placement of the DEARS central site due to its security, positioning relative to the other available MDEQ monitoring locations and the DEARS neighborhoods. DEARS equipment was set up at a site within the larger MDEQ site (double fencing) and only DEARS-authorized personnel had access to the equipment. This particular site had been the subject of a recent 2002 EPA air toxics research study (DATPS, 2004). This provided the means to more accurately determine which possible methodologies had the sensitivities to collect a high percentage of analytes above their detection limits. Aluminum stands and bluff bodies were used to support the monitoring equipment at this site (Figure 2d). Additional spacing between monitors was employed at this site due to operation of a 16.6 lpm dichotomous sampler and a high volume (113 lpm) Tisch sampler used for SVOC collections. Both of these instruments are described in detail later. A minimum of 2 m separation between these and the other lower volume samplers was maintained. All inlets were positioned 2 m above the ground.

Measurement methods

Daily monitoring was based on a 24-hr integrated time period, running from ~ 9 am to 9am. The various methods and sample collection scheme have been summarized in Table 2. The majority of the collected environmental measures were $PM_{2.5}$ based. $PM_{2.5}$ sample collections were collected at all four spatial locations (personal, residential indoor, residential outdoor, and central community) using the Personal Environmental Monitor (PEM). Details about its use have been reported elsewhere (Williams et al., 2000a,b,c,d; Williams et al., 2003a,b; Rodes et al., 2001; Riediker et al., 2004; Olson et al., 2008). The PEM utilizes a 37 mm Teflo filter (Gelman Sciences, Ann Arbor, Michigan). Filter samples collected by the PEM were analyzed by gravimetric analysis following a minimum of 24-hr equilibration in an environmental weighing chamber. The techniques used to perform the gravimetric analysis and considerations to successfully perform these at low mass loadings have been reported elsewhere (Lawless and Rodes, 1999; Williams et al 2000d; Williams et al., 2003a). Following gravimetric analysis, the Teflon filters were analyzed by for selected elements by X-ray Fluorescence (XRF). Details about the normal XRF operational procedures employed for these types of samples have been reported by Dzubay et al., (1988) and Landis et al., (2001).

Personal DataRam-1000 (pDR) nephelometers (Thermo Scientific, Waltham, MA) were operated at all four spatial locations (residential indoor, residential outdoor, ambient and personal) throughout the study. We have reported upon the use of such devices as an aid in determining the impact of daily activities upon a personal's total PM exposure (Rea et al., 2001; Wallace et al., 2006a,b). These same reports provide information on how nephelometric estimates compare with

more traditional filter based approaches. The pDR normally operates in a passive particle diffusion mode. We modified the pDR by placing a 2.5 μm PEM inlet and a short drying column upstream of the pDR's optical bench via short lengths of tubing. Size fractionated particles ($\leq$2.5 μm) entered the optical detector of the pDR and exited past an in-line temperature and relative humidity (RH) sensor. This provided the means to evaluate relative humidity and nephelometer performance. The device was deployed in this manner for the first three seasons. However, the drying column used was determined to occasionally discharge particles causing spurious peaks. This led to the decision to remove the drying train even if this meant loss of data due to RH saturation of the detector as will sometime occur. Nephelometers were operated without the drying tubes for the final three seasons. An analysis of the effects of RH on nephelometer data versus collocated gravimetric samples has recently been completed. This has provided the means to establish a simple algorithm for RH correction of the data from the final seasons. A full description of the modified pDR and the algorithm that has been established will be reported elsewhere.

Additional PEM-based samples were collected for the determination of elemental and organic carbon (EC-OC). These were collected at all locations with the exception of on the person. During the recent Research Triangle Park PM Panel Study (Williams et al., 2003a,b), it was observed that similar collections as those employed here for EC-OC often resulted in excessive OC artifact on personal and indoor samples. This is believed to be due to SVOCs from a variety of indoor sources that have little to do with OC of ambient origin (Ray et al., 2005; Sihabut et al., 2005). While there have been a number of suggested approaches of dealing with the OC artifact

(Turpin et al., 2000; Olson et al., 2005), it was decided such procedures would not be employed in the DEARS due to their expense. Olson et al., (2005) reported that even when utilizing extensive artifact correction methodologies, OC varied by micro-environment, suggesting that systematic OC correction may be difficult. Furthermore, they also reported lower denuder efficiencies compared with previous studies, possibly the result of higher concentrations of polar organic compounds that are expected in micro-environmental samples. Based upon these findings, we determined that there still remained sufficient doubt at this point in a fully acceptable OC correction methodology and therefore none was instituted in the DEARS. PEMs (2.5μm) were therefore deployed with a single 37 mm quartz filter. Filters were analyzed for EC-OC by Sunset Laboratories (Hillsborough, North Carolina) using the NIOSH 5040 protocol (Birch and Cary, 1996).

A novel optical absorbance analysis was performed to estimate black carbon (BC) as well as environmental tobacco smoke (ETS) on the filters collected by the PEM and other non-quartz based filters. This technique involved a spherical photometer as previously described (Lawless et al., 2004). While this device was not expected to be equivalent to more sophisticated methodologies attempting to determine carbonaceous species (like EC-OC), or even the components of ETS, data from this device was immediately useful in the field in situations were ETS compliance with the participants came into question. A portable unit was placed in the field laboratory where filters were examined for ETS impact. Such data provided field staff with the ability to quickly investigate high ETS samples with the participants and determine if this was an issue of compliance or passive exposure beyond their control.

A prototype personal coarse PM monitor (C-PEM) was designed by RTI International and evaluated in the DEARS. It was designed to directly collect both $PM_{2.5}$ and $PM_{10-2.5}$ size fractions on Teflon-based media using a 2 lpm sampling rate. Data collections were limited to non-personal locations. A dichotomous sampler at the central community site was operated to aid in its evaluation. Gravimetric analyses were performed as previously described. Patent rights are currently being pursued for this RTI International device and specifics about its operation will be reported elsewhere.

$PM_{2.5}$ particle-bound nitrate was collected at all locations (except personal) using mini-denuders. The mini-denuder operated at a 0.8 lpm flow rate and consisted of a size selective inlet, two honeycomb denuders, and a single 15 mm sodium carbonate coated glass fiber filter. The design and evaluation of this sampler have been reported by Demokritou et al (2001).

Nitrogen dioxide, sulfur dioxide, and ozone were collected using Ogawa passive dosimeters. Nitrite-coated filters were used for the collection of gaseous ozone and triethylamine-coated filters were used for the separate collection of nitrogen dioxide and sulfur dioxide. These filters were subsequently extracted with water and the extracts analyzed by ion chromatography. These devices have been used previously in other EPA air monitoring studies and the details of their use reported (Varns et al., 2001; Murkerjee et al., 2004). These devices are typically capable of producing environmental limits of detection on the order of 3-5 ppb for these named gases based upon a 24-hr integrated sampling period.

Three carbonyls (formaldehyde, acetaldehyde and acrolein) were measured as part of the DEARS at all spatial localities. This was performed using a passive monitor, the Personal

Aldehyde and Ketone Sampler (PAKS). Zhang et al., (2000) have published upon this passive monitor and the theory behind its development. It utilized a C-18 absorbent bed coated with dimethylaminonaphthalene-1-sulfonyl hydrazine (dansyl hydrazine) contained within a polyethylene cartridge. The recovered PAKS were extracted with 2 ml of acetonitrile and then analyzed via HPLC with fluorescence detection. Theoretical PAKS sampling rates of 4.6 ml/min for acrolein at temperatures of 25 °C have been reported (Zhang et al., 2000). Formaldehyde and acetaldehyde had slightly higher reported sampling rates. A full description of the use of the PAKS in the DEARS will be reported in the future.

VOCs were collected using 89 mm X 6.4 mm o.d. Perkin Elmer ceramic-coated stainless steel diffusion tubes at all spatial locations. These automated thermal desorbtion tubes were loaded with 40/60 Carbopack X (Supleco, Bellefonte, PA). McClenny et al., (2005) have reported upon this methodology and its applicability for 24 hr integrated monitoring as was performed in the DEARS. While the device has the capability of collecting a large number of VOCs, a total of 25 were ultimately selected for the DEARS relative to their value for future source apportionment modeling (Williams, 2008). These included a mixture of nine aromatics (e.g., benzene, toluene), and 16 chlorinated hydrocarbons (e.g., carbon tetrachloride, chlorobenzene). The minimum detection limit for a majority of these have been determined to be under 40 ppt (parts per trillion) for a 24-hr sampling period.

Particle-bound SVOCs were collected at all locations except for personal. Harvard Impactors (HI) operating at 10 lpm and employing a single 37 mm Teflo filter (Gelman Sciences, Ann Arbor, Michigan) were used. Williams et al., (2003a) and Liu et al., (2003) have previously reported

upon the use of this sampler for indoor and outdoor PM air monitoring. Comparisons of the HI and the PEM have been reported by Wallace et al., (2003, 2006b). Williams et al., (2000d) have suggested potential SVOCs losses with the PEM and the HI used here for such collections and operating at a higher flow rate than the PEM might be more susceptible to such loses. Olson et al., (2008) have demonstrated that daily residential samples collected at 10 lpm for 24 hr using the HI can provide sufficient material for the determination of many important molecular markers for source apportionment.

A larger collection of SVOCs was performed at the community monitoring site using a Tisch -TE-1202 high volume sampler (Tisch Environmental, Cleveland, OH). McDow et al., (2008) have reported upon the use and subsequent analysis of organic markers from this sampler from a recent study. This $PM_{2.5}$ size fractionated cyclonic monitor operated at a nominal flow rate of 113 lpm and employed a 10 cm quartz fiber filters (Gelman Sciences, Ann Arbor, Michigan). Operating this sampler enabled us to collect ~ 160 m^3 of air in a given 24-hr sampling period. All of the preliminary organic marker research needed for source apportionment in the DEARS would first be performed using these samples from the community site. Data from this analysis would then be used to determine which markers might be routinely and successfully measured using the 10 lpm HI samples collected from the residential indoor and residential outdoor locations.

Daily residential indoor air exchange (AE) values were estimated for every home. This was performed using the perfluorocarbon tracer (PFT) method first reported by Dietz and Cote (1982) and Dietz et al., (1986). The preparation of the tracer sources and the tracer receptor tubes was performed under contract to the Brookhaven National Laboratory (BNL-Upton, NY). Guidance

was provided by BNL relative to the types and numbers of tracer sources placed in each home. Source(s) were placed in the homes 24 hr prior to the first day of measurement to allow for adequate distribution.

A total of five survey instruments were used in the DEARS. In brief, these survey instruments provided the means to collect information such as:

- participant descriptors such as age, gender, occupation, ethnicity,
- detailed description of each house, including room size/volumes, heating and air conditioning systems,
- potential activities that might be associated with known or suspected sources of PM, VOC, SVOCs, carbonyls other pollutants of interest,
- daily time activity diaries based upon 15-min intervals of both location, activity and level of exertion. This diary was also used to record participant-recalled exposure events, and
- source surveys taken within a 0.5 mile radius of the participant's home in which observable or potential pollutant sources where logged. Logging was done using geo-positioning (GPS) equipment. Examples of such sources were gas stations, busy highways, construction sites, and train tracks to name but a few. No attempts were made to directly estimate source strengths from these observations.

Quality assurance

Initial data quality indicators (DQIs) were established based upon either historical or anticipated results and are reported in Table 3. In some cases, the listed DQIs for minimum detection limits

were significantly reduced as the study progressed. Written operating procedures were developed before the study and then used in the training of all field and laboratory staff. Operating procedures and the project's comprehensive Quality Assurance Project Plan were examined after every season in order to improve data collection and quality. The DEARS had a large quotient of quality assurance and quality control samples built into its design. Blank media (e.g., PM filters, Ogawa badges, Perkin Elmer tubes) were analyzed prior to the initiation of each season to ensure that media of acceptable quality was available. Normally, a single lot of media or a relatively small number of lots were used to assist in the determination of laboratory blanks. Field and shipping blanks often exceeded 10% of the samples for a given environmental measure each season. Blank data were then used to correct all raw field data. Negative values being reported here are the result of such data corrections from field and laboratory blanks. A minimum of 5% field sampling duplicates were performed for a majority of all measures with the exception of some personal monitoring procedures (e.g., $PM_{2.5}$ nephelometry) due to participant burden concerns. Laboratory duplicates (where samples could be split or reanalyzed) were performed for a minimum of 5% of the samples collected..

Intensive audit checks of both field and laboratory situations were performed each season. Evaluations were documented each monitoring season (including staff training) and were then used to highlight areas requiring immediate improvement. Following each season a "lessons learned workshop" was conducted. Such efforts enabled procedures to be reviewed for means to improve precision, completeness, or other quality assurance indicators before the start of the next season. Computer-assisted checks were automatically performed on the raw data to indicate the

presence of missing or mislabeled samples, samples not meeting QA specifications for flow rate or collection period/date, database transcription accuracy, and other possible sources of error.

Results

A total of 1700 contacts were made relative to securing the 137 total participants. Of the 1532 potentially eligible households, a total of 522 were formally screened for participation. The majority of those residences not screened (987) were either no longer occupied or refused an invitation to be screened. Smoking households (180) represented a significant number of those who failed to meet the preliminary inclusion list for screening. While household recruitment rates varied across the various EMAs (15.1- 51.9%), the mean aggregate rate was 34.1%. Participant retention between the summer and winter monitoring sessions was determined to average 73% indicating the success of the DEARS retention strategy. Table 4 provides a summary of participant demographics for those who enrolled into the study. Nearly 90% of all participants lived in single family dwellings. Almost 80% of those who participated were females and this could reflect the non-availability of males in the home to participate due to work or other considerations. Approximately 66% of the enrollees were not employed. This would suggest that many of the residents were either retired or stay-at-home residents. Participant ages ranged from 18 to 79 years with a mean of 42. The majority were African-American (50%), followed by Hispanics and others (31%). Less than 20% of the cohort was Caucasian.

Cumulative data collection rates for the environmental metrics are summarized in Table 5. Nearly 9700 filter-based PM samples were collected. Initial quality assurance review indicated

that valid sample collection occurred well over 95% of the time for most types of samples. These rates are an indication of the sample being collected for the correct participant, during the correct period of time, and at the correct flow rate (if applicable).

The sample collections for season #6 (winter 2007) were substantially lower than for the other five seasons. The overall scope of this season had to be scaled down due to budgetary considerations. In doing so, participant compliance records were examined from season #5 and every attempt was made to retain only the most compliant participants while still ensuring that we maintained good spatial variability across all of the EMAs. The total number of participants in this final season was 20 (as compared to the normal of 40). The minor reduction in scope during the final season is not expected to have an adverse influence on the data analysis.

Table 5 provides insight as to the value of using passive-based monitors when feasible. Collection rates for the Perkin Elmer tubes (VOCs), PAKS (carbonyls) and the criteria pollutant gases measured by Ogawa badges (nitrogen dioxide, sulfur dioxide, and ozone) routinely had some of the highest collection efficiencies (>95%). This should not be surprising as they have no moving parts, do not require any power supplies and are simple to place and recover. The real-time nephelometer (pDR) routinely had a completeness efficiency of > 90%. Even so, the completeness percentage represented here will require modification as we further review data for this monitor concerning the issues related to the initial use of the drying apparatus in the first three seasons.

Summary statistics associated with select PM and gaseous co-pollutant mass concentrations are reported in Tables 6-7 for all participant-days. These values represent preliminary summaries

that have passed initial QA reviews for data collections. The summaries are provided here to reflect the overall trends observed in the DEARS. Even though the DEARS had a participant and residential indoor exclusion concerning tobacco smoking, some participants were non-compliant or had guests who did not abide by these constraints. We estimate this to be as high as 19% of all indoor sampling events. ETS impacted data have not been excluded in the summary statistics presented here. Very specific analyses will be performed in the future to fully determine the impact of environmental and human exposure factors like ETS, season, daily household operations, and human activity patterns on pollutant concentrations.

Ambient $PM_{2.5}$ mass concentrations were typically just below the annual National Ambient Air Quality Standard of 15 $\mu g/m^3$ (median = 14.0 $\mu g/m^3$). There were however, daily maximums that exceeded the 35 $\mu g/m^3$ daily standard (maximum = 66.4 $\mu g/m^3$). Season #2 (winter 2005) had the highest number of exceedences (14.3%) while season #4 (winter 2006) had the lowest (0%). Personal exposures to total $PM_{2.5}$ mass often exceeded that associated with ambient or outdoor measures. It is expected that cooking and other indoor exposure events, including the presence of ETS, influenced the summary statistics presented here. Personal ETS exposures are probably skewing this initial observation of these primary relationships. Data from residence surveys indicate that few of the study participants had central air conditioning. Therefore, most homes were operated in the summertime with their windows open allowing full infiltration of ambient PM. The relative closeness of the median values between indoor, outdoor and ambient $PM_{2.5}$ mass concentrations (14.0, 14.5, 14.0 $\mu g/m^3$, respectively) supports this conclusion.

Seasonality is expected to be a factor relative to PM infiltration into homes. As discussed

above, homes were often open during the summer but more tightly sealed in the winter due to the cold temperatures. The personal/ambient sulfur ratio is one means of defining the personal exposure factor (F_{pex}) to $PM_{2.5}$ of ambient origin (Wallace and Williams, 2005). A similar approach (indoor/ambient sulfur ratio) has also been used to define infiltration of ambient $PM_{2.5}$ into residential locations (F_{inf}). Results indicate that the median $PM_{2.5}$ F_{pex} was 0.68. In other words, based upon sulfur as a marker of PM of ambient origin, 68% of the total $PM_{2.5}$ mass individuals were routinely exposed to was associated with ambient sources. The range of values associated with F_{inf} in the study ranged from 0.16 to 6.4 with a median of 0.7. Values for both of these exposure factors that exceed 1.0 are indicative of sulfur sources other than that associated with PM of ambient origin or resuspension of previously deposited PM. ETS is a candidate for being responsible for many of these observations. Some DEARS participants burned candles, operated kerosene heaters and had other potential sources of sulfur-related particles in their residences which will also need to be examined for their impact upon these exposure factors. The overall closeness of the F_{pex} and F_{inf} (0.68 versus 0.70) values suggests that DEARS participants often spent considerable amounts of time in their own residences or locations with similar infiltration factors. Surveys and time activity pattern data will be used to further document this preliminary assumption. Median $PM_{10-2.5}$ mass concentrations were observed to be higher indoors as compared to outdoor and ambient locations (10.0, 7.4, 7.5 $\mu g/m^3$), respectively. This might be suggesting that resuspension of coarse PM tracked into residences was occurring. The presence of carpet and other floor coverings in the various residences, along with other potential exposure factors such as recent residential remodeling or cleaning activities, will be examined to

see if there are reasonable explanations for the homes reporting daily $PM_{10-2.5}$ mass concentrations as high as 335 $\mu g/m^3$.

Select gaseous pollutant data are reported in Table 7. Median ambient measures of ozone were ~ 20 times higher than personal concentrations. This finding is reflective of the degradation of ozone as it penetrates the indoor environment where DEARS participants spent a majority of their time. Personal NO_2 exposures were sometimes significantly higher than ambient conditions, with one maximum observed at 474 ppb. Preliminary investigations of such incidences often revealed the use of multiple gas appliances in the participant's residence. In such circumstances, DEARS participants were immediately contacted and informed of the potentially hazardous situation and the need to have their appliances serviced for possible malfunctions. Personal SO_2 concentrations were routinely at or well below the determined Ogawa's limit of detection for this pollutant (3.1 ppm). Personal exposures to this pollutant ranged from -2.2 to 14 ppb over the full duration of the study. Seasonality is expected to be a significant factor relative to the gaseous co-pollutant concentrations, especially for O_3 and NO_2, and will be examined in the future.

Discussion

Data from the DEARS will be used to identify the contribution of various pollutant sources (automotive, industrial and natural sources) to air pollutant concentrations at the community, neighborhood and potentially the personal level. The DEARS was fielded with a geographically purposeful, household recruitment strategy. This will allow the data to be potentially more useful than if a convenience-type recruitment scheme had been utilized. The full extent of this value will

not be known until data analyses are more fully realized. The study has already benefited the local communities involved. Each of the DEARS participants has received detailed information about their own potential exposures. Community groups and environmental institutions, along with city, county and state air quality officials have been briefed on preliminary findings. Some of these findings are now available on the DEARS website (www.epa.gov/dears). This website also provides listings of the planned analyses associated with the project's statistical analysis plan. Such documentation is located on the "Background" link. The Study Design document present at this location fully documents the planned analyses.

Collection of personal, residential indoor, residential outdoor and community-based measures in the DEARS will allow for the estimation of personal exposure and residential infiltration factors for specific pollutants and potentially their sources of origin. These data in turn, will be used to further evaluate and refine human exposure models that characterize the magnitude of exposure along with its uncertainty and variability. An example of this type of model is the US EPA's Stochastic Human Exposure and Dose Simulation (SHEDS). The SHEDS model is being used to model potential human exposures to air toxics and PM (Georgopoulos et al., 2005). These models are needed to reduce the uncertainty of current risk assessments using ambient-based environmental monitoring. In addition, the field data collection methods developed and applied in the DEARS will be used as a prototype for other community-based air toxic programs.

Data from the DEARS will allow the US EPA to more fully investigate the uncertainty of using community-based central monitors for epidemiological studies, especially for those pollutants that might not be as homogeneous as $PM_{2.5}$ mass concentrations. The knowledge

gained will then be used in planning future epidemiological studies and/or as direct inputs in the risk assessment process. Little is actually known about the homogeneity of various PM mass constituents. The same holds true for many air toxics. The DEARS will provide the means to investigate intra- and inter-personal variability for many of the monitored pollutants.

The DEARS will have a major impact upon source apportionment. Source apportionment has often had to rely upon elemental findings in its attempt to estimate the contribution of various source categories to the local airshed. This is often because of its availability and usually has little to do if this is the best choice for doing apportionment. The DEARS will provide the means to investigate source impacts at the community and neighborhood level and has the potential of being applicable to both residential indoor as well as personal levels of exposures. What makes the DEARS database so unique for this purpose is that it will allow not only ambient PM constituents to be used in the apportionment process, but also VOCs, SVOCs and potentially even the information gained from the personal and residential survey information. The DEARS represents one of the most complete human exposure measurement studies linked to intensive survey and questionnaire findings. The study has resulted in an extensive integrated database containing personal, residential indoor, residential outdoor and community-based environmental measurements for a wide variety of PM and air toxic components. A wealth of survey data have been collected. Databases have been developed using the Statistical Analysis System (SAS) hierarchy for ease of data queries. These databases are currently undergoing full validation with the intention of making them available in a publically-accessible format sometime after 2010.

A number of novel methodologies were employed in the DEARS for the first time or deployed

more extensively than in earlier studies. Examples of these include the PAKS, the Perkin Elmer VOC diffusion tubes, the C-PEM, and a size fractionated $PM_{2.5}$ nephelometer. These extensive evaluations, often numbering in the thousands of attempts will allow the research community-at-large to take advantage of the information gained concerning their performance characteristics and their utility for future studies. This is especially important considering the need to minimize participant burden during personal monitoring.

The DEARS will provide the means to determine if proximity of a residence to mobile or stationary sources has an impact on personal to source relationships. Its data will be used to calculate infiltration factors, penetration rates and removal rates for different pollutants and different housing conditions. Its design which focused upon single family or independent duplex housing situations, does have limitations in that it is not fully applicable for such analyses for other demographic situations (large communal settings like apartments). The impact of climate (summer vs. winter seasons) on these factors will also be evaluated. Time-activity and real-time $PM_{2.5}$ data will be used to determine the impact of spending time in non-residential locations and personal activities on exposure. This will be critical in understanding the importance of commuting and work place activities on exposures to non-ambient sources.

Acknowledgments

The US Environmental Protection Agency through its Office of Research and Development funded and conducted the research described here under contract 68-D-00-012 (RTI International), EP-D-04-068 (Battelle Columbus Laboratory), 68-D-00-206 and EP-05-D-065 (Alion Science and Technology). It has been subjected to Agency review and approved for

publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. Janet Burke, Shaibal Mukerjee, Gary Norris, David Olson, William McClenny, Lucas Neas, Gina Andrews, Jack Suggs, BJ George, Margaret Sieffert, and George Bollweg (US EPA) are acknowledged for their assistance in the development of the study objectives and its primary statistical plan. Dennis Williams, Karen Oliver, Lydia Brouwer, Herb Jacumin, of Alion Science and Technology were responsible for preparation of sampling media. Randy Newsome, Andrew Dart, Jeff Portzer, Phil Lawless and Jeremy Seagraves of RTI International were responsible for overseeing a majority of the field data collections. The US EPA acknowledges the kind assistance of Ann Chevalier, Dan Ling, Craig Fitzer, Catherine Simon, and MaryAnn Heindorf of the Michigan Department of Environmental Quality. Jill Kearney and Rose Dugandzic (Health Canada) are thanked for their helpful review comments of the original study design. We also acknowledge Kathy Edgren (CAAA) and Farid Shamo (ACCESS) who provided assistance in the recruiting of study participants. We are most thankful for the many DEARS participants who agreed to assist us with the collection of this important dataset.

References

Birch, M. and Cary, R., Elemental carbon-based method for monitoring occupational exposures to particulate diesel exhaust. *Aerosol Science and Technology* 1996: 25: 221-241.

Boudet C., Zmirou, D., Poizeau, D., Can one use ambient air concentration data to estimate personal and population exposures to particles? An approach with the EXPOLIS study. *Science of the Total Environment* 2001: 267: 141-150.

Census 2000. US Bureau of the Census.Washington, D.C 20410. Available at: www.census.gov

Chow, J., Wilson, W., Engelbrecht, J., Freeman, N., Hashim, J., Jantunen, M., Michaud, J., deTejada, S., Watson, J., Wei, F., Yasuno, M., Zhu, T., Exposure measurements. *Chemosphere* 2001 : 49: 873-901.

DATPS 2004. Data analyses for Detroit, Michigan, Air Toxics Data Collections in 2001. Sonoma Technology final report STI-903553-2557-FR. (www.ladco.org/toxics/reports/white%20paper%20phase%203/Detroit.pdf).

Demokritou, P., Kavouras, I., Ferguson, S., Koutrakis, P. Development and laboratory performance evaluation of a personal multipollutant sampler for simultaneous measurements of particulate and gaseous pollutants. *Aerosol Science and Technology* 2001: 35: 741-752.

Dietz, R., and Cote, E. Air infiltration measurements in a home using a convenient perfluorocarbon tracer technique. *Environment International* 1982: 8: 419-33.

Dietz, R., Goodrich, R., Cote, E., Wieser, R. Detailed description and performance of a passive perfluorocarbon tracer system for building ventilation and air exchange measurements, measured air leakage of buildings. ASTM STP 904, H.R. Trechsel and P. L. Lagus, Eds., American Society for Testing and Materials, Philadelphia, 1986: 203-264.

Duvall, R., Norris, G., Dailey, L., Burke, J., McGee, J., Gilmour, I., Gordon, T., Devlin, R. Source apportionment of particulate matter in the US and associations with lung inflammatory markers. *Inhalation Toxicology* 2008: (In press).

Dzubay, T., Stevens, R., Gordon, G., Olmez, I., Sheffield, A., Courtney, W. A composite receptor method applied to Philadelphia aerosol. *Environmental Science and Technolology* 1988: 22: 46-52.

Edwards. R., Jurvelin, J., Koistinen, K., Saarela, K., Jantunen, M., VOC source identification from personal and residential indoor, outdoor, and workplace microenvironments in EXPOLIS-Helsinki, Finland. *Atmospheric Environment* 2001: 35: 4829-4841.

Evans, G., Highsmith, R., Sheldon, L., Suggs, J., Williams, R., Zweidinger, R., Creason, J., Walsh, D., Rodes, C., Lawless, P. The 1999 Fresno particulate matter exposure studies: comparison of community, outdoor, and residential PM mass measurements. *J. Air & Waste Manage. Association* 2000: 50: 1887-1896.

Georgopoulos, P., Wang, S., Vyas, V., Sun, Q., Burke, J., Vedantham, R., McCurdy, T., Ozkaynak, H. A source to dose assessment of population exposures to fine PM and ozone in Philadelphia, PA during a summer 1999 episode. *Journal of Exposure Science and Environmental Epidemiology* 2005: 15: 439-457.

Hammond, D., Dvonch, J., Keeler, G., Parker, E., Kamal, A., Barres, J., Yip, F., Brakefield-Caldwell, W. Sources of ambient fine particulate matter at two community sites in Detroit, Michigan. *Atmospheric Environment*. 2008: 42: 720-732.

Helm, D., Jantunen, M., Rotko, T., Reporting personal results to participants of exposure studies. *Science of the Total Environment* 2000 : 262: 191-195.

Hopke, P., Ramadan, Z., Paatero, P., Norris, G., Landis, M., Williams, R., Lewis, C. Analysis of particle compositions measured in the EPA 1998 Baltimore Exposure Panel Study. *Environmental Science and Technology* 2003: 37: 3289-3302.

Jurvelin, J., Vartiainen, M., Jantunen, M., Pasanen, P., Personal exposure levels and microenvironmental concentrations of formaldehyde and acetaldehyde in Helsinki metropolitan area, Finland. *J. Air and Waste Management Association* 2000: 51: 17-24.

Jurvelin, J., Edwards, R., Saarela, K., Laine-Ylijoki, J., De B.ortoli, M., Oglesby, L., Schlapher, K., Georgoulis, L., Tischerova, E., Hanninen, O., Jantunen, M., Evaluation of VOC measurements in the EXPOLIS study. *J. Environmental Monitoring* 2001: 3: 159-165.

Keeler, G., Morishita, M., Young, L. Characterization of complex mixtures in urban atmospheres for inhalation exposure studies. *Experimental and Toxicologic Pathology* 2005: 57: 19-29.

Kousa, A., Oglesby, L., Koistinen, K., Künzli, N., and Jantunen, M. Exposure chain of urban air PM2.5—associations between ambient fixed site, residential outdoor, indoor, workplace, and personal exposures in four European cities in the EXPOLIS-study. *Atmospheric Environment* 2002: 36: 3031-3039.

Kwon, J., Weisel, C., Turpin, B., Zhang, J., Korn, L., Morandi, M., Stock, T., Colome, S., Source proximity and outdoor-residential VOC concentrations:Results from the RIOPA study. *Environmental Science and Technology* 2006: 40: 4074-4082.

Koistinen, K., Kousa, A., Tenhola, V., Hanninen, O., Jantunen, M., Oglesby, L., Kunzli, N., Georgoulis, L., Fine particle (PM2.5) measurement methodology, quality assurance procedures, and pilot results of the EXPOLIS study. *J Air and Waste Management Association* 1999: 49: 1212-1220.

Landis, M., Norris, G., Williams, R., Weinstein, J. Personal exposures to $PM_{2.5}$ mass and trace elements in Baltimore, Maryland. *Atmospheric Environment* 2001: 35: 6551-6524.

Lawless, P. and Rodes, C. Maximizing data quality in the gravimetric analysis of personal exposure sample filters. *J. Air Waste Management Association* 1999: 49: 1039-1049.

Lawless, P., Rodes, C., and Ensor, D. Multiwavelength absorbance of filter deposits for determination of environmental tobacco smoke and black carbon. *Atmospheric Environment* 2004: 38: 3373-3383.

Li, M., McDow, S., Tollerud, D., Mazurek, M. Seasonal abundance of organic molecular markers in urban particulate matter from Philadelphia, PA. *Atmospheric Environment* 2005: 40: 2260-2273.

Liu, S., Box, M., Kalman, D., Kaufman, J., Koenig, J., Larson, T., Lumley, T., Sheppard, L., Wallace, L. Exposure assessment of particulate matter for susceptible populations in Seattle. *Environmental Health Perspectives* 2003: 111: 909-918.

McBride, S., Williams, R., Creason, J. Bayesian hierarchical modeling of personal exposure to Particulate Matter. *Atmospheric Environment* 2007: 41: 6143-6155.

McClenny, W., Oliver, K., Jacumin, H., Daughtrey, H., Whitaker, D. 24 hr diffusive sampling of toxic VOCs in air onto Carbopack X solid adsorbent followed by thermal desorption/GC/MS analysis-laboratory studies. *Journal of Environmental Monitoring* 2005: 7: 248-256.

McDow, S., Mazurek, M., Li, M., Alter, L., Graham, J., Felton, H., McKenna, T., Pietarinen, C., Leston, A., Bailey, S., Argao, S. Speciation and atmospheric abundance of organic compounds in PM2.5 from the New York City Area. I. Sampling Network, sampler evaluation, molecular level blank evaluation. *Aerosol Science and Technology* 2008: 42: 50-63.

Meng, Q., Turpin, B., Korn, L., Weisel, C., Morandi, M., Colome, S., Zhang, J., Stock, T., Spektor, D., Winer, A., Zhang, L., Lee, J., Giovanetti, R., Cui, W., Kwon, J., Alimokhtari, S., Shendell, D., Jones, J., Farrar, C., Maberti, S. Influence of ambient (outdoor) sources on residential indoor and personal PM2.5 concentrations: analysis of RIOPA data. *Journal of Exposure Analysis and Environmental Epidemiology* 2005: 15: 17-28.

Meng., Q., Turpin, B., Lee, J., Polidori, A., Weisel, C., Morandi, M., Colome, S., Zhang, J., Stock, T., Winer, A. How does infiltration behavior modify the composition of ambient PM2.5 in indoor spaces? An analysis of RIOPA data. *Environmental Science and Technology* 2007: 41, 7315-7321.

Mukerjee, S., Smith, L., Norris, G., Morandi, M., Gonzales, M., Noble, C., Neas, L., Ozkaynak, H. Field method comparison between passive air samplers and continuous monitors for VOCs and NO_2 in El Paso, Texas. *Journal of Air and Waste Management Association* 2004: 54: 307-319.

National Research Council-National Academy of Science. 1998. Research Priorities for Airborne Particulate Matter I: Immediate Priorities and a Long-Range Research Portfolio. National Academy Press. Washington DC.

Naumova, Y., Offenberg, J., Eisenreich, S., Meng, Q., Polidori, A., Turpin, B., Weisel, C.,

Morandi, M., Colome, S., and Stock, T. Gas/particle distribution of polycyclic aromatic hydrocarbons in coupled outdoor/indoor atmospheres. *Atmospheric Environment* 2003: 37: 703-719.

NEI 2002. 2002 National Emissions Inventories for the US Technology transfer network clearinghouse for inventories and emissions factors (www.epa.gov/ttn/chief/net).

Nerriere, E., Zmirou-Navier, D., Blanchard, O., Momas, I., Ladner, J., Moullec, Y., Personnaz, M-B., Lameloise, P., Delmas, V., Target, A., Desqueyroux, H., Can weuse fixed ambient air monitors to estimate population long-term exposure to air pollutants? The caseof spatial variability in the Genotox ER study. *Environmental Research* 2005: 97: 32-42.

Nerriere, E., Guegan, H., Bordigoni, B., Hautemaniere, A., Momas, I., Ladner, J., Target, A., Lameloise, P., Delmas, V., Personnaz, M-B., Koutrakis, P., Zmirou-Navier, D., Spatial heterogeneity of personal exposure to airborne metals in French urban areas. *Science of the Total Environment* 2006: 373: 49-56.

Olson, D. and Norris, G. Sampling artifacts in measurement of elemental and organic carbon: low volume sampling in indoor and outdoor environments. *Atmospheric Environment* 2005: 39: 5437-5445.

Olson, D., Turlington, J., Duvall, R., McDow, S., Stevens, C., Williams, R. Indoor and outdoor concentrations of organic and inorganic molecular markers: source apportionment of PM2.5 using low volume samples. *Atmospheric Environment* 2008: 42: 1742-1751.

Paatero, P. The Multilinear Engine - a table-driven least squares program for solving multilinear problems, including the n-way parallel factor analysis model. *J. Computational and Graphical Statistics* 1999: 8: 854-888.

Ray, J. and McDow, S. Dicarboxylic acid concentration trends and sampling artifacts. *Atmospheric Environment* 2005: 39: 7906-7919.

Rea, A. W., Zufall, M. J., Williams, R. W., Howard-Reed, C., Sheldon, L. The influence of human activity patterns on personal PM exposure: a comparative analysis of filter-based and continuous particle measurements. *J. Air & Waste Manage. Association* 2001: 51: 1271-1279.

Reff, A., Turpin, B., Porcja, R., Giovennetti, R., Cui, W., Weisel, C., Zhang, J., Kwon, J., Alimokhtari, S., Morandi, M., Stock, T., Maberti, S., Colome, S., Winer, A., Shendell, D., Jones, J., Farrar, C., Functional group characterization of indoor, outdoor and personal PM2.5: results from RIOPA. *Indoor Air* 2004: 15: 53-61.

Riediker, M., Williams, R., Devlin, R., Griggs, T., Bromberg, P. Occupational exposure of North Carolina State Highway patrol troopers to air toxics and particulate matter. *Environmental Science and Technology* 2003: 37: 2084-2093.

Riediker, M., Devlin, R., Griggs, T., Herbst, M., Bromberg, P., Williams, R., Cascio, W. Cardiovascular effects in patrol officers are associated with fine particulate matter from brake wear and engine emissions. *Particle and Fibre Toxicology* 2004: 1:2.

Rodes, C., Lawless, P., Evans, G., Sheldon, L., Williams, R., Vette, A. The relationships between personal PM exposures for elderly populations and indoor and outdoor concentrations for three retirement center scenarios. *J. Exposure Analysis and Environmental Epidemiology* 2001: 11: 103-115.

Rogge, W., Mazurek, M., Hildemann, L., Cass, G., Simoneit, B. Quantification of urban organic aerosols at a molecular level: identification, abundance and seasonal variation. *Atmospheric Environment* 1993: 27: 1309-1330.

Rotko, T., Kousa, A., Alm, S., Jantunen, M., Exposures to nitrogen dioxide (NO2) in EXPOLIS-Helsinki: Microenvironment, behavorial and sociodemographic factors. *J. Exposure Analysis and Environmental Epidemiology* 2001: 11: 216-223.

Schauer, J., Rogge, W., Hildemann, L., Mazurik, M., and Cass, G. Source apportionment of airborne particulate matter using organic compounds as tracers. *Atmospheric Environment* 1996: 30, 3837-3855.

Schauer, J., and Cass G. Source apportionment of wintertime gas-phase and particle-phase air pollutants using organic compounds as tracers. *Environmental Science and Technology* 2000: 34: 1821-1832.

Sihabut, T., Ray, J., Northcross, A., McDow, S. Sampling artifact estimates for alkanes, hopanes, and aliphatic carboxylic acids. *Atmospheric Environment* 2005: 39: 6945-6956.

Thornbug, J., Rodes, C., Lawless, P., Williams, R. Evaluation of a new coarse particulate matter personal sampler and comparison with measured indoor and outdoor concentrations in Detroit. Exploring Innovative Approaches in Exposure Assessment. 2007. Proceedings of the 17th Annual Conference of the International Society of Exposure Analysis, Research Triangle Park, North Carolina, October 14-18, 2007, pp:16.

Turpin, B., Hering, S., Huntzicker, J. Investigation of organic aerosol sampling artifacts in the Los Angeles Basin. *Atmospheric Environment* 1994: 28: 3061-3071.

US EPA Particulate Matter Research Program: Five Years of Progress. 2004. EPA/600/R-04/058.

Washington, DC.

Varns, J., Mulik, J., Sather, M., Glen, G., Smith, L., Stallings, C. Passive ozone network of Dallas: a modeling opportunity with community involvement. *Environmental Science and Technology* 2001: 35 :845-855.

Vette, A. F., Rea, A. W., Lawless, P. A., Rodes, C .E., Evans, G., Highsmith, V. R., Sheldon, L. Characterization of indoor-outdoor aerosol concentration during the Fresno PM exposure studies. *Aerosol Science & Technology* 2001: 34: 118-126.

Wallace, L.A., Pellizzari, E., Hartwell, T., Sparacino, C., Sheldon, L., and Zelon, H. Personal exposures, indoor-outdoor relationships and breath levels of toxic air pollutants measured for 355 persons in New Jersey. *Atmospheric Environment* 1985: 19: 1651-1661.

Wallace, L. and Williams, R. Use of personal-indoor-outdoor sulfur concentrations to estimate the infiltration factor, outdoor exposure factor, penetration coefficient, and deposition rate for individual homes. *Environmental Science and Technology* 2005: 39: 1707-1714.

Wallace, L., Williams, R., Suggs, J., Sheldon, L., Zweidinger, R., Rea, A., Vette, A., Leovic, K., Norris, G., Landis, M., Stevens, C., Conner, T., Rodes, C., Lawless, P., Thornburg, J., Liu, S., Ryan, A., Kalman, D., Kaufman, J., Koenig, J., Larson, T., Lumley, T., Sheppard, L., Brown, K., Sarnat, J., Suh, H., Wheeler, A., Koutrakis, P., Lippmann, M., Kendall, M., 2003. Exposure of High Risk Sub-populations to Particles and Associated Co-pollutants-Final Report (APM21). ORD Report EPA/600/R-03-145. December 2003.

Wallace, L., Williams, R., Rea, A., Croghan, C. Continuous week long measurements of personal exposures and indoor concentrations of fine particles for 37 health-impaired North Carolina residents for up to four seasons. *Atmospheric Environment* 2006a: 40: 399-414.

Wallace, L., Williams, R., Suggs, J., Jones, P. Estimating Contributions of Outdoor Fine Particles to Indoor Concentrations and Personal Exposures: Effects of Household Characteristics and Personal Activities. 2006b. ORD Report (APM 214). EPA/600/R-06/023. NTIS# PB2006-11353, March 2006. Washington, DC.

Weisel, C., Zhang, J., Turpin, B., Relationships of indoor, outdoor and personal air (RIOPA). Part I, Collectin methods and descriptive analyses. Health Effects Institute report # 130-I. 2005, Boston, MA.

Williams, R., Watts, R., Stevens, R., Stone, C., Lewtas, J. Evaluation of a personal air sampler for twenty-four hour collection of fine particles and semivolatile organics. *J. Exposure Analysis and Environmental Epidemiology* 1999: 2: 158-166.

Williams, R., Creason, J., Zweidinger, R., Watts, R., Sheldon, L., Shy, C. Indoor, outdoor, and personal exposure monitoring of particulate air pollution: the Baltimore elderly-exposure pilot study. *Atmospheric Environment* 2000a: 34: 4193-4204.

Williams, R., Suggs, J., Zweidinger, R., Evans, G., Creason, J., Kwok, R., Rodes, C., Lawless, P., Sheldon, L. The 1998 Baltimore particulate matter epidemiology-exposure study: part 1-comparison of ambient, residential outdoor, indoor and apartment particulate matter monitoring. *J. Exposure Analysis Environmental Epidemiology* 2000b: 10: 518-532.

Williams, R., Suggs, J., Creason, J., Rodes, C., Lawless, P., Kwok, R., Zweidinger, R., Sheldon, L. The 1998 Baltimore particulate matter epidemiology-exposure study: part 2-personal exposure assessment associated with an elderly study population. *J. Exposure Analysis Environmental Epidemiology* 2000c: 10: 533-543.

Williams, R., Suggs, J., Zweidinger, R., Evans, G., Creason, J., Kwok, R., Rodes, C., Lawless, P., Sheldon, L. Comparison of $PM_{2.5}$ and PM_{10} monitors. *J. Exposure Analysis Environment Epidemiology* 2000d: 10: 497-505.

Williams, R., Wallace, L., Suggs, J., Evans, G., Creason, J., Highsmith, R., Sheldon, L., Rea, A., Vette, A., Zweidinger, R., Leovic, K., Norris, G., Landis, M., Stevens, C., Howard-Reed, C., Conner, T., Rodes, C., Lawless, P., Thornburg, J., Liu, L.-J., Kalman, D., Kaufman, J., Koenig, J., Larson, T., Lumley, T., Sheppard, L., Brown, K., Suh, H.,Wheeler, A., Gold, D., Koutrakis, P., Lippmann M. Preliminary Particulate Matter Mass Concentrations Associated With Longitudinal Panel Studies. 2002. ORD report EPA/600/R-01/086 (February 2002).

Williams, R., Suggs, J., Rea., A., Leovic, K., Vette, A., Croghan, C., Sheldon, L., Rodes, Thornburg, J., Ejire, A., Herbst, M., Williams Sanders Jr. The Research Triangle Park particulate matter panel study: PM mass concentration relationships. *Atmospheric Environment* 2003a: 37: 5349-5363.

Williams, R., Suggs, J., Rea, A., Sheldon, L., Rodes, C., Thornburg, J. The Research Triangle Park particulate matter panel study: modeling ambient source contribution to personal and residential PM mass concentrations. *Atmospheric Environment* 20003b: 37: 5365-5378.

Williams, R. EPA's Detroit Exposure and Aerosol Research Study. EPA Research Highlights, *AWMA Environmental Manager*, October 2005, pp43.

Williams, R., 2008. The US EPA Detroit Exposure and Aerosol Research Study (DEARS) website. (www.epa.gov/dears).

Zhang, J., Zhang, L., Fan, Z., Ilacqua, V. Development of the personal aldehydes and ketones sampler based upon a solid sorbent. *Environmental Science and Technology* 2000: 34: 2601-

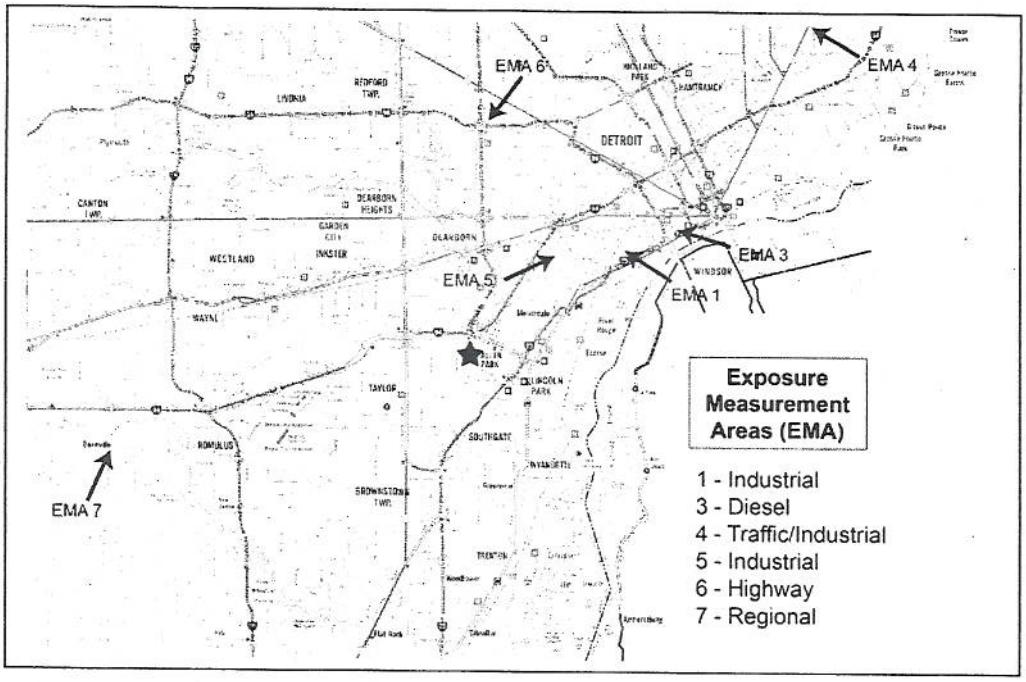
2607.

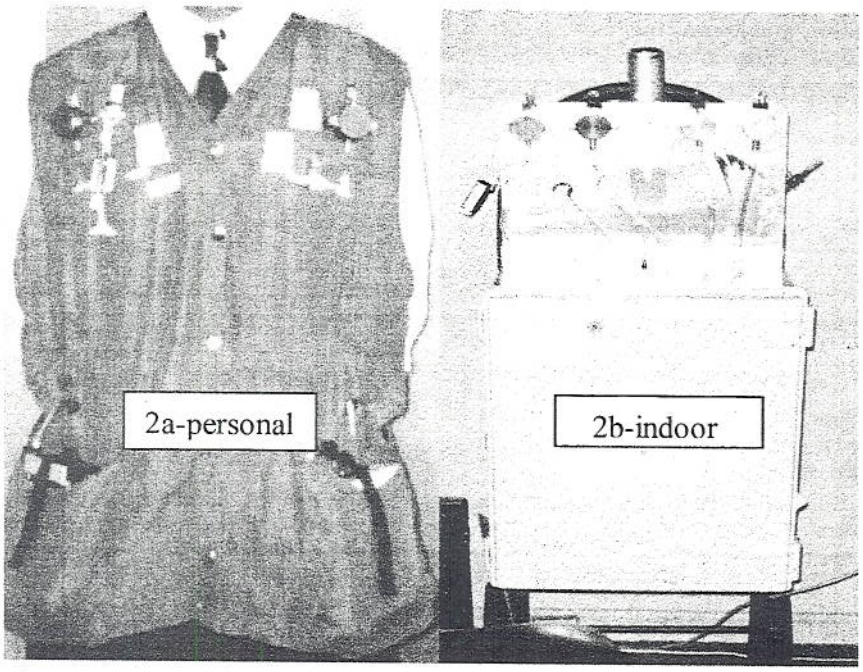
Zhao, W., Hopke, P., Norris, G., Williams, R., Paatero, P. Source Apportionment and analysis on ambient and personal exposure samples with a combined receptor model and an adaptive blank estimation strategy. *Atmospheric Environment* 2006: 40: 3788-3801.

Figure Captions

Figure 1. General locations of the DEARS monitoring locations. Their classification was a priori based upon the NEI, information from the MDEQ and other sources. EMA #2 (not shown) in the Wyandotte area was originally planned but ultimately not incorporated into the monitoring.

Figure 2 a,b,c,d. Personal monitoring (a) was performed used a nylon vest with active and passive monitors positioned in the breathing zone. Residential indoor (b) and outdoor monitors (c) deployed the same equipment with the exception of weather shielding. Community monitoring (d) was conducted at a State of Michigan air monitoring site located at Allen Park.


EMA 6
EMA 4
EMA 5
EMA 3
EMA 1
EMA 7
DETROIT
DEARBORN
WESTLAND
WAYNE
TAYLOR
ROMULUS
SOUTHGATE
LINCOLN PARK
Exposure Measurement Areas (EMA)
1 - Industrial
3 - Diesel
4 - Traffic/Industrial
5 - Industrial
6 - Highway
7 - Regional


2a-personal
2b-indoor

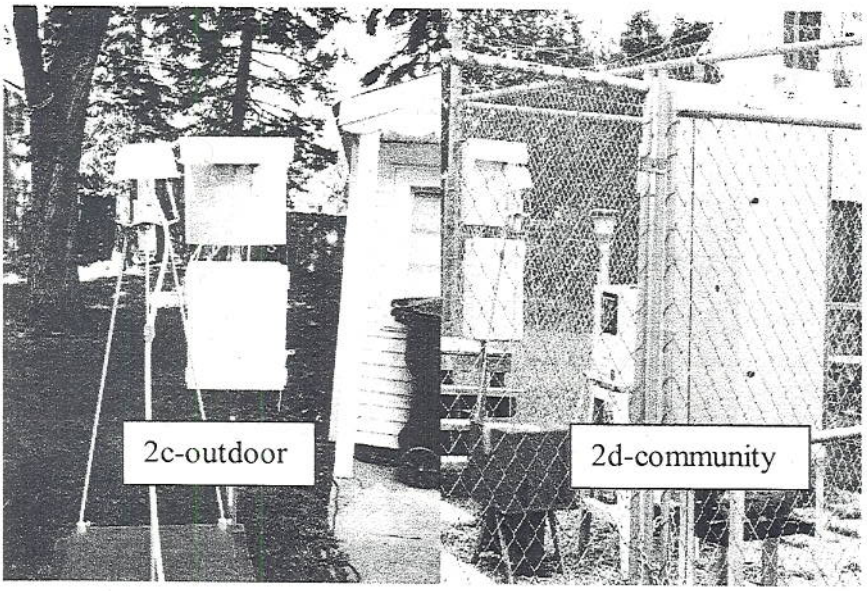

2c-outdoor
2d-community

Table 1. DEARS residential neighborhoods and possible source impacts.

EMA#	Census tracts	Potential source impacts[b]	Neighborhood proximity to freeway[c]
1	5238	heavy industrial	≥300 m
3	5209, 5211, 5234	diesel truck traffic	≤300 m
4[c]	5003	industry and automotive	≤300 and ≥300
5	5241	industrial	≥300 m
6	5401, 5402, 5403, 5404, 5421,5422, 5426	mobile source (freeway)	≤300 m
7	5870	regional	≥300 m
Allen Park	5766	industrial and freeway	≤300 m

[a]This represents the general area of the neighborhood involved (decimal degrees).
[b]Neighborhoods within 300 m of busy roadways were considered as potentially impacted by near-road mobile source emissions in the establishment of the study areas. Source impacts defined here are those believed from a priori determinations of the NEI and other information gathered before the study was initiated. These descriptors have yet to be evaluated with the DEARS data.
[c]The residential areas for EMA 4 changed after the first 2 years to exclude near-road influences. This EMA therefore had an eventual combination of homes either within or beyond 300 m of a major roadway.

Table 2. DEARS sample collection and analysis methods.

Metric	Type	Field collection	Sample Preparation	Analysis	Analysis reference
$PM_{2.5}$ mass	P, I, O, A	2 lpm PEM filter-based	filter taring and impactor oiling	gravimetric	Lawless and Rodes (1999)
$PM_{2.5}$ elements	P, I, O, A	2-4 lpm PEM filter-based	filter taring and impactor oiling	ED-XRF	Dzubay et al., (1988)
$PM_{2.5}$ EC-OC	I, O, A	2 lpm PEM filter-based	thermal bake-out of quartz filter; impactor oiling	thermal-optical reflectance	Birch and Cary (1996)
$PM_{2.5}$ nephelometry	P, I, O, A	2 lpm personal DataRam (pDR)	calibrate pDR with ammonium sulfate; zero each day before use	data logger recovery	Wallace et al., (2006a)
$PM_{2.5}$ BC, ETS	P, I, O, A	2 lpm PEM filter-based	establish optical properties of representative ETS and black carbon (BC)	transiometric radiometer	Lawless et al., (2004)
$PM_{2.5}$ nitrate	I, O, A	0.8 lpm mini-denuder filter-based	coat denuder and install quartz filter	aqueous extraction; IC	Demokritou et al., (2001)
$PM_{10\text{-}2.5}$ mass	I, O, A	2 lpm C-PEM filter-based	filter taring and impactor oiling	gravimetric	Thornburg et al., (2007)
$PM_{10\text{-}2.5; 2.5}$ mass:elements	A	16.6 lpm dichotomous filter-based	filter taring	gravimetric; ED-XRF	Williams et al., (2002)
NO_2, O_3, $S0_2$	I (NO_2) P, A	Ogawa passive diffusion monitor	treatment of glass fiber filters with reactive substrate, installation in dosimeters	aqueous extraction; IC	Varns et al., (2001)
Carbonyl	P, I, O, A	PAKS, DNSH-coated C-18 passive diffusion monitor	DNSH-treatment of C-18 substrate and assembly of PAKs dosimeters	acetonitrile extraction and then HPLC-Fl	Zhang et al., (2000)
VOC	P, I, O, A	Perkin-Elmer passive diffusion tube	thermal desorbtion of Carbopak-X tubes	thermal desorbtion GC/MS	McClenny et al., (2005)
$PM_{2.5}$ SVOC	A	113 lpm Tisch	Thermal bake-out of quartz filters and cassette assembly	solvent extraction then GC/MS	McDow et al., (2008)
$PM_{2.5}$ SVOC	I, O, A	10 lpm Harvard Impactor filter-based	filter taring and impactor oiling	solvent extraction then GC/MS	Olson et al., (2005)
Air exchange	I	Perfluorocarbon tracer source and receptor tubes	strategic placement of source(s) and receptors	thermal desorption GC	Dietz and Cote (1982)

P=Personal, I=indoor, O=outdoor, A= ambient, XRF=x-ray fluorescence, EC-OC=element/organic carbon, BC=black carbon ETS=environmental tobacco smoke, IC= ion chromatography, HPLC-FL=LC with fluorescence detection, GC=gas chromatograph, MS=mass spectroscopy.

Table 3. DEARS pre-study target data quality indicators (DQIs).

Metric		MDL	MQL	% Precision (±)	% Accuracy (±)	% Completeness	
						Collection	Analysis
PEMs	$\mu g/m^3$	1.75	5.1	20	5	95	99
HIs	$\mu g/m^3$	0.8	2.4	20	5	95	99
CPEM2.5	$\mu g/m^3$	2.0	5.0	20	20	95	99
CPEM10-2.5	$\mu g/m^3$	2.0	5.0	20	20	95	99
Tisch	pg/m^3	1.0	3.3	NA	20	90	NA
Dichot	$\mu g/m^3$	1.0	3.0	10	10	95	99
SVOCs	ng/m^3	~0.02	~0.06	30	20	95	90
VOCs	pptv	~50	~150	20	30	95	90
Acrolein	$\mu g/m^3$	0.5	1.5	15	20	95	95
Acetaldehyde	$\mu g/m^3$	5.0	15.0	15	15	95	95
Formaldehyde	$\mu g/m^3$	6.0	18.0	15	20	95	95
Nitrate	$\mu g/m^3$	0.1	0.3	10	10	95	90
SO2 badge	ppm	8.0	24	10	20	95	95
NO2 badge	ppm	3.0	9.0	10	20	95	95
O3 badge	ppm	3.0	9.0	10	20	95	95
MIE-PM2.5	$\mu g/m^3$	1.5	4.5	20	5	90	NA
PFT-air exchange	exchange/hr	0.1	0.3	15	25	95	95
EC-OC	$\mu g/m^3$	0.2	0.6	5	5	95	95
PM-XRF	ng/filter	~50	~50	20	10	95	95
Surveys	counts	NA	NA	NA	NA	95	NA

MDL= minimum detection limit, MQL= minimum quantitation limit
PEM=Personal Environmental Monitor, HI= Harvard Impactor, CPEM=Coarse PEM
MIE=Personal DataRam (pDr), Dichot=dichotomous sampler, EC-OC= elemental/organic carbon.

Table 4. Cumulative DEARS participant demographics and related statistics.

Demographic	N	Mean or % of total	Std	Min	Max
Age (years)	133	42.0	15.1	18.0	78.0
Race-missing	4	2.9%			
Race-Caucasian	25	18.4%			
Race-African-American	42	30.7%			
Race-Other including Hispanics	69	50.7%			
Gender-missing	1	0.7%			
Gender-male	30	21.9%			
Gender-female	106	77.4%			
Employed outside the home-missing	1	0.7%			
Employed outside the home (No)	46	33.6%			
Employed outside the home (yes)	90	65.7%			
Home description-(other)	1	0.7%			
Home description-missing	2	1.5%			
Home description-mobile home	2	1.5%			
Home description-external entry apartment	2	1.5%			
Home description-duplex	11	8.0%			
Home description-one family detached structure	119	86.9%			
Age of home (years)	134	63.9	23.8	6.0	125.0
Estimated time away from home each day (hr)	135	5.0	3.9	0.0	18.0
Estimated commuting time one-way to work (min)	47	17.4	12.3	0.0	59.0

Table 5. DEARS sample collection by season.

		PM	PERS	In/Out PM	CPEM	Dichot	EC-OC	PM nitrate	Gas	PAKS	VOC	pDR	SVOC	PFT
Season 1 Summer 2004	# deployed	792	208	504	--	77	469	462	680	680	723	609	457	213
	#valid	734	189	468	--	74	436	430	675	675	713	547	433	212
	%Completeness	92.7	90.9	92.9	--	96.1	93.0	93.1	99.3	99.3	98.6	89.8	94.7	99.5
Season 2 Winter 2005	# deployed	1655	180	464	920	91	469	440	767	669	713	551	452	190
	#valid	1574	157	435	891	91	450	407	760	660	711	508	423	190
	%Completeness	95.1	87.2	93.8	96.8	100.0	95.9	92.5	99.1	98.7	99.7	92.2	93.6	100.0
Season 3 Summer 2005	# deployed	1936	210	542	1096	88	560	559	1021	772	883	661	539	214
	#valid	1878	194	520	1080	84	557	546	1016	765	878	604	526	213
	%Completeness	97.0	92.4	95.9	98.5	95.5	99.5	97.7	99.5	99.1	99.4	91.4	97.6	99.5
Season 4 Winter 2006	# deployed	1832	185	532	1024	91	560	568	1090	768	850	623	575	201
	#valid	1801	179	524	1008	90	552	540	1078	764	838	581	560	200
	%Completeness	98.3	96.8	98.5	98.4	98.9	98.6	95.1	98.9	99.5	98.6	93.3	97.4	99.5
Season 5 Summer 2006	# deployed	2131	215	671	1130	91	710	721	1278	936	983	656	737	218
	#valid	2088	197	658	1118	91	705	700	1266	926	976	625	719	215
	%Completeness	98.0	91.6	98.1	98.9	100.0	99.3	97.1	99.1	98.9	99.3	95.3	97.6	98.6
Season 6 Winter 2007	# deployed	1310	94	432	704	80	426	434	667	537	530	362	442	115
	#valid	1269	91	416	683	79	410	398	654	535	526	340	432	114
	%Completeness	96.9	96.8	96.3	97.0	98.8	96.2	91.7	98.1	99.6	99.2	93.9	97.7	99.1
Total	# deployed	9656	1092	3145	4874	518	3194	3184	5503	4362	4682	3462	3202	1151

PM=all PM samples; PERS=personal samples; In/Out= residential PM samples; CPEM=coarse PM; Dichot=dichotomouse sampler at Allen Park
EC-OC= element and organic carbon; PMnitate=nitrate by mini-denuder; gases=All Ogawa badges; PAKS=carbonyls; VOC=PE tubes
pDR=PM2.5 nephelometry; SVOC= HI PM2.5 samples; PFT=air exchange by tracer
In addition, a total of 340 Tisch high volume samples were successfully collected through all 6 seasons.

Table 6. Select environmental PM-based findings from the DEARS.

Metric	Days	Seasons	Min ($\mu g/m^3$)	Max ($\mu g/m^3$)	Mean ($\mu g/m^3$)	Std Dev ($\mu g/m^3$)	Median ($\mu g/m^3$)	99% ($\mu g/m^3$)
Personal $PM_{2.5}$	874	1-6	-0.5	255.8	20.3	20.9	15.6	113.6
Indoor $PM_{2.5}$	973	1-6	-1.3	297.8	18.7	20.1	14.0	91.2
Outdoor $PM_{2.5}$	1347	1-6	-1.1	85.6	16.3	9.7	14.5	43.4
Ambient $PM_{2.5}$	189	1-6	2.8	66.4	16.9	10.6	14.0	63.0
Indoor $PM_{10-2.5}$	438	4-6	-0.6	335.4	12.8	18.5	10.0	63.1
Outdoor $PM_{10-2.5}$	585	4-6	-1.9	31.1	8.2	4.9	7.4	23.0
Ambient $PM_{10-2.5}$	87	4-6	0.5	19.1	7.9	4.0	7.5	19.1
$PM_{2.5}$ personal exposure factor	788	1-5	-0.01	4.09	0.7	0.29	0.68	1.56
$PM_{2.5}$ residential infiltration factor	855	1-5	0.16	6.45	0.7	0.33	0.70	1.48
PFT air exchange (h^{-1})	916	1-6	0.1	17.0	1.5	1.5	1.0	7.5

Table 7. Select environmental gaseous co-pollutant findings from the DEARS.

Metric	Days	Seasons	Min (ppb)	Max (ppb)	Mean (ppb)	Std Dev (ppb)	Median (ppb)	99% (ppb)
Personal O_3	936	1-6	-5.4	43.2	2.1	3.3	1.0	15.0
Ambient O_3	199	1-6	3.0	53.0	25.0	11.5	24.0	52.0
Personal NO_2	891	1-6	-3.0	474.0	29.9	37.4	23.1	188.0
Outdoor NO_2	989	3-6	-1.0	65.0	20.3	9.7	20.0	48.0
Ambient NO_2	198	1-6	0.0	48.0	23.9	8.2	23.1	47.5
Personal SO_2	928	1-6	-4.0	12.4	0.5	1.7	0.0	6.0
Ambient SO_2	195	1-6	-2.2	14.0	2.8	2.8	2.0	14.0