2003 Progress Report and Research Plan on the

Air Resources Board's Vulnerable Populations Research Program

August 2003

California Environmental Protection Agency

Air Resources Board

State of California
California Environmental Protection Agency
AIR RESOURCES BOARD

Vulnerable Populations Research Program

2003 Progress Report and Research Plan

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Table of Contents

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EXECUTIVE SUMMARY

The Vulnerable Populations Research Program (VPRP) 2003 Progress Report and Research Plan presents the Air Resources Board's (ARB's) current activities and priorities for future activities in the implementation of this Program. The overall goal of the VPRP is to provide the scientific support, through research efforts, for ARB's regulatory and non-regulatory programs that aim to protect all California residents, including those subpopulations considered especially vulnerable, from the adverse effects of air pollution. The major objectives of the VPRP are to identify susceptible subpopulations, to quantify the degree to which their health is compromised, and to characterize their exposures to air pollutants.

July 1999 the VPRP was authorized by the Californian Legislature and Governor Gray Davis. The program was approved for a 10-year span. Subsequent budget cuts at ARB have required that the VPRP must now compete with other ARB research, however, several recently completed or ongoing research projects, funded under other programs, complement the objectives of the VPRP. In addition, the ARB has built up its capabilities in exposure assessment and analysis of health databases, and is able to take on a greater number of internal research projects than was originally envisioned.

The Program describes several components to be implemented. One of these components is the sponsorship of a major epidemiological study to determine the effects of different components of PM, in combination with other ambient air pollutants and environmental factors, on the natural history of asthma in young children. Another component of the Program is to assess the scope of the problem. This includes the use of readily available databases to identify statewide geographic and temporal patterns of the diseases of interest and the most affected populations. The last component of this Program is the development the VPRP Research Plan. This Plan was developed largely from the collaboration of ARB staff, the VPRP External Advisory Committee (EAC), and collaborators at local, California, and U.S. agencies. The VPRP Research Plan contains recommendations and priorities for future research activities that will fill data gaps not being addressed by other funding organizations.

As the VPRP was being initiated, it became clear that the Program could benefit and support three of ARB's primary regulatory and non-regulatory programs with improved scientific information on vulnerable populations, and these linkages greatly influenced the implementation of the VPRP. These programs are:

- The Ambient Air Quality Standard setting authority of the ARB.
- The Toxic Air Contaminant Identification and Control Program.
- The Environmental Justice Program.

In 1999, the California Legislature adopted the Children's Environmental Health Protection Act (Senate Bill 25, Escutia, 1999). The Act specified requirements for the ARB related to the protection of infants and children from environmental health hazards. One requirement was that the ARB, in consultation with the Office of Environmental Health Hazard Assessment (OEHHA), review all existing health-based ambient air quality standards to determine whether they adequately protect the health of the public, including infants and children. The ARB is required to revise the highest priority air quality standards determined to be inadequate. Among several standards deemed possibly inadequate, the existing standards for particulate matter less than 10 micrometers in aerodynamic diameter (PM10) were the first to undergo full review because the statewide potential for significant health impacts associated with PM exposure was determined to be large and wide-ranging. The standards for ozone and nitrogen dioxide were also deemed possibly inadequate and are currently under review. Research initiated and planned under the VPRP and related programs includes; the impacts of PM and other pollutants on children's health, children's exposure to air pollution, and identifi-

cation of the most toxic chemical components of PM. The results of these studies will support ongoing and future reviews of California's ambient air quality standards.

The ARB has authority to identify and control toxic air contaminants (TACs). A TAC is defined as an air pollutant that may cause or contribute to an increase in mortality or in serious illness, or that may pose a present or potential hazard to human health. The goal of the air toxics program is to reduce public health risks from TACs through incorporation of best available control technologies or maximum degree of reduction. Once a substance has been identified as a TAC, the ARB will evaluate the need for control. To date, almost 200 substances have been identified as TACs. In 1998, the ARB identified diesel particulate matter (PM) as a TAC (ARB and OEHHA, 1998). Diesel PM is estimated to be responsible for about 70% of the cancer risk from airborne toxics in California, and ARB adopted the Diesel Risk Reduction Plan in September 2000 (ARB, 2000). The Diesel Risk Reduction Plan envisions a 75 percent reduction in diesel PM emissions in California by 2010 and an 85 percent reduction by 2020. Research initiated under the VPRP and related programs includes development of monitoring methods for diesel PM, school bus and bus stop exposures to diesel PM, and an in-house review of biomarkers for TAC exposures.

Senate Bill 115 (Solis, 1999) and the ARB's Environmental Justice (EJ) Policies and Actions, adopted in December 2001, require all ARB programs, including research, to be conducted in a manner that ensures EJ. SB 115 defines EJ as "…the fair treatment of all races, cultures, and incomes with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies." The VPRP includes specific EJ research projects on low-cost easy-to-use monitoring technologies and indoor/personal exposures to air pollutants in low-income, of color and heavily impacted communities. In addition, every research project initiated under the VPRP includes a significant EJ component, from the community selected and children recruited for FACES to the specific routes chosen for the school bus study of diesel PM exposures.

Historically, research efforts to fill gaps on air pollution impacts on "the most vulnerable members of society" have focused on children, the elderly, and people with pre-existing cardiovascular and/or pulmonary disease, and individuals who spend a large amount of time out-of-doors. Recent actions taken to address the requirements of SB 25 add emphasis to the need to study children's health. The results of the TAC identification program highlighted the need to understand exposure of vulnerable populations to diesel PM exposures. SB 115 and results from studies indicating that low-income neighborhoods and communities of color are often subject to high air pollution burdens justifies the need to include these communities as a vulnerable subpopulation.

Over the first three years of the Program, we implemented the initial components of the VPRP. The FACES investigators completed the two-year pilot phase, submitted an interim report, and began the final two-year phase. Investigators for other ARB-funded health and exposure studies of vulnerable populations begun prior to the VPRP reported final results or significant interim findings. We performed an initial analysis of a statewide hospitalization database to develop an understanding of the spatial patterns of cardiovascular and respiratory disease incidence. We formed the VPRP EAC to review research progress, provide input on the future direction of the program, and summarize research occurring at their institutions. We investigated methods to better assess community and personal exposure to air pollutants.

As a result of the needs for sound scientific foundations to the ARB programs named above, we have identified 10 broad research questions with remaining data gaps regarding vulnerable populations. We have organized the research questions into two major categories: 1) *Health Effects*, and 2) *Exposure Assessment*.

These two categories were selected because they represent the scope of research that is anticipated during the next few years on vulnerable populations. Furthermore, they define the natural progression of research, from identifying the impacts associated with air pollution (i.e., *Health Effects*) to characterizing exposures (i.e., *Exposure Assessment*). Additional research is needed to facilitate the application of effective exposure reduction strategies, which was previously described in the *Technology Advancement and Pollution Prevention* section of ARB's Strategic Plan for Research (ARB, 2001a). For each of the questions, we have defined the issue and summarized prior results, described research conducted and funded by ARB and other groups, and identified research needs and research to be conducted or funded by ARB with realistic timeframes.

Health Effects

1. *Which populations have heightened susceptibility to air pollution and what are the factors that contribute to increased susceptibility?*

   We are funding research on children's health impacts (including asthmatics) from long-term exposure to air pollution. This study includes minority and low-income groups. Future research may include studies of infants, the elderly, and those with preexisting cardiopulmonary disease. Research funded by others is focused on evaluating the effects of socioeconomic status, race, ethnicity, gender, and other factors that may contribute to increased susceptibility.

2. *Which pollutants and what levels of those pollutants cause health effects? What pollutant characteristics are most responsible for the health effects?*

   Much controversy remains as to which components of air pollution and at what levels these pollutants cause health effects. Several researchers have begun to try and disentangle the specific component(s) of the air pollution 'mix' by evaluating the health effects of a particular pollutant while taking into account the effect other pollutants simultaneously present. These types of analyses continue to prove difficult due to the fact that many air pollutants are highly correlated and researchers are still developing the best biostatistical methods to deal with correlated data. We are funding research on this issue through the Children's Health Study (CHS), FACES, and other projects.

3. *Does air pollution influence the development and progression of disease?*

   Little is known about the influence of air pollution on the development and progression of disease. Studies have begun to address these issues, however, they are difficult to conduct due to the long-time frames people must be evaluated to determine the development and progression of disease. Most of the research in this area has examined the effects of air pollution on children with pre-existing asthma and on elderly subjects with pre-existing cardio-pulmonary diseases.

4. *When and where in an individual's lifetime do the most harmful exposures occur? When is a person most vulnerable to air pollution?*

   Several investigators have begun to address this question by looking at air pollution exposures and health effects during different stages of a child's development. Studies of the adverse effects of air pollution on birth outcomes have been conducted as well as studies looking at the development of disease in relation to living in high pollution communities.

5. *Are health outcomes correlated with air pollution exposures?*

   One approach to evaluating the health effects of air pollution on populations is to analyze data from existing data sources. Ongoing efforts by ARB and other agencies are underway to use existing databases to determine areas of potential research interest, and correlate health information to air pollution and socioeconomic factors. A key component of this

effort is the California's Centers of Excellence for Environmental Public Health Tracking Program, which is an integral part of the Centers for Disease Control (CDC) funded effort to develop a national environmental health tracking network.

Exposure Assessment

6. *Have air pollution control programs improved air quality and health in all communities?*

   California's air pollution control programs have reduced county-level emissions and air quality episodes for criteria pollutants and air toxics. Our preliminary analysis for ozone shows that these reductions have occurred in equal measure in low- and high-income communities. We will complete this analysis for other criteria pollutants, including estimates of health effects using available relationships. Two other studies, one retrospective and the other using new surveys, will track actual health improvements in California.

7. *Which communities are most impacted by air pollution? What are their cancer and non-cancer health effects?*

   Preliminary results indicate that in California a higher percentage of children who are Hispanic, Asian, and black, or from low-income families, live near freeways and major roads. Several other recent studies have also shown that proximity to roadways appears to lead to many adverse health effects, including reproductive, cardiovascular, and respiratory disease effects. We will use contemporary air quality and census data to identify California communities with high pollutant levels, including estimates of cancer and non-cancer health effects using available relationships, and will continue to study the effect of traffic pollution in several ongoing California health studies.

8. *What screening methods can be used to identify the most impacted communities and individuals?*

   Monitoring programs to determine pollutant burdens in communities or for individuals that live near sources are extremely expensive and it is difficult to predetermine the most suitable neighborhoods to study. Easy-to-use, low-cost monitoring technologies, while not accepted as official data for record, are suitable as a screening tool to indicate areas for further study and exist for ozone, benzene, formaldehyde, and carbon monoxide. ARB and other agencies have moved in this direction by releasing a solicitation for grants to support the commercialization of additional air monitoring technologies, by developing community protocols for this type of equipment, and by attempting to develop a specific measure of diesel particles. Another useful tool is biomonitoring of hair, urine, or blood for tracers of an individual's pollutant exposures. Although it may not be able to identify the source of the exposure, it can be useful for identifying total exposure in a community.

Other questions of interest on the effects of air pollution on vulnerable populations include: *9. What are the cumulative impacts of air pollution?,* and *10. What are the near-source exposures to toxic air pollutants?* These questions are being addressed through in-house work conducted as part of the Neighborhood Assessment Program and other EJ initiatives headed by the Planning and Technical Support Division, and therefore are not included in this document.

I. INTRODUCTION

The Vulnerable Populations Research Program (VPRP) 2003 Progress Report and Research Plan provides the framework necessary to guide project sponsorship under the auspices of the VPRP. The Report provides detailed information on the background of the VPRP (Section I), the progress of research initiated under the VPRP (Section II), and data gaps and recommended research (Section III). This section discusses the Program requirements and scientific context in which the VPRP was implemented, defines vulnerable populations for the purposes of this Program, and describes the regulatory and non-regulatory programs that the VPRP benefits and supports.

Program Background

The Californian Legislature and Governor Gray Davis authorized the VPRP in July 1999 with specific funding for extramural research and staffing for intramural research activities. The program was approved for a 10-year span. Subsequent budget cuts at ARB have removed the specific funding earmark for extramural research and projects must now compete with other ARB research priorities in the annual research planning process (ARB, 2001), however, several recently completed or ongoing research projects, funded under other programs, complement the objectives of the VPRP. In addition, the ARB has built up its capabilities in exposure assessment and analysis of health databases, and is able to take on a greater number of internal research projects than was originally envisioned.

The overall goal of the VPRP is to provide the scientific support, through research efforts, for ARB's regulatory and non-regulatory programs that aim to protect all of California's citizens, including those subpopulations considered especially vulnerable, from the adverse effects of air pollution. The major objectives of the VPRP are to identify susceptible subpopulations, to quantify the degree to which their health is compromised, and to characterize their exposures to air pollutants.

The program authorization language for the VPRP described several components to be implemented over the course of the first five years of the Program. The first component is the sponsorship of a major epidemiological study to determine the effects of different components of PM, in combination with other ambient air pollutants and environmental factors, on the natural history of asthma in young children. The study, the Fresno Asthmatic Children's Environment Study (FACES), will provide the ARB with valuable information regarding the influence of ambient pollutants on both the short-term and long-term natural history of asthma in this sensitive population. The second component of the Program is to assess the scope of the problem. This includes the use of readily available databases to identify statewide geographic and temporal patterns of the diseases of interest (e.g., asthma, acute or chronic respiratory disease, birth outcomes) and the most affected populations. The last component is the development of a Research Plan, which results largely from the collaboration of ARB staff, the VPRP External Advisory Committee (EAC), and collaborators at local, California, and U.S. agencies. The Research Plan contains recommendations and priorities for future research activities that will fill data gaps not being addressed by other funding organizations.

The ARB's mandate is to promote and protect the public health of all Californians. Recent results from several epidemiological studies indicate that there are segments of our society that are potentially more vulnerable to the effects of air pollution than others. For example, results from Children's Health Study (CHS) show that children with asthma who are exposed to higher concentrations of particles are much more likely to develop bronchitis (McConnell et al., 1999). Findings of this nature illustrate that for the State to promote public health programs protective of all Californians, we must first understand which segments of our society are potentially more susceptible to the effects of air pollution, and what those effects are. The characteristics of California's air pollution, climate, and popula-

tion are unique when compared to the rest of the country, and therefore, federal-based policies may not adequately protect Californians. Over the years, the overall goal of the ARB's Health Research Program has been to identify and quantify the adverse health effects of air pollutants, and to provide the requisite information to guide California-specific policies that lead to mitigation of those adverse effects. The ARB has been a major sponsor of air pollution health effects research and thus previous research programs and efforts have laid the groundwork for the conception and implementation of the VPRP.

Definition of Vulnerable Populations

For the purposes of the VPRP, the definition of vulnerability is broad, to include not just those factors inherent to an individual (commonly known as host factors), but also socioeconomic, cultural, and external influences. Traditionally, populations have often been defined as vulnerable due to intrinsic genetic factors - gender, race, and preexisting disease conditions. Although these characteristics may biologically predispose certain individuals to more severe adverse effects of air pollutants and are therefore important in defining vulnerable populations, factors outside of the biological makeup of the individual must be considered. An important factor that may contribute to subpopulation vulnerability is their potential for greater or unique exposures, which may result from their activity patterns or higher levels of environmental contaminants in their communities. Socioeconomic status and housing characteristics, for example, must be taken into account when defining the true breadth of potentially vulnerable populations in California. Any subpopulation, whether defined by age, disease status, genetics, or community, is collectively categorized as a potentially vulnerable population.

Anticipated Needs of ARB's Programs

As the VPRP was being initiated, it became clear that the Program could benefit and support three of ARB's primary regulatory and non-regulatory programs with improved scientific information on vulnerable populations, and these linkages greatly influenced the implementation of the VPRP. These programs are:

- The Ambient Air Quality Standard setting authority of the ARB.
- The Toxic Air Contaminant Identification and Control Program.
- The Environmental Justice Program.

Children's Environmental Health Protection Act

In 1999, the California Legislature adopted the Children's Environmental Health Protection Act (Senate Bill 25, Escutia, Stats. 1999, Ch. 731 section B; Health and Safety Code section 39606). SB 25 specified requirements for the ARB related to the protection of infants and children from environmental health hazards. One requirement is that the ARB, in consultation with the Office of Environmental Health Hazard Assessment (OEHHA), review all existing health-based ambient air quality standards to determine whether they adequately protect the health of the public, including infants and children. The ARB is then required to revise the highest priority air quality standards determined to be inadequate.

In response to SB 25, the ARB, in consultation with the OEHHA, evaluated the adequacy of all of California's health-based ambient air quality standards (ARB and OEHHA, 2000). The staff evaluation, approved by the ARB in December 2000, found that the standards for particulate matter (including sulfates), ozone, and nitrogen dioxide may not be adequate to protect public health and should undergo an intensive review to determine how the standards should be revised.

In June 2002, after a lengthy evaluation by ARB and OEHHA staff, the ARB adopted new ambient air quality standards for PM2.5 and PM10 (particulate matter less then 2.5 microns in diameter and less than 10 microns in diameter, respectively). The ARB established annual-average standards – never to be exceeded – of 12 $\mu g/m^3$ for PM2.5 and 20 $\mu g/m^3$ for PM10, to complement the existing 24-hour

PM10 standard of 50 $\mu g/m^3$, also never to be exceeded. These State standards are effective as of July 5, 2003. These PM standards are more health protective than the current National annual-average standards: PM2.5 of $20\mu g/m^3$, and PM10 of $50\mu g/m^3$. The health benefits from attaining the standards are substantial. For example, a quantitative risk assessment estimated that attainment of the annual-average PM10 standard from current ambient levels would result in a reduction of approximately 6,500 cases (3,200-9,800 for a 95% confidence interval) of premature mortality per year in California (ARB and OEHHA, 2002).

In 2003, the ARB will review the current one-hour standard for ozone and in 2004, the one-hour standard for nitrogen dioxide. Although research from the VPRP will not be on a time frame to assist with the first round of standard reviews, results of the program will be used in the second round for all the pollutants for which California ambient air quality standards are set. For example; studies that examine the health effects from extremely small "ultrafine" particles (less than 0.1 microns in diameter) could be used in the next review of the PM standard. Considerations of a PM standard that only includes the course fraction of PM10 may be considered as research helps us understand the mixture of components in the course fraction and the effects of it on health and welfare.

Toxic Air Contaminant Program

The ARB has authority to identify and control TACs. A TAC is defined as an air pollutant that may cause or contribute to an increase in mortality or in serious illness, or that may pose a present or potential hazard to human health. The goal of the air toxics program is to reduce public health risks from TACs through statewide control, however local air districts can adopt more stringent regulations. Once a substance has been identified as a TAC, the ARB will evaluate the need for control. To date, almost 200 substances have been identified as TACs. When a control measure is developed, certain criteria established in law, such as the availability of control technology, costs, and risk must be addressed and are included in the staff report.

The second event that reinforced the need of the VPRP was the ARB's identification of diesel particulate matter as a toxic air contaminant (TAC) in 1998, following a 10-year review process (ARB, 1998). This action was followed by the ARB's subsequent adoption of the Diesel Risk Reduction Plan in September 2000. The Diesel Risk Reduction Plan envisions a 75 percent reduction in diesel emissions in California by 2010 (and an 85% reduction by 2020) through the use of particle traps, low sulfur fuels, advanced engine technologies, and alternative fuels (ARB, 2000).

The average risk or chance of developing cancer from air toxics in urban areas across the State, as measured from the ARB's ambient air monitoring network and including an estimate for diesel particulate matter (diesel PM) based on emission inventory data, is estimated to be on average about 750 in a million. About 70 percent of that risk is attributable to the diesel PM contribution. These risk estimations are based on the assumption that the public breathes the average concentrations measured in the network, or estimated for diesel PM, continuously for seventy years. On an annual basis, these Statewide risks translate to about 400 new cancer cases per year. Understanding the true risk to the public from air toxics is critical to ensure that valuable, limited resources are spent addressing the greatest health issues in communities.

An example of an area where information is needed to better address the risk from air toxics in communities is development of a monitoring method for diesel PM. Currently, there is no available monitoring method to directly measure diesel PM. Because some communities are often located in or near industrialized areas where there is a higher percentage of diesel trucks or equipment operating, a monitoring method is needed to better understand the true impacts from this important TAC.

Environmental Justice

Senate Bill 115 (Solis; Stats 1999, Ch. 690; Government Code § 65040.12(c)) and the ARB's Environmental Justice (EJ) Policies and Actions, adopted in December 2001, require all ARB programs, including research, to be conducted in a manner that ensures EJ. SB 115 defines EJ as "…the fair treatment of all races, cultures, and incomes with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies."

On December 13, 2001, the Air Resources Board approved the Policies and Actions for Environmental Justice, which established a framework for incorporating environmental justice into the ARB's programs consistent with the directives of the State law (ARB, 2001b). These policies apply to all communities in California, but recognize that environmental justice issues have been raised more in the context of low-income neighborhoods and communities of color. As part of the Actions and Polices for Environmental Justice, the ARB committed to develop technical information and tools to assess and reduce cumulative emissions, exposures, and health risks. Since that time, the ARB has been developing tools to make emission data more accessible to the public, tools for professions to assess localized impacts, and tools and maps for a statewide overview of total cumulative impacts.

Much of this effort is being developed as part of the Board's other programs such as the emission inventory, modeling, and the neighborhood assessment programs. The ARB web-site already includes maps showing estimated cancer health risks on a regional basis, and will soon have updates to those maps. In addition, later this year, a visualization tool for mapping emission sources on the Internet will be available that will allow one to view a map of a community and the spatial array of facilities and emissions in that community. Other in-house efforts include developing regional and micro-scale modeling protocols for developing statewide cumulative impact maps that will allow the public to view cumulative risk at a much more refined scale than is currently available. Tools are also under development that will allow local decision-makers to assess cumulative air pollution impacts of proposed projects. All of this work will complement the health research being done by the Vulnerable Populations Research Plan.

Much of ARB's research in the Vulnerable Populations Research program relates to Environmental Justice Policy VII, which states: "It shall be the ARB's policy to support research and data collection needed to reduce cumulative emissions, exposure, and health risks in all communities, especially low-income and minority communities." The specific research areas related to this policy include: Investigate non-cancer health effects; correlate health information with air pollution and socioeconomic status (SES); measure progress with periodic health surveys; assess cumulative emissions, exposures and health risks; develop tools to determine near-source TAC risks; and develop methods to assess community and individual exposures.

Plan Development Process

We have worked with a variety of research and public health organizations at both the state and national level during the development of this plan. We surveyed all major U.S. research funding organizations and communicated extensively with our VPRP EAC to gather information about work ongoing at various institutions. The Report was peer reviewed by the Research Screening Committee (Health and Safety Code, section 39705), a legislatively created body that oversees all ARB research programs.

II. RESEARCH PROGRESS

Over the first three years of the Program, we implemented the initial components of the VPRP. The FACES investigators completed the two-year pilot phase, submitted an interim report, and began the final two-year phase. Investigators for other ARB-funded health and exposure studies of vulnerable populations begun prior to the VPRP reported final results or significant interim findings. We performed an initial analysis of a statewide hospitalization database to develop an understanding of the spatial patterns of cardiovascular and respiratory disease incidence. We formed the VPRP EAC to review research progress, provide input on the future direction of the program, and summarize research occurring at their institutions. We investigated methods to better assess community and personal exposure to air pollutants.

Fresno Asthmatic Children's Environment Study

Many of the known biological responses associated with air pollution exposures could potentially alter an individual's risk of getting a disease or influence the way an existing disease progresses. For example, even though the evidence that air pollution causes asthma is only beginning to emerge (McConnell et al., 2002), air pollution is known to induce asthmatic episodes in people with the disease. Repeated episodes of asthma may damage or alter the respiratory tract of asthmatics, leading to worsening of the disease and a poorer quality of life. The FACES and CHS are beginning to examine some of the questions surrounding asthma disease progression, but much work is yet to be done to understand the relationships between air pollution and disease.

The initial VPRP description contained a specific project that was to evaluate observations of elevated childhood asthma in Fresno. Fresno was selected because it is the largest population center in the San Joaquin Valley, with high 24-hour-average PM2.5 (160 $\mu g/m^3$) and PM10 (199 $\mu g/m^3$) concentrations and the second and third highest asthma hospitalization rates in California for black and Hispanic children, respectively. Health scientists have established that asthma sufferers have more breathing problems when PM is high and that children exhibit more asthma problems than adults do.

Investigators at the University of California at Berkeley, the California Department of Health Services, private consultants, and the ARB developed an epidemiologic field investigation to determine how young children known to have asthma are affected by various environmental and lifestyle factors on a day to day and longer term basis. FACES includes 44% Hispanic, 12% black, 1% Asian, and 15% low-income families (less than $15,000 household income) among the 250 participants. The study is anticipated to span approximately four years, but was authorized as a two-phase project. The Board has considered and approved Phase I, and voted to provide full funding for Phase II with a decision point after the first year to ensure that certain conditions are met. Phase II began in February 2003.

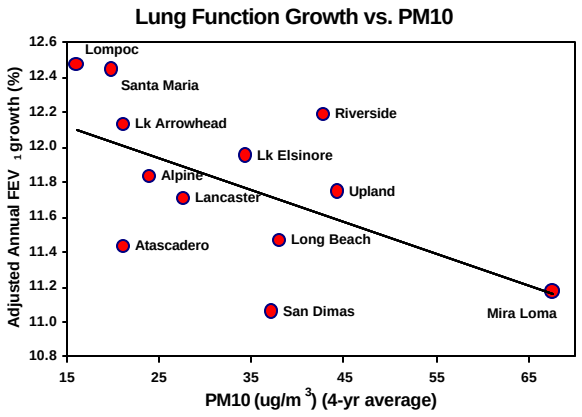
The project is comprised of two fully integrated components: an epidemiological health component and an exposure assessment component. As requested by the ARB, the interim report represents a summary of the work accomplished through approximately the first two years of the project. The report includes updates on the state-of-knowledge related to asthma and air pollution in the context of the study objectives, a reiteration of the specific hypotheses and aims, a progress report on the key elements of the study, and major accomplishments during this period. One major accomplishment was the development of a strategy for classification of asthma severity, which will be critical to be able to examine changes in asthma progression over time as opposed to changes in asthma control over time. Progress has been made in the many monitoring aspects of the FACES project, including monitoring in the homes, identifying pollens and spores, endotoxin measurements, the gathering of ambient data from mobile monitoring trailers, and the development of the exposure models. Analysis of effects of air pollution exposure on the

FACES subjects found that multi-day moving averages provided a better model fit than did single-day lags for the occurrence of asthma symptoms. The magnitude of the results seen, while not final, was consistent with published scientific study results.

Other ARB-funded Health Effects Studies

Southern California Children's Health Study

The Children's Health Study (CHS), which began in 1992, is a long-term epidemiologic study of the health effects of children's chronic exposures to southern California air pollution. About 5500 children in 12 communities have been enrolled in the study; two-thirds of them were enrolled as fourth-graders. The CHS includes 28% Hispanic, 5% black, and 5% Asian among its participants. Data on the children's health, their exposures to air pollution, and many factors that affect their responses to air pollution are gathered annually until they graduate from high school. Concentrations of four pollutants (ozone, nitrogen dioxide, acid vapor, and PM) have been continuously measured in each community throughout the study and for brief periods in schools and some homes. In addition, each child's lung function is tested every spring. Annual questionnaires ask about the children's respiratory symptoms and diseases, such as chronic cough and asthma; level of physical activity; time spent outdoors; and many other factors known to influence children's responses to air pollution, such as parental smoking and mold and pets in the household (Peters et al., 1999a).



Several peer-reviewed papers have recently been published from data collected from the CHS. Some of the pertinent findings include:

- Children living in high ozone communities, who actively participate in several sports, are more likely to develop asthma than children in these communities not participating in sports (McConnell et al., 2002).
- Children living in communities with higher concentrations of nitrogen dioxide, particulate matter, and acid vapor have lungs that develop and grow more slowly and are less able to move air through them. This decreased lung function growth may have permanent adverse effects in adulthood (Gauderman et al., 2000; 2002).
- Children who moved away from study communities had increased function growth if the new communities had lower particulate pollution, and had decreased lung function growth if the new communities had higher particulate pollution (Avol et al., 2001).
- Days with higher ozone concentrations resulted in significantly higher school absences due to respiratory illness (Gilliland et al., 2001).

In addition to concerns that children are frequently considered vulnerable due to the fact that their lungs are still developing and they spend more time outdoors, have a higher lung surface-to-body mass ratio, and have higher respiratory rates than adults (Adams,1993), evidence from the CHS indicates that there may be subsets of children who are more vulnerable than others. For example, CHS investigators reported that children with asthma who are exposed to higher concentrations of particles are much more likely to develop bronchitis (McConell et al., 1999). Findings such as these substantiate the need to have programs focused on issues of vulnerability such as the VPRP.

Huntington Park Asthmatic Children's Study

This investigation was funded by ARB and the SCAQMD and undertaken to add important information to the sparse literature that exists

evaluating exposure to volatile organic compounds (VOCs) and measures of health in asthmatics. Understanding the impact of VOCs alone and in combination with criteria air pollutants is important to guide future regulations to protect sensitive populations at risk, including asthmatics.

Participants included 26 Hispanic children, ages 10-16, living in Huntington Park, East Los Angeles County, a highly industrialized area flanked by major freeways and trucking routes. This pilot study was designed to evaluate the relationship of the daily occurrence and severity of asthma to VOC exposure among asthmatic school children using subject time-activity reports, breath sample gas chromatography-mass spectrometry, and personal, indoor home, and outdoor stationary site VOC samplers. Furthermore, the investigation included an exposure assessment study to estimate the associations between breath, personal, indoor, and outdoor concentrations of VOCs. Investigators reported associations between bothersome or more severe asthma symptoms recorded in diaries and breath concentrations of benzene. Ambient VOCs (including benzene, toluene, *m,p*-xylene, and *o*-xylene), measured on the same day as breath VOCs, showed notably stronger and significant associations with symptoms. Generally, indoor VOC concentrations were higher than breath VOCs. Personal exposures correlated well with indoor exposures, but did not correlate with outdoor measurements for most VOCs. These findings, coupled with experimental and other epidemiologic evidence in the literature, suggest that the pro-inflammatory and irritant nature of traffic-related pollutants can lead to adverse effects in asthmatic children (Delfino et al., 2003).

Particulate Air Pollution and Morbidity in the Central Valley

Particulate air pollution and its continued impact on public health is a major focus of current research efforts. Understanding the impact of PM is important to guide future regulations to protect sensitive populations at risk. Assigning specific health effects to individual air pollutants is a difficult task and few studies have examined the effects of different size fractions and chemical components of PM. This study was designed to address these issues and examined the relationship between PM and other pollutants and acute cardiopulmonary morbidity. This investigation examined the relationship of daily ambient measures for PM2.5, PM10, the coarse fraction of PM, selected chemical components of PM, NO_2, and ozone with daily hospital admissions and emergency room visits for cardiopulmonary disease. The study population used was the Kaiser Permanente, Northern California membership residing in the San Joaquin Valley of California from 1996 through 2000. Strong positive associations were found between PM10, PM2.5, and CO and acute and chronic respiratory hospitalizations in Kaiser Permanente members. For a 10 $\mu g/m^3$ increase in PM10 (using a four-day average), there was a 2.3% increase in the rate of acute respiratory hospitalizations and a 5.5% increase in the rate of chronic respiratory hospitalizations. For PM2.5 there was a 4.1% increase in acute respiratory hospitalizations and a 7.5% increase in chronic respiratory hospital admissions. For a 10 $\mu g/m^3$ increase in PM10 (using a four-day average), there was a 3.4% increase in the rate of acute respiratory emergency room visits and a 3.8% increase in the rate of chronic respiratory emergency room visits. For PM2.5 the increase was 5.2% for acute respiratory emergency room visits and 6.5% for chronic respiratory emergency room visits. For acute respiratory hospitalizations, the results were strong and consistent for those over 50. Studies such as these can provide the information needed to determine levels at which air pollutants contribute to adverse health impacts and will aid the ARB in setting ambient air quality standards to protect even the most sensitive subpopulations in California (Van den Eeden et al., 2002).

Cardiovascular and Respiratory Hospitalization Data Analysis

We performed an exploratory investigation of whether currently available data sets on

healthcare within California may be useful in evaluating potential links between susceptible subpopulations and ambient air pollution levels. As part of the analysis, publicly available versions of the Office of Statewide Health Planning and Development (OSHPD) data sets were obtained along with information from the 2000 census (1990-2000). A preliminary evaluation of rates of specific diseases (e.g., cardiovascular and respiratory endpoints) and relationships to race and ethnicity for CA counties for 1998 was performed. Upon first glance the results indicated that several areas of the State, such as Imperial County, had elevated respiratory disease admittance rates for Hispanics (this category was also high for non-Hispanics), however, uncertainties related to the data included: 1) Hispanic and non-Hispanic categories in the census data were not comparable to the OSHPD hospital admission data, therefore making a direct comparison difficult; 2) age distributions in different populations were not standardized, which may affect disease rates among individual populations; 3) county-level data may prove inaccurate as some counties have very few numbers of specific ethnic groups, therefore associated disease rates may prove unreliable; and 4) data are only for hospital admissions, which means other information such as emergency room visits and those whose disease has been managed via regular physician visits or out-patient clinics will not be reflected in the evaluation.

An additional GIS-based analysis was designed that utilized similar OSHPD health outcome data sets and associated air pollution levels at a more spatially refined zip-code level for Sacramento. Results of this analysis confirms the potential utility of the GIS-based tools. The interpretation of results, however, proved challenging due to the combined lack of spatial resolution of the various air pollution, health outcome, and socioeconomic data sets utilized.

VPRP External Advisory Committee

The VPRP External Advisory Committee (EAC) was formed from academic and other experts in the fields of epidemiology, biostatistics, toxicology, exposure assessment, atmospheric sciences, and environmental justice, and representatives from most of the major U.S. organizations that fund health and exposure research. The EAC provides input on several aspects of the VPRP, including providing information regarding ongoing programs at their respective institutions. The individuals at these institutions ensure that work sponsored by the ARB is complementary to national programs already in place. The two major U.S. funding organizations for research on vulnerable populations are the National Institute of Environmental Health Science (NIEHS) and the U.S. Environmental Protection Agency (U.S. EPA), and their programs are briefly described below. Research sponsored or conducted by other U.S. institutions are described in Section III as part of the eight broad research questions.

National Institute of Environmental Health Sciences

NIEHS has developed a number of research and outreach programs to address health disparities, and is recognized as the leader in this endeavor. The research component improves our understanding of the environmental causes of health disparities. The outreach components, such as the Environmental Justice Grants and the Community-Based Prevention/Intervention Research grants, help empower disadvantaged communities with resources to effect healthful change. The aggregate NIEHS programs will give researchers a clearer understanding of the role of environmental factors in health disparities, improve the ability of affected communities to direct change, and increase the pool of minority scientists with both the understanding and credibility needed to design and implement studies that address these important problems.

NIEHS will also fund the continuation of the CHS. The primary objectives of the continuation of the CHS are to: address the question of whether the observed changes in pulmonary function persist to adulthood; study asthma incidence with the goal of identifying environmental and host factors; examine the

genetic variation in oxidative stress pathways that modulate response to air pollution; and develop new biostatistical methods.

Recently NIEHS funded nine projects in response to a Request for Applications that was issued (in conjunction with National Human Genome Research Institute) to encourage projects that promote public understanding of the social, ethical, and legal implications of conducting environmental health research involving human subjects in areas such as gene-environment interactions (interplay between genetics and the environment), environmental health hazards, and disease susceptibility.

Some of the projects that were funded focus on:

1. Increasing a community's understanding of how genes interact with specific environmental agents (e.g., asbestos and lead).

2. Developing educational materials to improve community health, environmental justice, and understanding of the role that both environmental and genetic factors play in how diseases develop. In addition, NIEHS, National Institute of Child Health and Human Development and National Institute of Nursing Research are seeking research grant applications to encourage research on how interactions between genes and the environment affect the health disparities of premature birth.

The research will increase our understanding of how different social, behavioral, and environmental conditions can interact with genetics to make women more susceptible to premature birth in high-risk racial and ethnic groups in the U.S. In addition, the proposal request addresses the need to identify genetic markers and how they increase the risk of premature birth among these high-risk groups.

U.S. Environmental Protection Agency

The U.S. EPA supports both a Children's Health Protection Program and an Environmental Justice Program. The purpose of EPA's Office of Children's Health Protection is to make the protection of children's health a fundamental goal of public health and environmental protection in the U.S. Children today face significant and unique health threats from a range of environmental hazards. They are often more heavily exposed and more vulnerable than adults to toxins in the environment. The U.S. EPA will work with partners, especially those in the Department of Health and Human Services, to ensure that children receive the protection they need and deserve, and to help our nation fulfill its obligation to protect future generations.

Children's Microenvironmental and Personal Exposure Study

Indoor and personal exposure monitoring are required under SB 25 to provide comprehensive data on the levels of children's exposure to air pollutants and to facilitate an assessment of the adequacy of the monitoring network in estimating children's exposures. Children's exposure to air pollutants inside classrooms were measured during the 2001-2002 school year in three of the selected SB 25 communities.

We contracted with the University of California at Los Angeles to measure pollutants inside school classrooms, at one location on the school grounds, and in a few residences. These measurements were taken at Hollenbeck Middle School in Boyle Heights, Wilmington Park Elementary School in Wilmington, and one northern California school. Pollutants to be measured include toxic gases, particulate matter, and formaldehyde and related compounds. A subset of students will wear small monitoring badges to measure their personal exposure to toxic gases in a 48-hour period. The contractor will also administer a health status survey to students in the monitored classrooms to determine the incidence of asthma and allergies. Additionally, to meet objectives of the ARB's Neighborhood Assessment Program, information on ways to reduce exposures to indoor and outdoor contaminants will be developed and distributed. Field measurements are completed and the final report on the entire project due by the end of 2003.

The study results will provide valuable information that will help the ARB identify differences between pollutant levels measured at network monitoring sites and children's indoor and personal exposures to air pollutants. The personal monitoring data will provide insight to children's actual exposures to toxic air pollutants. The microenvironmental monitoring data collected at locations where children spend most of their time – at school and at home – will expand our knowledge of how indoor sources contribute to children's exposures. Finally, this information will be useful in identifying additional sources that may require emission reductions in the future.

Other ARB-funded Exposure Studies

COPD Exposure Study

Previous studies of human exposure to PM have shown that the relationship between ambient concentrations and human exposures is very complex. The objective of this study was to characterize the chemical composition of personal, indoor, and outdoor fine particulate (PM2.5) exposures for 15 individuals with Chronic Obstructive Pulmonary Disease (COPD) living in metropolitan Los Angeles. This project was an addition to a $1 million PM exposure study funded by U.S. EPA. Newly-developed Harvard mini-samplers were used to measure daily average concurrent personal, indoor, and outdoor mass concentrations of PM2.5, as well as PM2.5 elemental carbon (EC), nitrate, and elemental concentrations, for each subject over seven consecutive days during Summer 1999 and/or Winter 2000.

Results indicate that personal PM2.5 exposures were higher than corresponding indoor and outdoor concentrations in both seasons. In contrast, outdoor EC and nitrate concentrations were higher than indoor and personal levels in both seasons, reflecting the fact that motor vehicles are their major source. For PM2.5 and EC, the contributions of particles of outdoor and indoor origin to personal and indoor levels varied by season, with a greater contribution of outdoor particles in the summer and a greater indoor source contribution in the winter. Indoor concentrations for all three particulate measures were more strongly associated with personal exposures as compared to outdoor concentrations, which may be attributed to the fact that the participants spent most of their time indoors at home. The results provide additional information to increase our understanding of exposures to PM and its components in sensitive subpopulations such as individuals with COPD, and facilitate interpretation of epidemiological studies on PM health effects.

In-vehicle Exposure Study

One of the most important routes of air pollution exposure occurs during time spent in vehicles. Due to relatively undiluted vehicle exhaust on roadways, in-vehicle concentrations of vehicle-related pollutants are typically five to ten times higher than those measured at monitoring stations. To measure the importance of this route of exposure for Californians, in 1997 we funded one of the largest and most thorough in-vehicle concentration studies ever conducted (Rodes et al., 1998). It included measurements of speciated and total mass of PM10 and PM2.5, fine particle number counts, black carbon, CO, and speciated VOCs. It was carried out in Los Angeles and Sacramento on a variety of arterial, highway, and carpool road types, and at various times of the day. In general, similarly elevated concentrations were measured inside vehicles for similar traffic conditions, regardless of location or road type, but the extent that roadside concentrations were elevated appeared to depend on the total volume of traffic. Further work continues to characterize concentration gradients due to roadways (Zhu et al., 2002a,b), but it is apparent that those who have long commutes in heavy traffic as well as the many people who live near heavy traffic are much more heavily exposed to traffic-related pollutants than others.

One area of special concern is exposure to diesel exhaust particulate matter (DPM). DPM is considered to be carcinogenic and appears to dominate urban air pollution cancer risk. Recent work by Fruin (2003), based on the measurements of Rodes et al. (1998),

showed time spent in vehicles accounted for one-third of total DPM exposures, on average, even though they typically averaged only 6% of their day (1.5 hours) in vehicles. The highest in-vehicle DPM concentrations occurred while directly following diesel vehicles. However, the roadway "background" concentrations, which tended to reflect total diesel vehicle volumes, mostly determined the overall in-vehicle exposures. Exposures were therefore highest in urban areas and on roads with heavy traffic.

School Bus Study

One special concern regarding children's exposures to air pollution is the time some children spend near to and riding diesel-powered school buses. To study this issue, we and the SCAQMD funded a comprehensive study of school bus-related exposures, in which measurements were made inside instrumented school buses along actual bus routes in Los Angeles, and at bus stops and areas of bus loading and unloading. The urban bus routes were through enthically diverse neighborhoods that were often primarily African American and Hispanic. Low-income neighborhoods as well as middle income neighborhoods were represented. Five conventional diesel buses were used, along with a diesel bus outfitted with a particulate trap and a school bus powered by natural gas, for comparison. Concentrations of diesel-vehicle-related pollutants such as black carbon, particle-bound PAHs, and NO_2 were consistently higher on board conventional diesel buses compared to the CNG bus, while the trap-outfitted bus exhibited intermediate concentrations. These differences tended to be greater when bus windows were closed. Concentrations were also higher when other diesel vehicles were being followed, and were higher on the urban routes with greater traffic density than on the rural/suburban route. Pollutants more regional in nature, such as PM2.5, showed smaller differences. A tracer gas (sulfur hexafloride) added to the bus exhaust confirmed these findings and showed that the degree to which the bus's own emissions contributed to bus cabin concentrations was greater for older and/or higher emitting buses, and greater when windows were closed. Bus-to-bus variations, however, were large. Exposures occurring while waiting at bus stops and during loading and unloading made relatively insignificant contributions to children's commute exposures.

Exposure Assessment Tool Development

Diesel PM Marker

There is wide interest among scientific, regulatory, and impacted communities in finding a marker that will allow identification of the contribution of diesel sources to ambient particulate matter. Initial studies used elemental carbon (EC) as a marker since diesel exhaust was the primary source, however, as diesel engines and fuels have become cleaner over time, EC from other combustion sources has become relatively more important, and EC should not be used a marker for ambient diesel exposure. Other proposed markers such as hopanes and steranes are emitted by both gasoline and diesel engines. At a December 2002 workshop sponsored by the Health Effects Institute on possible ways to improve estimates of diesel exposure, the conclusion of the assembled experts was that at this time there is no marker specific to diesel (HEI, 2002). The importance from a health point of view of estimating diesel exposure has led to a significant amount of effort in this area. The U.S. Department of Energy is conducting a major study on PM from gasoline and diesel engines and the results should be available this summer. Another on-going project, sponsored by the Coordinating Research Council (CRC)(E55/59 Heavy-Duty Vehicle Chassis Dynamometer Testing for Emission Inventory, Air Quality Modeling, Source Apportionment, and Air Toxics Emissions Inventory) contains an element that is focused on chemical analysis of diesel exhaust.

We are funding several research projects in this area. As part of a source apportionment study of fine and ultrafine PM, the University of California at Davis (UCD), is developing source profiles for gasoline and diesel engines. A study by the University of California at San Diego is using single particle aerosol

time-of-flight mass spectrometry to determine the contributions of gasoline and diesel vehicle emissions to ambient PM. This study will be conducted in coordination with the ARB project at UCD to apply novel derivatization methods to probe the oxygenated organic species in the particle phase of vehicular exhaust. In addition, the ARB Monitoring and Laboratory Division is working on a diesel PM chemical marker study. Preliminary results indicate a unique pattern of C_{12} to C_{16} hydrocarbons present in both source and ambient samples. Additional samples for analysis will be collected as part of CRC's E55/E59 project. However, none of the current research efforts will result in a routine method for characterizing diesel PM exposure in the community any time soon.

Low-cost Monitoring Technologies

In 2002, we released a solicitation for grants to support the commercialization of air monitoring technologies to meet several important goals as described below. The grant program, which is being co-funded by the California Energy Commission (CEC), is for a total of up to $1,000,000, provided viable responses are received. The effort is also being conducted in conjunction with the New York State Energy Research and Development Authority (NYSERDA) which has released a related solicitation for a total of $500,000.

The ARB's overall goal is to provide people and organizations that are concerned about their local or indoor air quality with practical means to monitor that air quality independently. Technologies supported by this program should be practical for measuring people's exposure where they live, work, recreate, or attend school. We are most interested in technologies to measure fine particulate matter, oxides of nitrogen (NOX), ozone, and certain toxic air contaminants. The goal of the CEC is to obtain technology to monitor exposures to PM and other pollutants from natural gas-fired power plants and neighborhoods that are potential source locations.

A primary consideration of this solicitation is technologies that have the potential for wide deployment to measure peoples' exposure to air pollutants during their daily activities. Specifically, the ARB is seeking technologies to provide measurements on a continuous or frequently integrated basis.

The technology characteristics that will allow wide deployment include:

- Low acquisition cost.
- Low operating cost (including maintenance requirements).
- Minimal need for laboratory analyses and off-site preparations.
- Portability (related to size, weight, ruggedness, and utility requirements).
- Simplicity of calibration and other quality-control procedures.

Other important characteristics are:

- The species measured. Particulate matter and ozone are of importance due to the large health impacts from exposure to these pollutants. In addition, high priority toxic air contaminants include hexavalent chromium, diesel PM, dioxins, PAH's, methylene chloride, percholorethylene, p-dichlorobenzene, 1,3-butadiene, acetaldehyde, formaldehyde, acrolein, benzene, and C_7-C_9 aromatic hydrocarbons.
- Adequate range of measurement, especially limit of detection (LOD).
- Good accuracy, reliability, and precision.
- Chemical and physical specificity in measurement (e.g., NO vs. NOX and PM10 vs. total PM).
- Absence of artifacts and interferences in measurement.

Although we are willing to consider and support technologies that are not yet in commercializable forms, the technology must be defined well enough for its costs of acquisition and operation to be estimated with reasonable confidence. The technology must also be distinguishable from commercially available technology that is already applied to ambient air monitoring.

After considering comments provided by a broad spectrum of stakeholders, we are recommending that two proposals receive funding as they address high priority needs and are believed to be positioned to be commercialized in the future. The recommended proposals including the name of the applicant's organization, the title of the proposal, as well as a brief description are as follows:

University of Southern California – A Simple, Low-cost Beta Attenuation Monitor (BAM) for Continuous Measurement of PM10, PM2.5, or Ultrafine Particle Concentrations

The principle of operation of the proposed device is based upon the well-characterized measurement of beta rays across a filter medium which is collecting particulate matter. The extinction coefficient, to an excellent approximation, is dependent only upon mass. By reducing manufacturing and supply costs in components such as the pump, the source, the detector and the filter advance mechanism, the projected retail cost can be reduced without significant loss in monitor performance.

Berkeley Sensor & Actuator Center – Development of a Low-cost Particulate Matter Monitor

A prototype instrument, employing a novel technique to deposit airborne particles on a piezoelectric crystal that serves as an added mass monitor, has been designed and successfully tested at the Lawrence Berkeley National Laboratory. The device monitors the mass of fine respirable particulate matter (having 2.5 or 10 micron diameters) deposited during a known sampling time; it also uses optical means (UV/IR) to differentiate among various types of particulate matter. The sensor response will be able to be related directly to the applicable Federal Reference Methods. This sensor also has the potential to provide on-board particle source identification for at least three of the major disease-causing particle sources: diesel exhaust, environmental tobacco smoke, and wood smoke.

In addition, NYSERDA funded one project:

Clarkson University - Electrical Aerosol Sizer

Initial funding was provided for laboratory research directed toward the development of new particle size measuring technology that may be able to distinguish elemental and organic carbon particles, which can be a major constituent in fine particulate mass in ambient air.

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III. REMAINING DATA GAPS AND RECOMMENDED RESEARCH

This Plan organizes research needs into two major categories:

1) ***Health Effects***; and

2) ***Exposure Assessment***.

These two categories were selected because they represent the scope of research that is anticipated over the next few years on vulnerable populations. Furthermore, they define the natural progression of research, from identifying the impacts associated with air pollution (i.e., *Health Effects*) to characterizing exposures (i.e., *Exposure Assessment*). Additional research is needed to facilitate the application of effective exposure reduction strategies, which was previously described in the *Technology Advancement and Pollution Prevention* section of ARB's Strategic Plan for Research (ARB, 2001a). Descriptions of remaining data gaps and recommended research for each of these categories is offered below, structured in the form of broad research questions. Within each question, we define the issue and summarize prior results (*Background*), describe research conducted and funded by ARB and other groups (*Ongoing Research*), and identify research needs and research to be conducted or funded by ARB with realistic timeframes (*Remaining Data Gaps and Recommended Research*).

Health Effects

The ARB and other funding organizations actively sponsor research to examine the adverse effects of air pollution on children, the elderly, and those with pre-existing health conditions, in addition to studies of the general population. Most studies include analyses of socioeconomic status to help identify if there is a predisposition to air pollution-related health effects due to gender, race, income level, or higher exposures. These studies lay the foundation for setting of ambient air quality standards protective of vulnerable populations and subsequent air pollution control programs for reducing community health impacts.

1. WHICH POPULATIONS HAVE HEIGHTENED SUSCEPTIBILITY TO AIR POLLUTION AND WHAT ARE THE FACTORS THAT CONTRIBUTE TO INCREASED SUSCEPTIBILITY?

We are funding research on children's health impacts (including asthmatics) from long-term exposure to air pollution. This study includes minority and low-income groups. Future research could include studies of infants, the elderly, and those with cardio-pulmonary disease. Research funded by others is focused on evaluating the effects of socioeconomic status, race, ethnicity, gender, and other factors that may contribute to increased susceptibility.

Background: Traditionally, we have considered susceptible groups to include children, the elderly, and those with preexisting disease. However, researchers recognize that people differ in their biologic susceptibility to environmental contaminants. Furthermore, people also differ in the amount of contaminant to which they are potentially exposed. Despite recognition of these findings, available technology has limited the ability of researchers to evaluate the biological factors that make some people more vulnerable than others. Fortunately, recent advances in our ability to assess biologic factors that influence risk have been made. We can now look at genetic factors, as well as the social and behavioral factors, that make people more vulnerable. This Plan will seek to sponsor projects that combine the information available through these recent advances with the more traditional methods of environmental health research.

Ongoing Research: Two ongoing research studies sponsored by ARB are evaluating children's health. However, these two studies also aim to examine if there are subpopulations of children within these studies that are more susceptible than others. For example, in the Children's Health Study, researchers are looking at factors such as nutrition (fruit and vegetable intake), and the influence that genes may play on children's response to exposure to ambient air pollution.

California Asthma Prevalence: A Comparison Between San Joaquin Valley and California Statewide Prevalence (2001)

- Recent health surveys show significantly higher prevalence of asthma in the San Joaquin Valley (SJV) than in the rest of California. Unfortunately, it is not possible to determine the incidence of new asthma cases from these data.
- Asthma prevalence was defined as persons who reported being diagnosed with asthma by a physician at any time in the past and who reported symptoms in the previous 12 months.
- (California averages are from the California Health Interview Survey, conducted by the UCLA Center for Health Policy Research (www.chis.ucla.edu). It was conducted through a random-dialing survey of about 74,000 persons, statewide, stratified by county population.)

County	Prevalence in Children (age 0 – 17) (%)	Prevalence in Adults (age 18+) (%)
Fresno	16.4	11.9
Kern	10.0	9.0
San Joaquin	10.1	8.9
Stanislaus	9.3	9.9
Tulare	10.5	8.8
Merced	11.8	11.7
Kings	14.7	10.0
Madera	11.1	11.2
SJV Average	**11.9**	**10.1**
California Average	**9.6**	**8.5**

All children from classrooms selected for the CHS were invited to participate so that investigators have a range of host and exposure factors to study. In FACES, children were selected based on the fact that they were active asthmatics. The investigators have attempted to recruit a sample representative of the Fresno population in order to better understand the role race and other socioeconomic factors might play in the progression of asthma.

A 2000 study by the California Department of Health Services (CA-DHS) entitled "California County Asthma Hospitalization Chart Book" examines county variations in asthma hospitalization rates in California. Data for hospital discharges from 1995 through 1997 were obtained from records of all hospital discharges in California, with the exception of federal facilities. All discharges with asthma as the primary diagnosis were selected, and rates were calculated for the three years combined using yearly population estimates by age, race, sex, and county. The study found that, "overall the rates for California asthma hospitalization decreased during 1995-1997 compared to previously published figures for 1991-1994…" and "blacks continue to have significantly elevated rates as compared to other racial/ethnic groups." The study further found that the costs associated with asthma hospitalizations do not seem to be influenced by racial/ethnic group but do seem to be affected by age. The total charges incurred per hospital stay for children are approximately two-thirds that of adults, which correlates with the fewer days spent per admission in the hospital by children.

Other researchers have also focused on the question of increased susceptibility to air pollution. Several studies indicate that age and pre-existing disease play a major role in susceptibility to the adverse effects of air pollution. Investigators at OEHHA have conducted several studies evaluating the influence of age and pre-existing disease in relation to mortality and morbidity. An investigation of mortality and air pollution in Riverside and San Bernardino Counties reported an association between daily levels of fine particles,

measured from visibility data, and all-cause and cardiovascular mortality, among a population of residents in these two counties. The group impacted was primarily elderly people with pre-existing heart and lung disease (Ostro, 1995b). A study of mortality and air pollution in Coachella Valley revealed an association between both PM10 and coarse particles with total (all-cause) mortality, cardiovascular mortality and mortality among those age 65 and over. The group impacted was primarily elderly people with pre-existing heart and lung disease. (Ostro, 1999a; 2000). An ongoing study by OEHHA of hospital admissions and emergency room visits in the Coachella Valley is reporting associations between both PM10 and coarse particles and hospital admissions and ER visits for pneumonia among both children and elderly people with pre-existing respiratory disease.

Race has also been investigated as a possibly influential factor on heightened susceptibility, especially among those with preexisting disease. A study of asthma and air pollution among African-American children in LA reported associations between daily concentrations of PM10 and asthma exacerbation among a cohort of 100 African-American children living in South Central Los Angeles (Ostro, 1995a; 2001).

Another organization actively involved in research attempting to address issues of heightened susceptibility to air pollution is the Health Effects Institute (HEI). HEI is conducting studies in two U.S. cities of indoor, outdoor and personal exposure of the elderly with Chronic Obstructive Pulmonary Disease to determine the contribution of ambient PM to exposure. HEI also sponsored the Reanalysis of the American Cancer Society and Harvard Six Cities Study, the first such study to identify the substantially higher estimates of risk for those with less education (and likely lower socioeconomic status). Furthermore, HEI has multi-city and single-city studies of mortality and hospitalization among elderly, heart patients, and diabetics, and among other sensitive groups underway, in addition to a series of toxicology studies examining effects and mechanisms in old, young, and diseased laboratory animals to test effect of age and prior disease on response. Controlled human exposure studies in Europe and two sites in the U.S. are also examining effects of exposure to PM for normal and asthmatic subjects.

Supported by a $1.5 million grant from the U.S. Department of Defense, research at the Salk Institute have identified a gene that may link certain pesticides and chemical weapons to a number of neurological disorders, including the Gulf War syndrome and attention deficit/hyperactivity disorder (ADHD). The finding, published in the March 17 online version of *Nature Genetics*, may be the first to demonstrate a genetic link between neurological disorders and exposure to organophosphate chemicals in mice.

The Salk Institute found that organophosphate exposure inhibited the activity of a gene called neuropathy target esterase, or NTE, in mice. The gene is active in parts of the brain controlling movement - the hippocampus, the cerebellum and the spinal cord. This inhibition either killed the mice before birth, or led to a range of behaviors very similar to ADHD. Some of the neurological problems were similar to symptoms seen in Gulf War syndrome. This work may be an example of how environmental factors may affect the nervous system.

More information is needed to identify the physiological, genetic, medical and other factors that contribute to susceptibility to PM and sulfates health effects. Age appears to be one factor in susceptibility to adverse effects resulting from exposure to PM and sulfates. Studies on children and neonates are critically needed. Subjects at risk of PM and sulfates-induced health effects need to be incorporated into research on the health impacts of these pollutants. Hypothesis-driven animal toxicological experimental studies, as well as human clinical studies, offer especially valuable opportunities to investigate issues that are related to biological sensitivity. This information will be very useful in optimizing research protocols and refining subject selection criteria so that future research targets the

most significant endpoints and most at-risk subpopulations.

Several mortality studies have examined whether socioeconomic status (SES) and related factors such as education and race/ethnicity affect the magnitude of PM-mortality associations. These studies help address the question of whether factors linked with poverty or educational attainment render individuals more susceptible to the adverse effects of exposure to air. To date the findings have been mixed. The prospective cohort studies investigating the potential impacts of longer-term exposure appear to find consistent effect modification by education on pollution (Dockery et al., 1993; Krewski et al., 2000; and McDonnell et al., 2000), whereas the acute exposure studies do not demonstrate much, if any, modification of these relationships (Zanobetti et al., 2000; Schwartz et al., 2000a; and Samet et al., 2000a).

The evidence to date, therefore, suggests that there may be a greater effect of PM among individuals from lower SES groups, although the actual risk factors are unknown. Candidate risk factors include poor nutrition, lower access to and use of health care, and higher air pollution exposures due to location of residences near PM sources such as freeways and industrial facilities.

Remaining Data Gaps and Recommended Research: Several questions remain regarding the importance of host and exposure factors with regard to health outcomes. Research efforts have begun to systematically evaluate the effects of age, pre-existing disease, and other factors on risk of disease in populations. This information will help to clarify factors that make some populations more vulnerable than others. This could lead to a clinical index against which to assess someone or group's risk due to pre-existing disease.

One area of emerging research interest is the health impacts of ultrafine particles. These particles are extremely small, having aerometric diameters of less than 0.1 micrometers. As a result, they have little mass in comparison to the PM10 and PM2.5 exposures. However, they may have large health impacts and have been implicated in toxicology studies as being more toxic than PM10 and PM2.5 particles. Several recent studies seem to implicate ultrafine particles in adverse cardiovascular health effects (Oberdörster et al., 1995; Seaton et al., 1995; Wichman et al., 2000).

2. *WHICH POLLUTANTS AND WHAT LEVELS OF THOSE POLLUTANTS CAUSE HEALTH EFFECTS? WHAT POLLUTANT CHARACTERISTICS ARE MOST RESPONSIBLE FOR THE HEALTH EFFECTS?*

Much controversy remains as to which components of air pollution and at what levels these pollutants cause health effects. Several researchers have begun to try and disentangle the specific component(s) of the air pollution 'mix' by evaluating the health effects of a particular pollutant while taking into account the effect other pollutants simultaneously present. These types of analyses continue to prove difficult due to the fact that many air pollutants are highly correlated and researchers are still developing the best biostatistical methods to deal with correlated data. We are funding research on this issue through the CHS, FACES, and other projects. For example, Delfino and colleagues (2003) evaluated the effects of VOCs on asthma symptoms while simultaneously considering criteria pollutants such as PM and ozone. Van den Eeden (2002) and colleagues also evaluated the effects of PM in the California Central Valley while taking into account the presence of ozone and other pollutants. Health Canada also recognizes the importance of the identification of the components of the air pollution mix, specifically that of PM, which are responsible for health effects and has made this a priority research area (Health Canada, 2003a).

Background: The ARB is responsible for setting ambient air quality standards (AAQS) protective of public health. One of the main goals of these standards is to ensure the levels set are protective of all Californians, including vulnerable populations. Part of setting

these standards involves knowing which pollutants are responsible for what effects, and at what concentrations. The VPRP will provide much needed data with regards to which pollutants are responsible for health effects, and at what concentrations these effects are seen. Research solicited through the VPRP has made identifying these key issues a priority. One pollutant of concern is PM. PM is not a single chemical pollutant, but rather a complex mixture. It is not known which components of PM are responsible for the many health effects (e.g., death, chronic bronchitis, asthma attacks) observed. To more effectively understand the health effects of PM exposure, we need to investigate the deleterious effects from specific PM components or characteristics (i.e., size, shape). In addition, the length of exposure that is important is unclear. Research is needed to clarify what time frame is important for various health effects (i.e. long term exposures [over a life-time] versus shorter-term exposures [1-hour, 8-hour, 24-hour]). This is especially important in vulnerable populations, such as elderly populations with cardiovascular disease, where fluctuations are associated with morbidity and mortality. Other pollutants of concern include ozone and NO_2, for which we are currently reviewing the literature for a possible revision of the ambient air quality standards, and TACs, especially diesel PM.

Ongoing Research: The ARB's FACES study strives to answer questions related to the particular components of PM, gaseous pollutants, TACs, and biologicals that are important in terms of the progression of asthma in young children. Several measurements taken at a variety of time-scales will allow investigators to evaluate not only the specific pollutant components that are important, but also the time-scales that influence asthma symptoms and lung function measurements.

The ARB is involved with several research activities concerning the health effects of PM exposure, including a collaborative effort with the University of California at San Francisco (UCSF); the University of California at Davis (UCD); and the University of California at Irvine (UCI), and an additional research agreement with the University of California at Los Angeles (UCLA) with the collaboration of the University of Southern California (USC).

The UCSF, UCD, UCI collaborative is examining health effects of PM exposure in California. Specifically, the goal is to determine the mechanisms that mediate adverse cardiopulmonary effects of inhaled PM, and to determine whether these mechanisms of injury are related to particle size. For this program, both animals and humans are exposed to ammonium nitrate and carbon black, two large components of PM2.5 in California.

UCSF is determining the effect in asthmatics of inhaling PM on airway inflammation, cellular function, and associated cytokine release. They are exposing human volunteers to PM alone and also to PM and ozone, varying the size of the PM (fine and ultra-fine), and varying the dose (1-day and 3-day). Bronchial lavage and biopsy samples from exposed individuals will be analyzed for changes in cell function and for mediator production. Both UCD and UCI will assist in the analyses.

UCD is studying mechanisms of short-term toxicity in the lungs of airway-sensitized rats, because adverse effects in human asthmatics may be similar. Focusing on mechanisms related to epithelial injury, UCD is determining the effects on airway functioning and on epithelial and interstitial cells following PM exposure. In particular the role of glutathione in PM toxicity is being explored. The biological endpoints measured are likely to serve as sensitive markers of exposure effects in California PM.

UCI is examining mechanisms of systemic responses (heart rate and blood pressure changes) in conjunction with measurements of oxidative stress, cell-mediated immune functions, and reactive oxygen product release from sensitive animal models exposed to particles in three different size ranges.

The collaboration of UCLA and USC primary's focus is the effect of traffic pollutants, particularly PM. USC has developed ambient aerosol concentrators of ambient particles for toxicological inhalation studies, and UCLA, in

collaboration with USC, is developing a transportable inhalation exposure facility to enable concentration of coarse, fine, and ultrafine particles for studies in biological models. The initial results from this collaboration suggest that exposures to combined fine plus ultrafine particles near heavy traffic can elicit allergic responses in animals that are also exposed to foreign protein.

We have also participated as a "Center Affiliate" with the National Environmental Respiratory Center (NERC) in Albuquerque. NERC performs clinical toxicological investigations of various complex mixtures (gases, semi-volatiles, and particles) emitted by common pollution sources like diesel and gasoline engines, and wood fireplaces. These studies may strengthen the causal inference between exposure and response through the characterization of biological relationships. Results from these investigations should provide important information for possible regulatory actions of specific air pollutants.

Health Canada has initiated several human clinical studies investigating cardio-respiratory effects of concentrated ambient fine particles and ozone on healthy and asthmatic adults and children. These multi-year, and multi-disciplinary studies examine physiological, biochemical and clinical effects of ambient fine particles and ozone on respiratory and cardiovascular systems of healthy and asthmatic subjects, including asthmatic children. Fine particles are obtained from downtown Toronto ambient air. The subjects undergo an exposure of known amount of air pollutants which are expected to cause mild and transient effects. Scientists observe the subtle cellular and molecular changes in cardio-respiratory systems to elucidate the mechanism(s) of air pollutant-induced adverse effects and to determine why certain people are more vulnerable to air pollution, and potential intervention strategies. These controlled human exposure studies are critical in providing the biologically plausible evidence for epidemiological findings which have shown a significant association between increased ambient particulate and ozone pollution and population mortality and morbidity, and in support of evidence-based policy making (Health Canada, 2003b).

Remaining Data Gaps and Recommended Research: A substantial amount of research and focus has been given to this research question by both ARB and federal agencies. Especially in regards to components and sources of PM, including diesel. The results of studies described above should provide critical insight into the components of air pollution driving the health effects seen in the epidemiologic literature. The results of ongoing research should be used to determine the need for further research in this area. Information gained from these studies will provide the information necessary to set standards protective of public health in California. A remaining need not covered by the current research projects is the further evaluation of the non-cancer endpoints for TACs. We also propose to compare acute and chronic RELs to peak observed air quality levels in California.

3. *DOES AIR POLLUTION INFLUENCE THE DEVELOPMENT AND PROGRESSION OF DISEASE?*

Little is known about the influence of air pollution on the development and progression of disease. Studies have begun to address these issues, however, these types of studies are difficult to conduct due to the long-time frames people must be evaluated to determine the development and progression of disease. Most of the research in this area has examined the effects of air pollution on children with pre-existing asthma and on elderly subjects with pre-existing cardio-pulmonary diseases.

Background: Many of the known biological responses associated with air pollution exposures could potentially alter an individual's risk of getting a disease or influence the way an existing disease progresses. For example, even though evidence that air pollution causes asthma is only just emerging (McConnell et al., 2002), it is known to induce asthmatic episodes in people with the disease. Repeated episodes of asthma may damage or alter the respiratory tract of asthmatics,

leading to worsening of the disease and a poorer quality of life.

Ongoing Research: The CHS investigators have begun to look at issues of disease development as they have the benefit of tracking these children over long periods of time. One recent publication reported that highly-active children who lived in high ozone communities were more likely to develop asthma than those who were not active. NIEHS is going to continue to fund this study so that children may continue to be followed. A question of intense research interest through this continuation is how the depressed lung function growth that the CHS investigators have reported manifests itself over time. FACES is also considering questions of disease progression in relation to asthma by evaluating asthmatic children over the course of at least four years to determine how exposure to PM and other components of air pollution affect the progression of their asthma and lung function growth.

OEHHA is also actively pursuing research into questions of disease development and progression in relation to air pollution. The East Bay Children's Respiratory Health Study is focused primarily on relationships between long-term exposures to traffic-associated pollutants and several respiratory disease outcomes, including asthma exacerbation, bronchitis, and wheeze. The study population included about 1100 elementary school children, nearly 90% of whom were nonwhite, many (approximately 1/3) from families living at or below the federal poverty level. Several other OEHHA studies have examined the impacts of air pollution on exacerbation of disease. Lipsett et al. (1997) reported that ambient PM 10 during the winter was associated with emergency room visits for asthma in Santa Clara County. In Los Angeles, PM 10 levels were associated with worsening respiratory symptoms among African-American children with asthma (Ostro 1995a; 2001). OEHHA staff also undertook an examination of the quantitative impacts of ambient particulate matter on several outcomes in asthmatics (Ostro et al., 1998). In a recent study in the Coachella Valley, OEHHA staff found that PM 10 and coarse particles were associated with decreases in heart rate variability (a measure of the heart's ability to cope with stress) among subjects with established coronary artery disease (Lipsett et al., 2003)

HEI is also actively pursuing research into the effects of air pollution on asthma development and progression. They are sponsoring a study in the Czech Republic on developmental effects and in New York on acute effects of exposure to PM.

Remaining Data Gaps and Recommended Research: Although researchers have begun to identify and study the progression and development of disease, answers to these questions are complicated and require that subjects be followed for many years. Results of several currently ongoing longitudinal cohort studies will help answer remaining questions.

It is also currently difficult to compare concentrations and exposures to pollutants that have different health endpoints. For example, little is known about the links between short-term acute effects such as respiratory irritation or aggravation of asthma and long-term effects such as developing chronic bronchitis or permanent reductions in lung function.

More research is also needed to determine the possible synergistic effects of exposures to multiple pollutants. This is an especially challenging area of research because of the vast numbers of possible exposure combinations and the usual difficulty of linking health effects to exposure. Very little research has been conducted in this area.

Richard T. Burnett of Health Canada has also identified the need to determine the effects of pollution on development of disease. He states that although there is some evidence that living in a polluted environment reduces life span, the association between long-term exposure and the development of heart and lung disease is much less clear. Health Canada understands the need for understanding the long-term health effects of breathing polluted air is a research priority (Health Canada, 2003a).

4. *WHEN AND WHERE IN AN INDIVIDUAL'S LIFETIME DO THE MOST HARMFUL EXPOSURES OCCUR? WHEN IS A PERSON MOST VULNERABLE TO AIR POLLUTION?*

Several investigators have begun to address this question by looking at air pollution exposures and health effects during different stages of a child's development. Studies of the adverse effects of air pollution on birth outcomes have been conducted as well as studies looking at the development of disease in relation to living in high pollution communities.

Background: Risk assessment determinations of lifetime cancer risk usually assume a 70-year lifetime exposure for an individual. Other assumptions might include (for adults) a 70 kg body weight and 20 cubic meters of air breathed, or similar values. For children, these values are smaller, such as 10 kg body weight and 5 cubic meters of air breathed. Of course, these are only averages, from which specific individuals will deviate. The 70 year lifetime exposure assumption is also not typically met for a given individual, as individuals almost always live in different locations throughout their lives, and move about in their day-to-day activities. Exposure assumptions such as these serve to allow comparisons of reasonable central-tendency estimates of exposures and risk for different situations and for prioritization of control efforts.

UCLA has carried out several studies on adverse birth outcomes and air pollution in the South Coast Air Basin records (Ritz et al., 1999, 2000; 2002). In these studies, pollution exposures were estimated using ambient monitor measurements to see if high average concentrations during specific periods of pregnancy were associated with an increased risk of low birth weight, premature birth, or birth defects. The first study found an increased risk of low birth weight for women who experienced high ambient carbon monoxide (CO) concentrations during their last trimester. The second study found an increased risk of premature birth for women who experienced high ambient PM10 or high ambient CO during the first six weeks or the last four weeks of their pregnancy. The third study found an increased risk of heart birth defects for women who experienced high ambient CO or ozone during their second month of pregnancy. No other time period or pollutant showed statistically significant associations.

Although the risks found were modest compared to some maternal risk factors, the findings were statistically significant, often showed an increasing risk with increasing concentrations, and generally agreed with research findings elsewhere in the world. The weaknesses of the studies included the lack of knowledge about actual exposures, common for this kind of large study, and the lack of complete information about maternal risk factors in birth. Similar results have been found in other parts of the world, such as China and the Czech Republic. However, some of the health effects (e.g., heart valve defects from air pollution exposures after organ development) need to be replicated to verify the results of these studies.

Other studies have found significant correlation's between the effects of the pollutant and when and where a person is most vulnerable to it. The study, "*Critical Windows of Exposure to Household Pesticides and Risk of Childhood Leukemia* ," found that professional pest control services used at any time from 1 year before birth to 3 years after was associated with a significantly increased risk of childhood leukemia, and the exposure during year 2 was associated with the highest risk. This research determined that Insecticide exposure early in life appear to be more significant than later exposures, and that highest risk was observed for exposure during pregnancy (Ma, 2002). Earlier studies corroborate the risk associated to pesticides during early in life exposure. Significant positive association of family pesticide use and childhood brain cancer (Davis, 1993), and occupational and home exposures of pesticides and childhood leukemia (Lowengart, 1987) have been found.

Ongoing Research: Several of the research studies discussed in this document provide critical insight into the question of whether

there are critical times in our lifetime when we are especially vulnerable. UCLA continues to look at birth outcomes in relation to air pollution with support of the NIEHS. FACES also will provide valuable insight into this question by following asthmatic children, aged 6-11 at recruitment, and understanding the impact of PM on asthma progression and lung development. The CHS may provide the best information to date regarding the effect of exposure to air pollution on a child's long-term lung development and respiratory health. The NIEHS also funds several Children's Environmental Health Research Centers around the nation that will provide critical information about childhood exposures and disease outcomes. The goals of the Center at USC are to study childhood determinants of respiratory susceptibility to air pollution, to assess the modulation of allergic inflammation by environmental tobacco smoke and to determine whether intervention measures can reduce sensitization to cockroach and dust mite and improve the health of a multiethnic cohort of asthmatic children in Los Angeles.

Remaining Data Gaps and Recommended Research: Future results of many of the currently ongoing studies will provide critical insights into the time in our lives when air pollution exposure is perhaps most important. To adequately answer this question requires longitudinal research that captures both the critical time of exposure and the outcomes. FACES, Children's Health Study, and many of the studies sponsored by the NIEHS Children's Environmental Health Centers will help to fill this gap.

5. *ARE HEALTH OUTCOMES CORRELATED WITH AIR POLLUTION EXPOSURES?*

One approach to evaluating the health effects of air pollution on populations is to analyze data from existing data sources. Ongoing efforts by ARB and other agencies are underway to use existing databases to determine areas of potential research interest, and correlate health information to air pollution and socioeconomic factors.

Background: The collection of original epidemiologic data from populations can be time consuming and costly. One alternative to generating new data is to use existing databases. State and national governments regularly collect information on select health outcomes, including birth defects, cancer, and heart disease. Several efforts are underway to implement systems to track asthma and other respiratory diseases. Once compiled, these databases will allow the opportunity to evaluate possible associations between air pollution and health outcomes while also considering socioeconomic status and other factors known to influence the air pollution-disease relationship.

Ongoing Research: Environmental public health tracking is the process of collection, integration, analysis, interpretation, and dissemination of data about environmental hazards; exposure to environmental hazards; and health effects potentially related to exposure to environmental hazards. Currently, no comprehensive systems exist at the state or national level to track many of the exposures and health effects that may be related to environmental hazards. (Pew Environmental Health Commission, 2000) Because current systems are inadequate and/or not linked together, and some hazards and chronic diseases are not tracked at all, it is difficult to study and monitor relationships among hazards, exposures, and health effects.

The California Department of Health Services has created an Environmental Health Tracking Expert Working Group in response to legislation supporting the establishment of an environmental health tracking program in California. (SB 702, Escutia, 2001, California Health & Safety Code section 104324; see www.catracking.com) A recommendations report by the working group to DHS and the California Legislature will be finalized this year.

In addition, the University of California has established a Center for Environmental Health Tracking (CEHT) at the U.C. Berkeley School of Public Health. The CEHT is working on the establishment of an Environmental

Public Health Tracking Network (EPHTN) for chronic diseases and environmental hazards and exposures. This CEHT-EPHTN is being developed at U.C. Berkeley with a subcontract to U.C. Los Angeles. This CEHT is one of three centers that are funded by CDC in an effort to develop a National Environmental Public Health Tracking Network. The other two centers are Johns Hopkins and Tulane.

A key component of the California's CEHT is implementing a pilot project in Alameda County. The pilot will serve as a "road test" of the tracking network, focusing on a small number of diseases and environmental hazards in a single county. Information will be centralized, processed, and provided for use by public health officials and interested community groups. Scientists with the California Department of Health Services and the California Environmental Protection Agency will be able to examine the data for "hot spots" of disease and relationships with environmental hazards, and to test hypotheses about these diseases. The pilot project will focus on health events and environmental data from Alameda County in 2001. Data will be collected regarding traffic patterns and the dispersal of traffic-related pollution, health care usage by people with asthma, such as hospitalizations and the purchase of asthma medications, and the birth of low birth weight and pre-term infants, which may also be associated with pollution exposure.

With this information, researchers hope to make progress regarding a number of public health concerns. The data collected will help to explore the locations of populations "at risk" for asthma and assess their exposure to traffic exhaust; examine possible connections between pollution caused by automobile and truck traffic and asthma, low birth weight, and pre-term birth; find the best ways of measuring asthma in populations; assess the potential and costs of environmental tracking of this kind and how such approaches may be applied to other diseases throughout California; and provide communities with an opportunity to address health concerns regarding traffic related exposures.

We analyzed statewide cardiovascular and respiratory hospitalization data from the Office of Statewide Health Planning and Development (OSHPD), and socioeconomic data from the 2000 census, to develop an understanding of the patterns and incidence of disease, as well as to discover data gaps that may exist in our understanding of disease incidence. A preliminary evaluation for California counties for 1998 OSHPD data indicated that several areas, such as Imperial County, had elevated respiratory disease admittance rates for Hispanics (this category was also high for non-Hispanics). However, uncertainties related to the data included: census data were not comparable to the OSHPD hospital admission data; age distributions in different populations were not standardized; county-level data may prove inaccurate as some counties have very few numbers of specific ethnic groups; data are only for hospital admissions, which means other information such as emergency room visits and those whose disease has been managed via regular physician visits or out-patient clinics will not be reflected in the evaluation.

As a result of the systematic collection of disease data, a hypothesis has developed about the possible relationship between brain cancer and air pollution. Although some controversy exists the Brain Tumor Society states that the incidence of brain cancer is on the rise, although the National Cancer Institute believe this may be due to improved clinical diagnosis. Recent research indicates there may be some biological plausibility to connect brain cancer and ultrafine particle pollution. A mechanism for ultrafine particle transport through the alveolar-capillary barrier has been proposed (Gumbleton, 2001). In addition, a direct pathway for respiratory tract-deposited ultrafine particles to extrapulmonary organs via neurons which includes trans-synaptic transport is known to exist (De Lorenzo and Darin, 1970). Intravenously administered ultrafine particles have been shown to cross the blood-brain barrier in pharmaceutical research (Kreuter, 2001). While additional animal studies of ultrafine particles are pending: dogs living in polluted areas of Mexico City

have been found to exhibit significant histologic lesions in the olfactory bulb as well as other brain regions compared to dogs living in rural unpolluted areas (Calderon-Garciduenas et al., 2002). A recent study by Li et al. demonstrated that ultrafine particle pollution in the Los Angeles basin is a more potent inducer of oxidative stress *in vitro* than the fine and coarse PM fraction (Li, et al., 2003). The South Coast Air Quality Management District recently established the Brain Tumor and Air Pollution Foundation. The Foundation will release a request for proposals next month for proposals for this program.

Another organization conducting air pollution research using routinely collected data is Health Canada. Health Canada is taking advantage of a unique opportunity to assess the effects of long-term exposure to air pollution in relation to health status. A relatively large cohort of Canadians (approximately 20,000) is being followed as part of the National Population Health Survey. The survey was initiated in 1994 and is repeated every two years. The survey includes question on the presence of several chronic conditions, including asthma, chronic bronchitis and emphysema, and heart disease, along with potentially confounding factors including demographics, smoking, and occupational history. The survey also captures place of residence each time participants are contacted. In 2002, a series of questions was added to help determine place of residence beginning in 1980. Once the 2002 data become available, a survival analysis will be conducted to assess the probability of development of disease in association with air pollution exposure. Data collected through the National Population Health survey also affords the opportunity to evaluate the acute effects of air pollution on the frequency of reporting of days of restricted activity, as well as cross sectional analysis of air pollution on the prevalence of cardio respiratory disease (Health Canada, 2003c).

Remaining Data Gaps and Recommended Research: We will use available statewide health databases of birth outcomes and mortality statistics from the Department of Health Services, hospitalization records from the Office of Statewide Health Planning and Development, and the cancer incidence from the National Cancer Institute. We will perform screening-level analyses using Geographic Information System techniques to evaluate the potential relationship between air pollution exposures in California communities for the pollutants of greatest health concern with monitored data (PM2.5, PM10, ozone), and possibly others (CO, SO_2, NO_2) and health endpoints. The relationship between pollutant and health endpoints (which may include premature mortality, low birth weight, and hospitalizations), and SES will be investigated. It should be pointed out that there are many confounding variables to be considered when performing these types of analyses, such as access to health care, etc. These factors can complicate the relationships between ambient air pollution and health endpoints and these variables will be considered in the analysis. We think the results of these types of studies will allow us to better target more in-depth research.

Exposure Assessment

Another major research priority concerns efforts to advance our understanding of exposures to air pollutants. Improved exposure assessments helps ensure that our regulatory activities focus on reducing the exposures that represent the greatest health risk. In addition, improved exposure assessment methods reduce the uncertainty in associations between exposure and health outcomes in both risk assessment and epidemiology. Efforts to increase our understanding of air pollutant levels and trends at the community level, may also help to improve emission inventories and estimates of near-source impacts, advance our knowledge of the cumulative impacts of multiple pollution sources, and further develop screening techniques to assess community and individual level exposures. These research activities will address two key regulatory priorities – to characterize and reduce community exposure to air pollutants and reduce emissions of and exposure to PM and TACs.

6. *HAVE AIR POLLUTION CONTROL PROGRAMS IMPROVED AIR QUALITY AND HEALTH IN ALL COMMUNITIES?*

California's air pollution control programs have reduced county-level emissions and air quality episodes for most criteria pollutants and air toxics. Our preliminary analysis for ozone indicates that these reductions have occurred in equal measure in low- and high-income communities (Table 1). In this analysis we used monitors from the California's Statewide Air Monitoring Network that had 20 years worth of ozone data. We assigned them to the appropriate census tract and corresponding 2000 socioeconomic status and demographic composition. We compared the ozone expected peak day one-hour concentration (EPDC) and assessed trends and rates of change for those monitors in both a low- or high-income community within the same county. By comparing the rates of change in ozone concentration for these monitors, we were able to determine whether our control programs had reduced ozone equally in both low- and in high-income communities. Additional screening-level analyses of this type may be preformed on other criteria pollutants, including estimates of health effects using available relationships. Two additional studies, one retrospective and the other using health data collection surveys, will track actual health improvements to air pollution related health endpoints observed in California.

Table 1. Percent Change of Ozone in Low- and High-Income Communities.

Basin	County	Monitor	%Non White[1]	Poverty Rate[2]	EPDC[3] 1Hr '81-'01	Pair[4] Corr.
SC	Los Angeles	LA-North Main	100%	0.37	54%	0.98
		Long Beach	52%	0.08	47%	
SC	Orange	Anaheim	80%	0.26	56%	0.99
		La Habra	68%	0.11	62%	
SC	San Bernardino	Upland	60%	0.21	57%	0.97
		Crestline	16%	0.08	50%	
SD	San Diego	Escondido	76%	0.27	42%	0.95
		Chula Vista	46%	0.02	37%	
SFB	Alameda	Oakland	98%	0.22	12%	0.77
		Hayward	52%	0.09	16%	
SFB	Contra Costa	Pittsburg-	82%	0.20	15%	0.67
		Concord	25%	0.04	10%	
SFB	Santa Clara	San Jose	77%	0.25	31%	0.93
		Los Gatos	16%	0.01	32%	
SFB	Solano	Vallejo	70%	0.16	14%	0.32
		Fairfield	56%	0.10	0%	

[1]Statewide average rate for non-white (non-Hispanic) is 54%.
[2] Statewide average rate for below poverty is 0.14.
[3]EPDC=Expected Peak Day Concentration of ozone.
[4]Correlation between EPDC's of 2 sites in each county.

Background: ARB is the agency responsible for emission controls on motor vehicles, and California is the only state in the U.S. allowed to establish more stringent standards than the U.S. EPA, although other states are permitted to adopt California's standards. Emissions of VOC and CO (and to a lesser extent NO_X) from new passenger vehicles are reduced by a factor of a hundred in comparison to pre-control vehicles in 1963, and the standards are now applicable for 150,000 miles. The use of reformulated gasoline and diesel fuels have resulted in further reductions in air pollutants. Stationary source NO_X emissions have been reduced by a factor of ten since 1980. From 1980 to 2000, emissions from passenger vehicles ($VOC+NO_X$) decreased from 5,500 to 2,400 tons/day and CO decreased from 31,000 to 12,000 tons/day, diesel particulate (from on-road sources) from 40 to 20 tons/day, and $VOC+NO_X$ (from stationary sources) from 2,800 to 1,200 ton/day.

A subsequent improvement in ambient air quality has been observed with peak ozone levels declining 50% over the past twenty years, and a 37% reduction in annual-average PM10. Cancer risk from known air toxics has been reduced 46% over the past 12 years. All of this has been achieved despite a 50% increase in population and a doubling of vehicle miles traveled, and the growth of California into the 5th largest economy in the world. However, levels of particles and ozone continue to exceed the ambient air quality standards, and air pollution in California contributes annually to as many as: 6,500 premature deaths; 340,000 asthma attacks; and 2,800,000 lost work days.

In the South Coast Air Basin, on-road emissions for CO_2, CO, and hydrocarbons were collected with an infrared remote sensing device rotated through 35 sites (Singer and Harley, 2000). Estimates of on-road running emissions for the SoCAB based on fuel sales and over 60,000 infrared remote sensor measurements are 4700 $\pm$ 500 10^3kg/day for CO and 550 $\pm$ 90 10^3kg/day for VOC, in agreement with estimates from California's mobile emission model, MVEI2002, of 5000

10^3kg/day for CO and 500 10^3kg/day for VOC (CARB, 2002). The relationship between income level and vehicle emissions was examined using census data resolved to the zip code level. On average, CO and VOC emissions factors of vehicles registered in the lowest income areas were double those of vehicle registered in the highest income areas. Differences in vehicle emissions between neighborhoods were due in part to differences in the prevalence of older vehicles, but also resulted because vehicles of the same age had higher emissions in lower-income areas (Singer and Harley, 2000).

Ongoing Research: The ARB and the SCAQMD are co-funding a study to quantify the economic value of the health benefits due to improvements in air quality in the South Coast Air Basin from 1980 to 2000. Trends in the occurrence of sickness and/or mortality, as reflected in 15 cardiac, cardiovascular, and respiratory health endpoints will be determined, after adjusting for changes in socioeconomic, behavioral, and medical factors occurring in the SoCAB during the time period related to these health endpoints. Trends and associations will then be evaluated to quantify the extent to which they may be related to the improvements in air quality. The economic value of these improvements will also be quantified. We anticipate results by spring of 2005. Because socioeconomic factors are an important consideration in the relationship between air pollution and health, the results of this study are expected to have implications for the Environmental Justice (EJ) Program.

It should be pointed out that these kinds of analyses are inherently difficult. There is a high correlation between many of the pollutants, which complicates the determination of which pollutant is having a potential effect on the outcome. In addition, a lack of knowledge about the actual pollutant exposures causing the health effects and the many confounders that can complicate the relationships between ambient air pollution and health endpoints places additional uncertainty on the results.

The pronounced changes in demographics that have occurred in the last 20 years in the SoCAB (including large ethnic, socioeconomic, and occupational shifts) as well as the more general statewide changes occurring in insurance coverage and access to medical care and advances in medical treatments themselves may have a pronounced effect on the analyses. Lastly, while ozone concentrations have dropped significantly over this twenty-year period, reductions in PM10 concentrations have been far less pronounced, and PM2.5 has only been measured for part of this time. Therefore, some of the pollutants such as PM10 and PM2.5 may not show associations with changes in health endpoints because they have not changed enough, have not been measured long enough, or both.

UC Berkeley and UCLA have one of the three Centers of Excellence (COE) for Environmental Public Health Tracking funded by the Centers for Disease Control (CDC). The COEs are an integral part of the CDC-funded effort to develop a national environmental health tracking network. As part of this effort, DHS is putting together an Environmental Health Tracking Planning Consortium. The UCLA Environmental Public Health Tracking group is linking ARB air quality data for PM10, PM2.5, ozone, and NO_2 with California Health Interview Survey data. After this linkage has been completed, a case-control study of asthma control vs. pollutant exposures will be done. It is not clear if the UCLA study or the Environmental Health Tracking Planning Consortium will consider socioeconomic factors.

Remaining Data Gaps and Recommended Research: We will determine air pollution trends in California communities for the criteria pollutants of greatest health concern with monitored data (PM2.5, PM10, ozone), and possibly others (CO, SO_2, NO_2), and will estimate health benefits using available relationships (e.g., ARB, 2002). Because we have an extensive monitoring network for PM2.5, PM10, and ozone, we will be able to analyze a diversity of air pollution environments. In addition, the range of socioeconomic conditions in California for these pollutants appear to be well represented (see Table 2). We will

not be doing TACs as the network is too sparse to find pairs of sites in the same county with low and high income, as required by the analysis method.

7. *Which communities are most impacted by air pollution? What are their cancer and non-cancer health effects?*

Studies show that poor and minority communities in California tend to bear a greater portion of the air pollution burden from TAC sources (e.g., Morello-Frosch et al., 2002), although this is not necessarily the case for the two criteria air pollutants (PM, ozone) believed to be responsible for the majority of California's air quality-related health problems. Also, preliminary results indicate that in California a higher percentage of children who are Hispanic, Asian, and black, or from low-income families, live near freeways and major roads. Several other recent studies have also shown that proximity to roadways appears to lead to many adverse health effects. We will continue to study the effect of traffic pollution in several ongoing California health studies. In addition, we will use contemporary air quality and the California 2000 census data to identify California communities with potentially high levels of pollutants. We will then produce estimates of potential non-cancer health effects using available relationships.

Background: Living close to roadways appears to lead to many adverse health effects, particularly of infants and children. Several European studies found reduced lung function and higher asthma, hayfever, and wheezing rates for children living near heavy truck traffic (Brunekreef, 1997; Weiland, 1994; Edward, 1994). The strongest association was in those living less than 300 meters from the roads and was still apparent in children living as far as 1000 meters away. A recently completed study in Huntington Park sponsored by ARB and SCAQMD found that children with asthma symptoms had higher breath levels of benzene, a marker for car traffic (Delfino, 2003).

Statewide, a study by the California Department of Health Services found that children who live near busy roads are disproportionately Hispanic, Asian, and black, and from low-income families (Gunier, RB et al., 2003). Other studies support this finding. (Ostro et al. 2002, Green et al. 2002) ARB-sponsored research found that children of all races have similarly high breathing rates that make them especially susceptible to the impacts of air pollution (Adams, 1993). Children (ages 0-12) breathe about twice the volume of air per unit of body weight, relative to adults (OEHHA, 2000).

Ultrafine particles – very small particles with a diameter less than 0.1 um, 1/800th the diameter of a human hair – have been postulated to be responsible for cardiovascular health effects due to their toxic components, large relative surface areas, and ability to pass through cell membranes. In Los Angeles, an ARB-sponsored study by USC found that levels of ultrafine particles near freeways are very high, dropping to background within 300 meters. The levels are similar for the 405 (<5% trucks) and the 710 (>25% trucks) Freeways, implicating both cars and diesel trucks.

ARB's diesel control program will reduce ultrafine particles from diesel trucks by a factor of 50-100 (Holmén and Ayala, 2002). Retrofits of the existing fleet, CNG-fueled buses, and roadside inspections are currently focused on EJ communities (e.g., Alameda Corridor). The zero-emission vehicle and other motor vehicle control programs continue to eliminate ultrafine particles from cars and light-duty trucks.

In Los Angeles, UCLA and ARB researchers found that low birth weight, premature birth, and heart birth defects are related to higher levels of air pollution (CO, PM10) associated with cars and trucks (Ritz, 1999; 2000; 2002). Similar results have been found in other parts of the world, such as China and the Czech Republic.

Ongoing Research: Based on findings of adverse health effects from proximity to freeways and major roadways in the Netherlands, children's health research in southern Califor-

nia (CHS), Oakland (OEHHA East Bay Study), and Fresno (FACES) is currently focused on the effects of traffic density. By default, the California studies include a range of income levels and ethnic groups. In response to the Los Angeles findings on birth outcomes, U.S. EPA and others are conducting studies of biological mechanisms.

Remaining Data Gaps and Recommended Research: Building on the approach by Wernette and Nieves (1992), it would be possible to determine air pollution concentrations for California communities and then examine relationships with socioeconomic status and other factors. The availability of new Geographic Information System (GIS) software tools and census track information will allow us to analyze communities in much finer detail than the coarse county-level analysis by Wernette and Nieves (1992). The initial focus will be on the pollutants of greatest heath concerns – PM2.5, PM10, and ozone – as the California networks are relatively dense for these regional pollutants. Health endpoints (premature mortality, asthma hospitalizations, lost work days, etc.) could be estimated using peer-reviewed dose-response functions (ARB, 2002). Using this information, it would be possible to identify communities with the highest ambient exposures and calculate the potential corresponding health effects (e.g., worst 10%, 20%).

The California statewide monitoring network was designed to capture the highest pollutant levels for counties and air basins irrespective of socioeconomic status and demographics. Our preliminary analysis, using the monitoring network year 2000, indicates that our network is generally representative of low-income households and white (non-Hispanic) groups. We assigned the appropriate census tract (and corresponding 2000 socioeconomic status and demographic composition) for each monitoring site for each pollutant. The average 2000 population size ranged from 3,574 (standard deviation of 1,880) people in rural areas to 5,268 people (standard deviation of 1,973) in urban areas. We compared the rate of households below the poverty level for each census tract containing a monitoring site to the Statewide rate (0.14). Similarly, we compared the rate of white (non-Hispanic) residents to the Statewide rate (0.46). Future analyses will look at other socioeconomic and demographic factors. The results are summarized in Table 2 and show that for all pollutants, except possibly sulfur dioxide, the range of socioeconomic conditions in California appears to be well represented by the network, and we can use the air quality data for subsequent analyses of pollutant exposure and long-term trends by socioeconomic status.

Table 2. Air Quality Monitoring Network Representativeness.

Pollutant	# Sites[1]	Poverty Rate		White Rate[2]	
		High ≥0.14	Low <0.14	<0.46	≥0.46
Ozone	181	51%	49%	31%	69%
PM10	152	59%	41%	34%	66%
PM2.5	81	69%	31%	42%	58%
CO	89	60%	40%	40%	60%
NO_2	110	57%	43%	40%	60%
SO_2	38	39%	61%	32%	68%
Lead	11	73%	27%	82%	18%
TACs[3]	48	75%	46%	38%	63%

[1] Monitors were counted if they were operational at anytime during 2000.
[2] White Non-Hispanic
[3] Includes Toxic Network and PAMS Network

Traditional ambient air monitoring is good at measuring regional pollutants, such as ozone, that change little in concentration over short distances. Traditional monitoring methods are too costly for characterization of near-source pollutant concentrations at the neighborhood level if sharp gradients in concentration exist. In general, concentrations of pollutants near specific sources decrease quickly with increasing distance, and many measurements are needed to accurately characterize these gradients. Examples of this situation might include homes downwind and within approximately 100 or 200 meters of busy freeways (Zhu et al., 2002a;b) or homes or schools downwind and within tens of meters for point or area sources such as gas stations or dry cleaners.

Dispersion modeling is often used to predict concentrations where monitors or direct measurements cannot or have not been made, but the commonly accepted models

have limited capabilities for areas close to individual sources.

It is also important to consider that studies including actual measurements of personal exposure generally have shown that personal exposures to air pollutants are significantly higher than what would be expected due to outdoor air concentrations alone. This is primarily due to indoor sources of those same pollutants. Examples include PM from cooking, benzene from gasoline stored in attached garages, and diesel particulate exposures during driving. Therefore, health impacts may also involve air pollution exposures unrelated to outdoor air concentrations.

8. WHAT SCREENING METHODS CAN BE USED TO IDENTIFY THE MOST IMPACTED COMMUNITIES AND INDIVIDUALS?

Monitoring programs to determine pollutant burdens in communities or for individuals that live near sources are extremely expensive – generally $100,000 to $150,000 in capital expenditures and $150,000 to $350,000 in annual operating costs depending on the number of pollutants to be measured – and it is difficult to pre-determine the most suitable neighborhoods to study. Easy-to-use, low-cost monitoring technologies, while not accepted as official data of record, are suitable as a screening tool to indicate areas for further study and exist for ozone, benzene, formaldehyde, and carbon monoxide. In collaboration with CEC and NYSERDA, we recently released a solicitation for grants ($1.5 M total) to support the commercialization of additional air monitoring technologies. The SCAQMD is developing community protocols for this type of equipment. Separate efforts funded by ARB, U.S. DOE, and HEI are attempting to develop a specific measure of diesel particles. Another useful tool is biomonitoring of hair, urine, or blood for tracers of an individual's pollutant exposures. Although it may not be able to identify the source of the exposure, it can be useful for identifying total exposure in a community. The CDC recently reported biomonitoring results for the U.S. We recently completed an assessment of biomarkers for California's top 5 TACs of concern for children and hexavalent chromium.

Background: Easy-to-use, low-cost monitoring technologies exist for CO, ozone, benzene, and formaldehyde, although some of these techniques only provide rough approximations of air pollutant levels. They have been successfully employed in health and exposure studies here in the U.S., Europe, and developing countries. For example, an ARB-funded study of environmental conditions in portable classrooms used teachers to deploy passive formaldehyde samplers in 1000 classrooms. Another ARB-funded study developed ozone badges.

Biomarkers are another promising technique and offer the ability to collect information that represents the total burden to air pollutants. The CDC recently reported biomonitoring results for a number of environmental contaminants for the U.S. (CDC, 2003).

Ongoing Research: We recently released a solicitation for grants to support the commercialization of air monitoring technologies that are practical for measuring people's exposure where they live, work, recreate, or attend school. The ideal technologies measure several pollutants of interest, are reliable, easy-to-use and low in cost. The grant program, which is being co-funded by the California Energy Commission, is for a total of up to $1,000,000, provided viable responses are received. The effort is also being conducted in conjunction with the New York State Energy Research and Development Authority (NYSERDA) which has released a related solicitation for a total of $500,000 (see page 16, Low-cost Monitoring Technologies).

There is wide interest among the scientific and regulatory communities in finding a marker (such as doping the diesel fuel) which will allow identification of the contribution of diesel sources to ambient particulate matter. Some initial studies used elemental carbon (EC) as a marker for diesel exhaust, however, because other combustion sources also emit EC, it should not be used a marker for ambient diesel exposure. Other proposed markers such as hopanes and steranes are emitted by

both gasoline and diesel engines. At a December 2002 Workshop sponsored by the Health Effects Institute on possible ways to improve estimates of diesel exposure, the conclusion of the assembled experts was that at this time there is no marker specific to diesel (HEI, 2002). The importance from a health point of view of estimating diesel exposure has led to a significant amount of effort in this area. The Department of Energy is conducting a major study on PM from gasoline and diesel engines and the results should be available this summer. Another on-going project, sponsored by the Coordinating Research Council, ARB, and others for heavy-duty vehicle chassis dynamometer testing, contains an element which is focused on chemical analysis of diesel exhaust. We are funding several research projects in this area as described in Section II.

The use of biomarkers (biological monitoring) to measure the level of a pollutant (or its metabolite), a toxic effect, or susceptibility in an exposed individual has been a topic of study for a number of years. This approach has become a tool for occupational as well as community health studies. An example of biological monitoring for exposure in a community health study is the measurement of blood levels of lead in children. Another example is determining exposure to tobacco smoke in smokers and non-smokers by measuring cotinine, a metabolite of nicotine in urine. Molecular techniques based on the interaction between the pollutant and DNA have been reported for diesel particulate matter and dioxins but appear to require further development to increase both sensitivity and specificity. Ideally, samples for community-based studies should be collected using non-invasive and convenient techniques. For example, hair, saliva, and urine could be collected for mass screening in the community. However, many generally accepted methods require blood samples or the use of other invasive approaches.

A number of factors that may influence or affect the results of biomarker studies needs to be considered, including: 1) the variability within and between individuals; 2) potential gender differences; 3) the ethical issues that may be raised when biomarkers are measured; 4) the ultimate health effects and potential risks based on biomarker measurements; 5) the sensitivity and specificity of biomarkers, especially at environmentally relevant concentrations; 6) societal perceptions of how the biological samples and data are to be used. 7) Statistical robustness in the number of measurements and sample size.

We investigated the types of biomarkers used for measuring selected toxic air contaminants identified by OEHHA that may have the greatest impact the health of infants and children. Those are polycyclic aromatic hydrocarbons (PAHs), diesel particulate matter (DPM), dioxins, acrolein, and lead. Hexavalent chromium was also discussed. Measuring exposure to environmental PAHs may be difficult at the levels of typical exposure, particularly since activities such as the smoking of tobacco and the ingestion of various foods (for example, charbroiled meat), will contribute to "background levels" that can interfere with the measurement. The biomarkers for dioxin are measured indicators of exposure, but some are obtained by invasive techniques and traditional analyses can be time-consuming and costly. Newer bioanalytical molecular approaches are being investigated and could be used for screening. Currently, no generally accepted biomarker method for acrolein or DPM exposure is available. For measuring lead, the concentration in blood is considered a standard measurement of exposure, but techniques such as measuring urinary levels could provide a good non-invasive screening tool for recent exposures. Chromium has been measured in urine, hair and blood; however, contamination of the samples appears to be a problem in obtaining accurate chromium values.

On January 2003, Centers for Disease Control and Prevention (CDC) released its "Second National Report on Human Exposure to Environmental Chemicals". The second report conducted biomonitoring on 116 environmental chemicals and measured the chemical or their metabolites in blood and urine samples from selected participants in the National

Health and Examination Survey (NHANES) study. This report provided biomonitoring on lead, mercury, cadmium, and other metals; dialkylphospate metabolites of organophospate pesticides; cotinine; and phthalates; Polycyclic aromatic hydrocarbons (PAGs); Sioxins, furans, and coplanar polychlorinated biphenyls (PCBs); Non-coplanar PCBs; Phytoestrogens; Selected organophosphate pesticides; Organochlorine pesticides; Carbamete pesticides; Herbicides; Pest repellents and disinfectants. Health disparities between financial classes in a society may also be related to disparities. One of the main purposes of this report was to determine whether exposure levels are higher among minorities, children, women of childbearing age, or other potentially vulnerable groups. An example of one of the NHANES studies from this second CDC report was the "Blood Mercury Levels in U.S. Children and Women of Childbearing Age, 1999-2000" (Schober et al., 2003). The objective of this study was to describe the distribution of blood mercury levels in U.S. children and women of childbearing age and the association with sociodemographic characteristics and fish consumption. A cross-sectional survey of the noninstitutionalized U.S. population was done for 1250 children aged 1 to 5 years and 2314 women aged 16 to 49 years. This study concluded that measures of mercury exposure in women of childbearing age and young children generally fall below levels of concern. However, approximately 8% of women had concentrations higher than the U.S. EPA recommended reference dose (5.8 µg/L). For those women who ate 3 or more servings of fish in the past 30 days compared with women who ate no fish in that period had almost 4-fold geometric mean mercury levels. Women who are pregnant or who intend to become pregnant should follow federal and state advisories on consumption of fish.

Remaining Data Gaps and Recommended Research: Once the screening techniques have been developed, an effort is needed to spur deployment to communities with air pollution concerns. SCAQMD is developing community monitoring protocols and may fund deployment of these low-cost technologies. The search for a diesel PM monitoring technique remains a high priority as evidenced by the studies described above. However, only a few have the potential to implemented on a routine basis, and applications of others will likely be limited to special studies. For most of the biomarkers for the toxic air contaminants we reviewed, new non-invasive techniques that are both sensitive and specific need to be further developed and validated for community health screening, especially for children and vulnerable populations.

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V. ACRONYMS

AAQS	Ambient air quality standards
ARB	California Air Resources Board
Cal/EPA	California Environmental Protection Agency
CEC	California Energy Commission
CHS	Children's Health Study
CO	Carbon monoxide
CRC	Coordinating Research Council
EJ	Environmental Justice
FACES	Fresno Asthmatic Children's Environment Study
GIS	Geographic Information System
HEI	Health Effects Institute
HSC	Health and Safety Code
NO_2	Nitrogen dioxide
NO_X	Oxides of nitrogen
OEHHA	Office of Environmental Health Hazard Assessment
PAHs	Polycyclic aromatic hydrocarbons
PIER	Public Interest Energy Research
PM	Particulate matter
PM2.5	Particulate matter equal to or less than 2.5 microns aerodynamic diameter
PM10	Particulate matter equal to or less than 10 microns aerodynamic diameter
RSC	Research Screening Committee
SB 25	Senate Bill 25 (Senator Martha Escutia, 1999), the Children's Environmental Health Protection Initiative
SIP	State Implementation Plan
SoCAB	South Coast Air Basin
SO_2	Sulfur dioxide
SO_x	Oxides of sulfur
TAC	Toxic Air Contaminants
U.S. DOE	United States Department of Energy
U.S. EPA	United States Environmental Protection Agency
VOC	Volatile organic compounds
VPRP	Vulnerable Populations Research Program
$\mu g/m^3$	Micrograms per cubic meter of air
μm	Micrometers