TECHNICAL PROPOSAL

FINE-SCALE SPATIAL AND TEMPORAL VARIABILITY OF PARTICLE NUMBER CONCENTRATIONS WITHIN COMMUNITIES AND IN THE VICINITY OF FREEWAY SOUND WALLS

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Statement of Significance

Although current federal, state, and local regulatory efforts are focused on reduction of ambient levels of particulate mass for PM_{10} and $PM_{2.5}$, recent studies have demonstrated that UF particles (less than ~100 microns in diameter) are more toxic. Other studies have shown that individual particles are capable of penetrating cellular membranes and causing cell damage, suggesting that particle number, rather than particle mass, may be more responsible for the potential health effects. Since UF particles make up the majority of ambient particle numbers but only a small fraction of ambient PM mass, and given that there is little or no correlation between ambient particle numbers and mass, measurements of ambient particle number concentrations have become increasingly important. However, measurements of ambient ultrafine (UF) particle number concentrations at a single central monitoring station may not be indicative of actual human exposure in the communities surrounding a single monitoring site. Due to their short atmospheric lifetimes and strong dependence on very local sources, UF particle numbers vary significantly on very short spatial and temporal scales. In order to address this problem and to more accurately estimate human exposure and the subsequent health impacts of UF particles, more intensive particle number measurements on finer spatial scales is needed.

The predominant sources of UF particles in urban areas are vehicular emissions and secondary production in the atmosphere from photochemical reactions of gaseous precursors. A previous jointly-funded ARB/AQMD study measured UF particle number concentrations at each of the Children's Health Study (CHS) communities at a single central monitoring station in each community. Results showed very predictable daily and seasonal patterns. But other studies showing that UF particle concentrations vary dramatically within 100 meters of roadways point out the need for more spatially resolved UF monitoring within impacted communities. The effects of freeway characteristics such as the existence of sound walls and the elevation of the roadway also need to be assessed. Better information on the local-scale variability and sources of UF particles will improve our understanding of human exposure to and the health impacts of this unregulated pollutant. Such information will lead to more effective control measures and perhaps UF particle standards that will reduce the public health risk.

The specific objectives of this proposal are: 1) To determine the fine-scale spatial variability of ambient particle number concentrations within a community, and thus determine the accuracy of using single central site monitoring to estimate of human exposure to ultrafine particle numbers; 2) To demonstrate the feasibility of locating and quantifying specific ultrafine particle sources within a community using highly time-resolved and spatially-resolved meteorological and particle number data; 3) To analyze highly time-resolved particle number data using several statistical techniques in order to determine regional vs. local contributions to

ambient particle number levels; 4) To examine how the variability of particle number concentrations within communities are effected by season and location of the community (source vs. receptor); and 5) To determine the effects of freeway sound walls and freeway elevation on particle number emissions into adjacent neighborhoods.

Abstract

Current regulatory efforts are focused on reduction of ambient levels of particulate mass for PM_{10} and $PM_{2.5}$, but recent studies have demonstrated that ultrafine (UF) particles (less than ~100 microns in diameter) are more toxic. Studies that show individual particles penetrating cellular membranes and causing cell damage, suggest that particle number rather than particle mass may be a more health relevant metric of ambient particles. The majority of ambient particle numbers are UF particles, but, due to their small size, only a small fraction of ambient PM mass is UF. Since there is generally low correlation between ambient particle numbers and mass, ambient particle number measurements are becoming more important. The majority of UF particles in urban areas come from either primary vehicular emissions or secondary production in the atmosphere from photochemical reactions of gaseous precursors. A previous study that measured UF particle number concentrations at a single central monitoring station in each of twelve CHS communities showed predictable daily and seasonal patterns, but low spatial correlation between sites. Other studies show how UF particle number concentrations vary dramatically within 100 meters of roadways.

Due to their short atmospheric lifetimes and strong dependence on very local sources, UF particle numbers vary significantly on very small spatial and temporal scales. Thus, Measurements of ambient ultrafine (UF) particle concentrations at a single central monitoring station may not be indicative of human exposure in the communities surrounding the monitoring site. In order to address this problem and more accurately assess the human exposure and the subsequent health impacts of UF particles, more intensive particle number measurements on finer spatial scales is needed. The main objective of this project is to better assess the spatial variability of ambient particle number concentrations <u>within</u> impacted communities and thus improve estimates of human exposure to UF particles.

Using 10-12 condensation particle counters (CPC) currently owned by ARB, the intra-community variability of UF number concentrations can be determined. The CPCs will be deployed at 12 individual sites within a particular community within a 3 km radius. The Wilmington/Long Beach community will be studied to examine the complex mix of industrial (refineries, power plants), and transportation sources (marine vessels, diesel trucks, port activities) influencing ultrafine particle levels in that area. Another inland community, Riverside, will be studied to examine the effects of aging and transport on particle number levels and intra-community variability. Each community will be monitored for 3 months in each of two seasons (summer and winter). Each CPC will be accompanied by a low-cost meteorological station recording highly time-resolved wind speed, wind direction, humidity and temperature data. Such information can be used with the CPC continuous number data to identify local sources based on wind speed and direction. A concurrent EPA-funded project will fund analysis of this type of data set using advanced statistical techniques.

Additional monitoring studies will be carried out in the vicinity of freeway sound walls to assess the effects of sound walls and roadway elevation on particle emissions into downwind neighborhoods.

Better information on the fine-scale spatial and temporal variability of UF particle number concentrations will improve our understanding of human exposure to this currently unregulated pollutant. Such information is essential in the implementation of future control measures and UF particle standards that aim to reduce the public health risk.

Project Objectives

Background

Recent research has demonstrated that numerous adverse health outcomes are associated with atmospheric particulate matter (PM). Epidemiological studies have shown significant relationships between ambient PM and respiratory and cardiovascular related mortality and morbidity (Adler et al., 1994, Dockery et al., 1993). The observed effects are even more significant in susceptible populations, such as the elderly, with pre-existing respiratory and cardiovascular diseases (Oberdörster, 2001). Although current federal, state, and local regulatory efforts are focused on reduction of ambient levels of particulate mass for PM_{10} and $PM_{2.5}$, recent studies have demonstrated that ultrafine particles (less than ~100 microns in diameter) are more toxic. Toxicological studies by Oberdörster et al. (1996) and Donaldson et al. (1998) have concluded that ultrafine particles (particles with diameters less than about 100 nm) are comparatively more toxic than larger particles with identical chemical composition and mass.

Due to their small size, ultrafine particles contribute very little to the overall PM mass, but comprise a significant majority of the number of airborne particles in the atmosphere (Oberdörster, 2001; Morawska et al., 1998). Many studies have suggested that particle number, rather than particle mass, may be more responsible for the potential health effects. Studies on rodents show that inflammatory response is more prominent when ultrafine particles are administered compared to larger particles (Oberdörster, 2001), suggesting either a particle number or surface area effect. In vitro toxicological studies have also shown that ultrafine particles have higher oxidative stress potential and can penetrate and destroy mitochondria within epithelial cells (Li et al., 2003). Penttinen et al. (2001) found that daily mean number concentration and peak expiratory flow (PEF) are negatively associated and that the effect is most prominent with particles in the ultrafine range. Another study by Peters et al. (1997) also found associations between number concentrations of ultrafine PM and lowered PEF among asthmatic adults.

As one of many sources contributing to urban air pollution in general, the combustion of fossil fuel in motor vehicles is the major primary emission source of ultrafine particle numbers to urban atmospheres (Shi et al., 1999; Cyrys et al., 2003). Recent studies have demonstrated that ultrafine number concentrations drop dramatically with increasing distance from busy freeways in the Los Angeles basin, confirming that vehicular pollution is the major source of ultrafine particles near and on the freeways, and that high particle number counts can be a very local phenomenon (on scales of 100-500 meters) (Zhu et al., 2002ab). Other combustion sources, such as food cooking and wood burning, can also be sources of ultrafine particles to the atmosphere (Kleeman et al., 1999).

In addition to primary, or direct, ultrafine particle emissions, photochemical secondary formation in the atmosphere is also responsible for the formation of ultrafine particles in the atmosphere. Kulmala et al. (2004) reviewed the observations of particle formation by secondary processes and showed that such particle formation events are more distinct in summer. Particle formation rates depend strongly on the intensity of solar radiation, but the exact mechanism by which the process occurs is not fully understood (Zhang and Wexler, 2002). Once formed, particles are transformed by coagulation and condensation in the atmosphere as they are advected downwind. This long-range transport, as well as photochemical particle formation in the atmosphere, can lead to increased particle number observations downwind of urban areas (Kim et al., 2002; Fine et al., 2004)

Given the demonstrated toxicity of ultrafine particles, and since there is little or no correlation between ambient particle numbers and mass (Sardar et al., 2004), measurements of ambient particle number concentrations have become increasingly important. However, measurements of ambient ultrafine particle number concentrations at a single central monitoring station may not be indicative of actual human exposure in the communities surrounding a single monitoring site. Due to their short atmospheric lifetimes and strong dependence on very local sources, ultrafine particle numbers vary significantly on very short spatial and temporal scales. In order to address this problem and to more accurately estimate human exposure and the subsequent health impacts of UF particles, more intensive particle number measurements on finer spatial scales is needed.

Previous studies measuring particle number concentrations in the atmosphere have either focused on one or two near-roadway sampling sites or several sampling sites separated by large distances (Shi et al., 1999; Sardar et al, 2004; Singh et al, 2004). For instance, a previous jointly funded ARB/AQMD study measured particle number concentrations at each of the Children's Health Study (CHS) communities at a single central monitoring station in each community (Sardar et al., 2004). Results showed predictable daily and seasonal patterns with generally low correlation with other co-pollutants such as PM mass and CO. But other studies showing that UF particle concentrations vary dramatically within 100 meters of roadways (Zhu et al., 2002ab) point out the need for more spatially resolved UF monitoring <u>within</u> impacted communities.

The Zhu et al. studies sampled near freeways without sound walls adjacent to the roadway shoulders. But the effects of freeway characteristics, such as the existence of sound walls and the elevation of the roadway, also need to be assessed. It has been suggested that the existence of freeway sound walls provide some protection to downwind residents from pollutants emitted from freeway vehicles. There have been no studies to date that have examined or demonstrated this potential phenomenon. It is possible that the degree of protection, or lack thereof, will vary with pollutant, or with the elevation of the freeway relative to the

downwind neighborhood. Detailed studies are needed to assess the effects of such freeway characteristics and determine whether sound walls can be used as a method to protect the public from freeway derived pollutants.

Specific Objectives

1. **To determine the fine-scale spatial variability of ambient particle number concentrations within a community, and thus determine the accuracy of using single central site monitoring to estimate human exposure to ultrafine particle numbers. (Tasks 3 and 5 below)**

2. **To demonstrate the feasibility of locating and quantifying specific ultrafine particle sources within a community using highly time-resolved and spatially-resolved meteorological and particle number data. (Tasks 3 and 5 below)**

3. **To analyze highly time-resolved particle number data using several statistical techniques in order to determine regional vs. local contributions to particle number levels. (Tasks 3 and 5 below)**

4. **To examine how the variability of particle number concentrations within communities are affected by season and location of the community (source vs. receptor). (Tasks 3 and 5 below)**

5. **To determine the effects of freeway sound walls and freeway elevation on particle number, CO, CO_2 and $PM_{2.5}$ mass emissions into adjacent neighborhoods. (Tasks 4 and 5 below)**

6. **To use the results of these analyses to explore the development of predictive models of human exposure to particle number concentrations in communities that may have only one monitoring site, using such input variables as wind speed and direction, known source locations and strength, regional vs. local contributions, season, and mixing height. (Task 5)**

Technical Plan

Project Description

In order to meet the objectives outlines above, a series of intensive monitoring campaigns will be carried out in Southern California over the three-year project period. The project utilizes a unique set of available resources enabling the first intra-community assessment of particle number concentrations ever attempted. Two communities of interest will be examined in this project. The first community will be located in the Wilmington/Long Beach, CA area, which includes a complex mix of industrial (refineries, power plants), and transportation sources (marine vessels, diesel trucks, port activities) influencing UF particle exposures. This community is relevant with respect to recent environmental justice concerns, since the much of the impacted area is low-income. The Wilmington and Long Beach areas are also the focus of several other previous, current and future studies, and all efforts will be made to coordinate the activities, results, and conclusions of these companion studies (see below). The second community will be located approximately 90 km inland in the city of Riverside, CA. The air pollution in Riverside is characterized by local emissions mixing with transported air masses from the upwind urban centers near downtown Los Angeles and the coast. As emissions are advected inland, they undergo chemical reactions in the atmosphere forming secondary PM components such as ammonium nitrate and secondary organic aerosol (SOA). The area is known for some of the highest PM levels in the United States. It has also been shown that new particle numbers can be formed by photochemical nucleation in the atmosphere in Los Angeles (Fine et al., 2004). Thus, Riverside represents a very different particle pollution situation as a “receptor” site than the upwind “source” site in Wilmington/Long Beach. Riverside has a long history as a location for air pollution measurements, and there are several studies planned for the future that can be coordinated with this project. Both communities are Children’s Health Study communities, and the results gathered by this project will help in the interpretation of their observed health outcomes as well.

Each of the two communities will be monitored for two separate 3-month periods, one in summer (July - September) and one in winter (January - March). Winters in the Los Angeles are generally characterized by stagnant conditions with lower temperatures, low wind speeds and low inversion heights. The impact of local emissions is therefore more prevalent. Conversely, summers include warmer temperatures, higher wind-speeds, less persistent inversions, and consistent on-shore flow conditions. Larger solar zenith angles also promote greater atmospheric photochemical activity. Sampling during two distinct seasons will help to assess the affect of season, photochemistry, and meteorology on the sources and variability of particle number concentrations within communities. A 3-month sampling period provides a sufficiently long data-set to use in the frequency analyses outlines below and also ensures that representative seasonal conditions are encountered.

For each community, twelve sampling sites will be chosen based on several factors. These include location of known sources, predominant wind directions, desired spatial coverage, exposure concerns (i.e. schools), availability, access, cost, power considerations, and security. An "ideal" siting pattern is pictured in Figure 1.

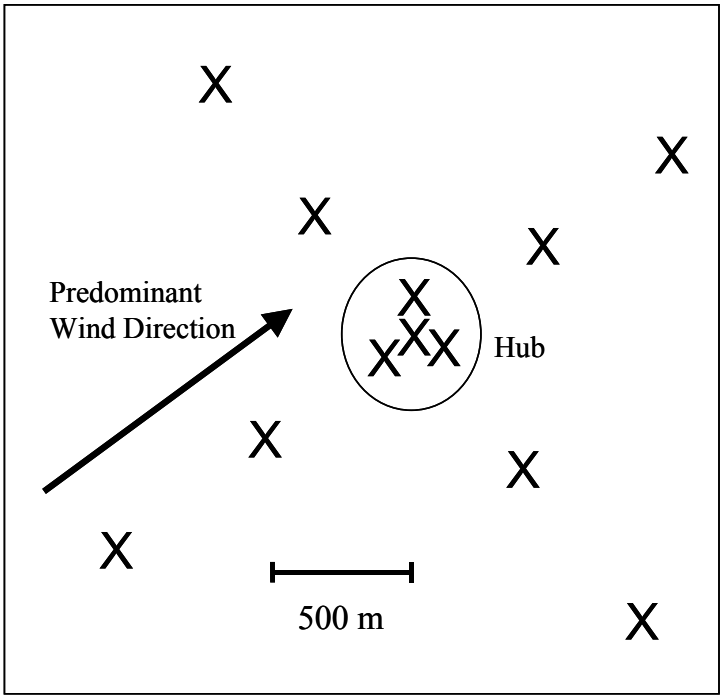

Figure 1. Ideal siting arrangement. X's denote sampling locations

Sites located along a line parallel to the predominant wind direction will allow for tracking of the evolution of particles as they move from site to site. Those sites perpendicular to the wind direction will pick up any unknown sources of particles and allow for better triangulation for locating sources based on wind direction. Wind directions are obviously variable, but such a configuration still provides good spatial coverage for any wind direction. All sites will be located within a 3 km radius. The site spacing will be on the order of 500-1000 m. At the "hub" will be sites located on a finer spatial scale at a location where exposure measurements are of great interest, most likely a K-12 school. Here the spacing may be on the order of 100 – 300 m. The actual siting pattern is subject to other considerations, so this "ideal" scenario will serve as a goal and provide a guideline for site selection. If possible, sites may be located downwind of known particle sources such as

freeways, restaurants, and industrial facilities. The project will aim to site at least one location at existing CARB or SCAQMD air pollution monitoring facilities. Additional routinely collected data at these sites will aid in the interpretation of the results. Governmental and public buildings (including schools) will be considered as sampling locations. Private businesses and private residences are also options. Secure areas are needed, including backyards, gated facilities and rooftops. Compensation to participants for power costs and other inconveniences are budgeted. Twelve sites will be sufficient to assess the variability of particle number concentrations on intra-community spatial scales. The use of additional sites by rotating the twelve CPCs around the community is not practical given the effort involved with securing additional monitoring sites. An ARB mobile monitoring platform will be available to monitor at additional sites on a short-term basis (see below).

In addition to the intra-community monitoring, this project will also assess the impact of freeway-adjacent sound walls on UF particle characteristics downwind. Monitoring will occur over two two-week intensive sampling campaigns. Two freeway sites will be chosen, one with the freeway at ground level with a sound wall, and one freeway raised at least 15 feet above the ground, also with a sound wall. Both sites will be near a section of roadway where there is break or end of the wall, so that simultaneous measurements with and without the wall can be compared. Sampling will be conducted at sufficient distance from the wall edge such that no edge effect influence results. Sampling sites will be located on either side of the wall and at several distances downwind from the wall as shown in Figure 2. Some CPCs will be fitted with longer vertical inlets to sample air near the top of the wall and perhaps additional vertical heights. These inlets will be well characterized for losses prior to deployment and at the site. The resulting data will provide a continuous map of how particle number concentrations vary near a sound wall and are affected by the existence of a sound wall. This configuration will allow for tracking the ultrafine particle characteristics on very small spatial scales near a freeway, and will examine whether the sound wall has an appreciable effect on exposure downwind of such walls.

The primary tool for measuring particle number concentrations is the condensation particle counter (CPC). CPCs measure particle number concentrations by supersaturating an incoming air stream with a condensing liquid and thereby growing smaller particle to a size at which they can be detected optically. Twelve TSI Inc. 3022A butanol-based CPCs are currently owned by ARB and were used for a previous jointly funded ARB/SCAQMD study in the twelve Children's Health Study communities in Southern California (Sardar et al., 2004). These communities were separated by distances of 6 to 100 km, and results showed that spatial correlations of particle number concentrations between sites were very low (Sardar et al., 2004). With the completion of this previous study, the CPCs and a lesser number of temperature-controlled outdoor enclosures are now available for this project. Each CPC will require its own enclosure, so additional enclosures will be

built to bring the total number to 12. All CPCs will be serviced and re-calibrated by the manufacturer prior to deployment. Furthermore, all CPCs in their individual enclosures will be collocated for approximately two weeks at the USC Particle Instrument Unit (PIU) for inter-comparison and precision tests. These tests will be repeated between every field campaign. Any non-correctable discrepancies will be noted and used to adjust the monitoring data in the future. Each CPC requires a laptop computer to record 1-minute resolution particle number concentration data. Site visits will be necessary at least twice a week to inspect the instrumentation and download the collected data.

Each enclosure will also have a low-cost meteorological station attached, recording 1-minute resolution wind speed, wind direction, temperature, and barometric pressure. The wind vane and sensors will be located on top of a pole extending vertically from the enclosure. The height of the sensors will be at least 20 feet above ground level. The meteorological stations will also be tested for inter-comparability at the same time the CPCs are tested at USC. In the field, data from existing weather stations will be used and compared to the data collected at the sampling sites. Detailed, spatially resolved meteorological data will provide the means to identify and locate local sources by triangulation based on wind direction.

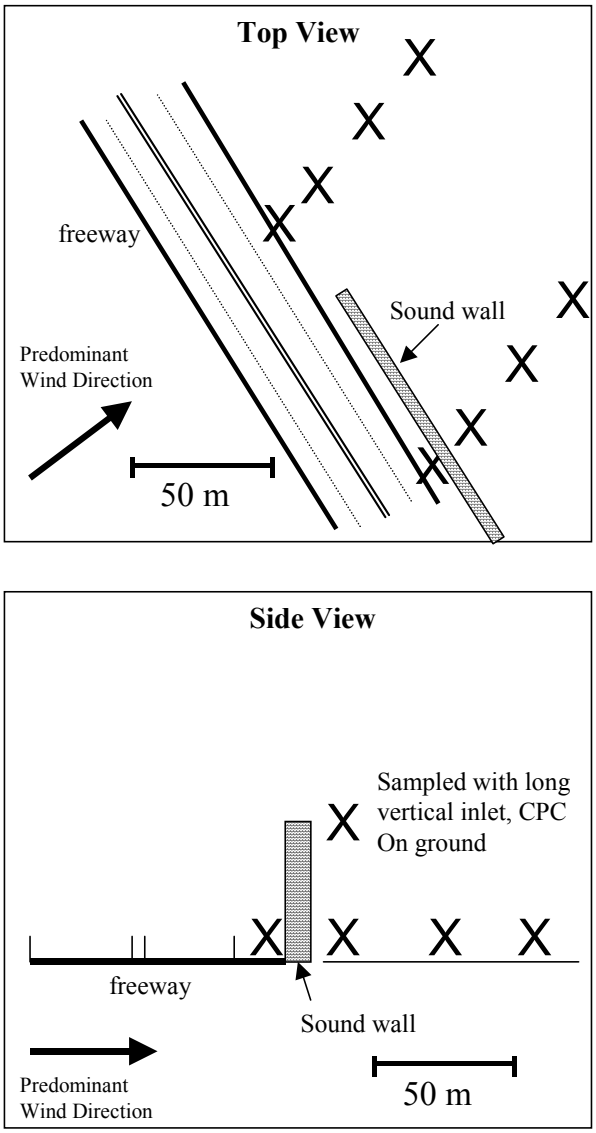

Figure 2. Ideal sampling configuration for the sound wall studies. Figures show ground level freeway scenario.

The sound wall monitoring campaign will include the addition of other available air pollution monitoring equipment. At least two hand-held Q-Trak CO/CO_2 monitors will be deployed within selected enclosures. Every day, these monitors may be moved to other enclosures to address specific measurement needs. The CO data will provide a measure of the atmospheric dilution characteristics in the vicinity of the freeway and sound

wall. In addition, two SMPS systems to measure particle size distributions (10 – 260 nm) will be attached to two of the CPCs at a time within the enclosures. These instruments will also be moved by rotation to provide data on particle size distributions at different sampling locations. Two $PM_{2.5}$ mass monitors (DataRAM, Thermo Electron Corp., Franklin, MA) will be deployed on a rotating basis as well. These nephelometers will be fitted with inlet diffusion dryers to eliminate the known effects of high relative humidity on the measurements. All additional instruments will be calibrated according to manufacturer specifications and tested for inter-comparability prior to deployment. The sound wall campaign will require daily site visits.

Sampling Matrix

Intra-community CPC Monitoring

- Twelve CPCs deployed within a community for saturation monitoring
- Two communities, Wilmington/Long Beach community (up-wind source site) and Riverside (inland receptor site)
- Three months in summer, Three months in winter at each community, for a total of 4 campaigns

Sound Wall Studies

- Two locations to be determined
    - One freeway at ground level with a sound wall
    - One raised freeway with a sound wall
- Two weeks of sampling each location
- CPCs also deployed nearby at a significant break in the sound wall.
- Additional continuous instrumentation to include:
    - 2 SMPS for size distributions
    - 2-4 CO/CO2 monitors
    - PM2.5 monitors (2 DataRAMs)

Data Management and Analysis

All data will be collected on a 1-minute basis, resulting in a very large data set requiring careful data collection, storage, and reduction protocols. Site visits will be conducted at least twice weekly to inspect the instruments and download data. Data will be downloaded to portable USB memory sticks in the field, transported back to USC, and uploaded to a personal computer hard drive. From there data will be archived on a central server with dual mirrored hard drives maintained by the USC Aerosol research group. Furthermore, data will be transferred to CDs on a weekly basis for additional archiving.

Such a large data set will inevitably include some amount of invalid data caused by uncontrollable events such as instrument malfunction and power outages. Data screening tools will be developed as needed to eliminate invalid data. For instance, particle number concentration values below 2000 or above 200,000 particles per cubic centimeter are suspect and will be flagged for further inspection. Zero values are known to be invalid. The investigators have years of experience in this area, having managed the USEPA Southern California Supersite for the previous five years. QA/QC and data reduction protocols developed for the Supersite will be applied to the data as appropriate. Data analysis will be performed using a combination of Microsoft EXCEL, MATLAB, and SASS software.

A large amount of data will be generated by these field campaigns, and a variety of techniques will be applied for the data analysis. Pearson correlations between concurrent measurements among sites will provide a direct measure of the spatial variability within the community. The degree of correlation will be examined as a function of inter-site distance. For sites located along a wind trajectory, inter-site correlations will be performed inserting a lag time based on measured wind velocities. Similar analysis has been preformed in a previous study between sites located 6 km apart (Glendora and Upland) and the degree of correlation of hourly particle number data increased when adjustments were made for the time of transport between sites as seen in Figure 3 (Sardar et al., 2004).

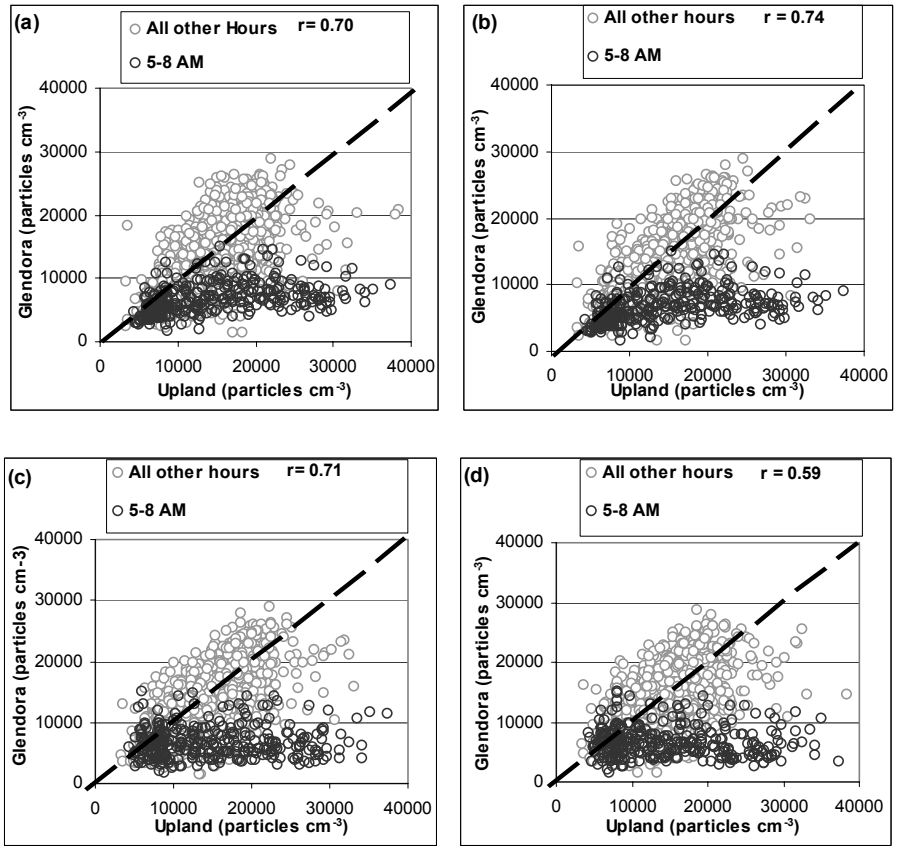

Figure 3. Comparison of PN concentrations in Upland and Glendora during summer, 2002. a) No lag time b) One hour lag time c) Two hour lag time, and d) Three hour lag time. Dashed lines indicate the ideal 1:1 relationship and are therefore not fits to the data.

The data from the sound wall sampling campaigns will be similarly analyzed, with inter-site correlations and detailed time series comparisons. Corresponding samplers from the sound wall site vs. the no-sound wall site will be compared, and differences will be attributed to the effects of the sound wall. The CO/CO_2 data will provide a measure of the dilution conditions and the effect of the sound wall on dilution rates downwind. These dilution rates will be compared to the diminishing particle number concentrations as the emissions move downwind, and any deviations from pure dilution effects will be attributable to particle processes such as

evaporation or coagulation. Two-dimensional concentration profiles (mapped onto the side view seen in Figure 2) will be created to illustrate the effects of the sound wall on CO, CO_2, $PM_{2.5}$ mass, and particle number concentrations in the vicinity of the wall an compared to the no-wall location. Cross correlations between co-pollutants will also be examined, as well as the diurnal cycles of each pollutant.

The collection of highly time-resolved particle number data (1-minute averages), accompanied by similarly time-resolved meteorological data, allows for several additional analysis techniques. A simple spectral analysis filtering technique using successive moving average subtraction has been applied to highly time resolved air pollution data to separate high frequency short-duration excursions from lower frequency baseline variations (Watson and Chow, 2001). Such analysis results in separate calculated time-series data for local (0.1 km-1 km), urban (1 km – 10 km), and regional-scale (10 km – 100 km) contributions to pollutant levels at a given site (Figure 4). Inter-site correlations between these "filtered" data sets will further confirm the local vs. regional nature of particle number concentrations and help to identify important sources.

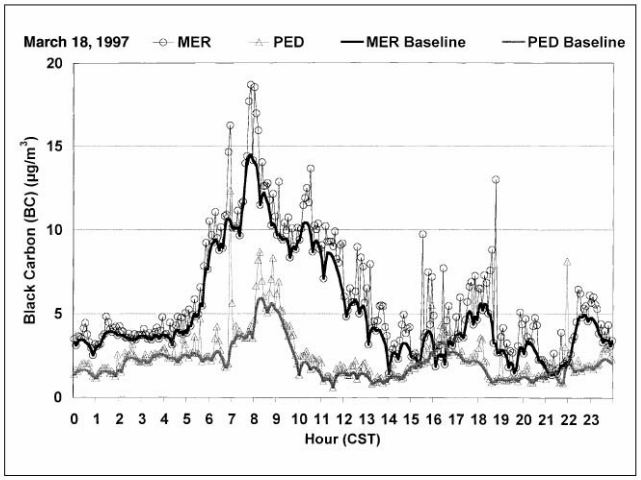

Figure 4. Example of baselines used to determine black carbon spikes for the MER and PED sites on March 18, 1997, using a 1-hr moving average. Similar results are seen for 30-min and 2-hr moving averages.

A separately funded project by the USEPA with Dr. Philip Fine as co-PI (PI: Dr. Ron Henry at USC) has as one of its primary goals to apply more advanced data analysis techniques to continuous air pollution data sets. Nonparametric regression methods using wind speed and direction have been shown to accurately locate nearby sources by triangulation. This analysis combines nonparametric regression methods with the joint probability

distribution of wind speed and direction determined by kernel density estimation methods that, like nonparametric regression, make no assumptions about the distribution of the data. The result is a Nonparametric Source Apportionment Model (NSAM) that can estimate the contribution of local sources to airborne particles and precursor gases (Yu et al., 2004). An example of the results for such an analysis is given in Figure 5, in this case using hourly PM_{10} data. In Figure 5a, the wind directions and wind speeds that result in the highest PM_{10} levels are easily observed. Distant sources are usually seen influencing the location at higher wind speeds. This data can be weighted by the wind probability density (Figure 5b) to apportion the measured pollutant as a function of wind speed and direction (Figure 5c). Figure 5d demonstrates the resulting quantitative apportionment of the measured parameter to different wind directions.

The data collected in this study, with much higher temporal and spatial resolution than any previous study, is ideal for this analysis. Having multiple sites will enable the identification of point sources by simple triangulation. It is known that the high particle number concentrations found near freeways diminish rapidly with distance from freeways. Therefore, line sources, such as roads or freeways, will result in a wide sector of wind directions contributing to the higher measured levels of particle numbers, with a probable maximum in the center of this sector and a strong dependence on wind speed. Regional contributions will appear as a consistent background level of particle numbers largely independent of wind speed. All identifications of potential sources can be verified by on-site ground observations inspections. The NSAM model can be applied separately to different times of the day, to weekdays vs. weekends, and to regional vs. local components based on the frequency analyses described above. This will further help identify the sources of particle numbers and their behavior over space and time. The NSAM analysis requires measurable and consistent wind speed and direction measurements. Under calm and more stagnant conditions, inter-site correlations will provide a measure of spatial variability at a time when very local sources are dominating number concentrations.

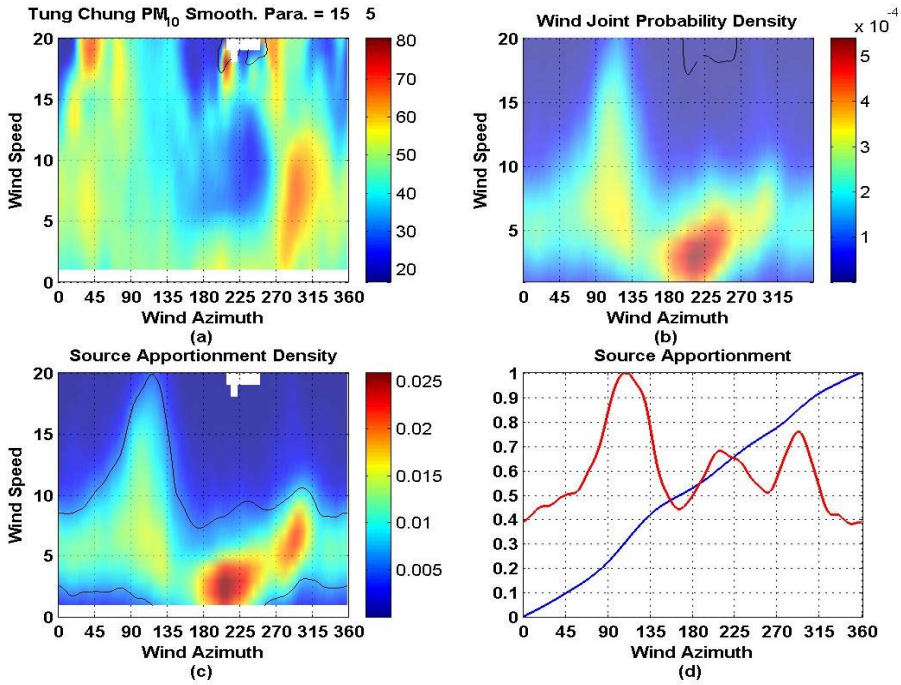

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Figure 5. NSAM approach applied to hourly PM_{10} for 2000 and 2001 at Tung Chung near Hong Kong International Airport. The solid black line in (a), (b), and (c) are points with a signal-to-noise ratio of 2 (Yu et al., 2004)

The USEPA project will also quantitatively examine the periodic nature of pollutant concentrations using the Lomb-Scargle periodogram developed for astrophysical research. Standard, finite fast Fourier analysis methods must have evenly spaced data with no missing data. Few if any air quality data sets of any length satisfy these requirements and thus these powerful methods have seldom been applied to air quality data. The Lomb-Scargle periodogram is an estimate of the power spectrum of a time series with missing data. Source variability information in the power spectrum can be used for source identification and apportionment. The strength and shape of daily, weekly, and seasonal variations are determined by automated methods. An example result of this spectral analysis is given in Figure 6 for 1-hour PM10 in Long Beach, CA. The significant periodicities at 1, 2, and 3 cycles per day describe the daily variation in PM10 (including the harmonic frequencies). The seasonal cycle is also clearly seen at frequency 0.00274 cycles per day = 1 cycle per year. The weekly cycle at 1/7 = 0.143 cycles per day is also seen. Other features, such as the relative strengths of the harmonics, may contain more useful information that can be related to actual behavior of

particle numbers in the atmosphere. Given the novelty of these measurements and analysis techniques, the exact meaning is not yet clear, but the interpretation of such features is a major goal of the EPA funded project. But using the finer temporally and spatial resolved data for particle number concentrations obtained in this study, such periodograms will be of great help in unraveling the sources and behavior of ultrafine particles in the targeted communities.

The results of these all these data analysis techniques will be integrated in order to explore the development of predictive models of human exposure to particle number concentrations. Other communities than the ones under study may have only one or no monitoring site for particle number concentrations. Variables such as wind speed and direction, known source locations and strength, season, and mixing height, may be somewhat predictive of outdoor particle number levels as a function of time and location. For instance, the frequency analysis outlined above will yield information on the regional contributions, expected to be uniform over the spatial scales of a community, vs. the local contributions, which may be estimated based on proximity to known point or line sources.

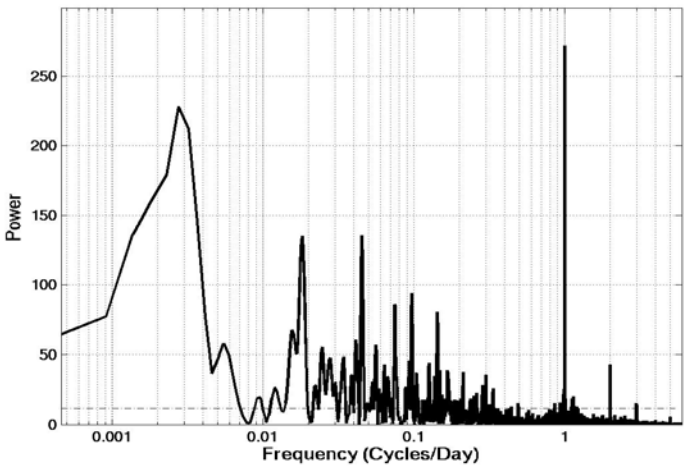

Figure 6. Lomb – Scargle periodogram for Long Beach 1 hour PM10 at or 1/2002 to 6/2003, 13062 possible data points about 5 percent missing data. 1 cycle/yr = 0.00274 cycles/day, 1 cycle/week = 0.143 cycles/day. The horizontal dashed line is the 95 % confidence limit.

Project Tasks

The project described above is divided into specific project tasks as follows:

Task 1. Initial construction, testing, calibration, and inter-comparison of all CPCs and enclosures (6 months)

In order for data from different sites to be comparable, it is essential that all instruments are in proper operating condition and show a high level of precision and inter-comparability. To accomplish this, all CPCs will be sent to the manufacturer (TSI Inc.) for servicing and re- calibration. Once they are returned, all 12 CPCs will be placed in their respective enclosures and run side-by-side for at least two week at the USC PIU location. Enclosures will be fitted with the meteorological stations at this time as well. All data from the CPCs and met stations will be compared for inter-comparability, and any discrepancies will be, if possible, fixed or quantified and recorded for future data adjustments. At the completion of this task, all instruments will be ready for field deployment.

Task 2. Identifying and securing sampling sites for the intra-community monitoring (6 months)

Concurrent to Task 1, Investigators will select potential sampling sites in the Wilmington/Long Beach Area. All efforts will be made to create a deployment pattern similar to the one described above in Figure 1. Schools, SCAQMD and CARB sampling sites, government and public facilities, private businesses, and private homes will all be considered. Power, security and financial compensation issues will all be addressed.

Task 3. Intra-community monitoring campaign (15 months)

The intra-community monitoring will occur over four distinct 3-month periods, encompassing two seasons (winter and summer) in each of two locations (Wilmington/Long Beach and Riverside). The instrumentation will be inspected and data will be downloaded at the sites twice weekly. This task also includes any instrument maintenance or recalibrations needed during or between sampling campaigns

Task 4. Freeway sound wall sampling campaign (4 months)

Two field campaigns will be conducted in the vicinity of freeway sound walls, each for two weeks in duration. One campaign will examine a freeway at the same vertical height as the surrounding community and the other will look at a freeway with a raised elevation relative to the surrounding community. Locations will be chosen near a break or end of the sound wall, such that identical “un-perturbed” measurements can be

made as a control. Sampling will occur at sufficient distances from this break to ensure that no edge effects are occurring. This task includes all siting activities, deployment, monitoring, maintenance, and daily site visits to inspect instruments and download data. The deployment of additional samplers such as the SMPS, CO/CO_2 monitors, and DataRAMs in a subset of the enclosures is also part of this task

Task 5. Data analysis and preparation of publications (24 months)

At the completion of the first field campaign, analysis of data from that campaign will begin and continue throughout the project as additional data is generated. This task includes all quality control of the data, including visual inspection of time series for outliers and other data exclusion criteria. Once the validity of data is confirmed, the analysis techniques outlined above will be applied, including inter-site correlations, average diurnal patterns, wind roses, frequency analyses, non-parametric regressions, and triangulation to locate specific sources. The results of these analyses will be used to explore the development of predictive models of human exposure to particle number concentrations in communities that may have only one monitoring site. Input variables will include wind speed and direction, known source locations and strength, regional vs. local contributions, season, and mixing height. This task also includes the preparation of papers to be submitted to leading peer-reviewed journals.

Task 6. Final report (3 months)

Preparation and submission of the draft final report to California Air Resources Board, and finalizing the report after CARB feedback

Existing Facilities

A monitoring project of this scope has never before been attempted on the community scale, and the twelve existing CPCs owned by CARB are a unique resource that will enable its execution. CARB also owns at least eight temperature controlled instrument enclosures that will be made available for this study. Additional enclosures will be purchased as needed.

The Southern California Particle Center and Supersite (SCPCS) maintains an air pollution sampling trailer on the USC campus near downtown Los Angeles known as the Particle Instrumentation Unit. The trailer contains numerous state-of-the-art particulate sampling instruments. The area around the trailer will be used as a staging area for preparing the enclosures, CPCs, computers, and meteorological stations. The initial instrument inter-comparisons will also be conducted in this area, and results can be compared to instruments running within the trailer. Existing space at the Aerosol Laboratory at USC will also be used for instrument maintenance. All computers to be used for data analysis and archiving are pre-existing at USC. The DataRAMs, Q-traks and SMPS that will be deployed in the sound wall studies are the property of the SCPCS and will be made available as needed.

Potential synergies and collaborations with other separately funded projects

- CARB is planning to sponsor the Desert Research Institute (DRI) to conduct an air toxics saturation monitoring campaign in the Wilmington area to address environmental justice concerns. The study calls for some particle measurements. Wilmington is an ideal place for such studies given the proximity of surrounding pollution sources such as the port, busy heavily-diesel freeways, refineries, etc. Although the details of this study are not yet known, including the sampling schedule and locations, all attempts will be made to coordinate DRI efforts with the project outlined in this proposal. The data collected by each study should be helpful to the interpretation of results from the other. Note that the project described in this proposal will require six months of lead-time from the date of funding to the beginning of actual field sampling. This time is needed to re-calibrate the CPCs, obtain and configure the enclosures, and do a side-by-side CPC and meteorological station inter-comparison. If the DRI Wilmington study is scheduled and carried out before these tasks are completed, it may not be possible to sample concurrently. Furthermore, the PI of this study retains the right to make independent scientific decisions as to the site

locations and sampling periods. But given the potential synergies between the studies, both scientific and logistical, and assuming the preliminary calibration work is complete, the goal will be to coordinate the efforts to the greatest extent possible.

- A CARB mobile monitoring platform will be available that will be equipped with one or more CPCs, an SMPS, gas monitors and several other continuous air pollution monitoring equipment. The facility can be used to enhance the spatial resolution of the intra-community fixed site measurements for selected periods of time. For instance, the vehicle can be parked for several hours at the same or additional sampling locations within the community and serve as an enhanced and/or additional sampling site providing more detailed data than the CPCs alone. Furthermore, if a potential source of particle numbers is suspected based on the fixed site CPC data, the mobile platform could be used to pinpoint that source and further characterize its emissions.

- A current study sponsored by USEPA at USC is looking at the seasonal and intra-community spatial variability of PM2.5 and UF mass in the Long Beach area. Results from that work will be compared to those from this project to provide a more complete picture of particle sources in the area. The EPA project also includes funding to analyze highly time resolved air pollution data using advanced frequency analysis and non-parametric regression for source apportionment (see above). The data generated by this project is ideal for such statistical models.

- The communities chosen will likely correspond to communities in the USC Children's Health Study, and these results will help their efforts in estimating their subjects' exposure to particle numbers. The infrastructure established by the CHS study may also help with the identification and procurement of suitable sampling sites, including schools and subjects' homes.

- The potentially re-funded EPA Southern California Particle Center has plans to acquire detailed physical, chemical and toxicological particle data at sites near the Ports of Los Angeles and Long Beach and at an inland receptor site (Riverside). These efforts will occur in the same communities chosen for this study, thus providing enhanced particle and source information to both efforts.

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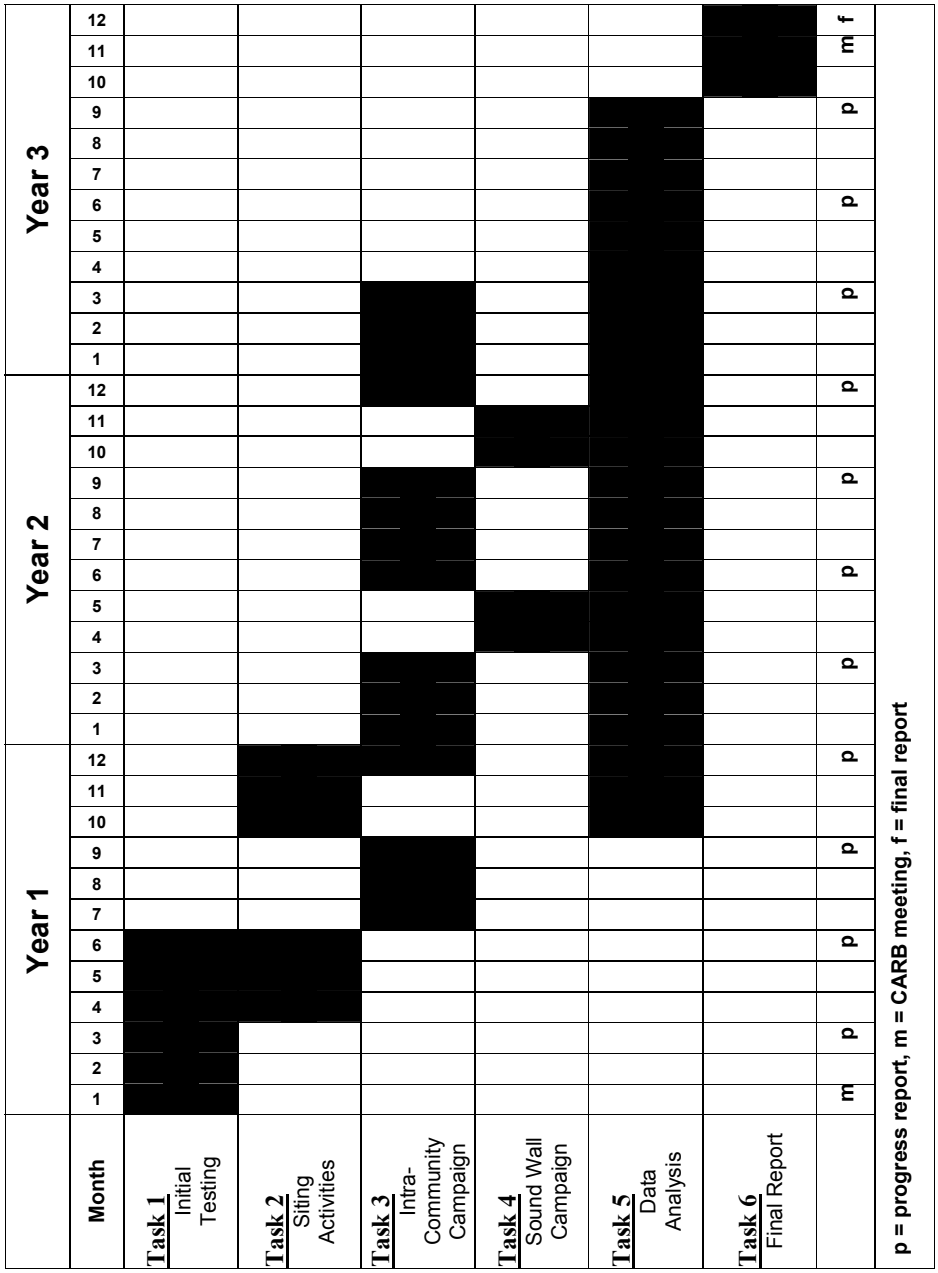
Detailed Work Plan

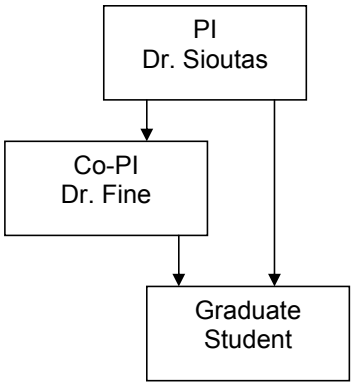
	Quarter:	1	2	3	4	5	6	7	8	9	10	11	12	
Personnel (Name, Title, Classification)	Task #													Total hrs by task
C. Sioutas	1	56	28											84
Professor	2		28		28									56
	3			56	18	28	18	28	18	28				194
Principal	4						28		28					56
Investigator	5				10	28	10	28	10	28	56	56		226
	6												59	59
Subtotal		56	56	56	56	56	56	56	56	56	56	56	59	675
P. Fine	1	125	62											187
Res. Asst. Prof.	2		63		65									128
	3			125	30	62	30	62	30	62				401
Co-Principal	4						65		65					130
Investigator	5				30	63	30	63	30	63	125	125		529
	6												125	125
Subtotal		125	125	125	125	125	125	125	125	125	125	125	125	1500
Graduate	1	250	125											375
Student	2		125		125									250
	3			250	75	150	75	150	75	150				925
	4						150		150					300
	5				50	100	25	100	25	100	250	250		900
	6												250	250
Subtotal		250	250	250	250	250	250	250	250	250	250	250	250	3000
Totals		406	406	406	406	406	406	406	406	406	406	406	409	4875

Project Schedule



Project Management Plan

Organizational Chart



Key Personnel

Principal Investigator: Constantinos Sioutas, Sc.D.

Dr. Sioutas received a Sc.D. from the Harvard School of Public Health, remained there as an assistant professor of Environmental Engineering, and then moved on to USC in 1998. He is currently a Professor of Civil and Environmental Engineering. He has co-authored over 130 publications in top scientific journals over the past 12 years. As co-director of the Southern California Particle Center and Supersite, a $30 Million, 12 year program, Dr. Sioutas has overseen numerous studies on air pollution and its effects on human health. He also holds 11 patents and has worked to develop new particle sampling technologies such as particle concentrators, personal samplers, and size-selective impactors and inlets.

Dr. Sioutas will be responsible for overall project management, both administrative and scientific. He will oversee all aspects of the sampling campaigns, providing guidance and direction to the other project personnel. He will also perform a portion of the data analysis. He will be responsible for the final report and overseeing the submission of several manuscripts for publication in leading journals

Co-Principal Investigator: Philip M. Fine, Ph.D.

Dr. Fine received a Ph.D. in Environmental Engineering Science from California Institute of Technology where he conducted research on the fine particle emissions from biomass combustion sources. He has over eleven years experience with ambient filter-based and continuous sampling methods and the chemical analysis

of ambient particulate matter. He has published several papers involving the analysis of particulate matter for individual organic compounds by GC/MS, having worked under the late Dr. Glen Cass at Caltech where these techniques were developed. He is an author or co-author on over 30 publications and has presented his research at conferences throughout the world. He has recently been involved with several projects at the Southern California Particle Center and Supersite, including the analysis of large sets of ambient air pollution data.

Dr. Fine will manage and supervise the field campaigns, including identifying and securing the sampling sites. He will be responsible for the proper maintenance and testing of the instrumentation, organizing the deployment of the instruments and archiving the data. He will provide scientific input to the PI, and oversee the graduate student working on this project. He will make trips to the field as necessary to troubleshoot problems and download data when the graduate student is not available. He will also perform much of the data analysis, and provide data to Dr. Henry at USC for analysis additional under the separately funded USEPA grant. He will assist in the writing of the publications and final report.

Graduate Research Assistant

A graduate student (yet to be identified) will carry out most aspects of the field campaigns, including twice weekly site visits to download the data. He will assist in all aspects of the project, including data analysis, manuscript preparation, and the final report.

Meetings including all project personnel will be held at least twice monthly to track progress and address any issues that may arise.

Curriculum Vitae for the PI and co-PI follow.

BIOGRAPHICAL SKETCH

Provide the following information for the key personnel in the order listed on Form Page 2.
Photocopy this page or follow this format for each person.

NAME	POSITION TITLE
Sioutas, Constantinos	Professor of Civil and Environmental Engineering

EDUCATION/TRAINING (*Begin with baccalaureate or other initial professional education, such as nursing, and include postdoctoral training.*)

INSTITUTION AND LOCATION	DEGREE (*if applicable*)	YEAR(s)	FIELD OF STUDY
Aristotelian University of Thessaloniki, Greece	B.S.	1986	Mechanical Engineering
University of Minnesota	M.S.	1988	Mechanical Engineering
University of Minnesota	M.S.	1989	Aerospace Engineering
Harvard University	Sc.D.	1994	Environmental Engineering

PROFESSIONAL EXPERIENCE

2004- Present Professor of Civil and Environmental Engineering, University of Southern California
1997-2003 Associate Professor of Civil Engineering, University of Southern California
1995-1997 Assistant Professor of Aerosol Science, Harvard University
1994-1995 Instructor/Research Associate, Harvard University
1992-1994 Doctoral Candidate/Aerosol Engineer, Harvard University
1989-1992 Advanced Product Development Engineer, 3M Company
1987-1989 Research Assistant, Department of Mechanical Engineering, University of Minnesota

FELLOWSHIPS, HONORS, AND AWARDS

3M Circle of Technical Excellence Recipient, 1991
Fulbright Foundation Fellow (1986-1987)
Fellow of the Greek National Institute of Scholarships (1980-1983)

PATENTS

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7. Sioutas*, C., Koutrakis, P., Ferguson, S.T., and Burton, R.M. "Development and evaluation of an ambient particle concentrator for inhalation exposure studies." *Inhalation Toxicology*, 7:633-644, 1995.
8. Sioutas*, C., Wang, P.Y., Ferguson, S.T., Koutrakis, P., and Mulik, J.D. "Laboratory and field evaluation of an improved glass honeycomb denuder/filter pack sampler." *Atmospheric. Environment*, 30 (6):885-895, 1996.
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Books and Book Chapters:

1. Sioutas, C., and Koutrakis P. (1996). Measurement of Acidic Particles and Gases. In *The Handbook of Environmental Chemistry*, (Editor Otto Hutzinger); pp. 201-232, Springer/Verlag.
2. Sioutas, C. and Koutrakis, P. "Characterization of Particles: Composition and Sources"; in *Particles in Our Air: Concentration and Health Effects*, (Editors Richard C. Wilson and John D. Spengler); pp. 15-40, Harvard University Press, 1996.

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Synergistic Activities

Deputy Director, Southern California Particle Center and Supersite; , is a renewable 6-year research program, established by the U.S. EPA in early 2000 for an initial award of $18 million. The largest research program in EPA's history, it is aimed at defining and understanding the health effects from exposure to airborne particulate matter. This multi-disciplinary program involves approximately 25 faculty from 5 institutions in Southern California (USC, UCLA, Caltech, UCI, UC Riverside) from fields as diverse as engineering, toxicology, medicine, epidemiology, and atmospheric chemistry.

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EDUCATION

California Institute of Technology, Pasadena, California
Ph.D., Environmental Engineering Science, January 2002
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Minor in Art History
Cumulative GPA: 3.9
Doctoral Thesis: *The Contribution of Biomass Combustion to Ambient Fine Particle Concentrations in the United States*
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University of California, Berkeley, California
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RESEARCH EXPERIENCE

University of Southern California, Los Angeles, California **2002 - present**
Research Assistant Professor
California Institute of Technology, Pasadena, California **1995 – 2002**
Graduate Student Researcher
Lawrence Berkeley Laboratory, Berkeley, California **1991 – 1993**
Undergraduate Co-operative Education Researcher

INDUSTRY EXPERIENCE

Pacific Environmental Services, Inc., Baldwin Park, California **1994 – 1995**
Environmental Engineering Consultant

EDUCATIONAL EXPERIENCE

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Caltech Pre-College Science Initiative, Pasadena, California **1999 – 2001**
Curriculum Developer

California Science Fair, Los Angeles, California **1998 – present**
Category Chairperson

California Institute of Technology, Pasadena, California **1997 – 1998**
Teaching Assistant

PROFESSIONAL AFFILIATIONS/SERVICE

Member of the American Association for Aerosol Research - Session Chairperson, AAAR 2000, 2001, 2004 conferences
Member of the American Chemical Society
External Scientific Advisory Committee, MESA Air Study, University of Washington, 2005
NSF Workshop – Emerging Issues in Nanoparticle Aerosol Science and Technology - contributing author to the final report, 2003
EPA STAR Grant Program – Peer Review Panels, 2003, 2004
Reviewed numerous manuscripts for several scientific journals, including *Aerosol Science & Technology, Environmental Science & Technology, Atmospheric Environment, Journal of the Air and Waste Management Association, Journal of Geophysical Research,* and *Journal of Exposure Analysis and Environmental Epidemiology*
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RESEARCH GRANTS

Principal Investigator, "A Simple, Low-Cost Beta Attenuation Monitor (BAM) for Continuous Measurement of PM10, PM2.5 or Ultrafine Particle Concentrations."
$143,830, June 2003 – June 2005
Innovative Clean Air Technology Program, California Air Resources Board.

Co-principal Investigator, (Henry P.I., USC) "New Technologies for Source Apportionment"
$450,000, February 2005 – January 2008
Environmental Protection Agency, National Center for Environmental Research STAR Program.

Co-principal Investigator, (Sioutas P.I., USC) "An Automated Aerosol Concentration System for the Collection of Suspended Particulate Matter in Aqueous Solutions Suitable for Toxicological Assays."
$214,195, December 2003 – November 2005
Asthma Consortium, South Coast Air Quality Management District.

Investigator, (Delfino P.I., UC Irvine) "Ultrafine PM and Cardiorespiratory Health"
$2,817,789 (USC School of Engineering Share: $715,000), December 2003 – November 2008
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PUBLICATIONS

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Arhami, M.; Kuhn, T.; **Fine, P. M.**; Delfino, R. J.; Sioutas, C. "Effects of sampling artifacts and operating parameters on the performance of a semi-continuous particulate EC/OC monitor." Submitted to *Environmental Science and Technology,* June, 2005.

Related Research

"A Simple, Low-Cost Beta Attenuation Monitor (BAM) for Continuous Measurement of PM10, PM2.5 or Ultrafine Particle Concentrations."
PI : Philip M. Fine (USC)
$143,830, June 2003 – June 2005
Innovative Clean Air Technology Program, California Air Resources Board.

"New Technologies for Source Apportionment"
$450,000, February 2005 – January 2008
PIs: Ronald C. Henry and Philip M. Fine (USC)
U.S. Environmental Protection Agency, National Center for Environmental Research STAR Program.

"An Automated Aerosol Concentration System for the Collection of Suspended Particulate Matter in Aqueous Solutions Suitable for Toxicological Assays."
$214,195, December 2003 – November 2006
PI; Constantinos Sioutas (USC)
Asthma Consortium, South Coast Air Quality Management District.

"Ultrafine PM and Cardiorespiratory Health"
$2,817,789 (USC School of Engineering Share: $715,000), December 2003 – November 2008
PIs; Ralph Delfino (UCI) and Constantinos Sioutas (USC)
National Institute of Environmental Health Sciences (NIEHS-NIH).

"SOUTHERN CALIFORNIA AIRBORNE PARTICULATE MATTER CENTER (SCAPMC)"
Renewal
$ 7,999,360 (USC School of Engineering Share: $2,135,231), September 2005-Septemebr 2011
Center Directors: John Froines. University of California, Los Angeles, and Constantinos Sioutas (USC)
U.S. Environmental Protection Agency.
:

Selected Relevant Publications by the Investigators

Kuhn, T.; Biswas, S.; **Fine P. M.**; Geller, M. G.; **Sioutas, C.** "Physical and Chemical Characteristics and Volatility of PM in the Proximity of a Light-Duty Vehicle Freeway." *Aerosol Science and Technology,* **39**, 347-357, 2005.

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