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**Appendix A**

**Pilot Study Report:  
Measuring Concentrations of Selected Air Pollutants  
Inside California Vehicles**

February 1, 1998

**PILOT STUDY REPORT:  
MEASURING CONCENTRATIONS OF SELECTED AIR POLLUTANTS  
INSIDE CALIFORNIA VEHICLES**

ARB Contract 95-339  
RTI Task 93U-6786-001

prepared by

Charles Rodes, PhD, Linda Sheldon, PhD, Don Whitaker  
Research Triangle Institute  
Research Triangle Park, NC 27709

Frank DiGenova  
Sierra Research  
Sacramento, CA 95814

Susanne Hering, PhD  
Aerosol Dynamics  
Berkeley, CA 94710

prepared for

Steve Hui  
Air Pollution Research Specialist  
California Environmental Protection Agency  
Air Resources Board  
P. O. Box 2815  
2020 L Street  
Sacramento, CA 95812-2815

## **Acknowledgments**

This Pilot Study project integrated the technical skills and personnel from a prime contractor, Research Triangle Institute (RTI), and two subcontractors, Sierra Research, Inc. (SR), and Aerosol Dynamics, Inc.(AD). SR provided the mobile sampling platform used in all commutes, on-board instrumentation to measure and record traffic conditions, drivers and a navigator (primary vehicle only) for all vehicles, and rental vehicles. SR also selected the commuting routes used for each phase of the study. AD provided the characterization of “real” California aerosol, calibration of the optical particle counter for these aerosols, and the (leased) Aethalometer for monitoring elemental carbon. AD also provided aerosol monitoring consulting, and assisted in the initial installations of the particle counter and Aethalometer. RTI provided all other equipment and technical services associated with both the Pilot and Main Studies, including the overall study design and project direction, field project direction, field operations technical staff, ICP/MS metals’ analyses (Pilot Study only), automated data collection, analyses and interpretations, quality assurance summaries, and reporting. Staff from ARB assisted in the field operations by providing local logistical coordination, and collecting samples and data from the ambient monitoring sites. SCAQMD provided logistical support in Los Angeles.

Specific individuals contributing to this project included:

**RTI** - Charles Rodes and Linda Sheldon (overall project direction), Don Whitaker (field management), Phil Lawless (filter weighing coordination and automated data collection), Mike Roberds (field operations - Pilot Study), Randy Newsome (sampling equipment design and construction, field operations - Main Study Sacramento), Tyson Mew (field operations - Sacramento), Andy Clayton (data analysis), Doris Smith and Jim Flanagan (quality assurance), Peter Grohse (ICP/MS analyses), Libby Cain (report preparation).

**Sierra Research** - Frank DiGenova (subcontract direction and field support, navigation), John Lee (traffic data collection, driving, navigation), Josh Willter (driving)

**Aerosol Dynamic** - Susanne Hering (subcontract direction, aerosol measurement consulting, and field support), Mark Stolzenburg (aerosol characterization, particle counter calibration, field support), Nathan Kreisberg (aerosol characterization, particle counter calibration, aerosol modeling).

**ARB** - Steve Hui (logistical support in Sacramento collection of ambient monitoring data, sampler assistance - Pilot and Main Studies), Peggy Jenkins (sampler assistance - Pilot Study)



## **Preface**

This report summarizes the field monitoring activities and the data collected from a Pilot Study conducted to assess the capabilities of methodologies for assessing in-vehicle air concentrations in California vehicles for a number of selected pollutants. The report is presented in a bulleted form, rather than a narrative style to focus on the key study design elements that either worked successfully or required consideration and improvement before subsequently implementing the Main Study. Extensive data analyses and inter-comparisons of the concentration data with other vehicular studies is not justified, given the limited number of commuting scenarios and the study design focus on testing and refining methodologies. A separate report summarizing the much more robust Main Study to follow the Pilot Study will focus on characterizing in-vehicle concentration levels.

## **1.0 PROGRAM DESCRIPTION**

### **1.1 BACKGROUND:**

The California Health and Safety Code (HSC) Section 39660.5 requires the California Air Resource Board (ARB) to assess human exposure to toxic pollutants. The ARB is also required to identify the relative contribution of indoor concentrations to total exposure, taking into account both ambient and indoor air environments. In order to assess a population's pollutant exposure, it is necessary to account for the important microenvironments where people spend their time. This requires information on how much time people spend in specific microenvironments and the corresponding pollutant air concentration in those microenvironments. Although the ARB has representative data on Californian's activity patterns (Wiley et al., 1991a, 1991b), very little pollutant concentration data are available for many microenvironments including vehicle passenger compartments.

### **1.2 STUDY DESIGN AND OBJECTIVES**

This overall goal of this program is an in-vehicle air monitoring study primarily for particles and a variety of organic and inorganic chemicals. The results of this program will be used by ARB to determine the need for, and feasibility of, additional in-vehicle pollutant measurements in future studies. The results will also be used by the ARB to improve estimates of current Californian in-vehicle exposures to selected pollutants, and to assess the relative contribution of in-vehicle exposure to total air exposure for these pollutants. In addition, the results may be used to identify actions that driver and passengers may take to reduce their in-vehicle exposures to air pollutants.

Table 1-1 lists the pollutants for monitoring in this program, and notes that some pollutants will be monitored in a Pilot Study only as a range-finding exercise. Primary emphasis was placed on obtaining reliable concentration data for particles and methyl *t*-butyl ether (MTBE). Measurements were obtained during actual commutes, inside passenger vehicles, immediately outside the vehicles, along the roadway where the vehicles travel, and at ambient monitoring sites. Measurements were made using driving scenarios that are likely to produce the full range of probable in-vehicle concentrations, but emphasis was given to scenarios likely to result in high in-vehicle exposures. Table 1-1 also lists the other data that were collected in addition to the chemical measurements and the required driving scenarios specified by ARB.

As a first step in developing a study design, a list of potential research objectives were formulated taking into account ARB's program goals as well as the important factors that can effect in-vehicle pollutant concentrations. These research objectives were finalized based on inputs from the ARB and results of pilot testing. The finalized research objectives were then used to define the data collection requirements and the data analysis approach for the Main Study. The design objectives considered for this program are given in Tables 1-2A and 1-2B organized by factors which can influence in-vehicle air concentrations.

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**TABLE 1-2A. Specific Research Design Objectives Grouped By Factor Type For Both the Pilot and Main Studies**

[Pilot Study (only) Objectives are **bold**; Main Study objectives are in *italics* ]

Methodology

**A1. Demonstrate in a Pilot Study that the measurement techniques selected for each contaminant are capable of meeting the study requirements**

Data Base Development

*B1. Measure the concentrations of selected pollutants ( $PM_{10}$  and  $PM_{2.5}$  particle mass, selected metals, selected VOC's, carbon monoxide, nitrogen dioxide, and selected PAH's) inside and outside California vehicles during commutes consisting of selected scenarios that define an expected range of exposures from "best" to "worst" case.*

Driver Selected Options

*C1. Evaluate the differences between inside and outside vehicle contaminant concentrations and their relationships to 3 driver (or passenger) adjusted ventilation control settings, to provide three air exchange rates (AERs).*

*C2. Evaluate the modification of the particle count and mass size distributions by the ventilation system as a function of 3 driver (or passenger) adjusted air exchange rate in a selected vehicle. [Note: particle count/size distribution measurements were subsequently added to the Main Study]*

*C3. Evaluate the influence of 3 freeway lane positions (carpool, normal, and slow-lane) on in-vehicle concentrations.*

Vehicle Factors

*D1. Evaluate the influence of 4 vehicle types (2 different sedans, a van, and a school bus) on occupant exposure levels.*

*D2. Evaluate the influence of 3 different lead-vehicle types (gasoline, light duty diesel [deleted by technical direction], heavy duty diesel) on occupant exposure levels.*

Roadway Factors

*E1. Evaluate the influence of 3 roadway types (freeway, arterial, and rural) on in-vehicle concentrations.*

*E2. Evaluate the influence of "worst-case" roadway settings (street canyon in LA compared to flat terrain in LA) on in-vehicle concentrations.*

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The program was conducted in two phases. Phase 1 is a Pilot Study; Phase 2 is the Main Study. Work on the Pilot Study was designed to address the following four objectives:

- To evaluate monitoring methods proposed for the Main Study,
- To collect monitoring data in Sacramento for the pollutants and other parameters proposed for the Main Study,
- To collect monitoring data in Sacramento for additional pollutants including real-time measurements for particles and carbon black and integrated measurements for PAH's, and
- To evaluate both method performance data and collected monitoring data to help define/finalize the research objectives and to develop study design for the Main Study.

This report describes the performance of the methods that were used during the Pilot Study. Method results and sample analysis data are then given. We have also provided conclusions drawn from this Pilot Study and have made recommendations for the Main Study.

### 1.3 EXPERIMENTAL DATA CAPTURE MATRIX

The Phase 1 Pilot Study field sampling was conducted from 2/26 to 3/3/97 in the Sacramento, California metropolitan area by the Research Triangle Institute (RTI), and its subcontractors, Sierra Research and Aerosol Dynamics. A total of 7 commutes ( 6 rush-hour freeway and 1 rural ), each lasting approximately 2 hours, were driven using a specially-designed test sedan (a 1991 Chevrolet Caprice) provide by Sierra Research as a mobile sampling platform. The test vehicle was outfitted to collect inside and outside samples and measurements for almost all pollutant (PM<sub>10</sub> and aldehydes were inside only). The inside vehicle measurements were collected near the driver's breathing zone to estimate the exposure concentrations. Outside samples were collected by drawing air from the front of the vehicle at ~ 20 LPM to a distribution manifold inside the car. The typical commute was 80 miles in length at an average speed of 37 mph. The freeway commute hours were 7 to 9 AM (3 commutes) and 4 to 6 PM (3 commutes). The freeway routes were selected based on historically elevated traffic density data. The rural commute was 107 miles at 48 mph.

Simultaneous samples and measurements for most of the same pollutants were collected in the vehicle, at 4 Roadside sites (freeway commutes only), and at the most proximal ARB fixed-site Ambient monitoring station. An access permit had previously been obtained from CalTrans to install and service the 4 Roadway sites at ARB-selected locations along the commuting route. The Roadside sites were located within 20 feet of the pavement, on the west side (predominantly downwind) of freeway. A driving protocol was established to highlight following heavy-duty diesel vehicles, where possible, to estimate maximum commuting pollutant concentration levels.

Three ventilation control settings in the 1991 Caprice were standardized to demonstrate their influence on the air exchange rate in the test car and, more importantly, their influences on-in-vehicle pollutant concentrations. These settings provided low, medium, and high levels of ventilation, with air exchange rates measured at a constants speed of 55 mph to be 39, 98, and 160 air changes/hour, respectively. For the Caprice, High AER was achieved with both front windows approximately 1/3 open, the vent setting open and the fan speed set to medium-high. Medium AER was achieved with all windows closed, the vent setting open and the fan speed set to medium-high. Low AER was achieved with all windows closed, the vent closed (recirculate)

Table 1-3. ARB In-Vehicle Exposure Pilot Study Integrated Sample & Data Capture Matrix													
Integrated Sample Collection		Total		Total		Total		Total		Total		Total	
Sample Type	I	O	A	R1	R2	R3	R4	All Dups	Planned	Valid	Quest.?	Total	Invalid
Particles (2.5u)	8[7]	8[7]	8[7]	4	4	4	4	2	42[39]	37		4	0
Particles (10u)	8[7]	-----	8[7]	4	4	4	4	2	34[32]	32		2	0
VOC's (multisorb)	8[7]	-----	-----	-----	-----	-----	-----	2	10[9]	9		0	0
VOC's (canister)	8[7]	8[7]	8[7]	4	4	4	4	2	42[39]	40*		0	0
Aldehydes (DNPH)	8[7]	-----	-----	-----	-----	-----	-----	2	10[9]	8		0	1
PAH's (quartz filter)	3[4]	3[4]	3[4]	-----	-----	3	-----	2	14[15]	13		0	2
NO2 (mol sieve)	16[14]	16[14]	16[14]	8	8	8	8	4	84(78)	78		0	0
Notes: The original plan to conduct 6 freeway-influenced commutes and 2 rural commutes was modified by ARB technical direction to include only 1 rural commute													
[N] bracketed number reflects revised number from deleting 1 rural commute and adding 1 PAH sample													
Field blanks and field controls not included in this table.													
Although the Inside and Outside Car samples for 2/26 AM were valid, the car was parked a significant portion of the time													
Only particle samples have been analyzed (for mass only) as of 3/18/97													
*One additional canister sample was collected to assess the car interior and equipment VOC contributions													
Invalidations: 1 aldehyde sample - insufficient battery charge; 2 PAH samples - pump failures													

## 2.0 SUMMARY AND RECOMMENDATIONS

### 2.1 METHODOLOGIES

This section summarizes the salient highlights of the Pilot Study methods described subsequently in Sections 3 (Field Monitoring) and 4 (Monitoring Methods). Since a primary objective of the Pilot Study was to evaluate methods, the implications and recommendations for the Main Study [MS], relative to each Pilot Study highlight are summarized. More detailed discussions and recommendations are provided in Sections 3, 4 and 5. A summary of the data highlights are found in the Measurement Data Section (2.2). In order to identify and coordinate all corrective actions needed prior to the Main Study, a summary of critical milestones was prepared and is included in Appendix A.

#### 2.1.1 PILOT STUDY PREPARATIONS

Prior to the commencement of field sampling, a number of activities were completed to enhance the quality and completeness of the collected data.

- Obtaining the encroachment permit from CalTrans to access the Roadside monitors in the Sacramento area required significantly more effort than was expected.  
[MS Recommendation(s): If roadside monitors are used in the Main Study, the same locations should be considered to simplify the permitting process.]
- The design and construction (by RTI) of a special, computer-controlled manifold system permitted both simultaneous and sequential inside and outside vehicle measurements on a 1 minute cycle.  
[MS Recommendation(s): The manifold system worked well and will be used in the Main Study without modification]
- The design and construction (by RTI) of a portable backseat monitoring platform supporting all integrated and continuous monitoring systems and the video camera proved adequate, except for periodic vibrations induced into the video camera.  
[MS Recommendation(s): The platform will be utilized as designed with the exception of the video camera support, which has been replaced by a “steady-cam” mount.]
- The selection (by Sierra Research) of optimum freeway and rural commuting routes that would highlight the range of expected exposure concentrations, while being representative of typical Sacramento commutes.  
[MS Recommendation(s): The same procedures will be follow to select the Main Study commuting routes]
- The calibration (by Aerosol Dynamics) of the PMS LAS-X continuous particle monitor with actual vehicular and ambient calibration aerosols, including characterization of the particle densities by particle size, proved invaluable. These calibration steps greatly enhanced the ability to computed mass concentrations from the particle count data.

- The rural commute with its very low traffic densities substantially taxed the Minimum Quantification Limits for almost all of the methods resulting from the very low pollutant levels. Apparently the emission rates from the exhausts of California gasoline-powered automobiles are currently effectively controlled for the measured pollutant - when the vehicle engine and emission systems are functioning properly. [MS Recommendation(s): The low concentrations observed for all pollutants during rural commutes suggested that a de-emphasis of these situations should be considered. A greater emphasis in the Main Study is being discussed for those scenarios that produce the highest exposures.]
- The 1991 Caprice data collection system with a driver and navigator worked as planned to collect vehicle spacing data, Level of Congestion, vehicle speed, periodic driving diaries, and video records of each commute, but some of the data proved difficult to accurately collect or was not found useful in the data analysis. [MS Recommendation(s): The collection of data using the manual switchbox will be greatly simplified for the Main Study to summarize only Level of Congestion (traffic density categories), freeing the navigator to provide a more detailed diary to accompany each video. The automatic computer collection of vehicle speed and lead-vehicle spacing will be continued.]
- An insurance issue concerning overnight parking security and the personnel authorized to drive the Sierra test sedan complicated the logistics of preparing the vehicle for sampling. [MS Recommendation(s): An agreement between RTI and Sierra Research will be in effect prior to the Main Study to provide insurance coverage for the test vehicle to eliminate these problems]

### 2.1.3 MONITORING METHODS

This section summarizes the performance highlights of the measurement methods for the Main Study. Additional details on the methodologies can be found in Section 4 or the Pilot Study Operation Manual (not presented here).

#### 2.1.3.1 Particle Mass

The collection of PM<sub>2.5</sub> and PM<sub>10</sub> particle samples proceeded smoothly in the field. Subsequent review of the inlet hardware, however, identified defective internal sealing ring problems with some of the PM<sub>2.5</sub> units (not the PM<sub>10</sub>).

- The flow control systems used for 2.0 and 4.0 LPM integrated sampling met specifications. [MS Recommendation(s): No changes will be made for the Main Study in the flow check or flow control set-up procedures. A new single-channel 4.0 LPM pump system will be available for the Main Study to minimize the labor and space required to use the dual channel pumps employed in the Pilot Study.]
- Defective internal sealing rings in several of the PM<sub>2.5</sub> inlet impactors produced random leaks that were not identified properly with the existing leak tests.

### 2.1.3.2 Elemental Analyses

Particle filters were digested for analysis. Digests were analyzed by ICP/MS for Cr, Si, Sr, Br, Ca, Ti, Fe, Zn, and Cu, and by GFAA for Pb, Cd, Ni, and Mn. Ion Chromatography was used for S, P, and Cl analyses. This scheme was a departure from the analysis plan requested of our trace metals laboratory, in that the increased sensitivity of ICP/MS was requested for Pb, Cr, Ni, and Mn. The laboratory substituted GFAA when an instrumental problem arose with the ICP/MS unit in order to meet the analysis schedule. XRF was not used in the Pilot Study, given its higher expected MQL for most metals as compared to ICP/MS and the very low observed particle concentrations.

Results of method controls and method blanks (reagents without filters) suggested that the proposed method (ICP/MS) could be used to analyze for the target elements on the Gelman Teflo<sup>®</sup> filter samples. Instrumental sensitivity, especially for GFAA was not sufficiently low to give high percent measurable for many of the elements including lead, cadmium, nickel, phosphorus, potassium, iron, and bromine. Erratic lab blank levels (reagents with filters) for several metals further increased the detection limits. The number of blank filters analyzed during the Pilot Study (only 2) was inadequate to characterize the background levels, given the sample-to-sample variability observed for some metals, strongly suggesting further work on blank metals' levels is needed.

- Given the altered analysis scheme used by the laboratory, the performance of the ICP/MS could not be evaluated for Pb, Cd, Cr, and Mn.

[MS Recommendation(s): The correct scheme will be followed in the Main Study.]

- The increased cost of ICP/MS over XRF (~ a factor of 3) may not warrant the improvement in detection limit for some metals, given the elevated backgrounds of metals in the Gelman Teflo<sup>®</sup> filters. Elevated and erratic (based on only 2 measurements) background levels were observed for calcium, chlorine, copper, potassium, phosphorus, silicon, strontium, titanium, and zinc. None of these elements was required by the RFP.

[MS Recommendation(s): The number of filters to be analyzed and the analysis method to be applied to the Main Study filters is under discussion. A better understanding of the frequency of elevated background levels in the Gelman filter batch purchased for this study will be addressed by analyzing (at RTI at no-cost to the project prior to the Main Study) at least 10 (versus 2 previously) blank filters for metals by ICP/MS.]

### 2.1.3.3 VOC Canister Method

Overall, the canister method showed good performance for all of the target VOC's.

- Method quantitation limits were sufficiently low to provide high percent measurable for all targets, except ethyl *t*-butyl ether (ETBE). Presumably, ETBE was not in use as a gasoline additive at the time of field monitoring and was, therefore, not present in air samples.

[MS Recommendation(s): No changes will be made in the analysis methodology for the Main Study VOC samples.]

- Recoveries for 1,3 butadiene (76 %) and methyl *t*-butyl ether (78 %) were slightly low which may have been due to prolonged storage of the samples prior to analysis.

[MS Recommendation(s): The 2 ppm MQL is considered acceptable for the Main Study, especially for the higher CO levels from greater traffic densities expected in Los Angeles.]

#### **2.1.3.8 Particle Size Distribution**

Overall the LAS-X particle counter worked well and provided valuable information on real-time particle counts and concentrations. The particle counter's undoubtedly better MQL (estimated to be at least a factor of 5) is difficult to appreciate, since it is not a gravimetrically-based device. The value of a real-time measurement is readily apparent in identifying the contributions of short term events and in the results of mitigation strategies to reduce levels.

- When the on-board power system was functioning properly (adequate voltage level and suitably filtered) in the car, the LAS-X operated smoothly, requiring little attention during sampling and no unplanned maintenance.

[MS Recommendation(s): The limited manpower required to operate the LAS-X combined with its excellent performance supports its inclusion in the Main Study.]

- The LAS-X data analysis and reduction to estimated PM<sub>2.5</sub> concentrations was very labor-intensive.

[MS Recommendation(s): Since the LAS-X data are collected and stored on a computer, the data reduction can be accomplished at a later date, if resources permit. This could be valuable for studying a few selected commutes in the Main Study to highlight the range between minimum and maximum PM<sub>2.5</sub> concentration scenarios.]

- The LAS-X one minute particle count averages correlated strongly with the Aethalometer black carbon analyzer, especially when the car was following a vehicle (gasoline or diesel powered) with a visibly smoking exhaust.

[MS Recommendation(s): The ability of the LAS-X to identify elevated particle exposure levels for single vehicles, supports its inclusion of the LAS-X in the Main Study.]

- The LAS-X one minute computed PM<sub>2.5</sub> mass concentrations provided greater detail during the commute of the actual exposure levels, as compared to the total commute gravimetric, integrated average.

[MS Recommendation(s): If the Main Study particle concentration levels are similar to or lower than those from the Pilot Study, the LAS-X estimated PM<sub>2.5</sub> concentrations may provide the only useable particle data.]

#### **2.1.3.9 Black (Elemental) Carbon**

- When the on-board power system was functioning properly in the car, the Aethalometer operated smoothly, requiring little attention during sampling and no unplanned maintenance.

[MS Recommendation(s): The limited manpower required to operate the units, supports its inclusion in the Main Study, especially since the data analyses are relatively straightforward. Unlike the LAS-X, which is owned by RTI, the Aethalometer would have to be leased from the manufacturer.]



- The interpretation of single events during commutes using the continuous in-vehicle monitoring data proved difficult if careful alignment of the various data collection time clocks (e.g. video, CO data logger, in-vehicle computer, LAS-X logger, and Aethalometer logger) was not accomplished.  
[MS Recommendation(s): Greater care must be taken in the Main Study to synchronize time clocks at the start of each commute within 15 seconds. A time synchronization procedure will be implemented in the Main Study at the kick-off meeting, requiring all time settings (including video camera clock) and data entries to be coordinated with the RTI field manager.]
- The videotapes of the drives provided information on roadway conditions (e.g. barrier walls, cut sections) and target vehicles, however, reviewing the tapes and correlating the events with pollutant levels was very labor intensive.  
[MS Recommendation(s): Videos will be made for each commute during the Main Study and archived for future data/information analyses, if additional resources are available for this activity.]
- The traffic speed and trailing distance (from the vehicle immediately in front) provided useful information on the commutes, however, associating these data with pollutant levels and scenarios was very labor intensive.  
[MS Recommendation(s): These data are collected automatically and will be collected in the Main Study. The amount of data reduced and summarized, however, is still under discussion.]

## 2.2 MEASUREMENT DATA SUMMARY

The individual analytical concentration data for each sample collected are given in Section 5. A summary of the composite means of the six freeway commutes, plus the single rural measurement for comparison, are shown in the extended Tables 2-1A, 2-1B, and 2-1C. These tables have been prepared primarily to simplify the review of the composite concentrations levels from various scenarios. Note that compositing can provide somewhat misleading interpretations, in that the number of observations in each category are small and not necessarily the same. See the footnotes following Table 2-1A describing formats, and the additional explanatory notes following Table 2-1C for clarifying information.

### 2.2.1 General Observations

- Measurements of  $PM_{2.5}$  and  $PM_{10}$  integrated particle concentration for 2-hour periods at 4 LPM and the expected higher concentrations in the Main Study should have (barely) adequate detection limits and precisions to characterize inside and outside exposure levels. The combination of limited data collection in the Main Study and only modest precision of the integrated methods, may make it impossible to readily distinguish the proportion of in-car particle concentrations due to vehicular emissions, as compared to those from the background. The strong performance of the LAS-X monitor in predicting  $PM_{2.5}$  concentrations suggests that it should be seriously be considered for inclusion in the Main Study to collect data. Given the current limitation on resources, however, its inclusion would require (a) minimal effort to make it functional (operate on the Caprice power system), and (b) only limited data analyses and interpretation would be applied.

[MS Recommendation(s): Supplement the optimized gravimetric measurements with the LAS-X computed  $PM_{2.5}$  estimates.]

**Table 2-1B. Summary Table of Measurements Comparing Six Freeway Commutes (Mean) with One Rural Commute (cont'd)**

	Commute	Ambient	Out-Car Mean	In-Car Mean	In-Car Range	Roadside Mean	Roadside Range
<b>PAH's (ng/m3)</b>							
Benzo[b]fluoranthene	Freeway	0.2	0.5	0.2	na	0.5	na
	Rural	0.1	0.3	0.0	na	na	na
Benzo[k]fluoranthene	Freeway	0.1	0.1	0.1	na	0.1	na
	Rural	0.1	0.2	0.0	na	na	na
Benzo[e]pyrene	Freeway	0.1	0.3	0.2	na	0.3	na
	Rural	0.0	0.0	0.0	na	na	na
Benzo[a]pyrene	Freeway	0.1	0.3	0.3	na	0.2	na
	Rural	0.1	0.1	0.1	na	na	na
Indeno[1,2,3-	Freeway	0.2	0.4	0.5	na	0.3	na
	Rural	0.0	0.2	0.1	na	na	na
Benzo[ghi]perylene	Freeway	0.2	0.8	1.0	na	0.6	na
	Rural	0.0	0.2	0.0	na	na	na
<b>PM<sub>2.5</sub> Metals (ng/m3)</b>							
Cadmium (Cd)	Freeway	0.16	0.23	0.09 (0.12)	0.0 - 0.12	0.24	0.0 - 0.46
	Rural	0.0	na	na	na		
Chromium (Cr)	Freeway	103.7	108.0	76 (122)	2.7 - 109	104	76.5 - 114
	Rural	0.0	na	na	na		
Manganese (Mn)	Freeway	14.6	5.6	6.4 (6.1)	.25 - 6.8	2.1	0.2 - 4.0
	Rural	0.0	na	na	na		
Nickel (Ni)	Freeway	0.0	0.0	25 (0.0)	na	10.3	0.0 - 29.0
	Rural	0.0	na	na	na		
Lead (Pb)	Freeway	9.2	7.6	15.7 (7.8)	11 - 24	5.3	3.1 - 9.0
	Rural	0.0	na	na	na		
Sulfur (S)	Freeway	293.3	356.0	342 (274)	231 - 575	299	166 - 392
	Rural	93.0	na	na	na	na	na

See footnotes following Table 2-1A and additional notes following Table 2-1C

- The limited sensitivities of the integrated PM<sub>2.5</sub>, PM<sub>10</sub> and CO methodologies did not permit a realistic determination of the utility of Roadside and Ambient monitoring stations to be used as surrogates to predict in-vehicle concentrations. This may also be true for the Main Study. Where the MQL's were sufficient, the VOC Inside and Outside vehicle concentrations were higher than Roadway, which were higher than those at the Ambient site.

[MS Recommendation(s): Although Roadside measurement gave better indications of the in-vehicle concentrations than did the Ambient station data, the cost-effectiveness of Roadside sampling is still under discussion.]

- If the 1991 Caprice air exchange measurements from the Pilot Study are representative of those determined during the Main Study for the other sedan the Sport Utility Vehicle, and the school bus, the number of commutes using both Low and High exchange rates should be reconsidered. The limited range of influences of air exchange rate from settings Vent 1 to Vent 3 on inside and outside pollutant concentration ratios appears to be insufficient to warrant expending additional resources to impose equal emphasis on both High and Low exchange rate.

[MS Recommendation(s): Emphasizing the High air exchange scenarios, while collecting only limited data for the Low AER, should provide adequate information to characterize the range of exposures..]

- The unexpectedly high particle counts and CO levels detected when following selected vehicles (e.g. most heavy duty diesels (but not all), poorly tuned vehicles, and a diesel school bus) suggests that closely following these vehicles may significantly contribute to in-vehicle concentrations. Although specific vehicle type identification is not part of this effort, subsequent review of video records, compared against continuous monitor data may provide valuable information in assessing exposure mitigation strategies.

[MS Recommendation(s): Continue the driving protocols developed for the Pilot Study, focusing on heavy duty diesels and smoking vehicles.]

- The limited range of influences of air exchange rate from Low to High on inside and outside pollutant concentration ratios appears to be insufficient to warrant expending additional resources to impose equal emphasis on both High and Low exchange rate. Emphasizing the High air exchange, while collecting only limited data for the Low AER, should provide adequate information to characterize the range of exposures. If the 1991 Caprice air exchange measurements from the Pilot Study are generally representative of those determined during the Main Study for the other vehicles, the number of commutes using both Low and High exchange rates should be reconsidered.

### 2.2.2 Specific by Pollutant Category

At this point in the overall program, the Pilot Study data have been analyzed primarily to validate the methodologies for the Main Study. Only limited observations are presented here as to levels and inter-comparability of the data.

### 3.0 FIELD MONITORING

This section provides more detailed descriptions of the field monitoring design and the supporting monitoring activities used during the Pilot Study.

#### 3.1 Methods and Approach

Field activities for the Pilot Study were conducted from February 22 to March 6, 1997 in Sacramento, California. Actual sample collections occurred from February 26 thru March 3. RTI, Sierra Research, Aerosol Dynamics, and ARB personnel who participated in the field effort and their responsibilities are shown in Table 3-1. All study activities including sample preparation, scheduling, instrument calibration, filter weighing, and record keeping focused around a work room set up in a local motel near one end of the planned commuting route. Preparation of the vehicle for sampling and data collections before and after each commute were accomplished in the parking area near the work room. A detailed schedule of planned daily events is given in Appendix C.

The overall design for the Pilot Study is described by the sampling design in Table 3-2, which shows the routes, the time of day, the ventilation settings, the commute lengths and the number of trips for each driving scenario. A gasoline-powered, California-registered, 1991 Chevrolet Caprice provided by Sierra Research was used as the sample and data collection platform for all test drives. In order to assure that the test vehicle was not contaminating the interior through leaks from the exhaust system and the engine compartment, the Caprice vehicle was inspected by Sierra Research prior to the start of the field activities (inspection results are included as Appendix D). In addition, a canister air sample was collected with the vehicle at rest to measure concentrations of VOC's in the car interior. Measured concentrations for all target VOC's, except toluene ( $1.0 \mu\text{g}/\text{m}^3$  was detected), were below the quantitation limit.

During this Pilot Study, two routes were selected and driven - a freeway and a rural commute, both in the Sacramento area. These routes were selected in consultation with the ARB project officer. One route was intended to represent commuting in heavy freeway traffic in the Sacramento area. This was on an approximately 30-mile stretch on Interstate 5, Business 80, and Interstate 80, extending from the I Street ramp of I-5 to the Madison Avenue Exit of I-80. During rush hour, both the inbound and outbound portion of this route took approximately 40 minutes to drive. Drives on this route took place either during the morning (7 to 9 am) or afternoon (4 to 6 pm) rush hours. The second route was intended to represent rural conditions with little traffic and a correspondingly low pollutant levels. This route was north of Davis, CA and used State Road E6 and County Roads 95, 27, and 99. The route was approximately 16 miles. The rural route was driven during midday (12 to 2 pm) on Saturday, 3/1. Table 3-3 summarizes information and driving times, driving distances, and average speed during each trip. Maps that show these two routes are included in Appendix E.

**TABLE 3-2. Design of the Pilot Study**

Trip	Date	Roadway Type	Ventilation Setting	Time	Roadway Monitoring
1	2/27	Freeway rush	mid	AM	no
2	2/26	Freeway rush	mid	PM	no
3	2/27	Freeway rush	high	AM	yes
4	2/27	Freeway rush	high	PM	yes
5	2/28	Freeway rush	low	PM	yes
6	3/1	Rural <sup>a</sup>	low	mid-day	no
7	3/3	Freeway	high	PM	yes

<sup>a</sup> A second rural trip was not conducted based on consultation and approval of ARB personnel in the field.

**TABLE 3-3. Distances for Vehicle Drives**

Commute	Location	Total Minutes	Total Miles	Average Speed (mph)
2/26 am	Freeway	135	56.7	25.2
2/26 pm	Freeway	138	85.6	37.2
2/27 am	Freeway	118	84.2	42.8
2/27 pm	Freeway	171	56.4	19.8
2/28 pm	Freeway	120	78.7	39.3
3/1 am	Rural	135	107	47.6
3/3 am	Freeway	116	88.7	45.9
Means:		133.3	79.6	36.8

**TABLE 3-4. Pollutant Sample Collection and Analysis Method Summaries**

Pollutant	Sample Collection	Sample Analysis
PM <sub>10</sub> Particles (integrated)	MSP 200 2.0 LPM PM <sub>10</sub> inlets, particle on 37 mm, 3.0 Tm Gelman Teflo filters	Gravimetric, on a modified Mettler AT20 microbalance, with computer control
PM <sub>2.5</sub> Particles (integrated)	MSP 200 4.0 LPM PM <sub>2.5</sub> inlets, particle on 37 mm, 3.0 Tm Gelman Teflo filters	Gravimetric, on a modified Mettler AT20 microbalance, with computer control
Particle Size Distribution	Particle Measurement Systems (PMS) Model LASX multi-channel analyzer	Computer data collection and size distribution analyses
Black Carbon	McGee Scientific Aethalometer	5 LPM on quartz fiber tape readings by optical absorption
VOCs	SUMMA passivated 6 liter evacuated canisters, sample rate of 25 cc/min; Multisorbent tubes	GC/MS with SIM enhancement
Formaldehyde	DNPH cartridges	Electron with acetonitrile, HPLC analysis Thermal desorption GC/MS, full scan
CO	Draeger Model 190, diffusion sensing (not pumped)	electro-chemical
NO <sub>2</sub>	OSHA Model ID-109, sampling rate of 100 cc/min through molec. sieve tubes	Extraction with TEA, analysis by polarography
Metals in PM <sub>10</sub> /PM <sub>2.5</sub> particles	PM <sub>10</sub> /PM <sub>2.5</sub> Teflon filters	X-Ray Fluorescence (XRF), energy dispersive, or  Ion-Coupled Plasma Mass Spectrometry (ICP/MS)
PAH	Particle phase (only) on 37 mm, 3.0 Tm Gelman Teflo filters at 8.0 LPM	Gas Chromatography/Mass Spectrometry

**TABLE 3-6. Sample Collection Schedule for Each Drive**

Sample Type	Inside Car	Outside Car	Ambient	Roadside 1*	Roadside 2	Roadside 3	Roadside 4	Total
VOCs (multisorb)	1							1
VOCs (canister)	1	1	1	1	1	1	1	7
Aldehydes (DNPH)	1							1
PAHs (quartz filter)	1	1	1			1		4
CO (Dräger) <sup>b</sup>	1	1	1	1	1	1	1	7
NO <sub>2</sub> mol. sieve	2	2	2	2	2	2	2	14
Particles (PM <sub>2.5</sub> )	1	1	1	1	1	1	1	7
Particles (PM <sub>10</sub> )	1		1	1	1	1	1	6
Particles (LAS-X)	1	1						2
Carbon Black <sup>b</sup>	1	1						2
Temp/% Rh <sup>b</sup>	1							1

\* Roadside sample collection schedule for four test drives.

<sup>b</sup> Continuous measurements.

For four of the vehicle runs, monitoring was conducted at four roadway sites. These sites were selected in consultation and with final approval by the ARB. Encroachment permits were obtained from the California Department of Transportation. Roadway sites are described in Appendix F. Also provided is the CalTrans encroachment permit information to conduct the Roadside sampling. Criteria for selecting these sites included a proximal location to the roadside with no more than a 5-foot elevation difference with the roadway surface, easy access from the freeway, a secure location, and a minimum of obstructions, including walls and trees. Monitoring equipment at each site was located 15 to 30 feet from the roadway. Sampling during freeway commutes was also conducted at one ambient monitoring station located at the ARB ambient monitoring station at 13th and T Streets in Sacramento.

In conjunction with the chemical monitoring data, the ancillary data shown in Table 3-5 was also collected. Information was collected on meteorological conditions, vehicle speed, and traffic conditions. Topographical or environmental conditions that might effect roadway pollutant concentrations were recorded via the switchbox. Drives were video taped. In addition, air exchange rates were measured during separate rural drives for the test vehicle under the three operating conditions.

All vehicle runs were nominally two hours. Either one or two runs were made per day. Vehicle runs were made on 2/26, 2/27, 2/28, 3/1, and 3/3. A detailed schedule of activities for all field monitoring activities is given in Appendix C.

After samples for formaldehyde, NO<sub>2</sub>, PAHs, and VOCs (multisorbent tubes) were collected, they were stored sealed in clean steel cans at 40 °C. VOC canisters were stored in a cool, clean area. All samples were shipped within seven days of collection to RTI via overnight carrier. Particulate filters were equilibrated at temperatures in the work room. An air conditioner in the room was the only source of temperature and humidity control. Filters were pre-weighed before samples were collected and then again within 24 hours after collection. Exposed, weighed filters were placed in labeled Gelman Analyslide petri dishes. All filter samples were hand-carried within seven days of collection to RTI on the return flight from California to Research Triangle Park.

For VOC and formaldehyde monitoring, several types of quality control samples were used throughout the study. Sampling media (cartridges or canister) equivalent to approximately 5% (or minimum of two) of the field samples were set aside as field blanks and were used to assess contamination and/or interferences of field samples. These samples traveled to the field site, returned to the laboratory and analyzed along with the field samples. Field controls were used to assess analyte recovery. Cartridges/canisters equivalent to approximately 5% of the field samples were spiked with known amounts of target analytes. As with the field blanks, these samples were shipped to the field, returned, and analyzed along with the field samples. Five percent of the samples were collected and analyzed in duplicate to evaluate precision.

For particles, metals, PAHs and NO<sub>2</sub>, field blanks each equivalent to 5% of the samples were deployed to assess background contamination. Field duplicates equivalent to 5% of the samples were collected to evaluate precision, respectively.

Since CO was measured using real-time monitoring methods, different QC procedures were used. In the field, an initial calibration was prepared on each monitor upon arrival in California using 0, 2, 10 and 22 ppm standards to assure proper operation prior to use. Analytical accuracy was checked by analyzing zero and span (22 ppm CO) gas standards at the beginning and end of each vehicle run. Precision was evaluated by deploying duplicate monitors.



pumps for PAH's. A complete evaluation (accomplishments and problem areas) for the Pilot Study is provided in Appendix G. The following is a summary of the most important aspects of the study.

- The technical skills of research field personnel from RTI, Sierra Research, and Aerosol Dynamics were suitable to meet the routine and unexpected demands of the field sampling.
- The number of personnel assigned to this field monitoring effort for the Pilot Study were adequate to complete the planned field monitoring, given the extended hours each day required to resolve technical problems. This includes the (gratefully acknowledged) assistance of ARB personnel to assist in servicing the Ambient site. Careful planning and preparations will be required to eliminate large, time-consuming problems during the Main Study.
- Several unplanned events related to pollutant monitoring that were unique to the Pilot Study methods substantially taxed the field monitoring staff. These included (a) the initial failures of the on-board vehicle system to provide power to the continuous monitors and the PAH pumps, (b) the decision to assign separate individuals to set out the four Roadway and Ambient sites.
- The route selection process met the study objectives, providing (a) a freeway commute route that highlighted heavy traffic densities in the Sacramento area for the AM and PM commutes, (b) a rural commute that substantially taxed the minimum detection limits of the methods resulting from the very low pollutant levels.
- Monitoring at roadway sites was difficult and had a substantial impact on the burden and cost of the field monitoring effort. Obtaining CalTrans permits required more time and was, therefore, more costly than anticipated. Access to roadway sites was difficult during freeway rush hour. The use of four roadway sites placed a heavy burden on equipment requirements which impacted acquisition, testing, shipping, calibration, and set up costs. Finally, there was some initial concern for the security of the expensive monitoring equipment at the Roadway sites. This concern appeared to be unfounded with reasonable care (security cables).
- The 1991 Caprice sampling platform with a driver and navigator worked as planned to collect vehicle spacing data, traffic density, periodic driving diaries, and video records of each commute.
- The initially-installed, on-board power system in the car proved inadequate to handle the power requirements of the sampling equipment and provide sufficiently filtered power to operate the optical particle counter. These problems were corrected prior to the start of the 2/28 commute in a temporary manner that permitted completion of the Pilot Study continuous monitoring. The excessive power drain of this corrective "fix" drained the

## 4.0 MONITORING METHODS

This section provides more detailed discussion of the integrated sample and continuous monitoring methods used in the Pilot Study. Specific recommendations for applying the methods in the Main Study are also provided.

### 4.1 Integrated Measurement

#### 4.1.1 Particles (PM<sub>2.5</sub> and PM<sub>10</sub>)

*Method Description* - The filter collection and weighing methods for gravimetrically-based PM<sub>10</sub> and PM<sub>2.5</sub> particles measurements are based on methods that have been used previously at RTI. The methods have been validated during the past three years on two large-scale exposure studies conducted for the U.S. EPA and a commercial client.

A summary of the specifications for the RTI PM<sub>10</sub> and PM<sub>2.5</sub> particle exposure monitoring systems is shown in Table 4-1. The MSP model 200 Personal Exposure Monitor (PEM) inlets for PM<sub>10</sub> and PM<sub>2.5</sub> are based on standard impactor theory, and demonstrate excellent cut point sharpness. Although PM<sub>2.5</sub> cut point impactors can exhibit substrate overloading during extended use, the combination of an additional "scalping" stage, and the short duration of sampling proposed in this study eliminated this concern. The MSP inlets are relatively wind speed insensitive, but the turbulence outside a moving vehicle is undoubtedly too harsh an environment for accurate coarse particle sampling. Thus, the inlets were not used external to a moving vehicle. Outside PM<sub>10</sub> measurements were not made. PM<sub>2.5</sub> inlets collected particles off of the manifold after air was drawn in from the outside.

As shown in Figure 4-1 the inlets incorporate a 5-jet inlet cover (10 holes for a 4 LPM version) that directs the inlet flow toward an oil-coated, sintered metal impactor ring. After impaction to achieve the design cut point, the remaining particles are drawn to the membrane filter substrate located in the inlet base. The oiled surface is clean and replenished prior to each sampling event. The inlets are placed in Ziplok bags after preparation to prevent stray particles from entering through the jet holes.

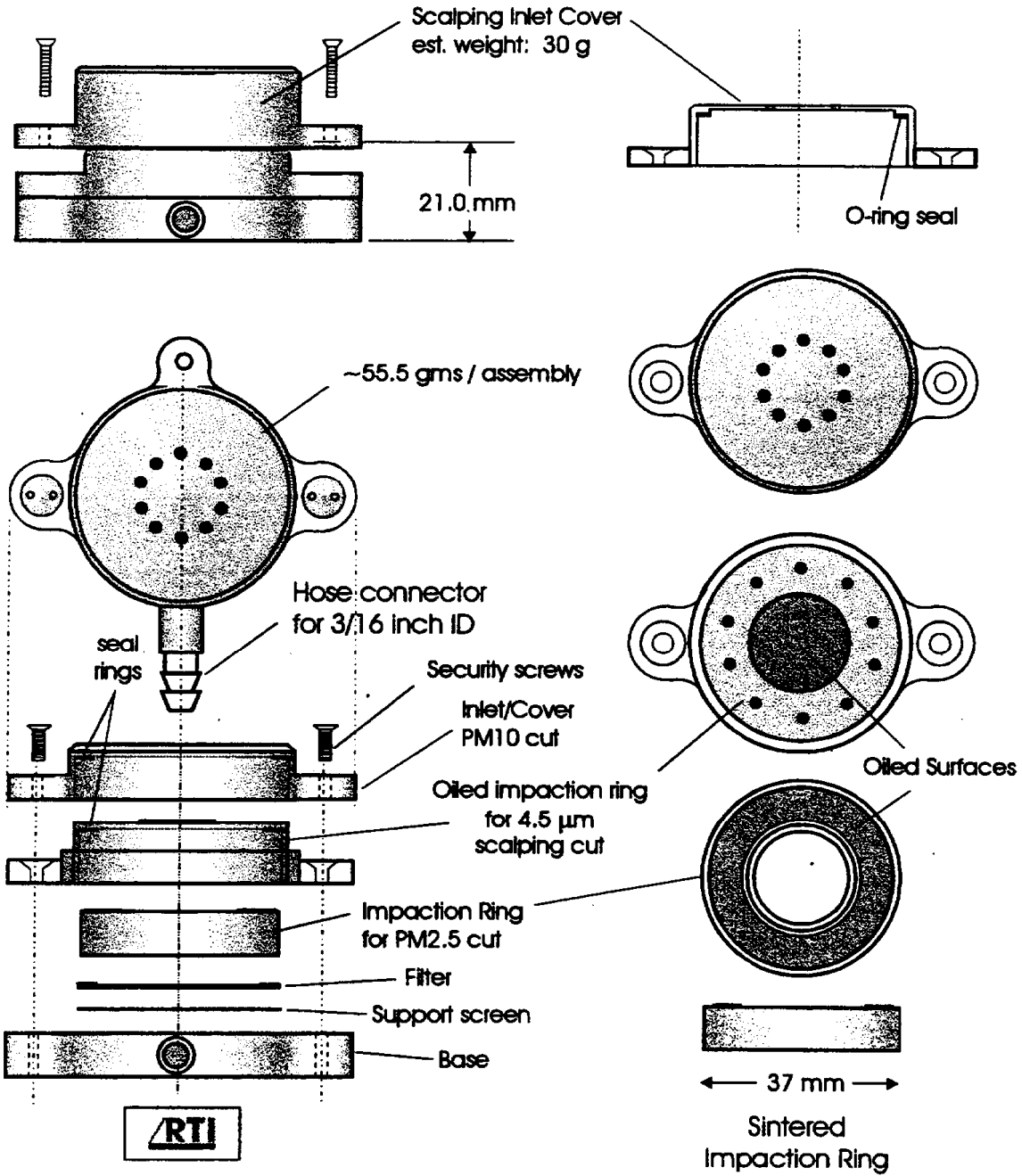
During monitoring, an electronically flow-controlled battery operated pump (modified BGI model AFC123) was used to sample air through the portable impactors. The impactor contained a 37-mm diameter Teflon filter having a 3- $\mu$ m pore size. For the PM<sub>10</sub> impactor, a constant flow rate of 2.0 L/min was used. For the PM<sub>2.5</sub> impactor, a constant flow rate of 4.0 L/min was used.

Flow rate checks were performed with a specially-designed orifice that seals over the MSP inlet. The pressure drop across the orifice is monitored with a Magnehelic gauge. The pressure drop versus flow rate calibration for the orifice is established against a NIST-traceable Gilibrator bubble flow meter.

Filters were weighed both before and after sample collection using a Mettler AT20 balance with a  $\pm 2$   $\mu$ g weighing precision in a single measurement. The balance was connected to a microcomputer with weighing software developed for gravimetric analysis of filters. All weighings were conducted in the field in the work room. Filters were equilibrated in the work room for at least 12 hours before weighing. Once tared, all filters were inspected for holes or other imperfections prior to use and were kept in a barcode-labeled Petri dish.

A set of ten filters was weighed as follows.

Figure 4-1  
**PM<sub>2.5</sub> and PM<sub>10</sub> Aerosol Sampling Inlets**  
**(MSP Model 200) Used in**  
**ARB In-Vehicle Pilot Study**



- Weighing the Teflon filters in an air conditioned (but otherwise uncontrolled for temperature and relative humidity) space in the motel work room generally proved adequate to meet the expected detection limit of 2.0  $\mu\text{g}$ , based primarily on the precision of successive weighings of the same filter. This limit inexplicably increased, however, to 3.4  $\mu\text{g}$  during the post-weighing period, significantly increasing the MQL for both  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  samples over a 2-hour commute. A summary of the particle concentration data exceeding the MQL's is given in Appendix H. This small increase proved significant, since the low ambient concentrations and small particle mass collections during the 2-hour commutes in the Pilot Study severely taxed the limits of the gravimetric analyses. The median mass collections per filter for all samples in the Pilot Study was only 11  $\mu\text{g}$  for  $\text{PM}_{2.5}$ , and 18  $\mu\text{g}$  for  $\text{PM}_{10}$ . In order to reduce the MQL as much as possible for the Main Study, every effort must be made to optimize the balance performance. A pre- and post-weighing location with a more temperature controlled and less draft-prone balance environment will be sought for both Sacramento and Los Angeles.
- The  $\text{PM}_{10}$  MSP sampling inlets functioned acceptably to collect integrated particle samples, except that the flowrate (2.0 LPM) was too low to provide an adequate sample volume and a reasonable MQL in a 2-hour commute. The low  $\text{PM}_{10}$  concentrations during the Pilot Study were generally at or below the method detection limits. Higher flowrate (4.0 LPM) inlets will be provided (by RTI) to double the collected volume and halve the MQL for  $\text{PM}_{10}$  in the Main Study. Increasing the inside sampling flowrates above 2 LPM had been avoided for the Pilot Study, since the air exchange rates in the test car were assumed to be significantly lower than was measured. Note that although  $\text{PM}_{2.5}$  is a subset of  $\text{PM}_{10}$ , the significantly higher MQL for the  $\text{PM}_{10}$  increased the probability that a  $\text{PM}_{2.5}$  value would occasionally be higher than a paired  $\text{PM}_{10}$ . This was also complicated by random internal leaks in the  $\text{PM}_{2.5}$  inlets.
- Outside the vehicle samples were collected through a sampling line run to the front of the car that operated at a flowrate of approximately 24 LPM. The line was originally PTFE Teflon, but was switched to polyethylene prior to the start of the Pilot Study. Testing with the LAS-X to evaluate ambient particle losses as a function of particle size showed that polyethylene material had significantly fewer losses. This was attributed to the larger static charging capacity of Teflon. The LAS-X testing showed that the size-specific LAS-X count measurements should be corrected when comparing inside and outside measurements using the sampling line (see Figure 4-2). Particle loss calculations using a theoretical model supplied by Aerosol Dynamics had not suggested particle sizes less than 2.5  $\mu\text{m}$  to be significantly affected by the sampling line. This model is not really appropriate, since it provides no compensation for particle diffusive losses. Mass losses based on these counts were estimated to be less than 5% for integrated  $\text{PM}_{2.5}$  samples. Note that the subsequently reported LAS-X outside data in this report are loss-corrected, while the integrated  $\text{PM}_{2.5}$  data are not. The experimental nature of the count-to-mass computation using the LAS-X is experimental, and currently not proven enough to warrant correcting gravimetric data. A table of estimated mass loss corrections will be provided in the Main Study report.

that will permit a semi-quantitative assessment of the potential gravimetric losses. Also, it was observed that the location of the outside line inlet at the center of the grill, did not always represent the air that was entering the vehicle through the open car windows during the high air exchange rate commutes. Moving the intake to the base of the windshield for the Main Study will significantly reduce the sampling line length, and more importantly, place the intake adjacent to the car vent system intake.

- The Gelman Teflo® filters lab blanks all lost a small, but measurable, 3 µg (mean of 4 filters) in weight from the pre-weighing until the post-weighing. The reason for this loss is not clear, but may be a plasticizer vaporization loss from the plastic support rings. All reported gravimetric data were corrected for this 3 µg loss. This potential for tare weight change will also be monitored in the Main Study.

*Recommendations-* The particle mass measurements should be performed in the Main Study using the same general procedures as for the Pilot Study with the following recommendations. The PM<sub>10</sub> inlet caps should be replaced with 4 LPM versions to double the total collected sample volume and thus reduce the MQL by a factor of 2.

- The faulty PM<sub>2.5</sub> inlets will be returned to the manufacturer for replacement of the sealing rings (already completed). The modified units will be evaluated prior to the Main Study.
- A revised leak test procedure will be developed and evaluated for the particle inlets that will identify internal leaks.
- Filter weighing should be conducted in a more closely temperature-controlled environment, if at all possible. This should improve the precision of the resulting measurements.
- The outside vehicle sampling line loss testing should be repeated immediately prior to the start of sampling in the Main Study.

#### 4.1.2 Metals (Elements)

*Method Description* - The 37 mm Teflon membrane filter samples for the analysis of elements and ionic species were digested using a modification of U.S. EPA SW 846 Method 3052. Metals were analyzed by graphite furnace atomic absorption (GFAA), inductively coupled plasma emission mass spectrometry (ICP/MS) and ion chromatography (IC).

Filter samples were first extracted with 0.1 M HClO<sub>4</sub> in an ultraclean cuvette and an exact volume (2 or 3 mL) removed for the IC measurement. The remaining extract was freeze-dried and digested with 50% nitric acid (1 mL) and a few drops of hydrofluoric acid until the digestate began to boil. The digest was cooled then diluted to the desired volume and analyzed. After samples were digested/extracted, they were transferred to the measurement laboratory in a sealed clean container to minimize contamination from room dust. Prior to ICP/MS analysis, samples were placed in an autosampler that was covered by a class 100 hood glove box enclosure to further avoid room dust contamination during measurement. ICP/MS measurement of the digestates/extract solutions were performed using U.S. EPA SW 846 Method 6020. Similar "clean" techniques were employed for GFAA determinations.

**TABLE 4-3. Method Performance Data for Elemental Analyses**

Analyte	Method	PM <sub>10</sub>			PM <sub>2.5</sub>			Field Blanks (ng/sample)
		MDL (µg/m <sup>3</sup> )	MQL (µg/m <sup>3</sup> )	%>MQL	MDL (µg/m <sup>3</sup> )	MQL (µg/m <sup>3</sup> )	%>MQL	
Primary Elements								
Pb	GFAA	10	30	8.3	5.0	15	22	2.1, 2.1
Cd	GFAA	1.2	3.6	0	0.60	1.8	5.6	0.32, 0.59
Cr	ICP/MS	4.0	12	100	2.0	6.0	100	3.1, 4.8
Mn	GFAA	3.6	11	92	1.8	5.4	89	2.1, 2.1
Ni	GFAA	46	140	0	23	69	5.6	9.5, 9.5
S	IC	520	1600	100	260	780	94	120, 123
Secondary Elements								
P	IC	1000	3000	0	520	1600	0	105, 698
Si	ICP/MS	5000	15000	100 (0) <sup>a</sup>	2500	7500	100 (0) <sup>a</sup>	21000, 21900
K	ICP/MS	1300	3900	0	630	1900	0	653, 2620
Ca	ICP/MS	2800	8400	100 (5)	1400	4200	78 (5)	2470, 5490
Ti	ICP/MS	13	39	100 (0)	6.3	19	100 (0)	7, 26
Fe	ICP/MS	1300	3900	0	630	1900	0	na
Zn	ICP/MS	260	780	100 (0)	130	390	100 (0)	131, 524
Cu	ICP/MS	13	39	83 (10)	6.3	19	94 (15)	12, 26
Sr	ICP/MS	2.6	7.8	100 (0)	1.3	3.9	94 (0)	3.0, 5.0
Br	ICP/MS	1600	4800	0	800	2400	0	26, 105
Cl	IC	320	960	42 (25)	160	480	56 (15)	250, 250

<sup>a</sup> For background corrected samples.

**TABLE 4-4. GC/MS Operating Conditions for Analyses of VOC's**

Parameter	Setting
<b>THERMAL DESORPTION<sup>a</sup></b>	
Trap Type	1 = Glass beads, 2 = Tenax TA, 3 = Open
<b>CARTRIDGE DESORPTION<sup>a</sup></b>	
Temperature	2400C
Carrier Gas Flow Rate	25 mL/min
Time	8 min
<b>TRAP 1<sup>b</sup></b>	
Initial Temperature	~1500C
Desorption Temperature	200C
Desorption Carrier Gas Flow Rate	10 mL/min
Desorption Time	4 min
<b>TRAP 2</b>	
Initial Temperature	~100C
Desorption Temperature	1800C
Desorption Carrier Gas Flow Rate	10 mL/min
Desorption Time	35 min
<b>TRAP 3</b>	
Initial Temperature	~1500C
Desorption Temperature	1000C
Inject Time	5 min
<b>GAS CHROMATOGRAPH</b>	
Instrument	Hewlett-Packard 5890
Column	DB-624 widebore fused silica capillary column
Temperature Program	350C (5 min) to 2000C (1 min) at 50C/min
Carrier Gas Flow Rate	1.8 mL/min
<b>MASS SPECTROMETER</b>	
Instrument	Hewlett Packard, Model 5988A
Ionization Mode	Electron Ionization Scan 35-350 m/z
Emission Current	0.3 mA
Source Temperature	2000C
Electron Multiplier	2000 volts <sup>c</sup>

<sup>a</sup> For multi-sorb tube analysis, <sup>b</sup> For canister sample, air sample metered into trap 1.

<sup>c</sup> Typical value.

storage will be minimized. Additional target VOCs may be added to the list of analytes; this list of analytes should be finalized by the ARB.

**TABLE 4-6. Method Performance Data for VOC Canister Samples**

Analyte	Method Quantitation Limit ( $\mu\text{g}/\text{m}^3$ )	Field Blank Concentration ( $\mu\text{g}/\text{m}^3$ ) (n=2)	Field Control % Recovery (n = 2)	% RSD Duplicate Samples
1,3-Butadiene	0.22	0.1	76	0
MTBE	0.65	0.2	78	0
ETBE	0.65	0.0	83	ND <sup>a</sup>
Toluene	0.75	2.0	90	8.6
<i>o</i> -Xylene	0.77	0.3	91	2.0
<i>m,p</i> -Xylene	0.74	0.7	83	1.8
Benzene	NA <sup>b</sup>	NA <sup>b</sup>	NA <sup>b</sup>	NA <sup>b</sup>

<sup>a</sup> Not detected in duplicate samples. <sup>b</sup> Not analyzed

#### 4.1.3.2 Multisorbent Tube VOC Collection

*Method Description* - VOCs in in-vehicle air samples were also collected and analyzed using a multisorbent cartridge technique. Multisorbent cartridge samples were collected for two reasons. First, it was felt that the cartridge techniques were more practical for field operations. Second, the exposed cartridges were analyzed by GC/MS in the full scan mode which allowed additional VOC's that were present in the automobile air samples to be identified (see Appendix I).

For this method, VOCs were collected by passing air through multisorbent cartridges containing Tenax TA and Carbonex 1000 (Supelco, Inc., Pittsburgh, PA). Air samples were collected at a flow rate of approximately 50 mL/min over a 2-hour period to give a nominal sampling volume of 6 L. Exposed cartridges were sealed in stainless steel cans at 4 °C in the field. Samples were shipped via overnight carrier to RTI within 7 days of collection. At RTI samples were stored at -20 °C until analysis. All samples were analyzed within 6 weeks of collection.

VOCs on exposed cartridges were thermally desorbed, focused, then analyzed by GC/MS using the conditions shown in Table 4-5. For quantitative analysis, VOC identifications were based on chromatographic retention times relative to the external quantitation standard and relative abundance's of the selected ion fragments shown in Table 4-4. Quantitation was performed using chromatographic peak areas derived from the selected ion profiles. Specifically, relative response factors (RRFs), or first order linear regression, for each target compound were



**TABLE 4-7. Method Performance for VOCs and Multisorbent Samples**

Analyte	Method Quantitation Limit ( $\mu\text{g}/\text{m}^3$ )	Field Blank Concentration ( $\mu\text{g}/\text{m}^3$ )	Field Control % Recovery	% RSD Duplicate Samples
1,3-Butadiene	0.22	ND	$31 \pm 7.3$	ND <sup>a</sup>
MTBE	0.75	ND	$101 \pm 24$	3.0
ETBE	0.75	ND	$108 \pm 9.8$	ND
Toluene	0.75	ND	$106 \pm 3.5$	9.7
<i>o</i> -Xylene	0.75	ND	$103 \pm 5.0$	7.1
<i>m,p</i> -Xylene	0.75	ND	$104 \pm 4.5$	9.0
Benzene	0.75	ND	$100 \pm 3.1$	4.5

<sup>a</sup> Not detected in duplicate pairs.

#### 4.1.4 Nitrogen Dioxide (NO<sub>2</sub>)

##### *Method Description* –

Nitrogen Dioxide in air samples was monitored using OSHA Method ID-109. Using this method, air samples were passed through SKC sorbent cartridges containing molecular sieve impregnated with triethanolamine (TEA). NO<sub>2</sub> in the air sample reacts with the TEA and is collected on the cartridge material. Samples were collected over 1-hour period at a flow rate of approximately 0.1 L/min for a nominal sample volume of approximately 6 L. Flow rates at the cartridge inlet were measured before and after sample collection using calibrated rotameters with a fixed-orifice bypass tube.

The nitrogen dioxide trapped on the sorbent tube was extracted with an aqueous TEA solution. An aliquot of the extract was treated with a solution containing diphenylamine, thiocyanate, and hydrochloric acid. The resulting nitrite ion was measured polarographically. Quantitation was accomplished using by the external standard method using calibration standards prepared in the range of 0.01 to 10 ppm nitrite solution.

*Method Evaluation* - Method performance data generated during the Pilot Study are given in Table 4-8. Results indicate that the method was not sufficiently sensitive to reliably measure nitrogen dioxide in air samples at the low levels found in the ambient air and in automobile samples.

*Recommendations* - Due to its limited sensitivity it is recommended that NO<sub>2</sub> monitoring not be conducted during the Main Study. Alternatively, work should be conducted to improve method sensitivity. Sensitivity could potentially be improved by increasing the sample volume. If this approach were taken, then a study of acceptable breakthrough volume would be required prior to field monitoring for the Main Study.

PAHs were recovered from the filter by sonication extraction with methylene chloride for a 30-minute period, soaking overnight, then sonic extraction for an additional 30 minutes. The solvent extract was separated from the cartridge material by filtering through silanized glass wool. The filtered extract was solvent exchanged into toluene and concentrated to 0.2 mL.

Deuterated surrogate standards were added to samples immediately prior to extraction to monitor overall method performance. External quantitation standards were added to sample extracts immediately prior to final concentration and analysis. Chrysene-d<sub>12</sub>, and benzo[e]pyrene-d<sub>12</sub> were used as surrogate standards. 1,2,3,4-Tetrachloronaphthylene and perylene-d<sub>12</sub> were used as external quantitation standards.

Sample extracts were analyzed by direct liquid injection capillary GC/MS. A 1 uL aliquot of the sample extract was injected using a split/splitless injection technique. Analytes separated on the GC column were introduced to a quadrupole mass spectrometer operating with electron ionization in the selected ion monitoring (SIM) mode. Sample constituents are characterized and quantitated by measuring ions characteristic of the target chemicals. Instrumental operating parameters are described in Table 4-10. Prior to analysis, the GC/MS system was calibrated by analyzing five calibration standards ranging in concentration from 5 to 500 ng/mL. For PAHs with no other chemical substituents, the M<sup>+</sup> ion is used as the primary quantitation ion because it is usually the ion with the greatest relative abundance for PAHs. The M+1 ion is included to verify compound identification.

**TABLE 4-10. GC/MS Operating Parameters for Analysis of PAHs**

Column Type:	30 m, DB-5, 0.25 mm i.d., 0.1 m film
Run Type:	Electron ionization; selected ion monitoring
Injection Type:	Splitless/Split (0.5 min)
Injection Temperature:	3000C
Interface Temperature:	3000C
Source Temperature:	2000C
GC Program:	Initial temperature = 1000C
	Initial program rate = 30C/min
	Final temperature = 3000C
	Final hold time = 20 minutes
Instrument:	Hewlett Packard 5988A
Multiplier Voltage:	2000 <sup>a</sup>
Emission Current:	300 mA <sup>a</sup>
Dwell Time:	75-250 msec

<sup>a</sup>A typical value.

could be increased by a factor of two by increasing the flow rates for the sampling pumps. Alternatively, RTI is acquiring a new GC/MS system that will have much lower detection limits ( $\sim 0.1$  pg/ $\mu$ L) compared to the systems currently in use (5 pg/ $\mu$ L). The feasibility of using this system for analyzing PAH samples could be evaluated. It should be noted however, that the MQLs report for this pilot study ( $1.0$  ng/ $m^3$ ) are similar to the  $0.9$  ng/ $m^3$  level that the California Office of Environmental Health Hazard Assessment suggests is required to cause  $10^{-6}$  excess cancer risk over a 70-year exposure period.

**TABLE 4-11. Method Performance for PAH Samples**

Estimated Method Quantitation Limit	1.0 ng/ $m^3$ for all PAHs
% of Samples with PAH levels > MQL	0%
% Recovery of Surrogate Standards (n=14)	Chrysene-D12 -- $97 \pm 9.4\%$ Benzo[e]pyrene-D12 -- $93 \pm 13\%$
% Recovery from NIST SRM (n=3)	Benzo[a]anthracene -- $73 \pm 19\%$ Benzo[a]pyrene -- $83 \pm 12\%$ Indeno[1,2,3-cd]pyrene -- $95 \pm 4\%$ Benzo[ghi]perylene -- $79 \pm 8\%$
Recovery from Method Controls (n=6)	Benzo[b]fluoranthene -- $96 \pm 7\%$ Benzp[k]fluoranthene -- $100 \pm 5\%$ Benzo[a]pyrene -- $91 \pm 11\%$ Indeno[1,2,3-cd]pyrene -- $82 \pm 18\%$ Benzo[ghi]perylene -- $78 \pm 16\%$
Amount on Field Blank	All not detected except Benzo[b]fluoranthene -- $0.08$ $\mu$ g/ $m^3$ Benzp[ghi]perylene -- $0.06$ $\mu$ g/ $m^3$
% RSD of Duplicate samples	No duplicates collected

*Recommendations -m* Currently, PAH monitoring is not proposed for the Main Study. If additional monitoring is requested by the ARB then both the need for and the feasibility of improving method quantitation limits should be investigated.

#### 4.1.6 Formaldehyde

*Method Description* - Formaldehyde was monitored inside the car during each test drive. Formaldehyde in air samples were collected by passing air through DNPH-coated Sep-Pak cartridges (Water Associates, Milford, MA). Samples were collected at a flow rate of approximately 300 mL/min using a battery-powered low volume pump. Samples were collected for a 2-hour period to give a nominal volume of 36 L. Flow rates at the cartridge inlet were measured before and after sample collection using calibrated rotameters with a fixed-orifice bypass tube.

loggers with extended memory. The monitors are pocket size, sensing and logging devices with accuracy reported by the manufacturer as  $\pm 2$  ppm CO. The monitors are powered by a single 9 V alkaline battery. The monitors utilizes a three-electrode electrochemical sensor for continuous measurement of CO. A scrubber containing charcoal and Purafil is used on the monitor inlet to reduce interferences. An integral data logger records sensor measurements 120 times per minute. These values are averaged by the monitor and 1 minute average values are stored by the monitor data logger. Stored values are downloaded at the end of the monitoring period via an RS-232 interface to a portable computer using software supplied by National Draeger, Inc.. Results will be reported as one hour average and peak CO concentrations.

Two CO monitors were used for each vehicle to monitor inside and outside CO concentrations; Teflon sampling lines were used to draw air sequentially, first near the driver's breathing zone, and then from the vehicle exterior via a sampling manifold. A computer controller electronic timer was used to switch solenoid positions between the interior and exterior sample line every 5 minutes. Fixed site CO monitors were placed in "weather tight", insulated sampling boxes to minimize effects due to ambient outdoor temperatures and moisture.

Prior to initial use in the field, each CO monitors was calibrated using certified carbon monoxide gas standards at concentrations of 0, 2, 10 and 21.5 ppm. In addition to the weekly checks, a zero and span (21.5 ppm) check was performed at the start and the end of each test drive. At the start of the test drive, the zero and span of the monitor was adjusted to give readings of zero and 21.5, respectively. At the end of the test drive, no adjustments were made for the zero and span, rather reading were recorded on log sheets prepared for this purpose.

*Method Evaluation* - Performance of the CO monitors was evaluated based of the calibration checks and the deployment of duplicate monitors. For each test drive, performance of the CO monitor was considered "in control" if there was less than a 2 ppm drift in either the zero or the span reading. This criterion was meet for all monitors with one exception. On day one, the zero reading for one monitor drifted to 3 ppm. Method quantitation limits were set at 2 ppm based on information from the instrument manufacturer. Results for duplicate monitors showed agreement in 1-hour average readings within the 2 ppm specifications.

*Recommendations* - The CO monitors worked well throughout the study. Although many of the readings especially at the ambient and roadway sites were at or below the MQL, the monitors are acceptable for measuring CO levels that are below the California ambient air monitoring standard of 9 ppm. It is recommended that the method for monitoring CO be used without modification during the Main Study.

#### **4.2.2 Particle Size and Mass Distributions**

*Method Description*- The size distribution and volume of fine particles both inside and outside of the vehicle were measured continuously in the size range from 0.1 to 3  $\mu\text{m}$ . Measurements were made using the LAS-X optical particle counter (Particle Measuring Systems, Boulder, Colorado). Prior to the study, the instrument was calibrated in the laboratory at Aerosol Dynamics Inc. The individual optical channel calibrations were performed using a differential mobility optical particle size spectrometer (DMOPSS) system, which was developed and deployed for two atmospheric visibility studies to provide *in-situ* calibration of optical counters for precise size distribution measurement (Stolzenburg et al., 1995) with ambient Berkeley, CA aerosols and with dioctyl sebacate aerosols. Calibrations were conducted using both dioctyl

Figure 4-3

Composite Mean Difference Between Measured and Computed LAS-X  
PM2.5 Concentrations as a Function of the Fraction of Ambient Air Input  
Into the Particle Size and Particle Density Computations

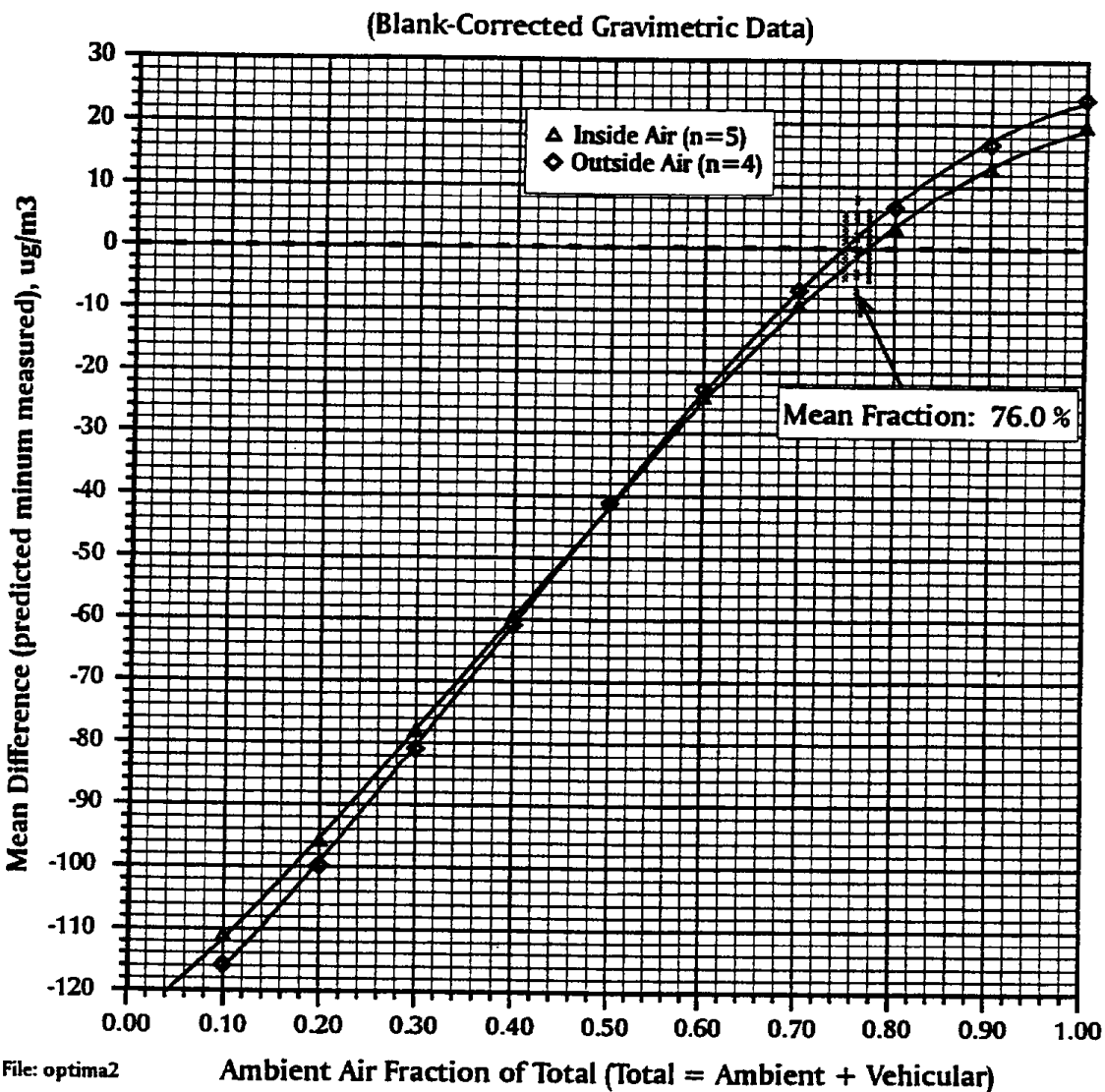
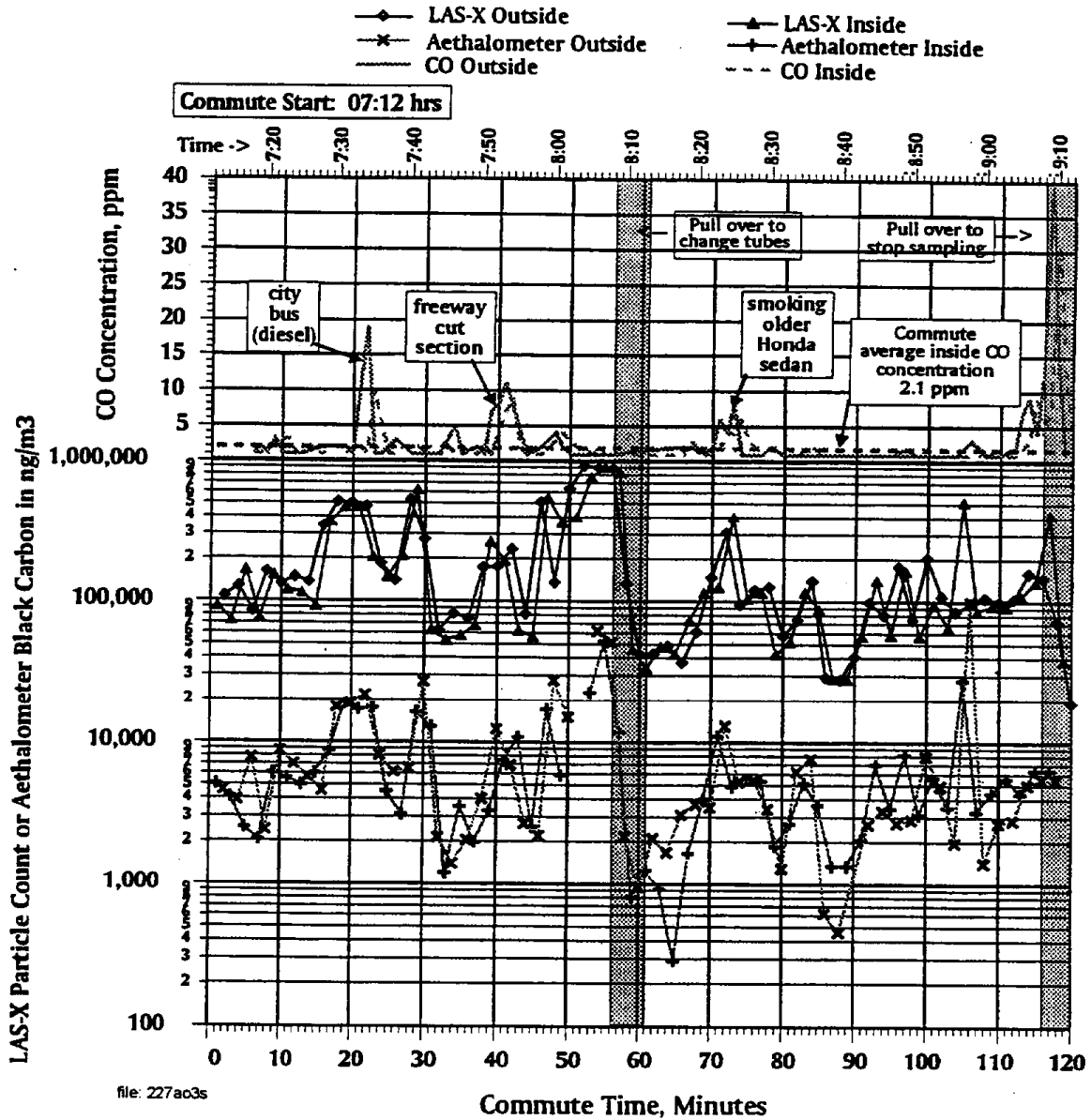


Figure 4-5

### LAS-X Particle Counts, Aethalometer Black Carbon and Carbon Monoxide (CO) Outside and Inside Test Car

2/27/97 AM

Particle Size Bin TOTAL



$$\text{AER} = (1/t) \ln (C_i / C_f) \quad (7)$$

where t = decay time (h), ,  
C<sub>i</sub> , C<sub>f</sub> is the initial, final concentration of CO in ppm.

*Method Evaluation* - Air exchange rates for the test vehicle were made on the rural route. Measurements of the three air exchange rate took approximately 2 hours. There were no logistical problems with implementing this procedure. There was, however, no way to assess the accuracy of the method, other than to cite the expected accuracy of the Draeger CO monitor (see Section 4.2.1). The main drawback to this method is that only a representative air exchange rate is obtained for the ventilation settings. Measurements of AER are not made during the test runs thus the AER during the test run could be substantially different that that was measured.

*Recommendations* - Despite this limitation, the method is recommended for the Main Study. Tests should be performed at the outset of the Main Study to characterize Sedan 1, Sedan 2, the sport/utility vehicle, and the school bus. If Sedan 2 and the SUV have the same range of air exchange rates as Sedan 1, the emphasis for the Main Study should be the high AER ventilation settings, which tend to maximize inside concentrations. If the additional vehicle AER data are significantly lower than Sedan 1, the emphasis should be balanced.

#### 4.4 TRAFFIC DATA

##### 4.4.1 In-Vehicle Data

###### *Method Description--*

Vehicle speed was recorded using a digital sender mounted on the drive-shaft for Sedan 1 and custom signal-conditioning circuitry. The signal from the OEM speed sender was also recorded as a backup. A grill-mounted laser range finder made to custom order for Sierra Research by Laser Atlanta, measured following distance from the car ahead. Accuracy of the measurement is approximately two feet. Lateral and longitudinal accelerometers were used to record total acceleration. All data were recorded once per second.

During on-road data collection, the test vehicle was driven by a two-member team that is familiar with the on-board equipment and drive protocols. The principal responsibility of the driver was, of course, to drive safely. The second technician served as a navigator and "observer," and uses a data entry switch box to log information of the selected parameters. These parameters were selected in consultation and final approval by the ARB. When necessary, the navigator kept a manual record of unusual events during each test drive. All drives were videotaped for later examination of any unusual events or to ascertain additional information about the test drive. Available data were obtained from CalTrans on roadway traffic counts relative to the selected commute route.

*Method Evaluation*- The collection of data for Level of Congestion and the Additional Parameter given in Table 3-5 using the-vehicle switch box was cumbersome and time consuming for the navigator. The utility of the Addition Parameter data was also not apparent during data analysis. The videotape of the drives provide excellent information on roadway conditions and target vehicles. CalTrans data are not always available for test runs and although it can provide good information for route selection, it does not appear to be useful for data analysis. For the freeway drives following distances were uniform throughout and therefore would not be a useful variable for data analysis.

## 5.0 DATA TABULATIONS

### 5.1 Data Tables

A compilation of the individual pollutant monitoring data for VOCs, formaldehyde, particle mass, black carbon, PAHs, carbon monoxide, and nitrogen dioxide is given in Tables 5-1A thru 5-1D by monitoring trip. These data represent 6 freeway commutes and 1 rural commute, all in the Sacramento area. Starred (\*) data are below the method MQL. A similar compilation for the primary elements (metals) is given in Tables 5-2A thru 5-2E. The commute-average data are based on the commute times (minutes) given in Table 3-3. The CO and NO<sub>2</sub> hourly data are nominally: (a) Hour 1 - first 60 minutes, and (b) Hour 2 - next 60 minutes [truncated if the commute was less than 120 minutes]. A table summarizing the PM<sub>2.5</sub> and PM<sub>10</sub> data separately is provided in Appendix H.

It should be noted that the Pilot Study data represent only a limited six-day monitoring period in Sacramento from February 26 to March 3, 1997. The meteorological conditions during that period resulted in a relatively "clean" ambient air setting compared to what might normally be expected in the winter in Sacramento or in the Summer/Fall (proposed time period for the Main Study) in either Los Angeles or Sacramento. The limited scope of the data suggests that only limited conclusions can be drawn, especially considering the low concentrations and the associated limits of detection for the respective methods.

We have based our conclusions on these monitoring data. However, it should be understood that some of the conclusion from the Pilot Study may not be directly applicable to a more polluted setting such as that anticipated for the Main Study later this year in Sacramento and Los Angeles. This becomes a very important consideration when evaluating the sensitivity of various monitoring methods. Methods that appear to be marginally suitable based on sensitivity may, in fact, be acceptable if the Main Study is conducted under more highly polluted conditions.

### 5.2 Data Interpretations

The data collected during the Pilot Study have been evaluated to answer several questions that address basic study design elements of the Main Study. These include:

**1. Are the measurement methods sufficiently sensitive to measure pollutant air concentrations during 2-hour driving periods?**

Results in Tables 5-1 and 5-2 provide information on air concentrations regardless of whether they are below the reported MQL. Data that are below the estimated MDL of MQLs are highlighted in the tables. The percentage of sample measurements that are above the reporting level are summarized in Table 5-3. In general, methods for VOCs, formaldehyde, continuous measures of PM<sub>2.5</sub>, continuous measures of carbon black, and peak measures for CO provided higher percent measurable values. Methods for PM<sub>2.5</sub> mass, PM<sub>10</sub> mass, NO<sub>2</sub>, and 1-h average CO provided measurement data that were in the range of the MQL or MDL values. Methods for the metals were typically near the MQL, but the results were dependent upon the specific metal measured. PAHs gave concentrations well below the MQL values.

It should be reiterated that although several methods appear to provide only marginal sensitivity for this Pilot Study. They may, in fact, provide acceptable sensitivity if the Main Study is conducted under more highly polluted conditions.



TABLE 5-1B. IN-TRAFFIC DATA (continued)

Analyte	Concentration						
	Ambient	Out-Car	In-Car	Road-1	Road-2	Road-3	Road-4
<b>Day 2 (2/27), AM, Freeway Rush -- Vent 3; high air exchange rate: ( 160 hr<sup>-1</sup> @ 55 mph)</b>							
VOCs (µg/m <sup>3</sup> )							
1,3-Butadiene	0.3	3.7	3.0 (ND*)	0.9	1.9	1.4	1.5
MTBE	3.5	18	17 (9.8)	4.7	9.1	8.0	7.7
ETBE	ND*	ND*	ND*	ND*	ND*	ND*	ND*
Benzene	--	--	(1.8)	--	--	--	--
Toluene	6.1	26	27 (32)	13	26	19	18
<i>m,p</i> -Xylene	2.9	18	18 (21)	4.3	11	8.6	9.2
<i>o</i> -Xylene	1.3	7.2	7.1 (7.3)	2.0	4.3	3.5	3.7
Formaldehyde	--	--	6.2	--	--	--	--
PM <sub>10</sub> (µg/m <sup>3</sup> )	75	NS	71	53	62	71	78
PM <sub>2.5</sub> (µg/m <sup>3</sup> )	6.0*	56 (38)	36 (32)	15	15	44	35
Carbon Black (µg/m <sup>3</sup> )	--	9.7	7.2	--	--	--	--
CO average (ppm)	0*, 0*	1.6*, 2.3	1.9*, 2.3	0*, 0*	--, --	1.5*, 0.7	0.1*, 0.1*
CO peak value (ppm)	ND	40	31	1.0	--	3.0	2.0
NO <sub>2</sub> (ppb)	61, 38	64, 9	65, 59	9.0*, 17*	69, 60	50, 43	108, 24
<b>Day 2 (2/27), PM, Freeway Rush -- Vent 3; high air exchange rate: ( 160 hr<sup>-1</sup> @ 55 mph)</b>							
VOCs (µg/m <sup>3</sup> )							
1,3-butadiene	0.4	1.5	1.4 (ND*)	1.4	1.7	1.1	2.0
MTBE	ND*	ND*	8.9 (3.8)	9.1	10	7.9	10
ETBE	ND*	ND*	ND*	ND*	ND*	ND*	ND*
Benzene	--	--	(4.6)	--	--	--	--
Toluene	5.9	15	15 (12)	14	22	13	19
<i>m,p</i> -Xylene	3.2	10	10 (7.8)	8.6	12	7.5	12
<i>o</i> -Xylene	1.2	4.0	4.3(2.7)	3.5	4.9	3.0	4.8
Formaldehyde	--	--	4.3	--	--	--	--
PAHs (ng/m <sup>3</sup> )							
Benzo[b]fluoranthene	0.2*	0.1*	ND*	--	--	0.3*	--
Benzo[k]fluoranthene	0.1*	0.03*	ND*	--	--	0.1*	--
Benzo[e]pyrene	0.1*	0.02*	ND*	--	--	0.2*	--
Benzo[a]pyrene	0.1*	ND*	0.2*	--	--	0.2*	--
Indeno[1,2,3-cd]pyrene	0.1*	0.1*	0.2*	--	--	0.3*	--
Benzo[ghi]perylene	0.2*	0.1*	1.0*	--	--	0.4*	--
PM <sub>10</sub> (µg/m <sup>3</sup> )	49	--	33*	113	73	21	79
PM <sub>2.5</sub> (µg/m <sup>3</sup> )	56	44 (50)	16* (54)	15*	15*	44	35
Carbon Black (µg/m <sup>3</sup> )	--	4.9	4.4	--	--	--	--
CO average (ppm)	ND, ND	2.0, 1.0*	1.2*, 0.5*	0.7*, 0.4*	0.2*, 0.1*	1.1*, 1.1	0.6*, 0.1*
CO peak value (ppm)	1.0*	5.0	3.0	4.0	2.0	3.0	2.0
NO <sub>2</sub> (ppb)	37*, 40*	84, 26	42*, 20*	55, 41	50, 57	47, 76	127, 46

<sup>a</sup> For VOC in-car number in parentheses is multisorbent tube date.

<sup>b</sup> Starred (\*) values are below the reported limit.

<sup>c</sup> No sample. <sup>d</sup> Not detected. <sup>e</sup> For CO and NO<sub>2</sub>, two one-hour average values are reported.

**TABLE 5-1D. IN-TRAFFIC DATA (continued)**

Analyte	Concentration						
	Ambient	Out-Car	In-Car	Road-1	Road-2	Road-3	Road-4
<b>Day 4 (3/1), AM, Rural – Vent 1; low air exchange rate: ( 39 hr<sup>-1</sup> @ 55 mph)</b>							
<b>VOCs (µg/m<sup>3</sup>)</b>							
1,3-Butadiene	ND*	ND*	ND* (ND*)	--	--	--	--
MTBE	1.0	1.4	1.6 (ND*)	--	--	--	--
ETBE	ND*	ND*	ND*	ND*	ND*	ND*	ND*
Benzene	--	--	(0.3)	--	--	--	--
Toluene	3.2	4.6	5.8 (5.0)	--	--	--	--
<i>m,p</i> -Xylene	1.5	1.8	3.4 (3.3)	--	--	--	--
<i>o</i> -Xylene	0.8	0.9	1.5 (ND*)	--	--	--	--
Formaldehyde	--	--	9.6	--	--	--	--
<b>PAHs (ng/m<sup>3</sup>)</b>							
Benzo[b]fluoranthene	0.1*	0.3*	ND*	--	--	--	--
Benzo[k]fluoranthene	0.1*	0.2*	ND*	--	--	--	--
Benzo[e]pyrene	ND*	ND*	ND*	--	--	--	--
Benzo[a]pyrene	0.1*	0.1*	0.1*	--	--	--	--
Indeno[1,2,3-cd]pyrene	ND*	0.2*	0.1*	--	--	--	--
Benzo[ghi]perylene	ND*	0.2*	ND*	--	--	--	--
PM <sub>10</sub> (µg/m <sup>3</sup> )	28*	--	18	--	--	--	--
PM <sub>2.5</sub> (µg/m <sup>3</sup> )	31	13* (26*)	24* (22*)	--	--	--	--
Carbon Black (µg/m <sup>3</sup> )	--	--	1.3	--	--	--	--
CO average (ppm)	0*, 0*	0*, 0*	0.6*, 1.7*				
CO peak value (ppm)	0*, 0*	0*, 0*	1, 7*				
NO <sub>2</sub> (ppb)	9.0*, 5.0*	1.0*, 1.0*	ND*, 29*	--	--	--	--

<sup>a</sup> For VOC in-car number in parentheses is multisorbent tube date.

<sup>b</sup> Starred (\*) values are below the reported limit.

<sup>c</sup> No sample. <sup>d</sup> Not detected. <sup>e</sup> For CO and NO<sub>2</sub>, two one-hour average values are reported.

**TABLE 5-2A. IN-TRAFFIC DATA FOR ELEMENTS**

Analyte	Concentration						
	Ambient	Out-Car	In-Car	Road-1	Road-2	Road-3	Road-4
<b>Day 1 (2/26), AM, Freeway Rush Air exchange rate (mid 98 1/h)</b>							
<b>PM<sub>2.5</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	0.01	0.05	0.03	--	--	--	--
Chromium	105	106	87	--	--	--	--
Manganese	2.3	2.5	2.5	--	--	--	--
Nickel	ND	ND	ND	--	--	--	--
Lead	6.6	8.4	12	--	--	--	--
Sulfur	343	269	575	--	--	--	--
<b>PM<sub>10</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	--	--	0.86	--	--	--	--
Chromium	--	--	9.5	--	--	--	--
Manganese	--	--	ND	--	--	--	--
Nickel	--	--	ND	--	--	--	--
Lead	--	--	11	--	--	--	--
Sulfur	--	--	265	--	--	--	--
<b>Day 1 (2/26), PM, Freeway Rush Air exchange rate (mid 98 1/h)</b>							
<b>PM<sub>2.5</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	0.24	--	0.11	--	--	--	--
Chromium	113	--	107	--	--	--	--
Manganese	1.4	--	6.8	--	--	--	--
Nickel	ND	--	25	--	--	--	--
Lead	6.9	--	11	--	--	--	--
Sulfur	237	--	269	--	--	--	--
<b>PM<sub>10</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	0.69	--	0.37	--	--	--	--
Chromium	200	--	192	--	--	--	--
Manganese	6.9	--	9.3	--	--	--	--
Nickel	53	--	28	--	--	--	--
Lead	8.5	--	13	--	--	--	--
Sulfur	345	--	465	--	--	--	--

**TABLE 5-2C. IN-TRAFFIC DATA FOR ELEMENTS (continued)**

Day 3 (2/28), PM, Freeway Rush Air exchange rate (low 39 1/h)							
	Ambient	Out-Car	In-Car	Road-1	Road-2	Road-3	Road-4
<b>PM<sub>2.5</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	--	0.40	--	ND	0.46	--	1.1
Chromium	--	110	--	114	114	--	112
Manganese	--	8.6	--	2.7	4.0	--	3.5
Nickel	--	ND	--	5.3	6.9	--	70
Lead	--	6.7	--	3.1	9.0	--	3.7
Sulfur	--	443	--	324	392	--	283
<b>PM<sub>10</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	ND	--	--	--	--	ND	--
Chromium	209	--	--	--	--	201	--
Manganese	20	--	--	--	--	7.5	--
Nickel	ND	--	--	--	--	ND	--
Lead	16	--	--	--	--	1.9	--
Sulfur	520	--	--	--	--	447	--

**TABLE 5-2D. IN-TRAFFIC DATA FOR ELEMENTS (continued)**

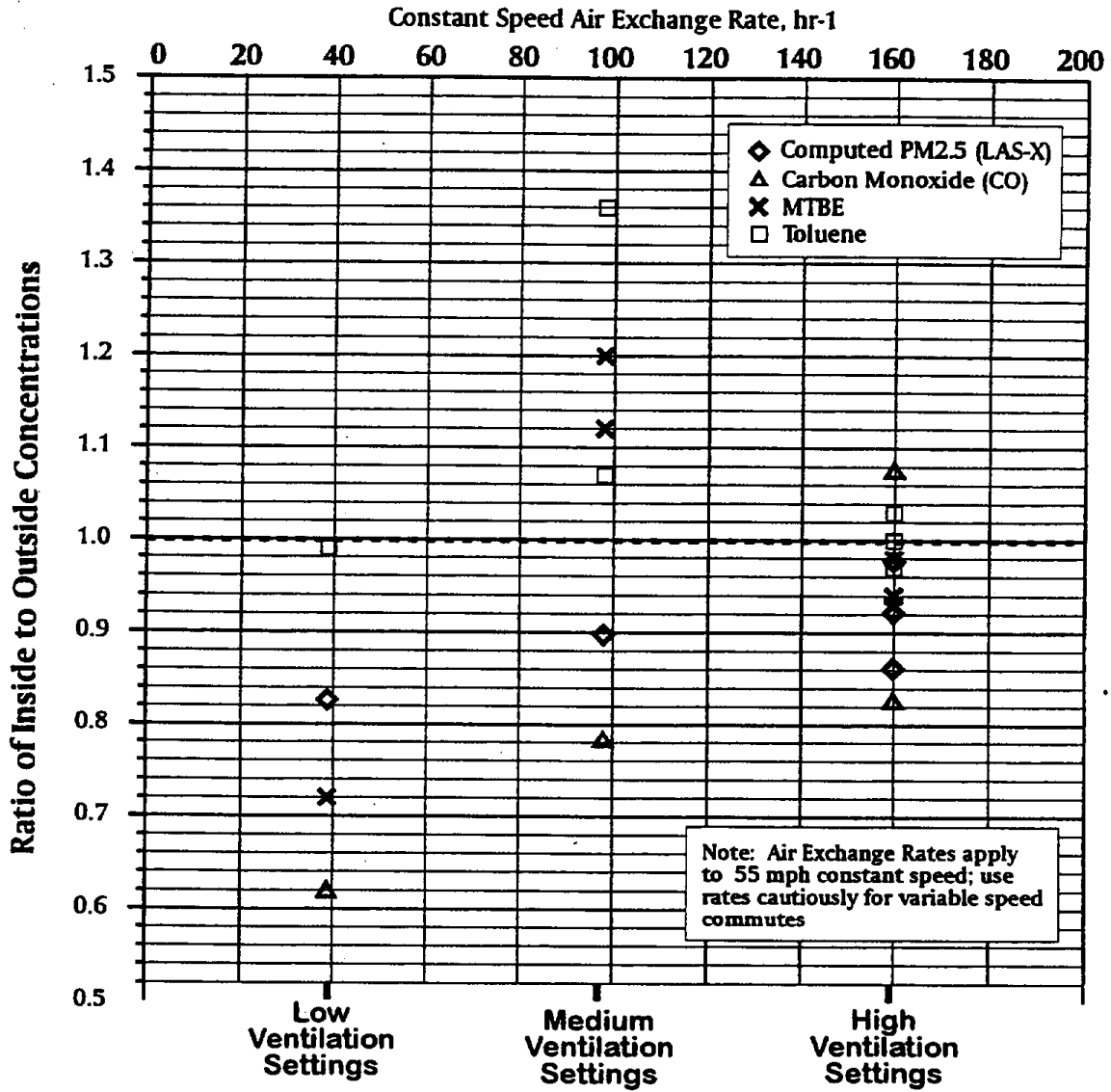
Day 4 (3/1), AM, Rural Air exchange rate (low 39 1/h)							
	Ambient	Out-Car	In-Car	Road-1	Road-2	Road-3	Road-4
<b>PM<sub>2.5</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	ND	--	--	--	--	--	--
Chromium	ND	--	--	--	--	--	--
Manganese	ND	--	--	--	--	--	--
Nickel	ND	--	--	--	--	--	--
Lead	ND	--	--	--	--	--	--
Sulfur	93	--	--	--	--	--	--
<b>PM<sub>10</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	--	--	--	--	--	--	--
Chromium	--	--	--	--	--	--	--
Manganese	--	--	--	--	--	--	--
Nickel	--	--	--	--	--	--	--
Lead	--	--	--	--	--	--	--
Sulfur	--	--	--	--	--	--	--

**TABLE 5-3. Percentage of Samples Above the Reporting Levels**

Analyte	% Above Reporting Level	Reporting Level
VOCs -- Canister		MQL estimated from concentration of lowest standard
1,3-Butadiene	92	
MTBE	100	
ETBE	0	
Toluene	100	
Xylenes	100	
Formaldehyde	100	MQL estimated from concentration of lowest standard
PAHs	0	MQL estimated from concentration of lowest standard
PM <sub>10</sub>	67	MQL based on precision of filter reweighing
PM <sub>2.5</sub>	64 (100)*	MQL based on precision of filter reweighing
CO 1-h average	20	MQL based on manufacturers specifications
CO peak	95	MQL based on manufacturers specifications
NO <sub>2</sub>	46	MDL based on precision of field blanks
Primary Elements		MQL based instrumental measurement precision of reagent water liquids
Pb	PM <sub>10</sub> - 8.3, PM <sub>2.5</sub> - 22	
Cd	PM <sub>10</sub> - 0, PM <sub>2.5</sub> - 5.6	
Cr	PM <sub>10</sub> - 100, PM <sub>2.5</sub> - 100	
Mn	PM <sub>10</sub> - 92, PM <sub>2.5</sub> - 89	
Ni	PM <sub>10</sub> - 0, PM <sub>2.5</sub> - 5.6	
S	PM <sub>10</sub> - 100, PM <sub>2.5</sub> - 94	

Figure 5-1

Relationships of Constant Speed Air Exchange Rate to the Ratios of Inside to Outside Concentrations During Freeway Commutes for Computed PM2.5 (LAS-X data), Carbon Monoxide (CO), Toluene, and MTBE

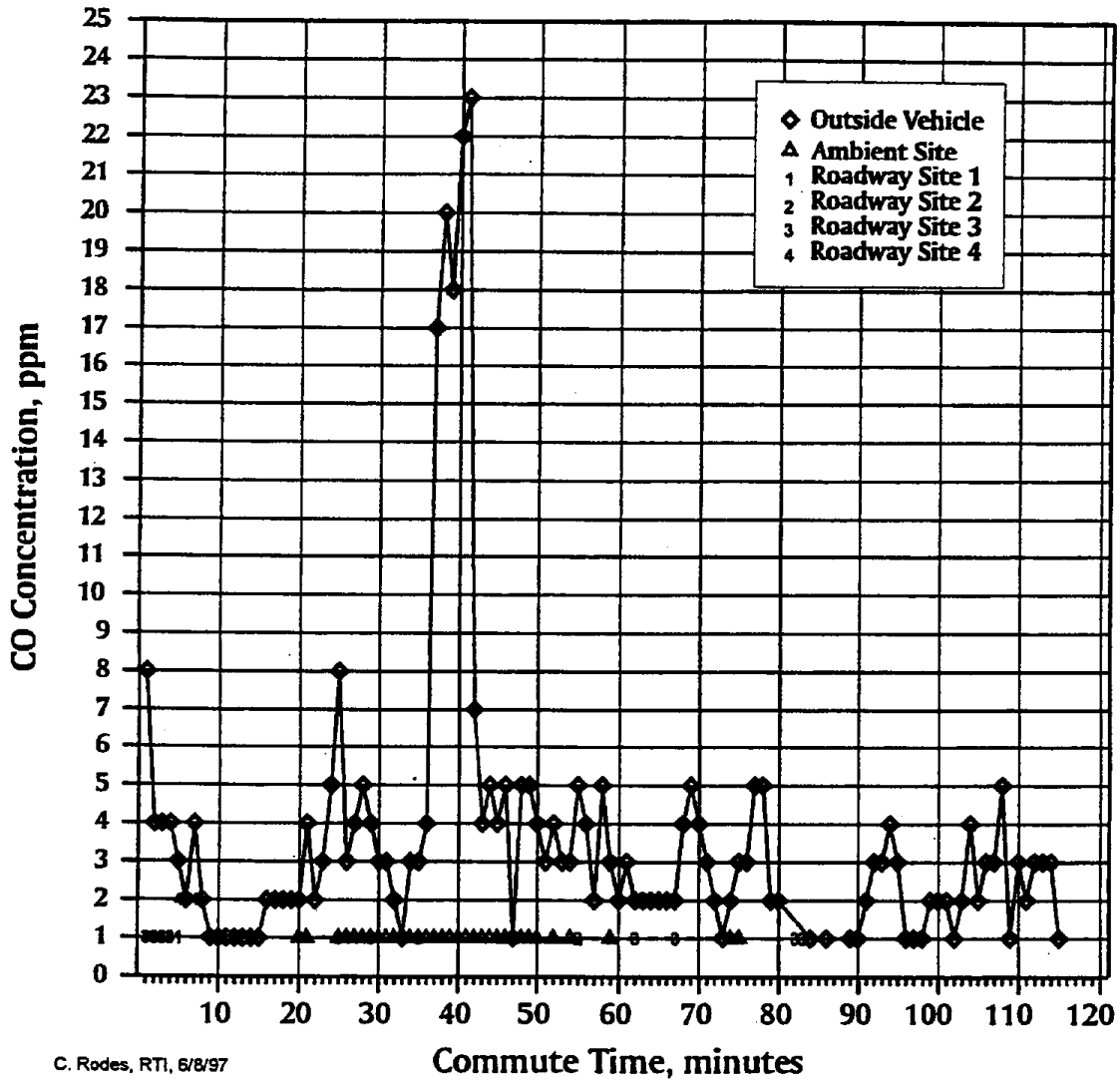


file: aeriesx1

See text for vent setting definitions

Figure 5-3  
 Relationship of Carbon Monoxide Outside Vehicle with  
 Ambient Site and Four Roadway Site Concentrations

3/3/97 AM commute



C. Rodes, RTI, 6/8/97

Several additional observations were made based on the real time CO, LAS-X particle monitoring data, video tapes, and traffic data. These include:

- The particle count data from the LAS-X readily demonstrated the influence of individual, high-emitting particle vehicles immediately in front of the car.
- The short-term particle count size distribution data showed almost no differences between the shapes of the size distributions for several vehicle types (see Figure 5-4). The differences between distributions were mostly in the size of the particle mode below 0.3  $\mu\text{m}$ . This is consistent with internal combustion engine particle emissions that are significantly less than 0.1  $\mu\text{m}$  in diameter.
- The Aethalometer readily detected the particle emissions when following diesel (or visibly smoking gasoline-powered) vehicles, as did the LAS-X. Both measurements tracked correlated closely (see Figure 5-5). A determination as to whether the Aethalometer black carbon levels could be used to predict PAH levels could not be made, due to the below detection level concentrations measured for the PAHs.
- Limited data following poorly tuned vehicles (visible assessment of the exhaust plumes) suggest that closely following these vehicles for periods of more than a few minutes may add significantly to the total commute-average exposures for particles and CO.
- The rapidity of particle and CO concentration changes on the freeway from following individual vehicles, demonstrated the importance of careful time synchronization between all the continuous measurements. This proved to be more difficult than expected with the Aethalometer and video camera because of their time setting sequences.
- Reduction of all continuous measurements to the same integration average (e.g., 1 minute) was very time consuming after the study because of the inconsistent time synchronizations.
- The video camera was extremely informative as to the sources and scenarios that produced elevated exposure levels. Reviewing each tape to record these events, however, is very time consuming.
- A more refined time synchronization procedure among real-time measurements must be devised to provide a clearer indication of single events and make it cost-effective to reduce the continuous monitoring data.
- Reduction of the vehicle switchbox data that describe the driving scenarios (including traffic density) were difficult to incorporate into a data analysis, given the low concentrations encountered, suggesting that only traffic density (level of congestion) may be worth retaining for the Main Study.



- Hourly traffic count data were obtained (by Sierra Research) from CalTrans for the locations most relevant to the Sacramento freeway commuting route. Concurrent count data for only a few periods over-lapping the Pilot Study commutes were available. These data were obtained, plotted and are given in Appendix J. They indicated that the selected morning and evening sampling windows for the Pilot Study (7 to 9 AM, and 4 to 6 PM) correctly targeted the periods of highest traffic densities. These same windows will be used in the Main Study.

**APPENDIX A**

RTI Milestone Schedule for the ARB In-Vehicle Exposure Study (Post Pilot Study)

C. Rodes, 6/6/97 (revised DRAFT)

Item #	Milestone Category	Item	Start Date	End or Critical Date	Output / Next Step / Result / Comment	Lead/Assisting Org.
16	Hardware Modification	Add external switches to particle sampler pumps	na	18-Jul	may require ordering some components	RTI
17	Hardware Modification	Add tandem 2 lpm pump to existing PM10 systems	na	18-Jul	make sure the additional equipment will be available in August	RTI
18	Hardware Modification	Add vibration damping to video and LAS-X platform	na	18-Jul	may require ordering some components; coordinate w/ Sierra	SR/RTI
19	Hardware Modification	Automate NO2 tube switching	na	18-Jul	add solenoids / remote switch / or timer	RTI
20	Hardware Modification	Build 4 lpm flow check orifice	na	18-Jul	may require ordering some	RTI
21	Hardware Preparation	Checkout samplers and prepare/clean substrates	na	18-Jul		RTI
22	Test Procedure	Upgrade inlet leak test procedure	na	18-Jul	Procedure / checklist	RTI
23	Hardware Modification	Upgrade power system in car for continuous monitors - if monitors are used in Main Study	na	18-Jul	Contingent on (a) decision to use continuous monitors, and (b) what power system would cost project	SR
24	Document Modification	Revise Field Operations Manual to reflect changes made during and since Pilot Study	na	18-Jul	send to ARB for review	RTI
25	Personnel Action	Identify additional vehicle drivers (including schoolbus) for Sacramento & LA	na	18-Jul	[list of potential sedan/SUV drivers already identified]	SR
26	Agreement Document	Prepare CalTrans request for encroachment permits for Sacramento & LA	na	18-Jul	Contact CalTrans as soon as roadside sites are identified	RTI/SR
27	Study Design Element	Select Ambient monitoring sites for Sacramento and LA	na	18-Jul	Make requests for permission to access	RTI
28	Study Design Element	Select Roadside monitoring sites for Sacramento and LA	na	18-Jul	Make requests for permission to access	RTI/SR
29	Hardware Modification	Redefine needed switchbox settings based on correlations with pollutant levels from Pilot Study	na	18-Jul	Delete several settings & add navigator observation diary?	RTI/SR
30	Study Design Element	Define driving protocols for the Main Study	na	18-Jul	Review & revise Pilot Study version	SR/RTI

**APPENDIX B**

## APPENDIX C

Monday, evening, 2/24

- \* Car will be returned to Sierra garage for overnight parking (every night)
- \* All filters will be numbered, pre-weighed, and loaded into petri dishes by Mike Roberds - if the temperature and humidity are within  $20 \pm 5$  °C and 30 to 70 % Rh (should not be a problem if room HVAC is functional). If outside humidity is extremely high and inside humidity cannot be brought below 70%, a dehumidifier will be obtained and the filters weighed on 2/25 PM.

Tuesday, AM, 2/25

- \* PM<sub>2.5</sub> and PM<sub>10</sub> inlets will be cleaned, oiled (as needed), loaded with a filter, sealed, and leak-tested.
- \* The in-vehicle continuous monitors - CO, LAS-X, and Aethalometer - will be turned ON each morning (at Sierra garage) and allowed to warm up for 1 hour.
- \* At the staging area, the CO data logger will be checked, the Aethalometer data logger will be checked, and the RTI laptop connected to the LAS-X and checked.
- \* The 3 continuous monitors will be put into the data collection modes.
- \* The computer system in the car will be checked and data collection initiated for laser, switch setting, and speed logging.
- \* The video camera will be loaded, clock time checked, and camera started.
- \* The Sierra driver and Sierra navigator will proceed to the start of the rush hour commute route and drive the route for 1-2 hours (time of day irrelevant) to (a) become familiar with the route, and (b) become familiar with the switch panel settings.

Tuesday, PM, 2/25

- \* Continuous monitors powered up for the duration of the sampling (thru 3/3)
- \* PM<sub>2.5</sub> and PM<sub>10</sub> inlets will be cleaned, oiled (as needed), loaded with a filter, sealed, leak-tested and placed into Ziplok bags.
- \* Fresh batteries will be installed as needed (batteries will be changed twice - initially and Friday PM) in all particle sampling pumps (4 AA alkalines/pump), NO<sub>2</sub> pumps, VOC multi-sorb pumps, and CO monitors (9V)
- \* The tripod for the Ambient site and the ground stakes for the 4 Roadside sites should be located and installed for the subsequent sampling days. *CalTrans must be notified so they can inspect.*
- \* After the car returns the CO, LAS-X, and Aethalometer data will be retrieved for evening review by Charles.
- \* The car computer data and video will be retrieved by Sierra, reviewed for reasonableness, and given to Charles for subsequent evening review.
- \* All particle sampling pumps, NO<sub>2</sub> tube pumps, PAH pumps, PAH inverter/battery systems will be checked for functionality.
- \* The operation of the in-vehicle integrated samplers, the switching manifold, and laptop data logging system will be demonstrated to the Sierra driver and navigator by Don.

Tuesday, evening, 2/25

- \* All filters will be pre-weighed, if not already weighed on 2/24

- \* Ambient Site Sampling Initiation [6:40 to 6:45 AM]
  - + The route will be driven by Mike and Steve to set out, secure, start the sampler, and note arrival/departure times for the Ambient site station only.
  - + After the placement and initiation of the ambient sampler, Mike will make a phone call to the Sierra driver to begin the 2 hour commuting run [may only be required on first sampling day].
  
- \* Commute Initiation [6:45 AM]
  - + All in-vehicle sampling pumps (particles, NO<sub>2</sub>, PAH, VOC, and aldehydes) and data logging (as required) will be started by Sierra navigator after the signal is received upon setup of the last roadside sample
  - + The commute drive route (see attached maps) will start at the motel staging area, proceed to the I Street on ramp of I5, proceed South to Rte 99, proceed East to Bus. 80, proceed North past the I80 merge, and turn around at Madison Ave., re-enter South on I80 and re-trace the route continuously for the 120 minute period.
  - + The study driving protocol, including data entry via switch panel will be followed.
  - + The front windows of the car will be lowered 1/3 open for the first 2 minutes of each commute that are on the freeway (Wed, Thur, and Fri) or rural route (Sat) to provide an initial in-traffic purge and then returned to the required position for the balance of the commute.
  - + Sierra navigator to monitor signal light on dash for proper activation of outside manifold solenoid switching - if light flash ceases, LAS-X/solenoid switching laptop computer must be re-initiated.
  - + After 120 minutes, the Sierra navigator will suspend all sampling pumps, VOC's, and data logging (as required).
  
- \* Mid-Commute [7:40 to 7:45 AM]
  - + The route will be driven to switch the NO<sub>2</sub> samplers from Hour 1 tubes to Hour 2 tubes at the Ambient site and each of the four roadside sites
  - + The Sierra navigator will switch the in-vehicle NO<sub>2</sub> samplers from Hour 1 tubes to Hour 2 tubes
  
- \* Commute Completion [8:45 AM]
  - + Car returns to staging area (motel)
  - + Mike will conduct final flow checks at the motel on each sampler, complete the data sheets, and secure the collected samples.
  
- \* Ambient Site Sampling Completion [8:40 to 8:45 AM]
  - + The route will be driven by Steve and Mike to stop the sampling and retrieve the sampling systems for the Ambient site station
  
- \* Sample Retrieval/Archival/Data Collection [9:00 to 11:00 AM]
  - + All sampling filters, cartridges, tubes, and canisters will be removed and placed in their respective storage/shipping containers

**Thursday, PM, 2/27**

- \* In-Vehicle Sample/Data Collection Preparation [2:30 to 4:00 PM]
- \* Roadside/Ambient Sample/Data Collection Preparation [2:30 to 3:50 PM]
- \* Roadside/Ambient Site Sampling Initiation [3:50 to 4:10 PM]
- \* Commute Initiation [4:00 PM]
- \* Mid-Commute [4:50 to 5:10 PM]
- \* Commute Completion [6:00 PM]
- \* Roadside/Ambient Site Sampling Completion [5:50 to 6:10 PM]
- \* Sample Retrieval/Archival/Data Collection [6:30 to 8:30 PM]
- \* Charles to leave Sacramento

**Friday, AM, 2/28 [Sampling Day 3: Freeway/High AER/Roadside Monitoring]**

Repeat Thursday, AM, 2/27, w/ Roadside Monitoring:

- + Change all batteries in particle sampling pumps prior to sampling

**Friday, PM, 2/28**

Repeat Thursday, PM, 2/27 w/ Roadside Monitoring:

**Saturday, AM, 3/1 [Sampling Day 4: Rural Commutes/Low AER/no Roadside Monitoring]**

Repeat Wednesday, AM, 2/26, w/o Roadside Monitoring; start time not critical. A staging area (starting point where car can be parked and samplers serviced) must be identified.

- \* Add an in-vehicle VOC sample collection with the car standing and OFF to determine if out-gassing from unidentified sources are affecting the inside collections.
- \* Conduct AER measurements (Low, Medium, and High vent settings) after first commute.
- \* Set-up ambient station at ARB location identified by Steve.:

**Saturday, PM, 3/1**

Repeat Wednesday, PM, 2/26 w/o Roadside Monitoring:

- \* Steve, Charles, Don, Mike and Frank will decide whether sample collections have been "successful" and determine whether an additional AM sampling commute run will be needed on Monday.

**Sunday, 3/2**

A day of rest

**Monday, AM/PM, 3/3 [Special Sampling Day]**

- \* Collect Samples to Replace Lost Samples Days 1 to 4 [6:30 AM to 10:00 AM]



**APPENDIX D**

under-hood fugitive emissions, a modified FID-based CVS sampling system\* was used together with a custom-made stainless steel dilution funnel to sample under-hood air for fugitive leaks, as described previously.\*\* No dilute concentrations in excess of 20 ppmC were observed, which is considered by EPA to be maximum allowable hydrocarbon concentration in "background" air for IM240, i.e., CVS-type testing.\*\*\*

Second, to check for potential fugitive hydrocarbon sources in the passenger compartment, a NDIR-type portable exhaust gas analyzer was used as a "sniffer." No measurable concentrations of hydrocarbons above background levels were detected.

Finally, the vehicle was visually checked for fugitive leaks by an automotive engineer and Qualified Environmental Professional from Sierra. No leaks were found.

### Conclusion

Based on the observations described above and previous test results, it was concluded that Sedan 1 was unlikely to have significant fugitive hydrocarbon leaks that might unduly influence inside or outside sampling.

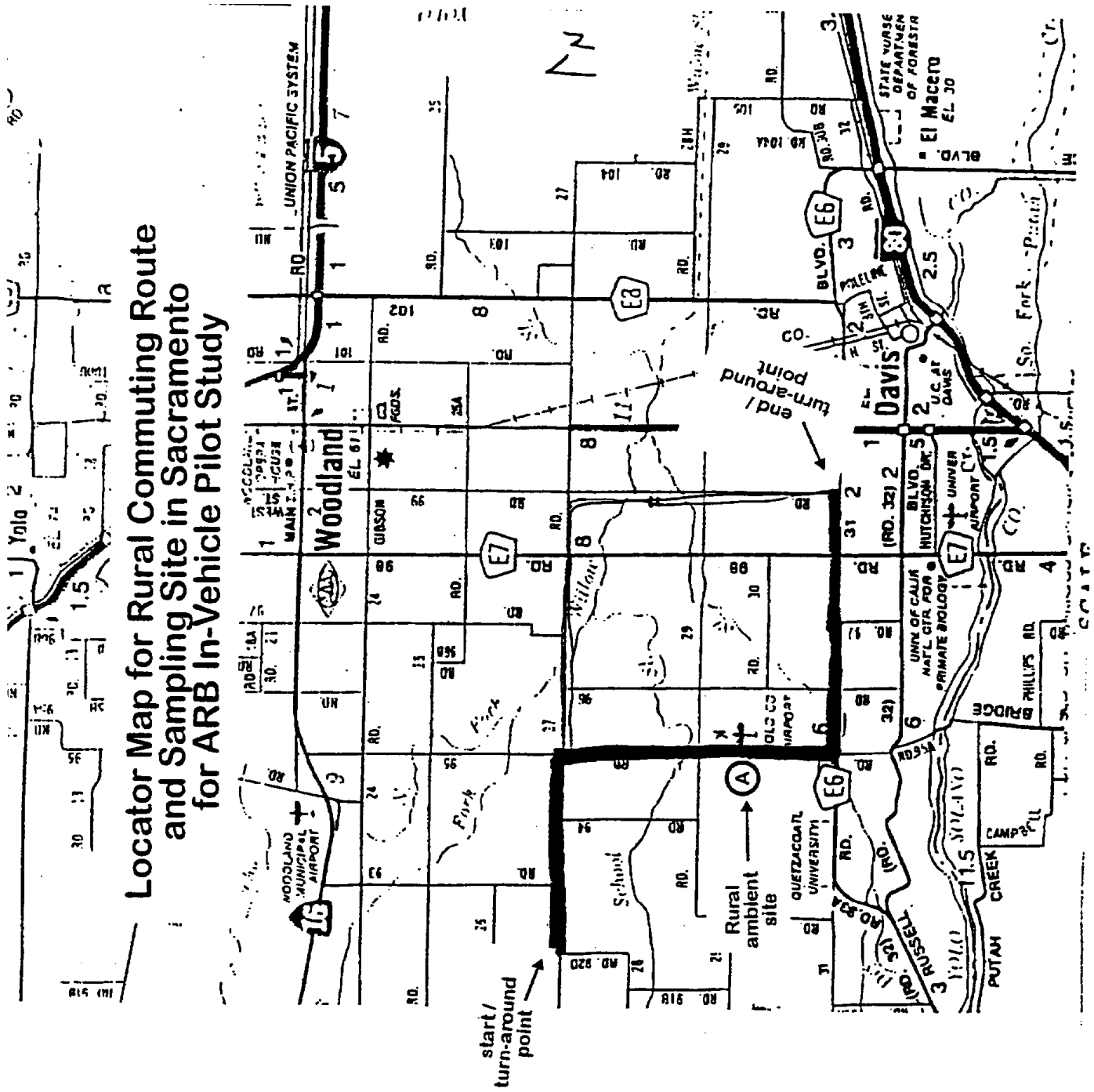
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\* Di Genova, Frank, et al., "The Potential Significance of Motor Vehicle Crankcase Emissions on the Mobile Source Emissions Inventory," presented at the 6th Coordinating Research Council Emissions Workshop, San Diego, CA, March 18-20, 1996.

\*\* Di Genova, Frank, et al., "Alternative Techniques for Detecting Excessive Evaporative Emissions During I/M Tests," SAE Paper No. 962093.

\*\*\* "High-Tech I/M Test Procedures, Emission Standards, Quality Control Requirements, and Equipment Specifications: IM240 and Functional Evaporative System Tests," Revised Technical Guidance, DRAFT, USEPA-AA-RSPD-IM-96-1, June 1996.

# Locator Map for Rural Commuting Route and Sampling Site in Sacramento for ARB In-Vehicle Pilot Study



**APPENDIX F**

February 18, 1997

The approximate locations of the four sampling sites are shown on the attached map. If you have any questions about the sampling locations, please call me. If you have questions about other aspects of the permit application or the project, please call Dr. Rodes at RTI or Mr. Hui at ARB.

cc. Charles Rodes, RTI  
Steve Hui, ARB  
Tira McCann, Caltrans

## Attachment

### California Department of Transportation Standard Encroachment Permit Application

#### Items 1, 2, 3, 4, 6, 7, and 8

The exact locations of the four encroachment locations on the Highway 51 (I-80 business) freeway from the downtown Sacramento J street intersection to the Auburn Boulevard interchange on I-80 (towards Roseville) have not been determined. They are proposed to be approximately equally spaced over this route. These locations will be used to place portable air pollution monitors temporarily for a study under contract to the California Air Resources Board (see Item 22). The exact locations will be selected by February 12, 1997, and provided to the CalTrans encroachment engineer immediately.

#### Item 22.

##### Roadside Air Sampling by the Research Triangle Institute for the California ARB

###### 1. Introduction:

The Research Triangle Institute<sup>1</sup> and its subcontractors, Sierra Research<sup>2</sup>, and Aerosol Dynamics<sup>3</sup> have been awarded a contract by the California Air Resources Board (ARB) in Sacramento, California (contract ARB 95-339, project officer: Steve Hui, ph 916-323-1530) to conduct vehicle occupant air pollution exposure studies while commuting on California freeways. The California Health and Safety Code (HSC) Section 39660.5 requires the ARB to assess human exposure to toxic pollutants. The ARB is also required to identify the relative contribution of indoor concentrations to total exposure, taking into account both ambient and indoor air environments. In order to assess a population's actual exposure to a pollutant, it is necessary to account for exposure in all microenvironments where people spend their time. This requires information on how much time people spend in specific microenvironments and the corresponding air concentration of toxic pollutants in those microenvironments. Although the ARB has representative data on Californian's activity patterns (Wiley et al., 1991a, 1991b), very little pollutant concentration data are available for many microenvironments including vehicle passenger compartments.

The purpose of this study is to measure concentrations of a number of pollutants inside vehicles while they are being driven on California roadways. The results of this study will be used by ARB to determine the need for, and feasibility of, additional in-vehicle pollutant measurements in future studies.

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<sup>1</sup> A not-for-profit research organization established in conjunction with North Carolina State University, Duke University, and the University of North Carolina, comprising approximately 1500 employees and conducting research studies in a broad variety of disciplines. mailing address: contact: Charles E. Rodes, PhD, ph. 919-541-6749, FAX 919-541-6749; P. O. Box 12194, Research Triangle Park, NC 27709.

<sup>2</sup> Sacramento, CA, contact: Frank DiGenova, ph. 916-444-6666

<sup>3</sup> Berkeley, CA, contact Susanne Hering, PhD, ph. 510-649-9360

compounds will require that a special 12 inch in diameter spherical canister (not shown in photo) be suspended just below one side of each shelter.

The experimental plan would consist of selecting the four roadside sites prior to the actual sampling, and the steel posts located and driven into the ground. Just prior to each 2 hour commuting run by the test vehicle, a technician would travel by car to each roadside location, attach an aluminum shelter with operational samplers to each post, start the samplers manually, and signal by cellular phone to begin the 2 hour commute by the test sedan. The technician is expected to be at each right-of-way location (time required to park, attach the shelter to the post, and start the samplers) less than 10 minutes per location. At the conclusion of each commute, the technician would return to each roadside location to remove the aluminum shelter, leaving the steel post for the next commute. The posts would be removed following the fourth commute.

The physical requirements of the four roadside sites are: (1) locations where Highway 51 and I-80 are proceeding in a northeasterly direction, (2) locations that are relatively unobstructed by nearby trees, (3) locations where the samplers can be within 10 to 25 feet of the roadway, and (4) locations where there is adequate space for the technician to safely pull off and park the service vehicle (rental compact sedan). The exact locations of the four roadside sites are currently being determined. Mr. Frank DiGenova of Sierra Research (916-444-6666) will provide the map copies of the four proposed roadside sampling locations to the CalTrans Encroachment Permit Engineer (Ms. Alicia Beyer; ph. 916-741-4408) to complete this application no later than February 12, 1997.

Minimal damage to the ground cover or other flora should occur as a result of the service vehicle pull offs, driving the posts into the ground, or servicing the samplers during the testing. No modifications to the roadside locations are required and no excavations will be performed.

### 3. Sampling Schedule

The proposed sampling schedule for the four Hwy 51/I-80 commutes would be on two selected days during the period from February 26, 1997 thru March 4, 1997. The morning 2 hr commutes would occur sometime during the interval of 6:30 to 10 AM, while the evening 2 hr commutes would occur between 3:30 and 7 PM.

#### Items 25,26,27,28, and 29

Charles E. Rodes, PhD, project engineer  
Research Triangle Institute  
P. O. Box 12194  
Research Triangle Park, NC 27709  
ph. 919-541-6749  
FAX 919-541-6936

**Accomplishments and Problem Areas for the Field Sampling Portion  
of the ARB In-Vehicle Exposure Pilot Study Conducted in Sacramento**

Prepared by C. Rodes, D. Whitaker, M. Roberds, and L. Sheldon  
Research Triangle Institute  
Research Triangle Park, NC 27709  
Revised 4/11/97

**1. Pre-Trip Preparations (RTP)**

**a. Lead-Time for Equipment Design/Procedures Documentation**

Successes

- All specialized equipment was designed, tested and shipped on schedule.

Problem Area

• ARB would like to see procedures/schedules/assignments prepared in more detail and one to three weeks before field sampling starts so they can review and comment.

Comment: We agree that careful planning improves both the data capture rate and the overall data quality. In some cases, however, it is not cost effective to prepare detailed documentation. Additionally, it is sometimes impossible to prepare documentation one to three weeks ahead of time. We will make every attempt to provide these documents in a timely manner for the Main Study.

**b. Manpower Requirements**

Successes

- The individuals and skills identified for design and testing were correct.

Problem Area

• Significantly more man-hours were required to prepare than were budgeted to modify and test the sampling hardware to maximize the probability of success.

Comment: This was partly due to (a) the request by ARB for substantial pre-field documentation that had not been budgeted, (b) discarding the originally planned ball valve Inside/Outside switching arrangement for the manifold as too cumbersome and costly, (c) re-designing the glass manifold to minimize losses, (d) the difficulty in finding an available Chevrolet Caprice matching the subcontractor's vehicle for design purposes, and (e) an underestimation of the amount of logistical pre-planning required for a study with this many elements.

**2. Shipping/Receiving**

Successes

- All equipment arrived intact and on time in Sacramento.
- Very few subsequent FedEx shipments were required to deliver omitted items.

This was a substantial accomplishment, considering the total number of items shipped.



- Access to the Sierra car proved problematical since it could not be left on-site (at the motel) in the evening and could not be driven by RTI personnel.

Comment: The access of RTI personnel (driving, if necessary, and overnight access) should have been a requirement. These items must be addressed for the Main Study.

- Sierra personnel who brought over car were sometimes stranded at the motel.

Comment: The utility/training of the Sierra personnel (driver & navigator) during setup and takedown should be reviewed prior to the Main Study to determine how best to use their time.

- Orientation and training of the Sierra personnel to assist in some of the setup/takedown activities was very limited, since the key RTI personnel were diverted to solving unexpected logistical and power problems.

Comment: A sufficient amount of time must be allotted prior to the Main Study for study participant orientations and training.

- Training of the Sierra personnel to assist in some of the setup/takedown activities was complicated because two different teams were used.

Comment: The number of study participants must be defined prior to the Main Study and the training requirements identified.

#### c. Schedules/Assignments (Daily and Project)

##### Successes

- In general the sampling schedules were comprehensive, such that no samples were lost due to omissions or assignment problems.

##### Problem Area

- Daily routine (morning and evening rush hour sampling in same day was too time consuming with the complex Pilot Study sampling scheme and total number of samples collected.

Comment: The desire to collect data (e.g. relate roadside sampling) at the same time that the methods were being tested and revised proved to be overwhelming. It would have been preferable to have had a lighter AM commute, followed by an intensive PM commute.

#### d. Ambient Site Sampling

##### Successes

- After-hours access to the ARB monitoring site was successfully arranged by Steve Hui and Peggy Jenkins.

##### Problem Area

- The duplicate PAH pumps failed to operate in both attempts. The reasons are still not clear, but appear to be associated with the pump timer.

### g. Time Synchronization

#### Successes

- The LAS-X data system recording flags of 0 (inside) and 1 (outside) during data collection greatly simplified the identification of sampling modes.

#### Problem Areas

- The Aethalometer data proved cumbersome to match with the LAS-X data, since its results were recorded on a separate data system.

Comment: Consideration should have been given to merging the Aethalometer output into the LAS-X data system..

- The synchronization of Roadside and Ambient sampling with the In-Vehicle sampling proved difficult.

Comment: It is still not clear how closely these sampling time windows should coincide.

- The synchronization of video with the In-Vehicle sampling proved difficult.

Comment: The video clock and the on-board computer clock should be made to agree within 10 seconds.

### h. Communications

#### Successes

- The communications between operators and with the Sierra car (in-transit) worked well with the cellular phones.

#### Problem Areas

- The planned sit-down all-hands meeting was never held so that major sampling problems could be resolved within the demanding time schedule.

Comment: This meeting should definitely be scheduled for the Main Study in both locations to make sure that the important elements of logistics and training are understood by all participants.

- The ability to contact the Sierra driver and navigator was problematical when a decision was made late in the evening concerning a revisions of the sampling schedule for the morning commute.

Comment: Home phone numbers should have been collected.

## 4. Work Spaces

### a. Motel

#### Successes

- The location of the motel at the end of the commute run was time efficient.

Comment: At least 1/3 of the weighings had to be repeated. It's isn't clear why the balance worked well the other 2/3's of the time, but the re-weighings undoubtedly improved the overall weighing precision.

## 6. Particle Inlet Preparation

### a. Work Space Requirements

#### Successes

- The inlet loadings and unloadings were readily accommodated on the small table in the motel room.

#### Problem Areas

- none

### b. Time Requirements

#### Problem Area

- The PM<sub>10</sub> inlet clamp that was shipped to Sacramento would not readily accommodate the taller PM<sub>2.5</sub> inlets.

Comment: A replacement clamp was FedExed overnight from RTP.

### c. Leaks

#### Problem Area

- The leak problems caused by improperly located sealing rings inside the PM<sub>2.5</sub> caps caused intermittent leak test problems.

Comment: Typically 2 out of 8 of the PM<sub>2.5</sub> inlets required reloading after the leak testing. Attempts to re-position the gaskets in the field were only partially successful. The intermittent leaks caused some erratic flow checks (took longer to setup/takedown) and some samples to be seriously under-collected.

### d. Filter Numbering System

#### Problem Area

- The number system adopted to readily identify field blanks and duplicates was too complicated for such an intensive study.

Comment: Correction of missed-assignments added time to the setup that was unnecessary.

## 7. Calibrations/Checks

### a. Particle Sampler Flows

#### Successes

- Pumps maintained the flowrate within limits, except for one marginal case that appears to be attributed to a leaking inlet rather than a pump problem.

- In general the samplers and flow controllers worked as expected, with battery consumption being low and requiring to changes during the Pilot Study.

- none

#### f. In-Car Manifold Loss Testing

##### Successes

- The losses in the Teflon line were evaluated as compared to a polyethylene line and no line (simulating the Inside sampling).

##### Problem Area

- This was an unplanned test that was conducted after a group discussion on the potential for excessive static charge losses in the Teflon material.

Comment: The losses for the Aethalometer were inadvertently not determined at the same time. The use of polyethylene may have been somewhat detrimental to NO<sub>2</sub> collection.

### 8. Battery Charging

#### a. NO<sub>2</sub> pumps

##### Successes

- The batteries charged as planned.

##### Problem Areas

- None

#### b. PAH pumps

##### Successes

- The battery inverter/charger system worked well.

##### Problem Areas

- None

#### c. Multi-sorb tube pumps

##### Successes

- The batteries charged as planned.

##### Problem Areas

- None

#### d. Aldehyde pumps

##### Successes

- The batteries charged as planned.

##### Problem Area

- Only one pump stopped prematurely, when it was discovered that the charger had be set in the wrong (trickle) mode.

**Problem Areas**

- The higher than expected AER values for the car required using higher than would have been desired initial CO concentrations to stay within the lower limit (1 ppm) of the CO monitor and collect enough points to construct a decay curve.
- The CO release method does not provide integrated AER data representing the composite AER existing for each 120 minute commute.

**e. Manual Data Entry (Forms)**

**Successes**

- The prepared forms worked well in identifying what was to be collected and when.

**Problem Areas**

- Some streamlining is needed to clean up the spreadsheets (e.g. no PM<sub>10</sub> was collected Outside).
- The sheer volume of forms to be completed and checked significantly increased the length of the day (evenings).

**f. Data File Backups**

**Successes**

- All hard drive data files were backed by floppy drive copies.

**Problem Areas**

- none

**9. Sample Collections**

**a. PM2.5/PM10 Particles**

**Successes**

- No samples appear to have been lost due to sampling problems.

**b. VOC canisters**

**Successes**

- No samples appear to have been lost due to sampling problems.

**Problem Area**

- The inherent flow drop due to reduced vacuum at the end of each sampling period may prove difficult to address.

**Comment:** An alternative orifice may be needed for the Main Study.

Problem Areas

- None

Inside, Outside, Roadside & Ambient Site Mass Concentrations

PM2.5 (blank corrected)								
Date	Run	R1	R2	R3	R4	A	I	O
2/26	1	na	na	na	na	58.5	35.4	52.5
2/26	2	na	na	na	na	34.1	63.5	23.8
2/27	1	14.6	14.9	44.3	35.2	6.0	36.3	56.4
2/27	2	27.8	23.4	18.6	6.2	56.4	15.9	44.5
2/28	1	42.9	39.5	22.6	51.1	9.3	27.7	48.9
3/1	1	na	na	na	na	30.6	24.1	13.3
3/3	1	25.7	34.6	void	31.1	54.5	32.3	9.4

Shaded cells indicate that an internal leak was suspected

PM10 (blank corrected)								
Date	Run	R1	R2	R3	R4	A	I	O
2/26	1	na	na	na	na	45.6	63.0	na
2/26	2	na	na	na	na	237.7	76.0	na
2/27	1	53.3	61.8	70.6	78.5	75.1	70.7	na
2/27	2	112.7	72.8	20.9	78.8	48.7	32.8	na
2/28	1	101.2	61.5	78.2	61.3	-18.4	53.6	na
3/1	1	na	na	na	na	28.0	18.4	na
3/3	1	19.5	19.8	62.7	96.2	27.4	84.1	na

Testing that PM2.5 is < PM10								
Date	Run	R1	R2	R3	R4	A	I	O
2/26	AM	-	-	-	-	<10 MQL	ok	-
2/26	PM	-	-	-	-	ok	ok	<2.5 MQL
2/27	AM	<2.5 MQL	<2.5 MQL	ok	ok	<2.5 MQL	ok	-
2/27	PM	ok	<2.5 MQL	<2.5 MQL	<2.5 MQL	<10 MQL	<2.5 MQL	-
2/28	AM	ok	ok	<2.5 MQL	ok	<2.5 MQL	ok	-
3/1	midday	-	-	-	-	<10 MQL	<2.5 MQL	<2.5 MQL
3/3	AM	<10 MQL	<10 MQL	>	ok	<10 MQL	ok	<2.5 MQL

Shaded cell indicates PM2.5 is greater than PM10 and both values are above the MQL's

**Background VOCs in Sedan 1**  
**"Grab" Sample - Pilot Study - Sacramento**

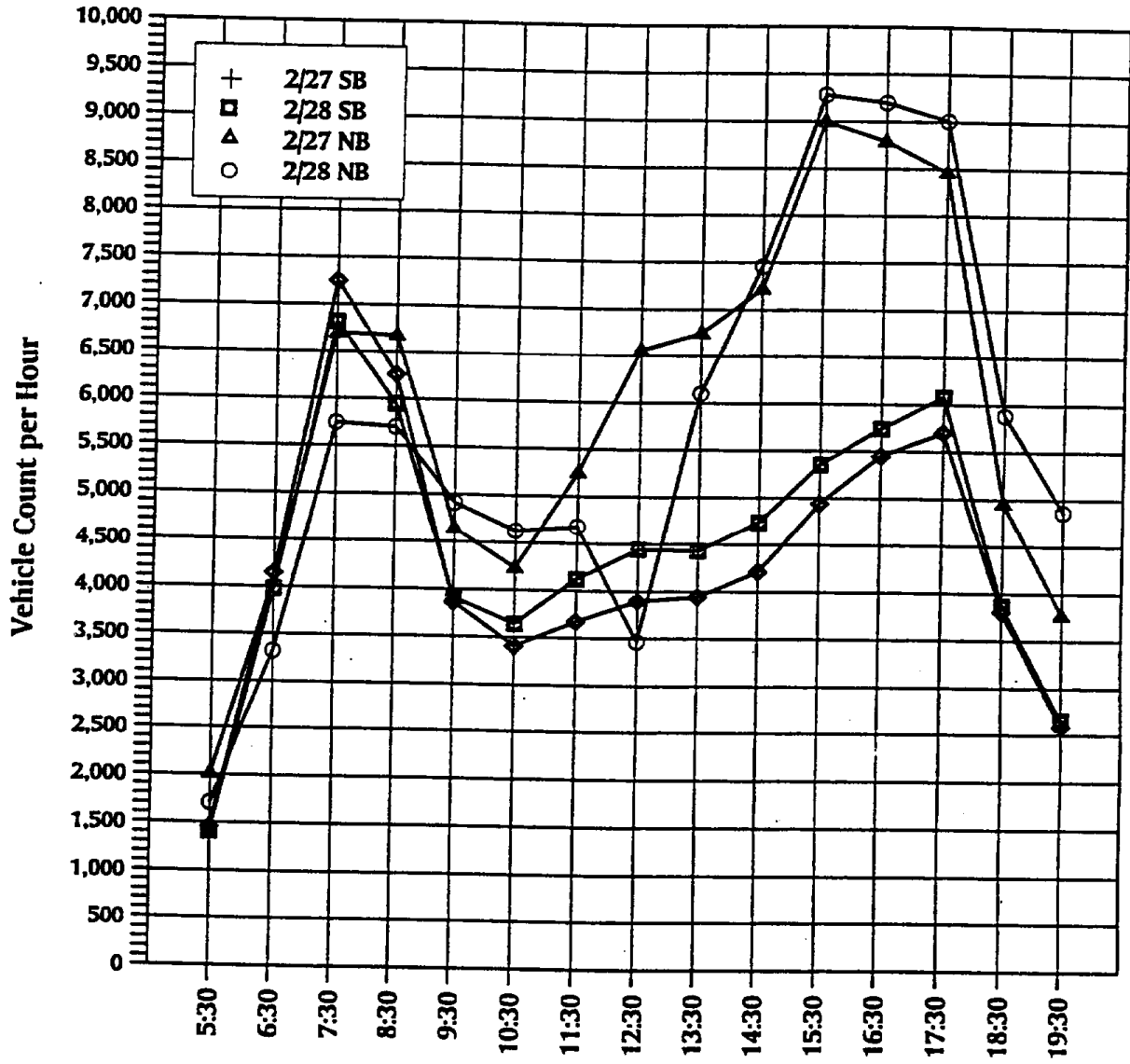
Analyte	Concentration ( $\mu\text{g}/\text{m}^3$ )
1,3-Butadiene	BDL <sup>a</sup>
MTBE	BDL
ETBE	BDL
Toluene	4.4
o-Xylene	1.1
m,p-Xylene	2.6
Benzene	NA <sup>b</sup>

<sup>a</sup>BDL = below detection limit

<sup>b</sup> Not Analyzed



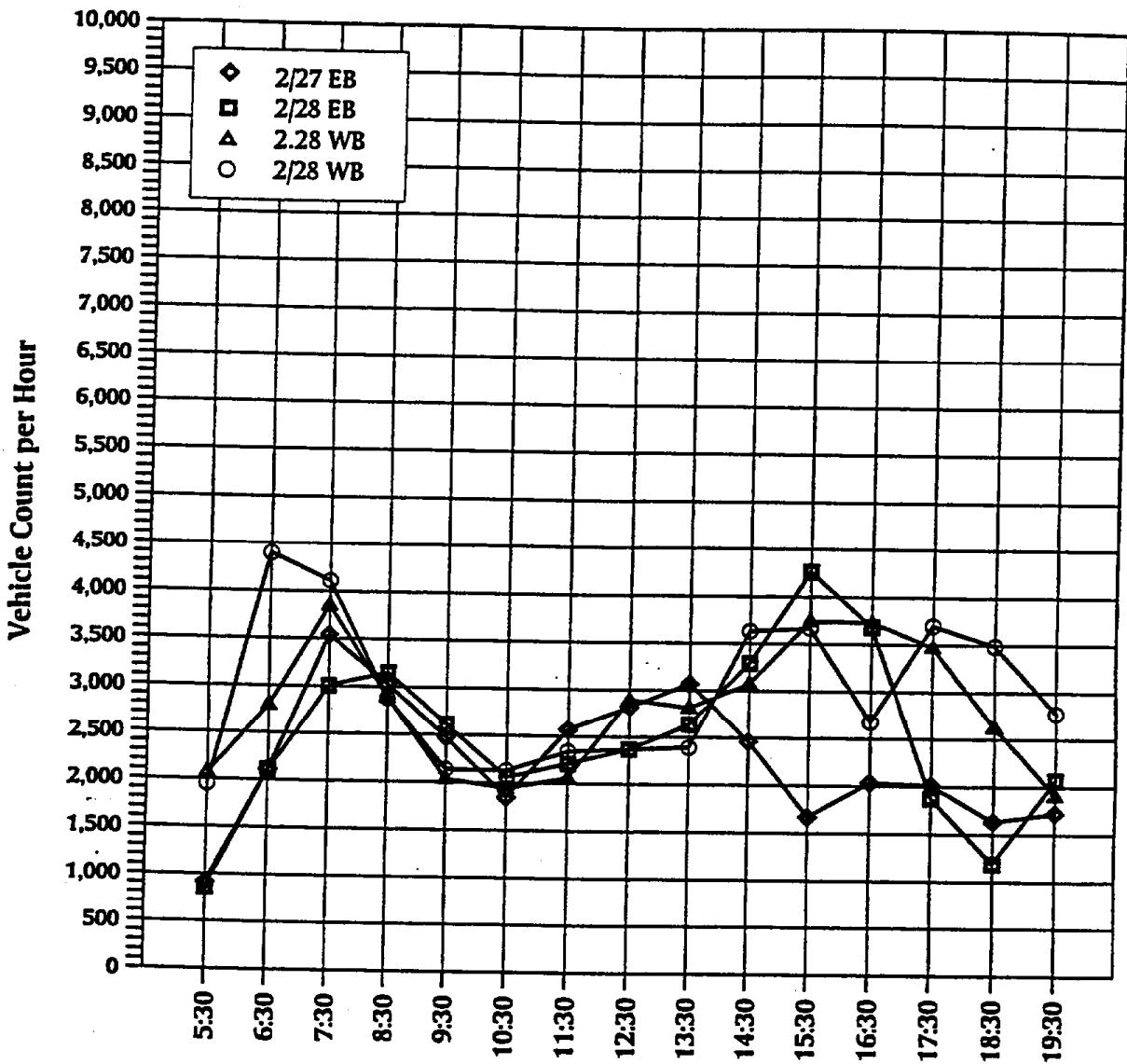
## I 5 at I-Street East and Westbound Traffic Count



file: trafcnt5

Center of 1 hour interval (e.g. 5:30 reps 5:00 to 6:00)

## I 80 at Raley Blvd. East and Westbound Traffic Count



file: trafcnt4

Center of 1 hour interval (e.g. 5:30 reps 5:00 to 6:00)

**Appendix B**

**ARB Fuel Analysis Results**

## Appendix B : Fuel Analysis Results

During the main study, field staff collected samples of the gasoline that they used to refuel the test vehicles. The purpose of the sample collection was to find out whether the content of the important oxygenate and aromatics in the gasoline were in normal concentration ranges. The samples were sent to the Air Resources Board for chemical analysis. The analysis was performed for four chemicals: MTBE, benzene, toluene, and *m,p*-xylene. The results of the analysis are listed in the table below. Based on the results, the mass percentage of these fuel chemicals in all the samples were within the normal range. Therefore, the fuel used to power the test vehicles for this study should not have an above-normal impact on the air measurements of these chemicals inside or just outside the vehicles.

Test Vehicle Fuel Content Analysis  
(Mass %)

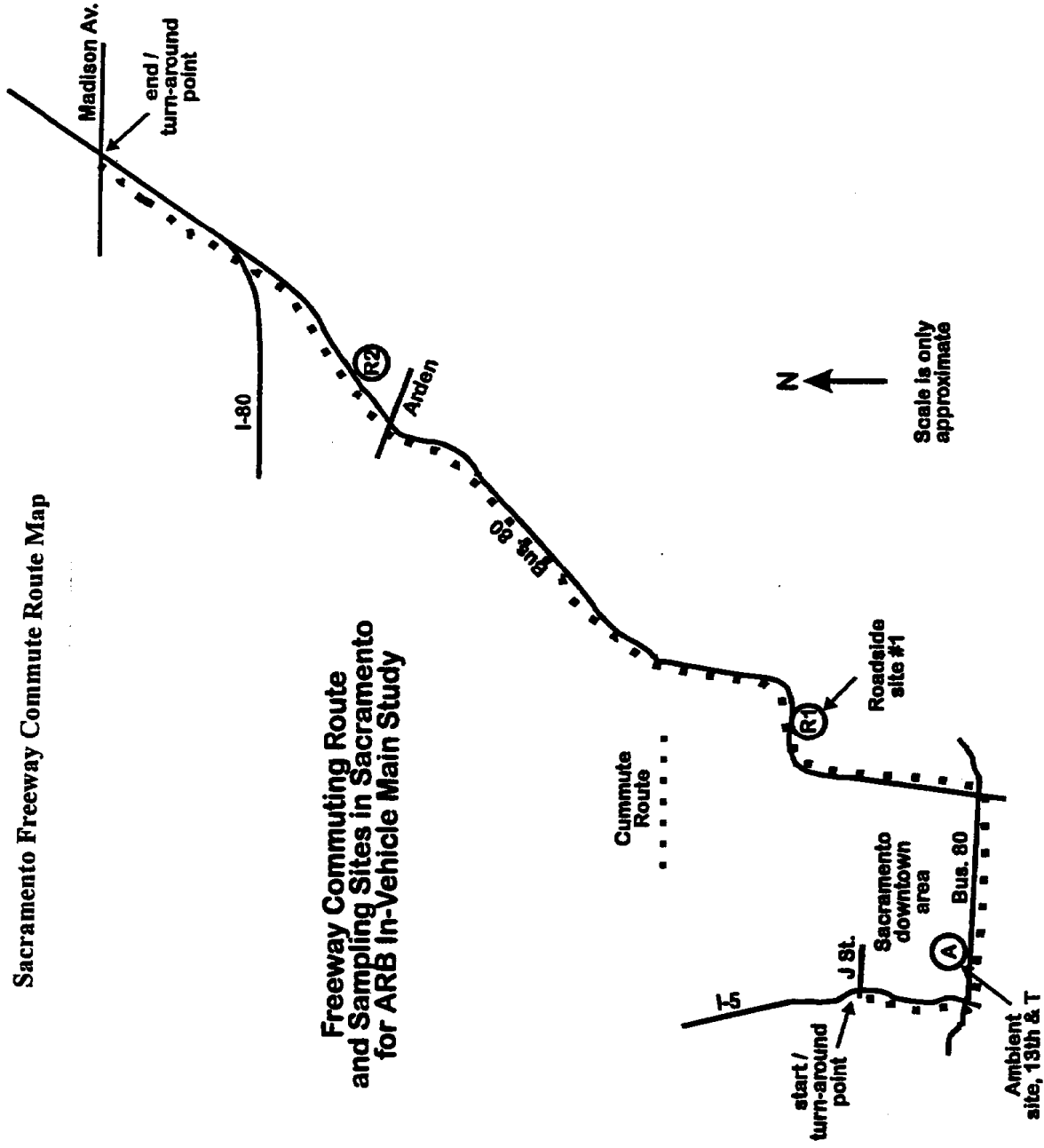
City	Vehicle	Sample date	MTBE	Benzene	Toluene	<i>m,p</i> -Xylene
Sacramento	Caprice	9/8/1997	11.39	0.74	6.51	6.43
	Caprice	9/10/1997	10.18	0.73	7.12	5.10
	Caprice	9/12/1997	10.98	0.78	5.87	5.87
	Caprice	9/13/1997	10.65	0.76	8.46	5.91
	Taurus	9/10/1997	10.14	0.73	7.13	5.09
	Taurus	9/12/1997	10.95	0.77	5.88	5.88
	Taurus	9/13/1997	10.64	0.76	8.48	5.80
Los Angeles	Caprice	9/24/1997	11.51	0.80	6.27	6.06
	Caprice	9/26/1997	11.28	0.67	3.41	4.12
	Caprice	9/28/1997	11.28	0.66	3.45	3.94
	Caprice	9/30/1997	11.35	0.67	3.41	4.24
	Caprice	10/1/1997	11.28	0.68	3.42	4.14
	Explorer	9/26/1997	11.23	0.68	3.41	4.02
	Explorer	9/28/1997	11.30	0.67	3.44	4.19
	Explorer	9/29/1997	11.32	0.67	3.41	4.18
	Explorer	10/1/1997	11.25	0.66	3.31	4.04

## **Appendix C**

### **Commute Routes; Roadside and Ambient Site Locations**

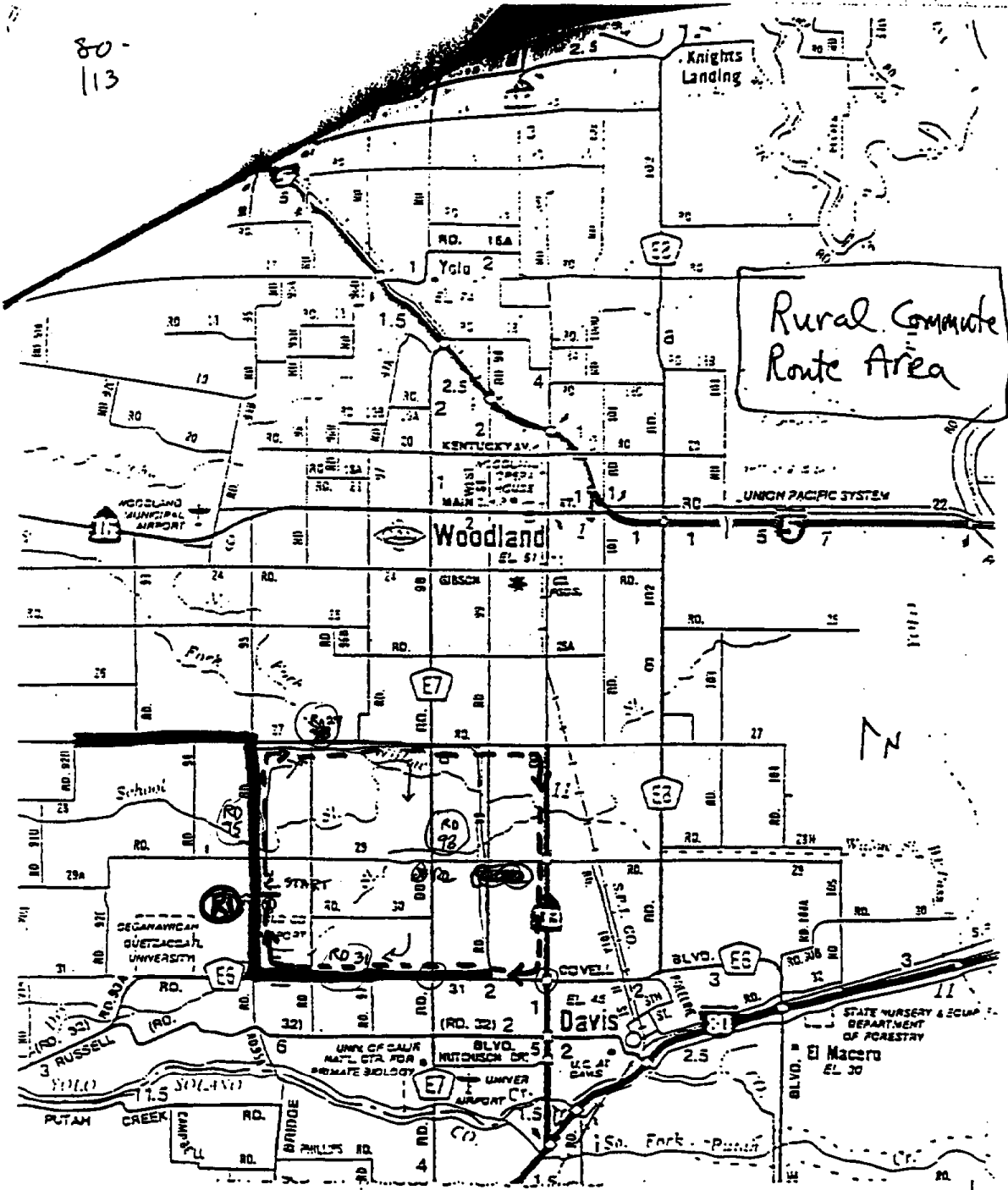
- Sacramento Freeway Commute Route Map
- Sacramento Arterial Commute Route Map
- Sacramento Rural Commute Route Map
  
- Los Angeles Freeway Commute Routes Map
- Los Angeles Arterial Commute Routes Map
  
- Roadside and Ambient Site Locations for Sacramento and Los Angeles

# Sacramento Freeway Commute Route Map



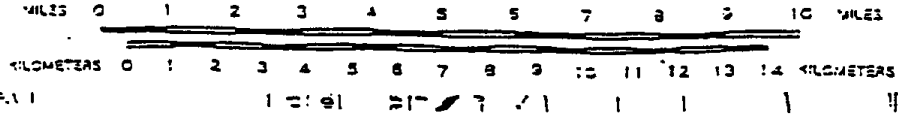
## Freeway Commuting Route and Sampling Sites in Sacramento for ARB In-Vehicle Main Study

80-113

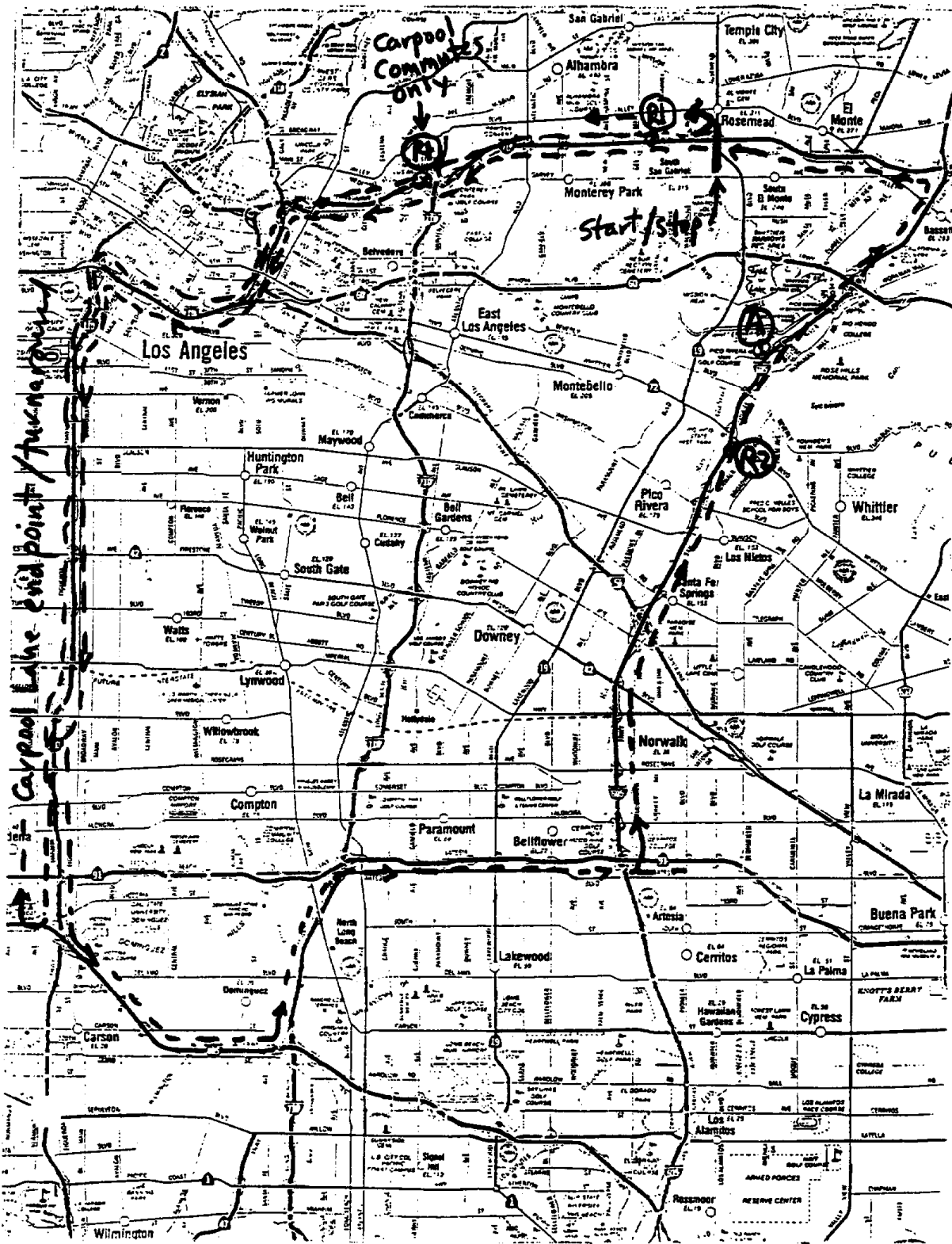


Rural Commute Route Area

SCALE



Sacramento Rural Commute Route Map



PM direction  
shown

Los Angeles Freeway Commute Routes Map



## **Appendix D**

### **Comparison of Study PM<sub>2.5</sub> Samplers with EPA Reference Method**

- Comparison Study Report
- Graphical Comparison of RTI vs EPA FRM PM<sub>2.5</sub> Sampler Data
- RTI PM<sub>2.5</sub> Inlet Comparison with EPA PM<sub>2.5</sub> Federal Reference Method Requirements

August 29, 1997

Peggy Jenkins, Manager  
Indoor Exposure Assessment Section  
Research Division  
California Air Resources Board  
2020 L Street  
Sacramento, CA 95814  
ph. 916-323-1504  
FAX 916-322-4357

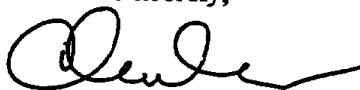
Peggy,

Attached is the data and a brief summary report for the leak test/field evaluation of the eight refurbished PM<sub>2.5</sub> inlets that were used in the Pilot Study. We revised the manual leak test procedure, showed that all inlets passed the test, and (more importantly) demonstrated an excellent collocated precision and accuracy under field conditions.

The revised leak test procedure uses a modified pump that applies a maximum of 12 inches of water across the inlet (rather than running the pump uncontrolled at ~3 inches of Hg). The normal pressure drop across the filter is only 2 to 3 inches of water. Adding too much vacuum potentially can distort the internal seals and was not a realistic test. The procedure has been added to the Field Operations manual.

We followed the experimental plan FAXed earlier, using collocated field exposures for 4 and 8 hour periods. The results are described in the summary. The test also demonstrated the performance of the new 4 LPM pumps and flow controllers to be used in the Main Study.

Sincerely,



Charles E. Rodes, PhD  
Senior Research Environmental Engineer  
Center for Engineering and Environmental Technology

cc: Steve Hui, ARB  
Linda Sheldon, RTI

- Observation: For the 7 acceptable filter samples for the 8-hour collocated inlet comparison, the mean concentration was  $16.3 \mu\text{g}/\text{m}^3$ , the standard deviation was  $\pm 1.5 \mu\text{g}/\text{m}^3$ , and the coefficient of variation was 9.0 %. For the 2 EPA samplers operating at the same time (one failed to operate properly), the mean concentration was  $15.2 \mu\text{g}/\text{m}^3$ , the standard deviation was  $\pm 1.0 \mu\text{g}/\text{m}^3$ , and the coefficient of variation was 6.6 %. The larger total collection averaging  $31 \mu\text{g}$  significantly improved the precision. The MSP standard deviation was only  $0.5 \mu\text{g}/\text{m}^3$  poorer than the much higher flowrate EPA samplers. Assuming the EPA samplers were correct, the MSP accuracies were excellent.

Recommendation: The modified MSP inlets are acceptable for use in the Main Study.

- Observation: Incorporating the filter blank weight changes appeared to bring the MSP concentration data almost exactly in agreement with the EPA reference samplers.

Recommendation: The mean field blank changes should be incorporated into a correction of the filter tare weights (as applied during the Pilot Study), if the corrections are greater than  $2 \mu\text{g}$ .

C. Rodes, RTI, 8/25/97

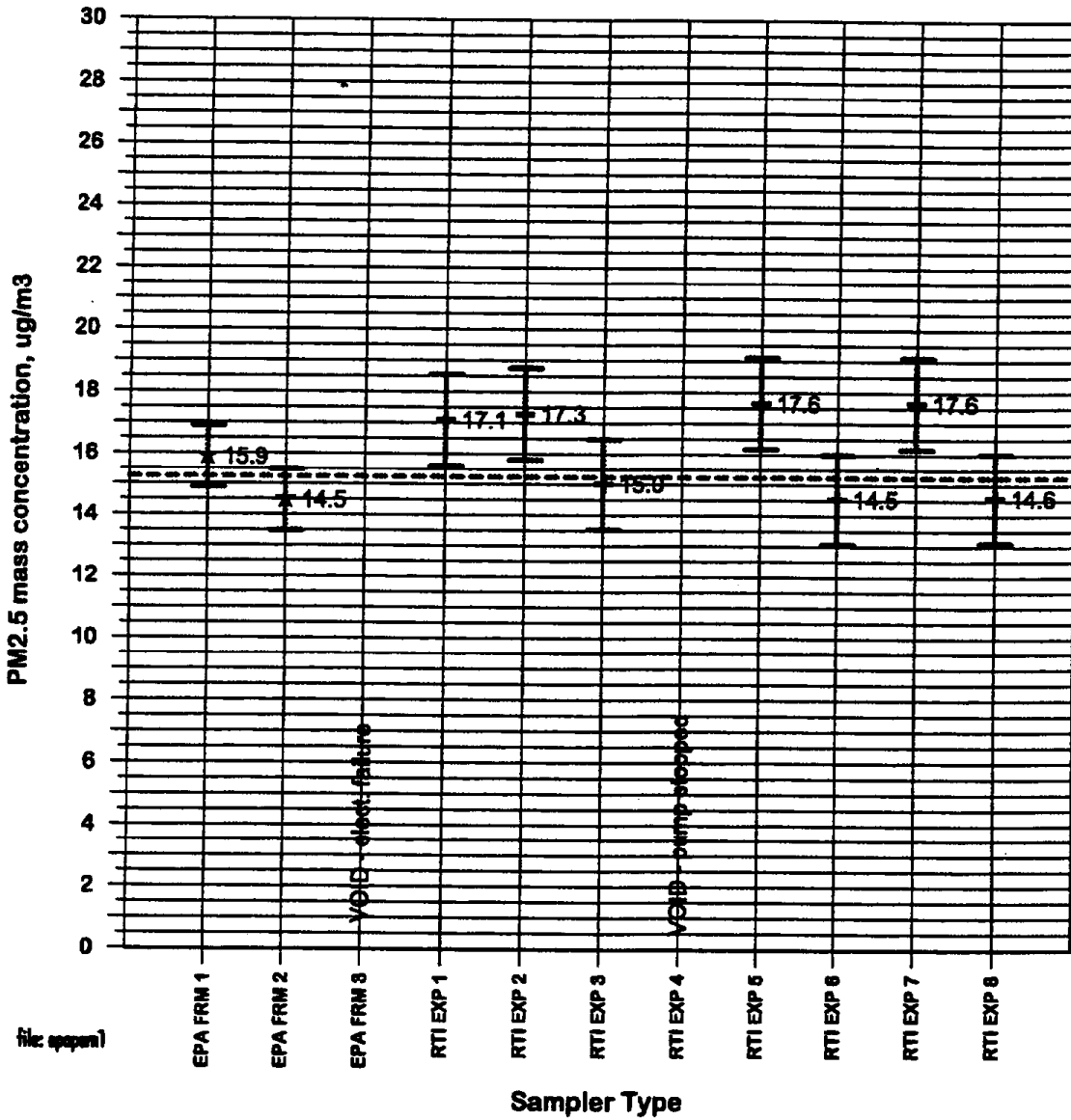
**ARB In-Vehicle Exposure Study**

**Mass collection data**

**Leak Test - Reproducibility Evaluation of 4.0 LPM MSP PM2.5 Inlets**

8/22/97									
	Date	Filter ID#	Filter Pre-wt. gm.	Filter Post-wt. gm.	Collection, ug	Sampled Volume, m3	Sampled Conc., ug/m3	Comments	EPA Data, ug/m3
1	18-Aug	ES01	0.110995	0.111008	13	0.956	13.59	Sample OK	14.25
2	18-Aug	ES02	0.105320	0.105330	10	0.956	10.46	Sample OK	11.75
3	18-Aug	ES03	0.112851	0.112863	12	0.972	12.34	Sample OK	12.50
4	18-Aug	ES04	0.112694	0.112702	8	0.967	8.27	Sample OK	
5	18-Aug	ES05	0.104335	0.104356	21	0.970	21.65	fibers on filter back	
6	18-Aug	ES06	0.101605	0.101623	18	0.961	18.72	fibers on filter back	
7	18-Aug	ES07	0.100209	0.100217	8	0.976	8.20	Sample OK	
8	18-Aug	ES08	0.108744	0.108756	12	0.961	12.48	Sample OK	
	18-Aug	ES09	0.110519	0.110529	10		void	fibers on filter back	
	18-Aug	ES10	0.107874	0.107872	-2		-2.07	equiv. collection	
<b>Notes:</b>									
1. Shaded area concentrations VOID: fiber on back of filter						n:	6		3
2. Statistics computed w/o VOIDs (ES05 & ES06)						mean:	10.89		12.83
3. EPA impactor operated for same time interval,						std. dev.:	2.29		1.28
but at 16.67 LPM						coef. var., %:	21.04		10.00
						max:	13.59		14.25
						min:	8.20		11.75
1	19-Aug	ES11	0.106522	0.106555	33	1.932	17.08	Sample OK	15.88
2	19-Aug	ES12	0.108068	0.108101	33	1.910	17.28	Sample OK	14.47
3	19-Aug	ES13	0.097867	0.097896	29	1.932	15.01	Sample OK	void
4	19-Aug	ES14	0.098262	0.098288	26	void	void	pump stopped	
5	19-Aug	ES15	0.102874	0.102908	34	1.927	17.64	Sample OK	
6	19-Aug	ES16	0.104141	0.104169	28	1.927	14.53	Sample OK	
7	19-Aug	ES17	0.101390	0.101424	34	1.927	17.64	Sample OK	
8	19-Aug	ES18	0.108281	0.108309	28	1.922	14.57	Sample OK	
	19-Aug	ES19	0.114805	0.114807	2		1.04	equiv. collection	
	19-Aug	ES20	0.117463	0.117465	2		1.04	equiv. collection	
						n:	7		2
						mean:	16.25		15.18
						std. dev.:	1.47		1.00
						coef. var., %:	9.04		6.57
						max:	17.64		15.88
						min:	14.53		14.47
Percent Data Capture (2 days): 94 %									

### Comparison of PM2.5 PEM's with EPA FRM PM2.5 Samplers at RTI RTP Field Site




## **Appendix E**

### **Gelman Teflo Filter Background Metals' Analyses**

- RTI Laboratory Report - ICP/MS Analyses for Background Elemental Analyses of ARB Study Gelman Teflo® Filters

Memorandum

To: Dr. Charles Rodes

From: Peter M. Grohse,   
Program Manager, Trace Metals Analyses

Subject: Analyses of Blank Teflo™ Filters

Attached are the trace metal analytical results for 10 blank Teflo™ filters. Procedures conformed to your memorandum accompanying the samples. Please call me if there are any questions at X6897.

**Analytical Results-Filter Analysis**

<b>Filter #</b>	<b>Cr</b>	<b>Mn</b>	<b>Ni</b>	<b>As</b>	<b>Cd</b>	<b>Pb</b>
1	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng
2	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng
3	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng
4	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng
5	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng
6	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng
7	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng
8	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng
9	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng
10	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng

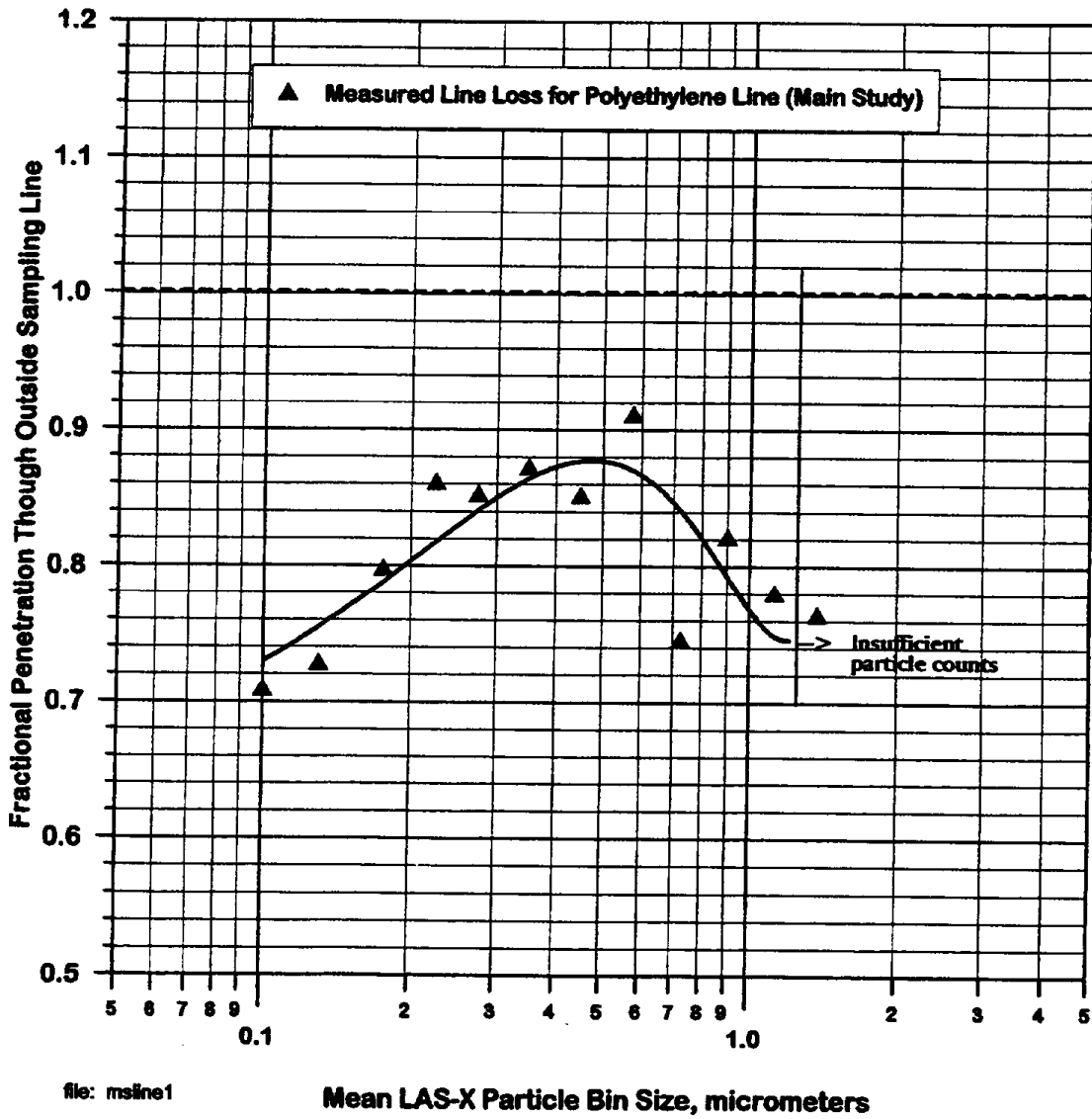


## **Appendix F**

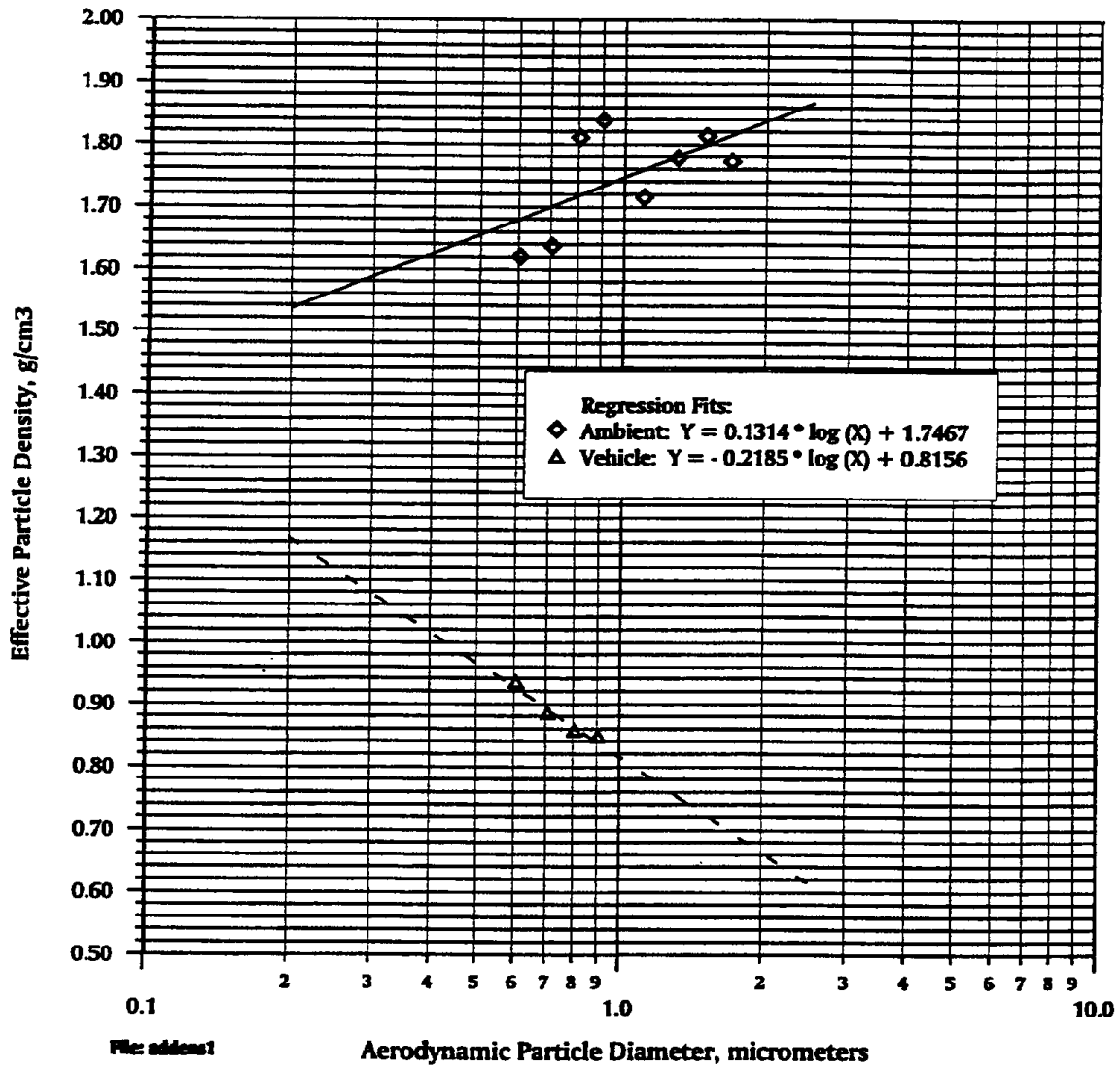
### **Outside Inlet Line Particle Loss Data; LAS-X Calibration Data**

- **Outside Sampling Line Particle Loss LAS-X Data**
- **LAS-X Bin Calibration Data - Aerosol Dynamics**
- **California Ambient and Vehicular Particle Density Data - Aerosol Dynamics**
- **Normalized Number Concentration Version of Figure 4-16**

### In-Vehicle Study Outside Sampling Line Penetration by Particle Size



## Aerosol Dynamics Estimation of Particle Densities by Size Using California Ambient and Vehicular Aerosols



## **Appendix G**

### **Sierra Navigator's Event Logs for Sacramento and LA Commutes**

- **Sacramento Commute Notes**
- **Los Angeles Commute Notes**
- **Commute Start and Stop Times**

# Sierra Research Notes

## Sacramento Caprice Data

Date	Trip Descriptn	Filename	Driver	Start Time	Odometer	End Time	Odometer
09/09/97	FNRH	09090.prn	FDG	09:05	56951.2	11:08	57054.5
09/09/97	FNRH	09092.prn	JML	12:05	57058.8	17:00	57161.7
09/10/97	FRH	09102.prn	JML	05:50	57161.7	10:00	57245.0
09/10/97	FRH	09105&6.prn	FDG	15:58	57245.7	18:00	57301.2
09/11/97	FRH	09111.prn	FDG	06:50	57305.0	08:51	57393.0
09/11/97	FRH	09113.prn	JML	15:59	57394.3	16:27	57407.8
inverter dies, park in lot to repair, no lasx or bc data in second file.							
09/11/97	FRH	09114.prn	JML	16:47	57407.8	18:00	57447.7
09/12/97	AR	0912.prn	RLH	05:30	57449.6	09:04	57498.0
09/12/97	AR	091210.prn	FDG	16:00	57541.3	18:00	57590.0
09/13/97	Rural	09133.prn	FDG	14:02	57624.8	16:03	57731.0
09/13/97	AER	09134.prn	FDG	16:30		16:50	
09/15/97	AR	09152.prn	RLH	05:47	57777.4	08:47	57827.4
09/15/97	AR	09155.prn	JML	16:00	57840.6	17:59	57884.9
09/16/97	SB	09161.prn	DM	07:45	57889.5	09:45	57931.5
09/16/97	SB	09165.prn	DM	13:45	57945.2	15:46	57971.9

### Caprice Notes

09/09/97 PM: diesel truck brake lockup ~15:10-15:15.

Odo 57058.8 start - 57153.2 end

09/12/97 Sacto PM AR/hi

#### second description

2614 emergency vehicle

2834 construction dust

5681 emergency vehicle

5914 construction dust

09/13/97 Rural drive by Davis

start 12:51:08 location Clarion odo 57,599.9

end 13:13:17 Davis>, 1st +C odo 57,615.8

15:33 following LDV but marked as HDD - made correction later (right after we turned into Rd 31).

09/15/97

06:15:13 start time

06:16:12

sec 6379 lot of smoke from HDD bus, sampling outside, confined space, 2 lanes each direction, trees on both sides + overhead.

sec 6839 following '40-'50 vintage Plymouth, LDV smoker, blue smoke, smell.

MRP125 lic. , sampling outside, before and after Morse (st?)

AM Bus

Passengers: Randy, Don, Frank, and Steve Hui.

Weather: Clear, cool ~65 deg. F

Caprice leads the bus.

Bus Odometer: 107439.8 @ 7:45 am

07:45 Start sample, bus idling in front of Abe Lincoln School  
07:46 Other bus pulls away.  
07:47 Idle at curb, door open  
07:50 Smell of diesel in front seat area. Vinyl seats, rubber floor mats.  
07:53 advance 50'  
07:55 many students present, increased veh traffic, still idling with door open, two other buses present and both are idling.  
07:56 another bus departs after 4 minutes.  
08:10 level of activity declining, still a few drop offs occurring  
08:13 Start route, south on Glenmore.  
08:14:10 R on Ellenwood  
08:14:52 L on Routier  
08:16:24 R on Old Placerville  
08:18:08 R on Bradshaw  
08:19:33 R on Business Park Dr.  
08:22:14 Stop for 1 minute by Fite Cir.  
08:23:14 Resume drive  
08:24:05 L on Routier  
08:25:00 R on Folsom  
08:26:12 R on Mather Feild Rd.  
08:26:38 R Mills Station  
08:28:00 Stop on Mills Station, Smell diesel  
08:30:19 L on Routier  
08:32:07 R on Lincoln Village Dr.  
08:33:20 L on Asral  
08:33:29 R on Redstone  
08:34:03 L at Lyra  
08:34:44 Stop at Burline  
08:35:40 Resume  
08:35:56 R on Burline  
08:36:25 Stop by Kobias  
08:37:25 Resume  
08:38:16 L on Granby  
08:39:38 R on Old Placerville  
08:41:05 R on Bradshaw  
08:41:58 R on Lincoln Village  
08:44:43 L on Routier  
08:45:51 R on Rockingham  
08:46:30 R on Glenmore  
08:47:30 Stop at school for 5 minutes with door open, little traffic  
08:52:39 Start repeat of route.  
08:53:37 R on Ellenwood  
08:54:34 L on Routier  
08:55:54 R on Old Placerville

Caprice follows the bus.

13:45:00 Start at 7991 Folsom near Power Inn Rd.  
13:47:20 Start On Ramp from Power Inn Rd. To I50 east  
13:47:53 Start Freeway I50  
13:52:15 Start Off Ramp I50 to Bradshaw south  
13:53:00 On Bradshaw Rd.  
14:00:40 Stop at School and wait  
14:30:15 Leave School  
14:40:15 Start 1 minute service stop on Horn Rd.  
14:47:45 Start 1 minute service stop on Mills Station Rd.  
14:53:30 Start 1 minute service stop on Lyra St.  
14:55:05 Start 1 minute service stop on Burline St.  
15:05:00 Stop and idle at school  
15:14:30 Leave School  
15:24:50 Start 1 minute service stop on Horn Rd.  
15:30:25 Start 1 minute service stop on Mills Station Rd.  
15:37:15 Start 1 minute service stop on Lyra St.  
15:39:00 Start 1 minute service stop on Burline St.  
15:45:00 End data collection - Bus odometer = 107150.0

1

**Sierra Research  
Event Log**

~~XXXXXXXXXX~~

Clock times are specified as PDT. Where shown in seconds, times are from start of data collection.

**9/24/97 Sacramento to LA drive (DM\*)**

- 9:30 leave gas station, odometer 57,988.1, added one quart of oil.  
LASX start at 12:02:28; end at 12:03:27.  
Camcorder 6 seconds ahead of other instruments.  
Zeroth data file is 092497a. First file is 092497p. Second file is 092497d (time was wrong). Third file is 092497x. LASX start 14:14:21; end at 14:15:21.

**9/25/97 am drive (FDG)**

(First column shows number of seconds from start of data collection.)

- Laser not reading reliably, apparently due to rain
- 435 Two car accident on I10 just west of I605 SB\*\* turn, brief slowing  
~600-1000 I605 SB, behind a long line of trucks
- ~723 Two car accident on I605 SB, no slowing
- Note that there is a carpool lane from about Route 72 to Route 91. WB on Route 91 there is a carpool lane.
- 3535 There is a truck scale on I405 WB just east of I110.
- I110 NB, carpool (2 or more) starts at Route 91.
- I110 EB, carpool and bus lane starts near I710

**9/26/97 am (FDG)**

(First column shows number of seconds from start of data collection.)

- Laser range finder was not operable during this run, apparently due to moisture from the previous day

---

\* Observer's initials (DM-Dwight Mitchell, FDG-Frank Di Genova, JML-John Lee, LLW-Lori Williams)

\*\* "SB" means southbound, etc.



**9/28/97 supplemental am run**

- Supplemental am run from Elm, EB on Valley; no videotape made due to short drive

**9/28/97 pm (FDG)**

- 5894 Following Oldsmobile burning oil for ~1 minute on I710 NB
- 6730 Following smelly, smoking tanker truck

**9/29/97 Freeway, rush, heavy duty influence, am drive (JML)**

In this drive, the observer noted carefully the locations of starts and ends for carpool lanes and used switch no. 2 to denote these as follows: 0 no carpool lane, 1 2-person minimum carpool lane, 2 3-person minimum carpool lane and 3 2 carpool lanes (one of these may be a bus lane, which was sometimes indistinguishable from a second carpool lane.)

I605 SB\*

6:48:40 @I5, start

6:53:25 turn off at Route 91

Route 91 WB

6:54:15 Start on Route 91

7:02:00 Transition from Route 91 to I110

I110 SB

7:17:50 Start carpool

7:38:00 End, left I110 to I10

I10 EB

7:45:00 Start at I710 off ramp

7:54:00 End past Rosemead Blvd before turnaround at Santa Anita

I605 SB

8:17:48 Start at I5

**9/29/97 Supplemental am freeway drive (JML)**

---

\* Southbound

- 17:16:30 MTA bus 1340, ethanol  
 17:27:19 MTA bus 4761, CNG, Route 447  
 17:50 Major congestion on Willow due to road construction @ Redondo

**10/2/97 Arterial, rush, a.m., low air-exchange, CCW (LLW)**

- 6:39 Switched to "Norm A/C" switch setting. Was incorrectly set to "Max" prior to this.  
 6:53 Target is cement truck, visible emissions on acceleration.  
 6:58 Target is "other diesel." Strong smell, visible emissions on acceleration.  
 7:22 Target is gasoline truck @ stoplight. Right turn (N) onto Avalon Blvd.  
 7:44:00 Target is small diesel delivery vehicle, Chevrolet 6.2L.. Smelly, but no visible emissions.  
 7:55:38 Entering depressed corridor area on 110 freeway N. (@ Slauson Ave.) Trip odom: 37.2 miles.  
 7:59:31 Exiting depressed corridor area on 110 freeway N. (1 exit before Exposition Blvd.) Trip Odom: 38.4 miles.  
 8:07 Missed left turn from Manchester onto Broadway N. Instead, turned left on Main St., left on 25th St., right on Broadway, heading N.  
 8:07:45 Target is CNG powered MTA bus #4629, route #345.  
 8:11:56 Beginning of "downtown corridor" section.  
 8:13:00 Target is ethanol powered MTA bus #1280, route # 30. Slight smoke visible on acceleration.  
 8:16:25 End of "downtown corridor" @ corner of 1st and Broadway. Trip odom: 52.1 miles.  
 8:19:44 Target is Dash Bus #73, visible smoke on acceleration.  
 8:20:36 Target is ethanol powered MTA bus #1280, route #30.  
 8:24:43 Target is diesel powered MTA bus #8624.

**10/2/97, Supplemental am drive, EB on Valley Blvd to Vagabond Inn parking lot**

- 8:36:20 Target is ethanol powered MTA bus #1470, route #76.

**10/2/97 pm**

- Computer crashed and was restarted during this drive  
 16:12:15-16:12:47 Following MTA bus 2931, diesel with high exhaust on left, light smoke on acceleration

7:20:24 windows up, drive away  
 7:23 enter I10 WB  
 7:27 follow other diesel (we had been following one car behind it for 1-2 miles already)  
 7:28:33 corrected switch setting to middle lane from RH truck lane  
 7:43 exit I10 at 101, Mission  
 7:45 WB at Caesar Chavez  
 7:48 following HDD MTA bus 1122, going SW on North High St., very smokey  
 7:50 right on Temple  
 7:51:12 left onto North Broadway  
 7:51:49 (start of street canyon), SB on Broadway  
 7:56 (end of street canyon) stop at Olympic  
 7:57 (start of 'non street canyon section,' for comparison)  
 8:01:52 left onto 30th St.  
 8:03:18 left onto Main  
 8:03:35 left onto 28th  
 8:04:20 right onto Broadway  
 8:05 paused near 23rd and Broadway waiting for bus 'target'  
 8:06:35 proceeding north on Broadway, no bus targets  
 8:10:45 pause for bus target near 12th  
 8:11:39 following MTA bus 2083, fast idle  
 8:14:53 @8th St.  
 8:18:25 following MTA bus 2041, very smokey, CA plate 079241, been on target but forgot to set target switch  
 8:20:09 continue, no target  
 8:21:30 waiting for bus target  
 8:22:11 resume target, MTA bus 2041, late on target switch, left on Sunset Blvd  
 ~8:24:00-8:24:30 Uphill, following MTA bus 2041, sampling outside, smokey  
 8:28:30 Made right turn, then U turn on Elysian Park  
 8:29:32 Right onto Marion Blvd, headed for I101  
 8:32:28 left on Glendale to I101 SB  
 8:34:42 entering I101 SB  
 8:36:11 I110 SB  
 8:38:14 passing I10 exit  
 8:41:20 60-70 feet behind Honda (could not acquire HDD target)  
 8:44:46 double distance  
 ~8:45 turned onto I105 WB  
 8:48 exit I105 at Crenshaw Blvd  
 8:49:20 EB on I105  
 8:50:33 following other diesel  
 8:51:51 ramp for I110 S  
 8:53 SB on I110  
 8:54:00 new target, other diesel, at 40 feet, smells  
 8:56 I405 SB  
 9:05 I405 SB to I710 NB

16:04:11 MTA bus 2089, lost it in red light, smoker  
16:08:17 MTA bus 8442, very smokey on acceleration, left exhaust  
16:21:40 outside sample during bus acceleration, expect very high concentrations  
16:23:27 end 15 min following of bus  
16:29:46 follow cement truck at about 30 feet in slow traffic  
16:32:30 lost target  
16:34:30 same cement truck at about 60 feet, smoking on acceleration  
16:37:38 resume following at 30 feet  
16:41:52 end following of cement truck  
16:43:40 HDD at 30 feet  
16:46:39 begin following at 60 feet  
16:50:34 end following at 60 feet  
16:58:28 idling at drive thru behind Chevy van

## **APPENDICIES**

**Appendix A.** Pilot Study Report: Measuring Concentrations of Selected Air Pollutants Inside California Vehicles

**Appendix B.** ARB Fuel Analysis Results

**Appendix C.** Commute Routes; Roadside and Ambient Site Locations

**Appendix D.** Comparison of Study PM<sub>2.5</sub> Samplers with EPA Reference Method

**Appendix E.** Gelman Teflo Filter Background Metals' Analyses

**Appendix F.** Outside Inlet Line Particle Loss Data; LAS-X Calibration Data

**Appendix G.** Sierra Navigator's Event Logs for Sacramento and LA Commutes

**Appendix H.** Measurement Data for Individual Commutes

**Appendix I.** Measurement Data for Individual Commutes (Non-Target Elements)

**Appendix J.** Data Treatment Guidelines for Summary Tables

**Appendix K.** Measurement Summary Data for Target Pollutants

**Appendix L.** Ranking of Los Angeles Particle Data for Video Relational Analysis

**Appendix M.** Field Operations Manual for Main Study

**Appendix A**

**Pilot Study Report:  
Measuring Concentrations of Selected Air Pollutants  
Inside California Vehicles**

February 1, 1998

**PILOT STUDY REPORT:  
MEASURING CONCENTRATIONS OF SELECTED AIR POLLUTANTS  
INSIDE CALIFORNIA VEHICLES**

ARB Contract 95-339  
RTI Task 93U-6786-001

prepared by

Charles Rodes, PhD, Linda Sheldon, PhD, Don Whitaker  
Research Triangle Institute  
Research Triangle Park, NC 27709

Frank DiGenova  
Sierra Research  
Sacramento, CA 95814

Susanne Hering, PhD  
Aerosol Dynamics  
Berkeley, CA 94710

prepared for

Steve Hui  
Air Pollution Research Specialist  
California Environmental Protection Agency  
Air Resources Board  
P. O. Box 2815  
2020 L Street  
Sacramento, CA 95812-2815

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This Pilot Study project integrated the technical skills and personnel from a prime contractor, Research Triangle Institute (RTI), and two subcontractors, Sierra Research, Inc. (SR), and Aerosol Dynamics, Inc.(AD). SR provided the mobile sampling platform used in all commutes, on-board instrumentation to measure and record traffic conditions, drivers and a navigator (primary vehicle only) for all vehicles, and rental vehicles. SR also selected the commuting routes used for each phase of the study. AD provided the characterization of “real” California aerosol, calibration of the optical particle counter for these aerosols, and the (leased) Aethalometer for monitoring elemental carbon. AD also provided aerosol monitoring consulting, and assisted in the initial installations of the particle counter and Aethalometer. RTI provided all other equipment and technical services associated with both the Pilot and Main Studies, including the overall study design and project direction, field project direction, field operations technical staff, ICP/MS metals’ analyses (Pilot Study only), automated data collection, analyses and interpretations, quality assurance summaries, and reporting. Staff from ARB assisted in the field operations by providing local logistical coordination, and collecting samples and data from the ambient monitoring sites. SCAQMD provided logistical support in Los Angeles.

Specific individuals contributing to this project included:

**RTI** - Charles Rodes and Linda Sheldon (overall project direction), Don Whitaker (field management), Phil Lawless (filter weighing coordination and automated data collection), Mike Roberds (field operations - Pilot Study), Randy Newsome (sampling equipment design and construction, field operations - Main Study Sacramento), Tyson Mew (field operations - Sacramento), Andy Clayton (data analysis), Doris Smith and Jim Flanagan (quality assurance), Peter Grohse (ICP/MS analyses), Libby Cain (report preparation).

**Sierra Research** - Frank DiGenova (subcontract direction and field support, navigation), John Lee (traffic data collection, driving, navigation), Josh Willter (driving)

**Aerosol Dynamic** - Susanne Hering (subcontract direction, aerosol measurement consulting, and field support), Mark Stolzenburg (aerosol characterization, particle counter calibration, field support), Nathan Kreisberg (aerosol characterization, particle counter calibration, aerosol modeling).

**ARB** - Steve Hui (logistical support in Sacramento collection of ambient monitoring data, sampler assistance - Pilot and Main Studies), Peggy Jenkins (sampler assistance - Pilot Study)



## **Preface**

This report summarizes the field monitoring activities and the data collected from a Pilot Study conducted to assess the capabilities of methodologies for assessing in-vehicle air concentrations in California vehicles for a number of selected pollutants. The report is presented in a bulleted form, rather than a narrative style to focus on the key study design elements that either worked successfully or required consideration and improvement before subsequently implementing the Main Study. Extensive data analyses and inter-comparisons of the concentration data with other vehicular studies is not justified, given the limited number of commuting scenarios and the study design focus on testing and refining methodologies. A separate report summarizing the much more robust Main Study to follow the Pilot Study will focus on characterizing in-vehicle concentration levels.

## **1.0 PROGRAM DESCRIPTION**

### **1.1 BACKGROUND:**

The California Health and Safety Code (HSC) Section 39660.5 requires the California Air Resource Board (ARB) to assess human exposure to toxic pollutants. The ARB is also required to identify the relative contribution of indoor concentrations to total exposure, taking into account both ambient and indoor air environments. In order to assess a population's pollutant exposure, it is necessary to account for the important microenvironments where people spend their time. This requires information on how much time people spend in specific microenvironments and the corresponding pollutant air concentration in those microenvironments. Although the ARB has representative data on Californian's activity patterns (Wiley et al., 1991a, 1991b), very little pollutant concentration data are available for many microenvironments including vehicle passenger compartments.

### **1.2 STUDY DESIGN AND OBJECTIVES**

This overall goal of this program is an in-vehicle air monitoring study primarily for particles and a variety of organic and inorganic chemicals. The results of this program will be used by ARB to determine the need for, and feasibility of, additional in-vehicle pollutant measurements in future studies. The results will also be used by the ARB to improve estimates of current Californian in-vehicle exposures to selected pollutants, and to assess the relative contribution of in-vehicle exposure to total air exposure for these pollutants. In addition, the results may be used to identify actions that driver and passengers may take to reduce their in-vehicle exposures to air pollutants.

Table 1-1 lists the pollutants for monitoring in this program, and notes that some pollutants will be monitored in a Pilot Study only as a range-finding exercise. Primary emphasis was placed on obtaining reliable concentration data for particles and methyl *t*-butyl ether (MTBE). Measurements were obtained during actual commutes, inside passenger vehicles, immediately outside the vehicles, along the roadway where the vehicles travel, and at ambient monitoring sites. Measurements were made using driving scenarios that are likely to produce the full range of probable in-vehicle concentrations, but emphasis was given to scenarios likely to result in high in-vehicle exposures. Table 1-1 also lists the other data that were collected in addition to the chemical measurements and the required driving scenarios specified by ARB.

As a first step in developing a study design, a list of potential research objectives were formulated taking into account ARB's program goals as well as the important factors that can effect in-vehicle pollutant concentrations. These research objectives were finalized based on inputs from the ARB and results of pilot testing. The finalized research objectives were then used to define the data collection requirements and the data analysis approach for the Main Study. The design objectives considered for this program are given in Tables 1-2A and 1-2B organized by factors which can influence in-vehicle air concentrations.

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**TABLE 1-2A. Specific Research Design Objectives Grouped By Factor Type For Both the Pilot and Main Studies**

[Pilot Study (only) Objectives are **bold**; Main Study objectives are in *italics* ]

Methodology

**A1. Demonstrate in a Pilot Study that the measurement techniques selected for each contaminant are capable of meeting the study requirements**

Data Base Development

*B1. Measure the concentrations of selected pollutants ( $PM_{10}$  and  $PM_{2.5}$  particle mass, selected metals, selected VOC's, carbon monoxide, nitrogen dioxide, and selected PAH's) inside and outside California vehicles during commutes consisting of selected scenarios that define an expected range of exposures from "best" to "worst" case.*

Driver Selected Options

*C1. Evaluate the differences between inside and outside vehicle contaminant concentrations and their relationships to 3 driver (or passenger) adjusted ventilation control settings, to provide three air exchange rates (AERs).*

*C2. Evaluate the modification of the particle count and mass size distributions by the ventilation system as a function of 3 driver (or passenger) adjusted air exchange rate in a selected vehicle. [Note: particle count/size distribution measurements were subsequently added to the Main Study]*

*C3. Evaluate the influence of 3 freeway lane positions (carpool, normal, and slow-lane) on in-vehicle concentrations.*

Vehicle Factors

*D1. Evaluate the influence of 4 vehicle types (2 different sedans, a van, and a school bus) on occupant exposure levels.*

*D2. Evaluate the influence of 3 different lead-vehicle types (gasoline, light duty diesel [deleted by technical direction], heavy duty diesel) on occupant exposure levels.*

Roadway Factors

*E1. Evaluate the influence of 3 roadway types (freeway, arterial, and rural) on in-vehicle concentrations.*

*E2. Evaluate the influence of "worst-case" roadway settings (street canyon in LA compared to flat terrain in LA) on in-vehicle concentrations.*

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The program was conducted in two phases. Phase 1 is a Pilot Study; Phase 2 is the Main Study. Work on the Pilot Study was designed to address the following four objectives:

- To evaluate monitoring methods proposed for the Main Study,
- To collect monitoring data in Sacramento for the pollutants and other parameters proposed for the Main Study,
- To collect monitoring data in Sacramento for additional pollutants including real-time measurements for particles and carbon black and integrated measurements for PAH's, and
- To evaluate both method performance data and collected monitoring data to help define/finalize the research objectives and to develop study design for the Main Study.

This report describes the performance of the methods that were used during the Pilot Study. Method results and sample analysis data are then given. We have also provided conclusions drawn from this Pilot Study and have made recommendations for the Main Study.

### 1.3 EXPERIMENTAL DATA CAPTURE MATRIX

The Phase 1 Pilot Study field sampling was conducted from 2/26 to 3/3/97 in the Sacramento, California metropolitan area by the Research Triangle Institute (RTI), and its subcontractors, Sierra Research and Aerosol Dynamics. A total of 7 commutes ( 6 rush-hour freeway and 1 rural ), each lasting approximately 2 hours, were driven using a specially-designed test sedan (a 1991 Chevrolet Caprice) provide by Sierra Research as a mobile sampling platform. The test vehicle was outfitted to collect inside and outside samples and measurements for almost all pollutant (PM<sub>10</sub> and aldehydes were inside only). The inside vehicle measurements were collected near the driver's breathing zone to estimate the exposure concentrations. Outside samples were collected by drawing air from the front of the vehicle at ~ 20 LPM to a distribution manifold inside the car. The typical commute was 80 miles in length at an average speed of 37 mph. The freeway commute hours were 7 to 9 AM (3 commutes) and 4 to 6 PM (3 commutes). The freeway routes were selected based on historically elevated traffic density data. The rural commute was 107 miles at 48 mph.

Simultaneous samples and measurements for most of the same pollutants were collected in the vehicle, at 4 Roadside sites (freeway commutes only), and at the most proximal ARB fixed-site Ambient monitoring station. An access permit had previously been obtained from CalTrans to install and service the 4 Roadway sites at ARB-selected locations along the commuting route. The Roadside sites were located within 20 feet of the pavement, on the west side (predominantly downwind) of freeway. A driving protocol was established to highlight following heavy-duty diesel vehicles, where possible, to estimate maximum commuting pollutant concentration levels.

Three ventilation control settings in the 1991 Caprice were standardized to demonstrate their influence on the air exchange rate in the test car and, more importantly, their influences on-in-vehicle pollutant concentrations. These settings provided low, medium, and high levels of ventilation, with air exchange rates measured at a constants speed of 55 mph to be 39, 98, and 160 air changes/hour, respectively. For the Caprice, High AER was achieved with both front windows approximately 1/3 open, the vent setting open and the fan speed set to medium-high. Medium AER was achieved with all windows closed, the vent setting open and the fan speed set to medium-high. Low AER was achieved with all windows closed, the vent closed (recirculate)



## 2.0 SUMMARY AND RECOMMENDATIONS

### 2.1 METHODOLOGIES

This section summarizes the salient highlights of the Pilot Study methods described subsequently in Sections 3 (Field Monitoring) and 4 (Monitoring Methods). Since a primary objective of the Pilot Study was to evaluate methods, the implications and recommendations for the Main Study [MS], relative to each Pilot Study highlight are summarized. More detailed discussions and recommendations are provided in Sections 3, 4 and 5. A summary of the data highlights are found in the Measurement Data Section (2.2). In order to identify and coordinate all corrective actions needed prior to the Main Study, a summary of critical milestones was prepared and is included in Appendix A.

#### 2.1.1 PILOT STUDY PREPARATIONS

Prior to the commencement of field sampling, a number of activities were completed to enhance the quality and completeness of the collected data.

- Obtaining the encroachment permit from CalTrans to access the Roadside monitors in the Sacramento area required significantly more effort than was expected.  
[MS Recommendation(s): If roadside monitors are used in the Main Study, the same locations should be considered to simplify the permitting process.]
- The design and construction (by RTI) of a special, computer-controlled manifold system permitted both simultaneous and sequential inside and outside vehicle measurements on a 1 minute cycle.  
[MS Recommendation(s): The manifold system worked well and will be used in the Main Study without modification]
- The design and construction (by RTI) of a portable backseat monitoring platform supporting all integrated and continuous monitoring systems and the video camera proved adequate, except for periodic vibrations induced into the video camera.  
[MS Recommendation(s): The platform will be utilized as designed with the exception of the video camera support, which has been replaced by a “steady-cam” mount.]
- The selection (by Sierra Research) of optimum freeway and rural commuting routes that would highlight the range of expected exposure concentrations, while being representative of typical Sacramento commutes.  
[MS Recommendation(s): The same procedures will be follow to select the Main Study commuting routes]
- The calibration (by Aerosol Dynamics) of the PMS LAS-X continuous particle monitor with actual vehicular and ambient calibration aerosols, including characterization of the particle densities by particle size, proved invaluable. These calibration steps greatly enhanced the ability to computed mass concentrations from the particle count data.

- The rural commute with its very low traffic densities substantially taxed the Minimum Quantification Limits for almost all of the methods resulting from the very low pollutant levels. Apparently the emission rates from the exhausts of California gasoline-powered automobiles are currently effectively controlled for the measured pollutant - when the vehicle engine and emission systems are functioning properly. [MS Recommendation(s): The low concentrations observed for all pollutants during rural commutes suggested that a de-emphasis of these situations should be considered. A greater emphasis in the Main Study is being discussed for those scenarios that produce the highest exposures.]
- The 1991 Caprice data collection system with a driver and navigator worked as planned to collect vehicle spacing data, Level of Congestion, vehicle speed, periodic driving diaries, and video records of each commute, but some of the data proved difficult to accurately collect or was not found useful in the data analysis. [MS Recommendation(s): The collection of data using the manual switchbox will be greatly simplified for the Main Study to summarize only Level of Congestion (traffic density categories), freeing the navigator to provide a more detailed diary to accompany each video. The automatic computer collection of vehicle speed and lead-vehicle spacing will be continued.]
- An insurance issue concerning overnight parking security and the personnel authorized to drive the Sierra test sedan complicated the logistics of preparing the vehicle for sampling. [MS Recommendation(s): An agreement between RTI and Sierra Research will be in effect prior to the Main Study to provide insurance coverage for the test vehicle to eliminate these problems]

### 2.1.3 MONITORING METHODS

This section summarizes the performance highlights of the measurement methods for the Main Study. Additional details on the methodologies can be found in Section 4 or the Pilot Study Operation Manual (not presented here).

#### 2.1.3.1 Particle Mass

The collection of PM<sub>2.5</sub> and PM<sub>10</sub> particle samples proceeded smoothly in the field. Subsequent review of the inlet hardware, however, identified defective internal sealing ring problems with some of the PM<sub>2.5</sub> units (not the PM<sub>10</sub>).

- The flow control systems used for 2.0 and 4.0 LPM integrated sampling met specifications. [MS Recommendation(s): No changes will be made for the Main Study in the flow check or flow control set-up procedures. A new single-channel 4.0 LPM pump system will be available for the Main Study to minimize the labor and space required to use the dual channel pumps employed in the Pilot Study.]
- Defective internal sealing rings in several of the PM<sub>2.5</sub> inlet impactors produced random leaks that were not identified properly with the existing leak tests.

### 2.1.3.2 Elemental Analyses

Particle filters were digested for analysis. Digests were analyzed by ICP/MS for Cr, Si, Sr, Br, Ca, Ti, Fe, Zn, and Cu, and by GFAA for Pb, Cd, Ni, and Mn. Ion Chromatography was used for S, P, and Cl analyses. This scheme was a departure from the analysis plan requested of our trace metals laboratory, in that the increased sensitivity of ICP/MS was requested for Pb, Cr, Ni, and Mn. The laboratory substituted GFAA when an instrumental problem arose with the ICP/MS unit in order to meet the analysis schedule. XRF was not used in the Pilot Study, given its higher expected MQL for most metals as compared to ICP/MS and the very low observed particle concentrations.

Results of method controls and method blanks (reagents without filters) suggested that the proposed method (ICP/MS) could be used to analyze for the target elements on the Gelman Teflo<sup>®</sup> filter samples. Instrumental sensitivity, especially for GFAA was not sufficiently low to give high percent measurable for many of the elements including lead, cadmium, nickel, phosphorus, potassium, iron, and bromine. Erratic lab blank levels (reagents with filters) for several metals further increased the detection limits. The number of blank filters analyzed during the Pilot Study (only 2) was inadequate to characterize the background levels, given the sample-to-sample variability observed for some metals, strongly suggesting further work on blank metals' levels is needed.

- Given the altered analysis scheme used by the laboratory, the performance of the ICP/MS could not be evaluated for Pb, Cd, Cr, and Mn.

[MS Recommendation(s): The correct scheme will be followed in the Main Study.]

- The increased cost of ICP/MS over XRF (~ a factor of 3) may not warrant the improvement in detection limit for some metals, given the elevated backgrounds of metals in the Gelman Teflo<sup>®</sup> filters. Elevated and erratic (based on only 2 measurements) background levels were observed for calcium, chlorine, copper, potassium, phosphorus, silicon, strontium, titanium, and zinc. None of these elements was required by the RFP.

[MS Recommendation(s): The number of filters to be analyzed and the analysis method to be applied to the Main Study filters is under discussion. A better understanding of the frequency of elevated background levels in the Gelman filter batch purchased for this study will be addressed by analyzing (at RTI at no-cost to the project prior to the Main Study) at least 10 (versus 2 previously) blank filters for metals by ICP/MS.]

### 2.1.3.3 VOC Canister Method

Overall, the canister method showed good performance for all of the target VOC's.

- Method quantitation limits were sufficiently low to provide high percent measurable for all targets, except ethyl *t*-butyl ether (ETBE). Presumably, ETBE was not in use as a gasoline additive at the time of field monitoring and was, therefore, not present in air samples.

[MS Recommendation(s): No changes will be made in the analysis methodology for the Main Study VOC samples.]

- Recoveries for 1,3 butadiene (76 %) and methyl *t*-butyl ether (78 %) were slightly low which may have been due to prolonged storage of the samples prior to analysis.

[MS Recommendation(s): The 2 ppm MQL is considered acceptable for the Main Study, especially for the higher CO levels from greater traffic densities expected in Los Angeles.]

#### **2.1.3.8 Particle Size Distribution**

Overall the LAS-X particle counter worked well and provided valuable information on real-time particle counts and concentrations. The particle counter's undoubtedly better MQL (estimated to be at least a factor of 5) is difficult to appreciate, since it is not a gravimetrically-based device. The value of a real-time measurement is readily apparent in identifying the contributions of short term events and in the results of mitigation strategies to reduce levels.

- When the on-board power system was functioning properly (adequate voltage level and suitably filtered) in the car, the LAS-X operated smoothly, requiring little attention during sampling and no unplanned maintenance.

[MS Recommendation(s): The limited manpower required to operate the LAS-X combined with its excellent performance supports its inclusion in the Main Study.]

- The LAS-X data analysis and reduction to estimated PM<sub>2.5</sub> concentrations was very labor-intensive.

[MS Recommendation(s): Since the LAS-X data are collected and stored on a computer, the data reduction can be accomplished at a later date, if resources permit. This could be valuable for studying a few selected commutes in the Main Study to highlight the range between minimum and maximum PM<sub>2.5</sub> concentration scenarios.]

- The LAS-X one minute particle count averages correlated strongly with the Aethalometer black carbon analyzer, especially when the car was following a vehicle (gasoline or diesel powered) with a visibly smoking exhaust.

[MS Recommendation(s): The ability of the LAS-X to identify elevated particle exposure levels for single vehicles, supports its inclusion of the LAS-X in the Main Study.]

- The LAS-X one minute computed PM<sub>2.5</sub> mass concentrations provided greater detail during the commute of the actual exposure levels, as compared to the total commute gravimetric, integrated average.

[MS Recommendation(s): If the Main Study particle concentration levels are similar to or lower than those from the Pilot Study, the LAS-X estimated PM<sub>2.5</sub> concentrations may provide the only useable particle data.]

#### **2.1.3.9 Black (Elemental) Carbon**

- When the on-board power system was functioning properly in the car, the Aethalometer operated smoothly, requiring little attention during sampling and no unplanned maintenance.

[MS Recommendation(s): The limited manpower required to operate the units, supports its inclusion in the Main Study, especially since the data analyses are relatively straightforward. Unlike the LAS-X, which is owned by RTI, the Aethalometer would have to be leased from the manufacturer.]



- The interpretation of single events during commutes using the continuous in-vehicle monitoring data proved difficult if careful alignment of the various data collection time clocks (e.g. video, CO data logger, in-vehicle computer, LAS-X logger, and Aethalometer logger) was not accomplished.  
[MS Recommendation(s): Greater care must be taken in the Main Study to synchronize time clocks at the start of each commute within 15 seconds. A time synchronization procedure will be implemented in the Main Study at the kick-off meeting, requiring all time settings (including video camera clock) and data entries to be coordinated with the RTI field manager.]
- The videotapes of the drives provided information on roadway conditions (e.g. barrier walls, cut sections) and target vehicles, however, reviewing the tapes and correlating the events with pollutant levels was very labor intensive.  
[MS Recommendation(s): Videos will be made for each commute during the Main Study and archived for future data/information analyses, if additional resources are available for this activity.]
- The traffic speed and trailing distance (from the vehicle immediately in front) provided useful information on the commutes, however, associating these data with pollutant levels and scenarios was very labor intensive.  
[MS Recommendation(s): These data are collected automatically and will be collected in the Main Study. The amount of data reduced and summarized, however, is still under discussion.]

## 2.2 MEASUREMENT DATA SUMMARY

The individual analytical concentration data for each sample collected are given in Section 5. A summary of the composite means of the six freeway commutes, plus the single rural measurement for comparison, are shown in the extended Tables 2-1A, 2-1B, and 2-1C. These tables have been prepared primarily to simplify the review of the composite concentrations levels from various scenarios. Note that compositing can provide somewhat misleading interpretations, in that the number of observations in each category are small and not necessarily the same. See the footnotes following Table 2-1A describing formats, and the additional explanatory notes following Table 2-1C for clarifying information.

### 2.2.1 General Observations

- Measurements of  $PM_{2.5}$  and  $PM_{10}$  integrated particle concentration for 2-hour periods at 4 LPM and the expected higher concentrations in the Main Study should have (barely) adequate detection limits and precisions to characterize inside and outside exposure levels. The combination of limited data collection in the Main Study and only modest precision of the integrated methods, may make it impossible to readily distinguish the proportion of in-car particle concentrations due to vehicular emissions, as compared to those from the background. The strong performance of the LAS-X monitor in predicting  $PM_{2.5}$  concentrations suggests that it should be seriously be considered for inclusion in the Main Study to collect data. Given the current limitation on resources, however, its inclusion would require (a) minimal effort to make it functional (operate on the Caprice power system), and (b) only limited data analyses and interpretation would be applied.

[MS Recommendation(s): Supplement the optimized gravimetric measurements with the LAS-X computed  $PM_{2.5}$  estimates.]

**Table 2-1B. Summary Table of Measurements Comparing Six Freeway Commutes (Mean) with One Rural Commute (cont'd)**

	Commute	Ambient	Out-Car Mean	In-Car Mean	In-Car Range	Roadside Mean	Roadside Range
<b>PAH's (ng/m3)</b>							
Benzo[b]fluoranthene	Freeway	0.2	0.5	0.2	na	0.5	na
	Rural	0.1	0.3	0.0	na	na	na
Benzo[k]fluoranthene	Freeway	0.1	0.1	0.1	na	0.1	na
	Rural	0.1	0.2	0.0	na	na	na
Benzo[e]pyrene	Freeway	0.1	0.3	0.2	na	0.3	na
	Rural	0.0	0.0	0.0	na	na	na
Benzo[a]pyrene	Freeway	0.1	0.3	0.3	na	0.2	na
	Rural	0.1	0.1	0.1	na	na	na
Indeno[1,2,3-	Freeway	0.2	0.4	0.5	na	0.3	na
	Rural	0.0	0.2	0.1	na	na	na
Benzo[ghi]perylene	Freeway	0.2	0.8	1.0	na	0.6	na
	Rural	0.0	0.2	0.0	na	na	na
<b>PM<sub>1,5</sub> Metals (ng/m3)</b>							
Cadmium (Cd)	Freeway	0.16	0.23	0.09 (0.12)	0.0 - 0.12	0.24	0.0 - 0.46
	Rural	0.0	na	na	na		
Chromium (Cr)	Freeway	103.7	108.0	76 (122)	2.7 - 109	104	76.5 - 114
	Rural	0.0	na	na	na		
Manganese (Mn)	Freeway	14.6	5.6	6.4 (6.1)	.25 - 6.8	2.1	0.2 - 4.0
	Rural	0.0	na	na	na		
Nickel (Ni)	Freeway	0.0	0.0	25 (0.0)	na	10.3	0.0 - 29.0
	Rural	0.0	na	na	na		
Lead (Pb)	Freeway	9.2	7.6	15.7 (7.8)	11 - 24	5.3	3.1 - 9.0
	Rural	0.0	na	na	na		
Sulfur (S)	Freeway	293.3	356.0	342 (274)	231 - 575	299	166 - 392
	Rural	93.0	na	na	na	na	na

See footnotes following Table 2-1A and additional notes following Table 2-1C

- The limited sensitivities of the integrated PM<sub>2.5</sub>, PM<sub>10</sub> and CO methodologies did not permit a realistic determination of the utility of Roadside and Ambient monitoring stations to be used as surrogates to predict in-vehicle concentrations. This may also be true for the Main Study. Where the MQL's were sufficient, the VOC Inside and Outside vehicle concentrations were higher than Roadway, which were higher than those at the Ambient site.

[MS Recommendation(s): Although Roadside measurement gave better indications of the in-vehicle concentrations than did the Ambient station data, the cost-effectiveness of Roadside sampling is still under discussion.]

- If the 1991 Caprice air exchange measurements from the Pilot Study are representative of those determined during the Main Study for the other sedan the Sport Utility Vehicle, and the school bus, the number of commutes using both Low and High exchange rates should be reconsidered. The limited range of influences of air exchange rate from settings Vent 1 to Vent 3 on inside and outside pollutant concentration ratios appears to be insufficient to warrant expending additional resources to impose equal emphasis on both High and Low exchange rate.

[MS Recommendation(s): Emphasizing the High air exchange scenarios, while collecting only limited data for the Low AER, should provide adequate information to characterize the range of exposures..]

- The unexpectedly high particle counts and CO levels detected when following selected vehicles (e.g. most heavy duty diesels (but not all), poorly tuned vehicles, and a diesel school bus) suggests that closely following these vehicles may significantly contribute to in-vehicle concentrations. Although specific vehicle type identification is not part of this effort, subsequent review of video records, compared against continuous monitor data may provide valuable information in assessing exposure mitigation strategies.

[MS Recommendation(s): Continue the driving protocols developed for the Pilot Study, focusing on heavy duty diesels and smoking vehicles.]

- The limited range of influences of air exchange rate from Low to High on inside and outside pollutant concentration ratios appears to be insufficient to warrant expending additional resources to impose equal emphasis on both High and Low exchange rate. Emphasizing the High air exchange, while collecting only limited data for the Low AER, should provide adequate information to characterize the range of exposures. If the 1991 Caprice air exchange measurements from the Pilot Study are generally representative of those determined during the Main Study for the other vehicles, the number of commutes using both Low and High exchange rates should be reconsidered.

### **2.2.2 Specific by Pollutant Category**

At this point in the overall program, the Pilot Study data have been analyzed primarily to validate the methodologies for the Main Study. Only limited observations are presented here as to levels and inter-comparability of the data.

## **APPENDICIES**

**Appendix A.** Pilot Study Report: Measuring Concentrations of Selected Air Pollutants Inside California Vehicles

**Appendix B.** ARB Fuel Analysis Results

**Appendix C.** Commute Routes; Roadside and Ambient Site Locations

**Appendix D.** Comparison of Study PM<sub>2.5</sub> Samplers with EPA Reference Method

**Appendix E.** Gelman Teflo Filter Background Metals' Analyses

**Appendix F.** Outside Inlet Line Particle Loss Data; LAS-X Calibration Data

**Appendix G.** Sierra Navigator's Event Logs for Sacramento and LA Commutes

**Appendix H.** Measurement Data for Individual Commutes

**Appendix I.** Measurement Data for Individual Commutes (Non-Target Elements)

**Appendix J.** Data Treatment Guidelines for Summary Tables

**Appendix K.** Measurement Summary Data for Target Pollutants

**Appendix L.** Ranking of Los Angeles Particle Data for Video Relational Analysis

**Appendix M.** Field Operations Manual for Main Study



## **Appendix A**

### **Pilot Study Report: Measuring Concentrations of Selected Air Pollutants Inside California Vehicles**



February 1, 1998

**PILOT STUDY REPORT:  
MEASURING CONCENTRATIONS OF SELECTED AIR POLLUTANTS  
INSIDE CALIFORNIA VEHICLES**

ARB Contract 95-339  
RTI Task 93U-6786-001

prepared by

Charles Rodes, PhD, Linda Sheldon, PhD, Don Whitaker  
Research Triangle Institute  
Research Triangle Park, NC 27709

Frank DiGenova  
Sierra Research  
Sacramento, CA 95814

Susanne Hering, PhD  
Aerosol Dynamics  
Berkeley, CA 94710

prepared for

Steve Hui  
Air Pollution Research Specialist  
California Environmental Protection Agency  
Air Resources Board  
P. O. Box 2815  
2020 L Street  
Sacramento, CA 95812-2815



### **Disclaimer**

The statements and conclusions in this report are those of the contractor(s) and not necessarily those of the California Air Resources Board. The mention of commercial products, their sources, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

## Acknowledgments

This Pilot Study project integrated the technical skills and personnel from a prime contractor, Research Triangle Institute (RTI), and two subcontractors, Sierra Research, Inc. (SR), and Aerosol Dynamics, Inc.(AD). SR provided the mobile sampling platform used in all commutes, on-board instrumentation to measure and record traffic conditions, drivers and a navigator (primary vehicle only) for all vehicles, and rental vehicles. SR also selected the commuting routes used for each phase of the study. AD provided the characterization of “real” California aerosol, calibration of the optical particle counter for these aerosols, and the (leased) Aethalometer for monitoring elemental carbon. AD also provided aerosol monitoring consulting, and assisted in the initial installations of the particle counter and Aethalometer. RTI provided all other equipment and technical services associated with both the Pilot and Main Studies, including the overall study design and project direction, field project direction, field operations technical staff, ICP/MS metals’ analyses (Pilot Study only), automated data collection, analyses and interpretations, quality assurance summaries, and reporting. Staff from ARB assisted in the field operations by providing local logistical coordination, and collecting samples and data from the ambient monitoring sites. SCAQMD provided logistical support in Los Angeles.

Specific individuals contributing to this project included:

**RTI** - Charles Rodes and Linda Sheldon (overall project direction), Don Whitaker (field management), Phil Lawless (filter weighing coordination and automated data collection), Mike Roberds (field operations - Pilot Study), Randy Newsome (sampling equipment design and construction, field operations - Main Study Sacramento), Tyson Mew (field operations - Sacramento), Andy Clayton (data analysis), Doris Smith and Jim Flanagan (quality assurance), Peter Grohse (ICP/MS analyses), Libby Cain (report preparation).

**Sierra Research** - Frank DiGenova (subcontract direction and field support, navigation), John Lee (traffic data collection, driving, navigation), Josh Willter (driving)

**Aerosol Dynamic** - Susanne Hering (subcontract direction, aerosol measurement consulting, and field support), Mark Stolzenburg (aerosol characterization, particle counter calibration, field support), Nathan Kreisberg (aerosol characterization, particle counter calibration, aerosol modeling).

**ARB** - Steve Hui (logistical support in Sacramento collection of ambient monitoring data, sampler assistance - Pilot and Main Studies), Peggy Jenkins (sampler assistance - Pilot Study)

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## **Preface**

This report summarizes the field monitoring activities and the data collected from a Pilot Study conducted to assess the capabilities of methodologies for assessing in-vehicle air concentrations in California vehicles for a number of selected pollutants. The report is presented in a bulleted form, rather than a narrative style to focus on the key study design elements that either worked successfully or required consideration and improvement before subsequently implementing the Main Study. Extensive data analyses and inter-comparisons of the concentration data with other vehicular studies is not justified, given the limited number of commuting scenarios and the study design focus on testing and refining methodologies. A separate report summarizing the much more robust Main Study to follow the Pilot Study will focus on characterizing in-vehicle concentration levels.

## **1.0 PROGRAM DESCRIPTION**

### **1.1 BACKGROUND:**

The California Health and Safety Code (HSC) Section 39660.5 requires the California Air Resource Board (ARB) to assess human exposure to toxic pollutants. The ARB is also required to identify the relative contribution of indoor concentrations to total exposure, taking into account both ambient and indoor air environments. In order to assess a population's pollutant exposure, it is necessary to account for the important microenvironments where people spend their time. This requires information on how much time people spend in specific microenvironments and the corresponding pollutant air concentration in those microenvironments. Although the ARB has representative data on Californian's activity patterns (Wiley et al., 1991a, 1991b), very little pollutant concentration data are available for many microenvironments including vehicle passenger compartments.

### **1.2 STUDY DESIGN AND OBJECTIVES**

This overall goal of this program is an in-vehicle air monitoring study primarily for particles and a variety of organic and inorganic chemicals. The results of this program will be used by ARB to determine the need for, and feasibility of, additional in-vehicle pollutant measurements in future studies. The results will also be used by the ARB to improve estimates of current Californian in-vehicle exposures to selected pollutants, and to assess the relative contribution of in-vehicle exposure to total air exposure for these pollutants. In addition, the results may be used to identify actions that driver and passengers may take to reduce their in-vehicle exposures to air pollutants.

Table 1-1 lists the pollutants for monitoring in this program, and notes that some pollutants will be monitored in a Pilot Study only as a range-finding exercise. Primary emphasis was placed on obtaining reliable concentration data for particles and methyl *t*-butyl ether (MTBE). Measurements were obtained during actual commutes, inside passenger vehicles, immediately outside the vehicles, along the roadway where the vehicles travel, and at ambient monitoring sites. Measurements were made using driving scenarios that are likely to produce the full range of probable in-vehicle concentrations, but emphasis was given to scenarios likely to result in high in-vehicle exposures. Table 1-1 also lists the other data that were collected in addition to the chemical measurements and the required driving scenarios specified by ARB.

**TABLE 1-1. Study Design Elements**

<p>Pollutants:</p>	<p>PM<sub>2.5</sub> particles,          PM<sub>10</sub> particles, metals,          VOC's (methyl <i>t</i>-butyl ether, ethyl <i>t</i>-butyl ether, 1,3,-butadiene, benzene, toluene, xylenes, ethyl benzene + 5 other VOC's),          CO,          NO<sub>2</sub>,          formaldehyde,          particle size distribution<sup>a</sup>,          black (elemental) carbon<sup>a</sup>,          PAHs<sup>a</sup></p>
<p>Other Measurement:</p>	<p>Vehicle speed,          traffic density (level of congestion),          trailing distance (to vehicle in front)          roadway traffic count (representative),          meteorology (wind speed, wind direction, relative humidity, and temperature);          route/drive characterization</p>
<p>Driving Scenarios:</p>	<p>Freeway - rush          Freeway - rush - carpool          Freeway rush - right lane          Freeway - non rush            Arterial roadway - rush          Arterial roadway - non-rush            Rural roadway            School bus commuting</p>

<sup>a</sup> Proposed for Pilot Study only.

As a first step in developing a study design, a list of potential research objectives were formulated taking into account ARB's program goals as well as the important factors that can effect in-vehicle pollutant concentrations. These research objectives were finalized based on inputs from the ARB and results of pilot testing. The finalized research objectives were then used to define the data collection requirements and the data analysis approach for the Main Study. The design objectives considered for this program are given in Tables 1-2A and 1-2B organized by factors which can influence in-vehicle air concentrations.

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**TABLE 1-2A. Specific Research Design Objectives Grouped By Factor Type For Both the Pilot and Main Studies**

[Pilot Study (only) Objectives are **bold**; Main Study objectives are in *italics* ]

Methodology

**A1. Demonstrate in a Pilot Study that the measurement techniques selected for each contaminant are capable of meeting the study requirements**

Data Base Development

*B1. Measure the concentrations of selected pollutants ( $PM_{10}$  and  $PM_{2.5}$  particle mass, selected metals, selected VOC's, carbon monoxide, nitrogen dioxide, and selected PAH's) inside and outside California vehicles during commutes consisting of selected scenarios that define an expected range of exposures from "best" to "worst" case.*

Driver Selected Options

*C1. Evaluate the differences between inside and outside vehicle contaminant concentrations and their relationships to 3 driver (or passenger) adjusted ventilation control settings, to provide three air exchange rates (AERs).*

*C2. Evaluate the modification of the particle count and mass size distributions by the ventilation system as a function of 3 driver (or passenger) adjusted air exchange rate in a selected vehicle. [Note: particle count/size distribution measurements were subsequently added to the Main Study]*

*C3. Evaluate the influence of 3 freeway lane positions (carpool, normal, and slow-lane) on in-vehicle concentrations.*

Vehicle Factors

*D1. Evaluate the influence of 4 vehicle types (2 different sedans, a van, and a school bus) on occupant exposure levels.*

*D2. Evaluate the influence of 3 different lead-vehicle types (gasoline, light duty diesel [deleted by technical direction], heavy duty diesel) on occupant exposure levels.*

Roadway Factors

*E1. Evaluate the influence of 3 roadway types (freeway, arterial, and rural) on in-vehicle concentrations.*

*E2. Evaluate the influence of "worst-case" roadway settings (street canyon in LA compared to flat terrain in LA) on in-vehicle concentrations.*

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**TABLE 1-2B. Specific Research Design Objectives Grouped By Factor Type For Both the Pilot and Main Studies (cont'd)**

Traffic Factors

- F1. Evaluate the influence of 2 freeway conditions (rush hour and non-rush hour) on in-vehicle concentrations.*
- F2. Evaluate the influence of the average traffic speed (occupant vehicle) and density (visual observation) on in-vehicle concentrations.*
- F3. Evaluate the influence of the average freeway traffic speed and density (closest available CalTrans data) on in-vehicle concentrations.*
- F4. Evaluate the influence of following distance on in-vehicle concentrations.*

Meteorological Factors

- G1. Evaluate the influences of meteorological variables (wind speed, wind direction, temperature, relative humidity and rainfall) on in-vehicle concentrations.*
- G2. Evaluate the influences of selected meteorological variables (wind speed and wind direction) on the associations between roadside (RS) measurements and in-vehicle concentrations.*
- G3. Evaluate the influence of selected meteorological variables (wind speed and wind direction) on the associations between ambient (AM) fixed site measurements and in-vehicle concentrations.*

Temporal Factors

- H1.** Evaluate the influence of weekday versus weekend on in-vehicle concentrations [deleted by technical direction].
- H2. Evaluate the variability of CO and fine particles inside and outside vehicles.*
- H3.** Evaluate the short term temporal variability in particle number and mass size distributions outside and inside a selected test vehicle [Note: particle count/size distribution measurements were subsequently added to the Main Study].

Spatial Factors

- I1. Determine the relationships of inside and outside vehicle concentrations to contemporaneous roadside and fixed-site ambient monitoring locations.*
-

The program was conducted in two phases. Phase 1 is a Pilot Study; Phase 2 is the Main Study. Work on the Pilot Study was designed to address the following four objectives:

- To evaluate monitoring methods proposed for the Main Study,
- To collect monitoring data in Sacramento for the pollutants and other parameters proposed for the Main Study,
- To collect monitoring data in Sacramento for additional pollutants including real-time measurements for particles and carbon black and integrated measurements for PAH's, and
- To evaluate both method performance data and collected monitoring data to help define/finalize the research objectives and to develop study design for the Main Study.

This report describes the performance of the methods that were used during the Pilot Study. Method results and sample analysis data are then given. We have also provided conclusions drawn from this Pilot Study and have made recommendations for the Main Study.

### 1.3 EXPERIMENTAL DATA CAPTURE MATRIX

The Phase 1 Pilot Study field sampling was conducted from 2/26 to 3/3/97 in the Sacramento, California metropolitan area by the Research Triangle Institute (RTI), and its subcontractors, Sierra Research and Aerosol Dynamics. A total of 7 commutes ( 6 rush-hour freeway and 1 rural ), each lasting approximately 2 hours, were driven using a specially-designed test sedan (a 1991 Chevrolet Caprice) provide by Sierra Research as a mobile sampling platform.

The test vehicle was outfitted to collect inside and outside samples and measurements for almost all pollutant (PM<sub>10</sub> and aldehydes were inside only). The inside vehicle measurements were collected near the driver's breathing zone to estimate the exposure concentrations. Outside samples were collected by drawing air from the front of the vehicle at ~ 20 LPM to a distribution manifold inside the car. The typical commute was 80 miles in length at an average speed of 37 mph. The freeway commute hours were 7 to 9 AM (3 commutes) and 4 to 6 PM (3 commutes). The freeway routes were selected based on historically elevated traffic density data. The rural commute was 107 miles at 48 mph.

Simultaneous samples and measurements for most of the same pollutants were collected in the vehicle, at 4 Roadside sites (freeway commutes only), and at the most proximal ARB fixed-site Ambient monitoring station. An access permit had previously been obtained from CalTrans to install and service the 4 Roadway sites at ARB-selected locations along the commuting route. The Roadside sites were located within 20 feet of the pavement, on the west side (predominantly downwind) of freeway. A driving protocol was established to highlight following heavy-duty diesel vehicles, where possible, to estimate maximum commuting pollutant concentration levels.

Three ventilation control settings in the 1991 Caprice were standardized to demonstrate their influence on the air exchange rate in the test car and, more importantly, their influences on-in-vehicle pollutant concentrations. These settings provided low, medium, and high levels of ventilation, with air exchange rates measured at a constants speed of 55 mph to be 39, 98, and 160 air changes/hour, respectively. For the Caprice, High AER was achieved with both front windows approximately 1/3 open, the vent setting open and the fan speed set to medium-high. Medium AER was achieved with all windows closed, the vent setting open and the fan speed set to medium-high. Low AER was achieved with all windows closed, the vent closed (recirculate)



and the fan speed set to "OFF". These ventilation setting scenarios are also designated as Vent 3, Vent 2, and Vent 1, respectively.

The Pilot Study measurements included 2-hour integrated samples ( $PM_{2.5}$  and  $PM_{10}$  particles, VOC's, and  $NO_2$  at all locations, plus PAH's and aldehydes at selected sites). Continuous measurements for CO were made at all locations. Particle size distribution using an optical particle counter (PMS LAS-X) and black carbon data (Aethalometer) were collected inside and outside the car. In order to increase the accuracy of estimated mass concentrations from the particle counter, the unit was calibrated by Aerosol Dynamics using real California vehicular and ambient aerosols. Continuous monitoring data were reduced to 1-minute averages to provide a data base of 120 values for each 2 hour commute. Summaries of the integrated samples and continuous data collected during the Pilot Study are given in Tables 1-3 and 1-4, respectively, defining the sampling matrix employed. The tabular data also indicate a high percentage of valid data collections. More detailed descriptions of the field monitoring and monitoring methods are provided in Sections 3 and 4.

Table 1-3. ARB In-Vehicle Exposure Pilot Study Integrated Sample & Data Capture Matrix													
Integrated Sample Collection													
Sample Type	I	O	Total Outside	Ambient A	R1	R2	R3	R4	All Dups	Total Planned	Total Valid	Total Quest.?	Total Invalid
Particles (2.5u)	8[7]	8[7]	8[7]	8[7]	4	4	4	4	2	42[39]	37	4	0
Particles (10u)	8[7]	----	8[7]	8[7]	4	4	4	4	2	34[32]	32	2	0
VOC's (multisorb)	8[7]	----	8[7]	8[7]	----	----	----	----	2	10[9]	9	0	0
VOC's (canister)	8[7]	8[7]	8[7]	8[7]	4	4	4	4	2	42[39]	40*	0	0
Aldehydes (DNPH)	8[7]	----	8[7]	8[7]	----	----	----	----	2	10(9)	8	0	1
PAH's (quartz filter)	3[4]	3[4]	3[4]	3[4]	----	----	3	----	2	14[15]	13	0	2
NO2 (mol sieve)	16[14]	16[14]	16[14]	16[14]	8	8	8	8	4	84(78)	78	0	0
Notes: The original plan to conduct 6 freeway-influenced commutes and 2 rural commutes was modified by ARB technical direction to include only 1 rural commute													
[N] bracketed number reflects revised number from deleting 1 rural commute and adding 1 PAH sample													
Field blanks and field controls not included in this table.													
Although the Inside and Outside Car samples for 2/26 AM were valid, the car was parked a significant portion of the time													
Only particle samples have been analyzed (for mass only) as of 3/18/97													
*One additional canister sample was collected to assess the car interior and equipment VOC contributions													
Invalidations: 1 aldehyde sample - insufficient battery charge; 2 PAH samples - pump failures													

Table 1-4. ARB In-Vehicle Exposure Pilot Study Continuous Data Capture Matrix													
Continuous Data Collection													
Data Type	Total Outside		Total Ambient A	Total Rdsde 1		Total Rdsde 2		Total Rdsde 3		Total Rdsde 4		Total Invalid	
	I	O		R1	R2	R3	R4	All Dups	Total Planned	Total Valid	Total Questionable		
LAS-X	8[7]	8[7]	----	----	----	----	----	----	----	16[14]	8	2	4
Aethalometer (black carbon) T & Rh in car	8[7]	8[7]	----	----	----	----	----	----	----	16[14]	8	2	4
	8[7]	----	----	----	----	----	----	----	----	8[7]	7	0	0
CO ( Draeger )	8[7]	8[7]	8[7]	4	4	4	4	4	2	42(39)	38	0	1
Notes:	[N] bracketed number reflects revised number from deleting 1 rural commute and adding 1 PAH sample												
	One continuous data entry implies collection of 120 one minute values (one commute)												
	Invalidations: Power failures in the car voided 100% of 2/26 AM & PM LAS-X & Aethalometer data and 25% of 2/27 PM; 1 CO collection lost in download failure												

## 2.0 SUMMARY AND RECOMMENDATIONS

### 2.1 METHODOLOGIES

This section summarizes the salient highlights of the Pilot Study methods described subsequently in Sections 3 (Field Monitoring) and 4 (Monitoring Methods). Since a primary objective of the Pilot Study was to evaluate methods, the implications and recommendations for the Main Study [MS], relative to each Pilot Study highlight are summarized. More detailed discussions and recommendations are provided in Sections 3, 4 and 5. A summary of the data highlights are found in the Measurement Data Section (2.2). In order to identify and coordinate all corrective actions needed prior to the Main Study, a summary of critical milestones was prepared and is included in Appendix A.

#### 2.1.1 PILOT STUDY PREPARATIONS

Prior to the commencement of field sampling, a number of activities were completed to enhance the quality and completeness of the collected data.

- Obtaining the encroachment permit from CalTrans to access the Roadside monitors in the Sacramento area required significantly more effort than was expected.  
**[MS Recommendation(s):** If roadside monitors are used in the Main Study, the same locations should be considered to simplify the permitting process.]
- The design and construction (by RTI) of a special, computer-controlled manifold system permitted both simultaneous and sequential inside and outside vehicle measurements on a 1 minute cycle.  
**[MS Recommendation(s):** The manifold system worked well and will be used in the Main Study without modification]
- The design and construction (by RTI) of a portable backseat monitoring platform supporting all integrated and continuous monitoring systems and the video camera proved adequate, except for periodic vibrations induced into the video camera.  
**[MS Recommendation(s):** The platform will be utilized as designed with the exception of the video camera support, which has been replaced by a “steady-cam” mount.]
- The selection (by Sierra Research) of optimum freeway and rural commuting routes that would highlight the range of expected exposure concentrations, while being representative of typical Sacramento commutes.  
**[MS Recommendation(s):** The same procedures will be follow to select the Main Study commuting routes]
- The calibration (by Aerosol Dynamics) of the PMS LAS-X continuous particle monitor with actual vehicular and ambient calibration aerosols, including characterization of the particle densities by particle size, proved invaluable. These calibration steps greatly enhanced the ability to computed mass concentrations from the particle count data.

[MS Recommendation(s): If the LAS-X is used in the Main Study, the same unit and calibration data will be applied]

### 2.1.2 FIELD MONITORING

The projected collection of 95% valid integrated samples and continuous data was successfully met for all pollutants, except for PM<sub>2.5</sub> gravimetric mass concentrations (see Section 2.1.3.1). In general all of the Pilot Study field monitoring objectives were successfully met. Overcoming some of the unforeseen problems in a timely manner at the outset of sampling, however, required a substantial application of time and intellect by study personnel.

- The successful collection of continuous data inside the test car required a substantial amount of effort and several design corrections to the mobile power system inside the vehicle.

[MS Recommendation(s): If continuous monitors are utilized in the Main Study, a more robust and electrically-filtered power system will be required. A replacement system for the car has been ordered (by Sierra Research to be installed prior to the Main Study.)]

- The attempt to follow specific vehicle types as part of the driving protocol was partially successful, but to a lesser degree than was expected. It often proved difficult to target (move behind) and remain behind a selected vehicle in heavy traffic. In some cases, it was also difficult to determine whether light- and medium-duty vehicles were actually diesel-fueled.

[MS Recommendation(s): The protocol to follow selected vehicle types should be revised to target only heavy duty diesels and visibly smoking automobiles (in that order).]

- The collection of samples at the Roadside and Ambient sites were relatively uneventful, except for the commuting time required to set-up and retrieve the samplers. Measurements at the roadside were significantly higher than the ambient sites, but were much lower than the in-vehicle concentrations. The Roadside site setup labor added significantly to the man-power needed for successful data collection. ARB personnel provided valuable assistance by servicing the Ambient monitoring site.

[MS Recommendation(s): Discussions are currently continuing as to the resources available and the ability of this study design to adequately demonstrate that Roadside monitors can be used to predict in-vehicle pollutant concentrations. The additional labor requirements to deploy and service the Roadside stations, however, influences their cost-effectiveness. The number of Roadway sites to be used in the Main Study is still under discussion.]

- The requirement to change the NO<sub>2</sub> tubes at all sites between hours 1 and 2 to collect hourly data substantially added to the man-power burden needed in the field, especially during heavy traffic periods.

[MS Recommendation(s): ARB has currently determined that the additional information provided by the integrated NO<sub>2</sub> measurements were not cost-effective and has eliminated NO<sub>2</sub> measurements from the Main Study]

- The rural commute with its very low traffic densities substantially taxed the Minimum Quantification Limits for almost all of the methods resulting from the very low pollutant levels. Apparently the emission rates from the exhausts of California gasoline-powered automobiles are currently effectively controlled for the measured pollutant - when the vehicle engine and emission systems are functioning properly. [MS Recommendation(s): The low concentrations observed for all pollutants during rural commutes suggested that a de-emphasis of these situations should be considered. A greater emphasis in the Main Study is being discussed for those scenarios that produce the highest exposures.]
- The 1991 Caprice data collection system with a driver and navigator worked as planned to collect vehicle spacing data, Level of Congestion, vehicle speed, periodic driving diaries, and video records of each commute, but some of the data proved difficult to accurately collect or was not found useful in the data analysis. [MS Recommendation(s): The collection of data using the manual switchbox will be greatly simplified for the Main Study to summarize only Level of Congestion (traffic density categories), freeing the navigator to provide a more detailed diary to accompany each video. The automatic computer collection of vehicle speed and lead-vehicle spacing will be continued.]
- An insurance issue concerning overnight parking security and the personnel authorized to drive the Sierra test sedan complicated the logistics of preparing the vehicle for sampling. [MS Recommendation(s): An agreement between RTI and Sierra Research will be in effect prior to the Main Study to provide insurance coverage for the test vehicle to eliminate these problems]

### 2.1.3 MONITORING METHODS

This section summarizes the performance highlights of the measurement methods for the Main Study. Additional details on the methodologies can be found in Section 4 or the Pilot Study Operation Manual (not presented here).

#### 2.1.3.1 Particle Mass

The collection of PM<sub>2.5</sub> and PM<sub>10</sub> particle samples proceeded smoothly in the field. Subsequent review of the inlet hardware, however, identified defective internal sealing ring problems with some of the PM<sub>2.5</sub> units (not the PM<sub>10</sub>).

- The flow control systems used for 2.0 and 4.0 LPM integrated sampling met specifications. [MS Recommendation(s): No changes will be made for the Main Study in the flow check or flow control set-up procedures. A new single-channel 4.0 LPM pump system will be available for the Main Study to minimize the labor and space required to use the dual channel pumps employed in the Pilot Study.]
- Defective internal sealing rings in several of the PM<sub>2.5</sub> inlet impactors produced random leaks that were not identified properly with the existing leak tests.

**[MS Recommendation(s):** (1) The (manufacturing QC and design) problems with MSP inlets were identified and corrected by the manufacturer, (2) The leak test procedure is being revised (by RTI), (3) The modified inlet design will be operated (by RTI) briefly in side-by-side testing with ambient PM<sub>2.5</sub> monitors to validate the corrections. The modified PM<sub>2.5</sub> MSP inlets are expected to be fully satisfactory for the Main Study]

- The PM<sub>10</sub> MSP sampling inlets functioned acceptably to collect integrated particle samples, except that the flowrate (2.0 LPM) was too low to provide an adequate sample volume and a reasonable MQL in a 2-hour commute.

**[MS Recommendation(s):** Higher flowrate (4.0 LPM) inlets will be provided (by RTI) to double the collected volume and halve the MQL for PM<sub>10</sub> in the Main Study.]

- Weighing the Teflon filter in an air conditioned (but otherwise uncontrolled for temperature and relative humidity) space in the motel work room generally proved adequate to meet the expected detection limit of 2.0 µg/filter, based primarily on the precision of successive weighings of the same filter. This detection limit inexplicably increased, however, to 3.4 µg during the post-weighing period, significantly increasing the MQL for both PM<sub>2.5</sub> and PM<sub>10</sub> samples over a 2-hour commute.

**[MS Recommendation(s):** In order to reduce the MQL as much as possible for the Main Study, every effort must be made to optimize the balance performance. A pre- and post-weighing location that is more temperature controlled and less draft-prone balance environment will be sought for both Sacramento and Los Angeles. ]

- Testing the outside sampling line and the manifold with the particle counter to evaluate ambient particle transport losses as a function of particle size showed that polyethylene tubing material had significantly fewer losses (~10% vs ~20% based on particle count) than the originally proposed Teflon material. The testing also showed that it was feasible to correct the individual LAS-X measurement channel data for the sampling line losses. This calculation is possible for the LAS-X data, since fractional loss information for each portion of the size distribution are available. The outside PM<sub>2.5</sub> particle counts computed from the continuous data were corrected for sampling line losses. The gravimetric PM<sub>2.5</sub> outside measurements, however, should not be corrected in the same manner, given the experimental nature of the LAS-X count to mass conversion. The integrated PM<sub>2.5</sub> loss in the sampling line were estimated to be less than 5%. A summary table will be prepared for the Main Study of the estimated correction factors for the gravimetric outside PM<sub>2.5</sub> mass concentration results for each commute.

**[MS Recommendation(s):** Polyethylene tubing will be retained for the Main Study outside sampling manifold. Loss testing will be repeated, immediately prior to the Main Study to verify the Pilot Study results. Additionally, the line length will be shortened by 1/2 by moving the intake from the front of the grill to the base of the windshield. This should not only reduce (the minimal) losses, but place the line intake closer to the inside ventilation intakes for the vehicles. ARB has decided that the maximum ventilation setting for the Main Study will not utilize an open vehicle window (as did the Pilot Study), thus emphasizing the location of the vent system intakes.]

### 2.1.3.2 Elemental Analyses

Particle filters were digested for analysis. Digests were analyzed by ICP/MS for Cr, Si, Sr, Br, Ca, Ti, Fe, Zn, and Cu, and by GFAA for Pb, Cd, Ni, and Mn. Ion Chromatography was used for S, P, and Cl analyses. This scheme was a departure from the analysis plan requested of our trace metals laboratory, in that the increased sensitivity of ICP/MS was requested for Pb, Cr, Ni, and Mn. The laboratory substituted GFAA when an instrumental problem arose with the ICP/MS unit in order to meet the analysis schedule. XRF was not used in the Pilot Study, given its higher expected MQL for most metals as compared to ICP/MS and the very low observed particle concentrations.

Results of method controls and method blanks (reagents without filters) suggested that the proposed method (ICP/MS) could be used to analyze for the target elements on the Gelman Teflo<sup>®</sup> filter samples. Instrumental sensitivity, especially for GFAA was not sufficiently low to give high percent measurable for many of the elements including lead, cadmium, nickel, phosphorus, potassium, iron, and bromine. Erratic lab blank levels (reagents with filters) for several metals further increased the detection limits. The number of blank filters analyzed during the Pilot Study (only 2) was inadequate to characterize the background levels, given the sample-to-sample variability observed for some metals, strongly suggesting further work on blank metals' levels is needed.

- Given the altered analysis scheme used by the laboratory, the performance of the ICP/MS could not be evaluated for Pb, Cd, Cr, and Mn.

[MS Recommendation(s): The correct scheme will be followed in the Main Study.]

- The increased cost of ICP/MS over XRF (~ a factor of 3) may not warrant the improvement in detection limit for some metals, given the elevated backgrounds of metals in the Gelman Teflo<sup>®</sup> filters. Elevated and erratic (based on only 2 measurements) background levels were observed for calcium, chlorine, copper, potassium, phosphorus, silicon, strontium, titanium, and zinc. None of these elements was required by the RFP.

[MS Recommendation(s): The number of filters to be analyzed and the analysis method to be applied to the Main Study filters is under discussion. A better understanding of the frequency of elevated background levels in the Gelman filter batch purchased for this study will be addressed by analyzing (at RTI at no-cost to the project prior to the Main Study) at least 10 (versus 2 previously) blank filters for metals by ICP/MS.]

### 2.1.3.3 VOC Canister Method

Overall, the canister method showed good performance for all of the target VOC's.

- Method quantitation limits were sufficiently low to provide high percent measurable for all targets, except ethyl *t*-butyl ether (ETBE). Presumably, ETBE was not in use as a gasoline additive at the time of field monitoring and was, therefore, not present in air samples.

[MS Recommendation(s): No changes will be made in the analysis methodology for the Main Study VOC samples.]

- Recoveries for 1,3 butadiene (76 %) and methyl *t*-butyl ether (78 %) were slightly low which may have been due to prolonged storage of the samples prior to analysis.



[MS Recommendation(s):. More rapid turn-(<7 days) around time of canisters will be used in the Main Study, not only to minimize storage losses, but to provide the number of canisters needed for collect all samples.]

#### **2.1.3.4 Nitrogen Dioxide**

- Method performance data indicated that the method was not sufficiently sensitive to reliably measure nitrogen dioxide in 1-hour air samples at the low levels found in the ambient air and in automobile samples. Precision was poor for several field samples that were at or below the method detection limit.

[MS Recommendation(s): NO<sub>2</sub> will not be collected during the Main Study by ARB technical direction.]

#### **2.1.3.5 PAH's**

- Recoveries of target PAH's from method controls and NIST SRM's were good. In addition, recoveries of surrogate standards in all filter samples was acceptable. Levels of PAH's in the single field blank were either very low or not detectable. Unfortunately, PAH's were not measured in any of the samples at concentrations higher than the MQL. Method sensitivity could be increased by a factor of two by increasing the flow rates for the sampling pumps. Alternatively, RTI is acquiring a new GC/MS system that will have much lower detection limits (~0.1 pg/μL) compared to the systems currently in use (5 pg/μL). The feasibility of using this system for analyzing PAH samples could be evaluated. It should be noted however, that the MQL's report for this pilot study (1.0 ng/m<sup>3</sup>) is the same order of magnitude as the 0.9 ng/m<sup>3</sup> level that the California Office of Environmental Health Hazard Assessment suggests is required to cause 10<sup>-6</sup> excess cancer risk over a 70-year exposure period, i.e. the methodology was sufficiently sensitive to suggest that even the highest measured PAH levels in the Pilot Study were below this elevated risk level.

[MS Recommendation(s): No PAH samples are planned for the Main Study.]

#### **2.1.3.6 Formaldehyde**

- Method performance data indicated that the method should provide sufficient accuracy, precision, and sensitivity to measure formaldehyde in automobile air samples in the Main Study.

[MS Recommendation(s): No changes in the aldehyde methodology are required.]

#### **2.1.3.7 Carbon Monoxide**

Method quantitation limits were set at 2 ppm based on information from the instrument manufacturer (Draeger). Results for duplicate monitors showed agreement in 1-hour average readings within the 2 ppm specifications for the elevated inside and outside of vehicle levels.

- Almost all Roadside and Ambient CO concentration readings during the 120 minute commutes were below the MQL in the Pilot Study, producing almost no meaningful data to attempt correlations analyses between inside-vehicle concentrations and the roadside.

[MS Recommendation(s): The 2 ppm MQL is considered acceptable for the Main Study, especially for the higher CO levels from greater traffic densities expected in Los Angeles.]

#### **2.1.3.8 Particle Size Distribution**

Overall the LAS-X particle counter worked well and provided valuable information on real-time particle counts and concentrations. The particle counter's undoubtedly better MQL (estimated to be at least a factor of 5) is difficult to appreciate, since it is not a gravimetrically-based device. The value of a real-time measurement is readily apparent in identifying the contributions of short term events and in the results of mitigation strategies to reduce levels.

- When the on-board power system was functioning properly (adequate voltage level and suitably filtered) in the car, the LAS-X operated smoothly, requiring little attention during sampling and no unplanned maintenance.

[MS Recommendation(s): The limited manpower required to operate the LAS-X combined with its excellent performance supports its inclusion in the Main Study.]

- The LAS-X data analysis and reduction to estimated PM<sub>2.5</sub> concentrations was very labor-intensive.

[MS Recommendation(s): Since the LAS-X data are collected and stored on a computer, the data reduction can be accomplished at a later date, if resources permit. This could be valuable for studying a few selected commutes in the Main Study to highlight the range between minimum and maximum PM<sub>2.5</sub> concentration scenarios.]

- The LAS-X one minute particle count averages correlated strongly with the Aethalometer black carbon analyzer, especially when the car was following a vehicle (gasoline or diesel powered) with a visibly smoking exhaust.

[MS Recommendation(s): The ability of the LAS-X to identify elevated particle exposure levels for single vehicles, supports its inclusion of the LAS-X in the Main Study.]

- The LAS-X one minute computed PM<sub>2.5</sub> mass concentrations provided greater detail during the commute of the actual exposure levels, as compared to the total commute gravimetric, integrated average.

[MS Recommendation(s): If the Main Study particle concentration levels are similar to or lower than those from the Pilot Study, the LAS-X estimated PM<sub>2.5</sub> concentrations may provide the only useable particle data.]

#### **2.1.3.9 Black (Elemental) Carbon**

- When the on-board power system was functioning properly in the car, the Aethalometer operated smoothly, requiring little attention during sampling and no unplanned maintenance.

[MS Recommendation(s): The limited manpower required to operate the units, supports its inclusion in the Main Study, especially since the data analyses are relatively straightforward. Unlike the LAS-X, which is owned by RTI, the Aethalometer would have to be leased from the manufacturer.]

- The expected correlation of the LAS-X and Aethalometer was observed when 1 min averages were compared, but the expected correlation with PAH integrated concentration levels could not be determined from the Pilot Study data because of the low PAH concentrations.

[MS Recommendation(s): The strong correlation with the Aethalometer suggests that the LAS-X could ultimately be used to predict in-vehicle black carbon levels for similar scenarios. Insufficient data were collected during the Pilot Study, however, from which to construct this relationship for the Main Study]

- The Aethalometer readily indicated the presence of smoking gasoline and diesel exhausts (as did the LAS-X), when the Caprice was behind these vehicles. The Aethalometer could be expected to be significantly more sensitive to vehicular soot particles than the non-specific LAS-X particle counts.

[MS Recommendation(s): This capability also supports the inclusion of the Aethalometer in the Main Study, if resources to cover the monthly lease and reduce the data permit.]

#### **2.1.3.10 Air Exchange Rate**

There were no logistical problems with implementing this procedure. There was, however, no way to assess the accuracy of the method. Review of the CO decay rate data showed that a simple 1st order decay model was followed closely by the Pilot Study measurements for all of the ventilation levels.

- The main drawback to the AER method as applied in the Pilot Study was that it represented air exchange rate for a specific vehicle ventilation settings at a specific vehicle speed. Measurements of AER were not made during the test runs to obtain commute averages, thus the composite AER during the test run could be significantly different from those measured at a constant speed. While the measured AER data do not exactly correspond to the conditions during the real commutes, they will be continued in the Main Study to provide a relative indication of ventilation between scenarios.

[MS Recommendation(s): Air exchange rate is a valuable measurement for assessing on a relative basis (at the same constant speed) the inside-to-outside concentration relationships. It will be determined for each test vehicle in the Main Study to determine whether those measured for the Caprice sedan in the Pilot Study were representative of newer vehicles. If resources permit, additional AER measurements will be made over a range of vehicle speeds.]

#### **2.1.3.11 In-Vehicle Traffic Data**

- The switch box procedures for collecting roadway information were cumbersome and time consuming for the navigator. The utility of these data (switch settings used are provided in Appendix B) was not apparent during data analysis and did not justify the extra labor required to collect the data. Most of the information about targets and scenarios was readily captured by the audio and video on the video tape record.

[MS Recommendation(s): Only Level of Congestion data will be recorded by the navigator using the switchbox in the Main Study.]

- The interpretation of single events during commutes using the continuous in-vehicle monitoring data proved difficult if careful alignment of the various data collection time clocks (e.g. video, CO data logger, in-vehicle computer, LAS-X logger, and Aethalometer logger) was not accomplished.  
[MS Recommendation(s): Greater care must be taken in the Main Study to synchronize time clocks at the start of each commute within 15 seconds. A time synchronization procedure will be implemented in the Main Study at the kick-off meeting, requiring all time settings (including video camera clock) and data entries to be coordinated with the RTI field manager.]
- The videotapes of the drives provided information on roadway conditions (e.g. barrier walls, cut sections) and target vehicles, however, reviewing the tapes and correlating the events with pollutant levels was very labor intensive.  
[MS Recommendation(s): Videos will be made for each commute during the Main Study and archived for future data/information analyses, if additional resources are available for this activity.]
- The traffic speed and trailing distance (from the vehicle immediately in front) provided useful information on the commutes, however, associating these data with pollutant levels and scenarios was very labor intensive.  
[MS Recommendation(s): These data are collected automatically and will be collected in the Main Study. The amount of data reduced and summarized, however, is still under discussion.]

## 2.2 MEASUREMENT DATA SUMMARY

The individual analytical concentration data for each sample collected are given in Section 5. A summary of the composite means of the six freeway commutes, plus the single rural measurement for comparison, are shown in the extended Tables 2-1A, 2-1B, and 2-1C. These tables have been prepared primarily to simplify the review of the composite concentrations levels from various scenarios. Note that compositing can provide somewhat misleading interpretations, in that the number of observations in each category are small and not necessarily the same. See the footnotes following Table 2-1A describing formats, and the additional explanatory notes following Table 2-1C for clarifying information.

### 2.2.1 General Observations

- Measurements of  $PM_{2.5}$  and  $PM_{10}$  integrated particle concentration for 2-hour periods at 4 LPM and the expected higher concentrations in the Main Study should have (barely) adequate detection limits and precisions to characterize inside and outside exposure levels. The combination of limited data collection in the Main Study and only modest precision of the integrated methods, may make it impossible to readily distinguish the proportion of in-car particle concentrations due to vehicular emissions, as compared to those from the background. The strong performance of the LAS-X monitor in predicting  $PM_{2.5}$  concentrations suggests that it should be seriously be considered for inclusion in the Main Study to collect data. Given the current limitation on resources, however, its inclusion would require (a) minimal effort to make it functional (operate on the Caprice power system), and (b) only limited data analyses and interpretation would be applied.

[MS Recommendation(s): Supplement the optimized gravimetric measurements with the LAS-X computed  $PM_{2.5}$  estimates.]

Table 2-1A. Summary Table of Measurements Comparing Six Freeway Commutes (Mean) with One Rural Commute

	Commute	Ambient	Out-Car Mean	In-Car Mean	In-Car Range	Roadside Mean	Roadside Range
<b>VOC's (<math>\mu\text{g}/\text{m}^3</math>)</b>							
1,3-Butadiene	Freeway	0.53	2.63	2.57 (0.28) <sup>1</sup>	1.4 - 3.1	1.24	0.83 - 1.63
	Rural	0.0	0.0	0.0 (0.0)		na <sup>2</sup>	na
MTBE	Freeway	3.93	13.00	13.98 (9.03)	8.9 - 19.0	7.22	6.15 - 8.58
	Rural	1.0	1.4	1.6 (0.0)		na	na
ETBE	Freeway	0.0 <sup>3</sup>	0.0	0.0	na	0.0	0.0
	Rural	0.0	0.0	0.0		na	na
Benzene	Freeway	na	na	na	1.7 - 4.6	na	na
	Rural	na	na	na		na	na
Toluene	Freeway	10.17	24.17	26.33 (29.83)	15 - 37	14.62	11.68 - 19.1
	Rural	3.2	4.6	5.8 (5.0)		na	na
<i>m,p</i> -Xylene	Freeway	4.38	15.00	16.83 (18.63)	10 - 21	7.67	5.68 - 9.83
	Rural	1.5	1.8	3.4 (3.3)		na	na
<i>o</i> -Xylene	Freeway	1.85	6.12	6.77 (6.47)	4.3 - 8.1	3.34	3.03 - 4.00
	Rural	0.8	0.9	1.5 (0.0)		na	na
Formaldehyde ( $\mu\text{g}/\text{m}^3$ )	Freeway	na	na	9.5	4.3 - 11.0	na	na
	Rural	na	na	9.6		na	na
PM <sub>10</sub> ( $\mu\text{g}/\text{m}^3$ )	Freeway	43.0	na	63.5	33 - 84	65.8	54.3 - 78.6
	Rural	28.0	na	18.0		na	na
PM <sub>2.5</sub> ( $\mu\text{g}/\text{m}^3$ )	Freeway	50.8	45.2 (49.0)	35.2 (44.6)	16 - 64	31.5	24.8 - 38.0
	Rural	31.0	13.0 (26.0)	24.0 (22.0)		na	na
Carbon ( $\mu\text{g}/\text{m}^3$ )	Freeway	na	5.96	7.08		na	na
	Rural	na	na	1.3		na	na
CO (ppm)	Freeway	0.1, 0.1 <sup>4</sup>	2.7, 2.4	2.2, 1.7		0.4, 0.4	0.2 - 0.9, 0.2 - 0.2
	Rural	0, 0	0, 0	0, 0		na	na
NO <sub>x</sub> (ppb) <sup>c</sup>	Freeway	42.2, 38.0	61.2, 41.0	78.3, 63.5		25.3, 33.5	25.3 - 86.0 17.5 - 51
	Rural	9.0, 5.0	1.0, 1.0	0.0, 29.0		na	na

See table notes following Table 2-1C

<sup>1</sup> values in parenthesis are duplicate analyses; <sup>2</sup> na: not available; <sup>3</sup> 0.0 indicates below MDL; <sup>4</sup> Hour 1, Hour 2

**Table 2-1B. Summary Table of Measurements Comparing Six Freeway Commutes (Mean) with One Rural Commute (cont'd)**

	Commute	Ambient	Out-Car Mean	In-Car Mean	In-Car Range	Roadside Mean	Roadside Range
<b>PAH's (ng/m3)</b>							
Benzo[b]fluoranthene	Freeway	0.2	0.5	0.2	na	0.5	na
	Rural	0.1	0.3	0.0	na	na	na
Benzo[k]fluoranthene	Freeway	0.1	0.1	0.1	na	0.1	na
	Rural	0.1	0.2	0.0	na	na	na
Benzo[e]pyrene	Freeway	0.1	0.3	0.2	na	0.3	na
	Rural	0.0	0.0	0.0	na	na	na
Benzo[a]pyrene	Freeway	0.1	0.3	0.3	na	0.2	na
	Rural	0.1	0.1	0.1	na	na	na
Indeno[1,2,3-	Freeway	0.2	0.4	0.5	na	0.3	na
	Rural	0.0	0.2	0.1	na	na	na
Benzo[ghi]perylene	Freeway	0.2	0.8	1.0	na	0.6	na
	Rural	0.0	0.2	0.0	na	na	na
<b>PM<sub>2.5</sub> Metals (ng/m3)</b>							
Cadmium (Cd)	Freeway	0.16	0.23	0.09 (0.12)	0.0 - 0.12	0.24	0.0 - 0.46
	Rural	0.0	na	na	na		
Chromium (Cr)	Freeway	103.7	108.0	76 (122)	2.7 - 109	104	76.5 - 114
	Rural	0.0	na	na	na		
Manganese (Mn)	Freeway	14.6	5.6	6.4 (6.1)	.25 - 6.8	2.1	0.2 - 4.0
	Rural	0.0	na	na	na		
Nickel (Ni)	Freeway	0.0	0.0	25 (0.0)	na	10.3	0.0 - 29.0
	Rural	0.0	na	na	na		
Lead (Pb)	Freeway	9.2	7.6	15.7 (7.8)	11 - 24	5.3	3.1 - 9.0
	Rural	0.0	na	na	na		
Sulfur (S)	Freeway	293.3	356.0	342 (274)	231 - 575	299	166 - 392
	Rural	93.0	na	na	na	na	na

See footnotes following Table 2-1A and additional notes following Table 2-1C

**Table 2-1C. Summary of Measurements Comparing Six Freeway Commutes with One Rural Commute (cont'd)**

	Commute	Ambient	Out-Car Mean	In-Car Mean	In-Car Range	Roadside Mean	Roadside Range
<b>PM<sub>10</sub> Metals (ng/m<sup>3</sup>)</b>							
	Freeway	0.17	na	0.62 (0.26)	0.37 - 0.86	0.28	0.0 - 0.75
	Rural	na	na	na	na	na	na
<b>Chromium (Cr)</b>	Freeway	262.0	na	161 (251)	9.5 - 239	176	67.7 - 239
	Rural	na	na	na	na	na	na
<b>Manganese (Mn)</b>	Freeway	24.2	na	18.8 (21)	9.3 - 25	24.3	2.5 - 46
	Rural	na	na	na	na	na	na
<b>Nickel (Ni)</b>	Freeway	13.3	na	28 (11)	na	0.0	na
	Rural	na	na	na	na	na	na
<b>Lead (Pb)</b>	Freeway	12.8	na	12.5 (8.3)	11 - 14	9.6	1.1 - 16.8
	Rural	na	na	na	na	na	na
<b>Sulfur (S)</b>	Freeway	466.2	na	478 (660)	265 - 639	398	256 - 507
	Rural	na	na	na	na	na	na
<b>In-Traffic Data</b>							
<b>Commute speed, mph.</b>	Freeway	na	na	35.0	na	na	na
	Rural	na	na	47.6	na	na	na
<b>Total miles</b>	Freeway	na	na	75.1	na	na	na
	Rural	na	na	107	na	na	na
<b>Trailing Distance, ft</b>	Freeway	na	na	94.8	na	na	na
	Rural	na	na	193.1	na	na	na
<b>Level of Congestion</b>	Freeway	na	na	3.6	na	na	na
	Rural	na	na	1.0	na	na	na

**Content Notes for Tables 2-1A, B, and C:**

- All data below the MDL were considered as and entered as 0.0 [see Table 5-1 for starred values that are below the detection limits]
- Means were computed even if the individual input data were below the MQL's
- Data are not necessarily paired, and inter-comparisons should be done with caution
- Some freeway means represent significantly fewer than 6 input values, especially for the metals
- No range is possible for rural data; many rural concentrations were below the MQL
- "Ambient" refers to study monitor data collected at ARB 13th and T St. monitoring site
- Carbon and carbon monoxide data are commute averages of 1.0 minute data
- Benzene data were not available from canister analyses; tabular results shown are from multisorb tubes
- No In-Car PAH analyses were above the MQL (no range reported)
- PAH samples were collected at only 1 roadside site (no range available)
- Only selected samples were analyzed for PM<sub>2.5</sub> and PM<sub>10</sub> metals; see Table 5-2 to identify selected samples; means reported represent up to 4 samples for In-Car, but no more than 2 for Roadside
- Data separated by a comma (,) are individual Hour 1 and Hour 2 values
- Data in parentheses () are duplicate analyses
- The PM<sub>2.5</sub> data are uncertain due to a random leak (see Section 3)
- An "na" means that no data are available

- The limited sensitivities of the integrated PM<sub>2.5</sub>, PM<sub>10</sub> and CO methodologies did not permit a realistic determination of the utility of Roadside and Ambient monitoring stations to be used as surrogates to predict in-vehicle concentrations. This may also be true for the Main Study. Where the MQL's were sufficient, the VOC Inside and Outside vehicle concentrations were higher than Roadway, which were higher than those at the Ambient site.

[MS Recommendation(s): Although Roadside measurement gave better indications of the in-vehicle concentrations than did the Ambient station data, the cost-effectiveness of Roadside sampling is still under discussion.]

- If the 1991 Caprice air exchange measurements from the Pilot Study are representative of those determined during the Main Study for the other sedan the Sport Utility Vehicle, and the school bus, the number of commutes using both Low and High exchange rates should be reconsidered. The limited range of influences of air exchange rate from settings Vent 1 to Vent 3 on inside and outside pollutant concentration ratios appears to be insufficient to warrant expending additional resources to impose equal emphasis on both High and Low exchange rate.

[MS Recommendation(s): Emphasizing the High air exchange scenarios, while collecting only limited data for the Low AER, should provide adequate information to characterize the range of exposures..]

- The unexpectedly high particle counts and CO levels detected when following selected vehicles (e.g. most heavy duty diesels (but not all), poorly tuned vehicles, and a diesel school bus) suggests that closely following these vehicles may significantly contribute to in-vehicle concentrations. Although specific vehicle type identification is not part of this effort, subsequent review of video records, compared against continuous monitor data may provide valuable information in assessing exposure mitigation strategies.

[MS Recommendation(s): Continue the driving protocols developed for the Pilot Study, focusing on heavy duty diesels and smoking vehicles.]

- The limited range of influences of air exchange rate from Low to High on inside and outside pollutant concentration ratios appears to be insufficient to warrant expending additional resources to impose equal emphasis on both High and Low exchange rate. Emphasizing the High air exchange, while collecting only limited data for the Low AER, should provide adequate information to characterize the range of exposures. If the 1991 Caprice air exchange measurements from the Pilot Study are generally representative of those determined during the Main Study for the other vehicles, the number of commutes using both Low and High exchange rates should be reconsidered.

### **2.2.2 Specific by Pollutant Category**

At this point in the overall program, the Pilot Study data have been analyzed primarily to validate the methodologies for the Main Study. Only limited observations are presented here as to levels and inter-comparability of the data.



#### **2.2.2.1 VOC's**

In general, the freeway levels were substantially higher than the rural commute for all pollutants. The In-Vehicle and Outside-Vehicle concentrations were also substantially higher than the Roadside data, which was in turn higher than the Ambient sites. There was essentially no difference between Inside and Outside the car. .

#### **2.2.2.2 Formaldehyde**

The freeway level was substantially higher than the rural commute

#### **2.2.2.3 PM<sub>10</sub> & PM<sub>2.5</sub>**

In general, the freeway levels were slightly higher than the rural commute. The higher In-Vehicle levels than the Outside-Vehicle levels for PM<sub>2.5</sub> are uncertain because of the sampling problems with the PM<sub>2.5</sub> inlets. PM<sub>10</sub> was generally higher than PM<sub>2.5</sub>, but not always. The Roadside data provided similar levels to the In-vehicle for both PM<sub>10</sub> and PM<sub>2.5</sub>.

#### **2.2.2.4 Carbon Black**

The freeway mean was significantly higher than the rural, while the In-Vehicle level was slightly higher than the Outside Vehicle concentration.

#### **2.2.2.5 CO**

The freeway levels were significantly higher than the (essentially non-detected) rural concentrations. The Outside-Vehicle levels were not significantly different from those Inside. The Inside and Outside levels were substantially higher than either the Ambient or Roadside sites.

#### **2.2.2.6 PAH's**

The PAH levels were all very low and below the detection limits, making it difficult to draw any conclusions between scenarios.

#### **2.2.2.7 Elements**

Freeway levels were significantly higher than rural levels. PM<sub>10</sub> levels were, in general higher than PM<sub>2.5</sub> levels (but not always). In-Vehicle and Outside-Vehicle levels (for PM<sub>2.5</sub>) were in most cases significantly higher than either the Roadside or the Ambient data.

#### **2.2.2.8 In-Traffic Data**

Rural commute speed was significantly higher than the freeway, making the total miles driven in the 2-hour commutes also higher. Trailing distance, due to higher traffic congestion, was substantially smaller for the freeways as compared to the rural commute.

### 3.0 FIELD MONITORING

This section provides more detailed descriptions of the field monitoring design and the supporting monitoring activities used during the Pilot Study.

#### 3.1 Methods and Approach

Field activities for the Pilot Study were conducted from February 22 to March 6, 1997 in Sacramento, California. Actual sample collections occurred from February 26 thru March 3. RTI, Sierra Research, Aerosol Dynamics, and ARB personnel who participated in the field effort and their responsibilities are shown in Table 3-1. All study activities including sample preparation, scheduling, instrument calibration, filter weighing, and record keeping focused around a work room set up in a local motel near one end of the planned commuting route. Preparation of the vehicle for sampling and data collections before and after each commute were accomplished in the parking area near the work room. A detailed schedule of planned daily events is given in Appendix C.

The overall design for the Pilot Study is described by the sampling design in Table 3-2, which shows the routes, the time of day, the ventilation settings, the commute lengths and the number of trips for each driving scenario. A gasoline-powered, California-registered, 1991 Chevrolet Caprice provided by Sierra Research was used as the sample and data collection platform for all test drives. In order to assure that the test vehicle was not contaminating the interior through leaks from the exhaust system and the engine compartment, the Caprice vehicle was inspected by Sierra Research prior to the start of the field activities (inspection results are included as Appendix D). In addition, a canister air sample was collected with the vehicle at rest to measure concentrations of VOC's in the car interior. Measured concentrations for all target VOC's, except toluene ( $1.0 \mu\text{g}/\text{m}^3$  was detected), were below the quantitation limit.

During this Pilot Study, two routes were selected and driven - a freeway and a rural commute, both in the Sacramento area. These routes were selected in consultation with the ARB project officer. One route was intended to represent commuting in heavy freeway traffic in the Sacramento area. This was on an approximately 30-mile stretch on Interstate 5, Business 80, and Interstate 80, extending from the I Street ramp of I-5 to the Madison Avenue Exit of I-80. During rush hour, both the inbound and outbound portion of this route took approximately 40 minutes to drive. Drives on this route took place either during the morning (7 to 9 am) or afternoon (4 to 6 pm) rush hours. The second route was intended to represent rural conditions with little traffic and a correspondingly low pollutant levels. This route was north of Davis, CA and used State Road E6 and County Roads 95, 27, and 99. The route was approximately 16 miles. The rural route was driven during midday (12 to 2 pm) on Saturday, 3/1. Table 3-3 summarizes information and driving times, driving distances, and average speed during each trip. Maps that show these two routes are included in Appendix E.

**TABLE 3-1. Personnel and Responsibilities for the Pilot Study**

Personnel	Responsibility
RTI Principal Investigator	<ul style="list-style-type: none"><li>• Oversee all field operations</li></ul>
RTI Field Chemist 1	<ul style="list-style-type: none"><li>• Prepare paperwork/labels for monitoring</li><li>• Prepare, set-up VOC, CO, PAH and NO<sub>2</sub> equipment, filters</li><li>• Tend Roadway 3 and 4 sites</li><li>• Prepare rack in car</li><li>• Perform CO decay tests for air exchange rate measurements</li><li>• Prepare car for test runs</li><li>• Set-up workroom</li><li>• Maintain equipment</li></ul>
RTI Field Chemist 2	<ul style="list-style-type: none"><li>• Weigh filters</li><li>• Prepare, set-up particle samplers and filters</li><li>• Tend Roadway 1 and 2 sites</li><li>• Download/backup data files</li><li>• Prepare car for test runs</li><li>• Set-up workroom</li><li>• Maintain equipment</li></ul>
Sierra Team Leader	<ul style="list-style-type: none"><li>• Schedule drivers</li><li>• Drive/navigate test vehicle</li><li>• Operate Aethalometer/LASX</li></ul>
Sierra Technicians 1 and 2	<ul style="list-style-type: none"><li>• Drive/navigate test vehicle</li></ul>
AD Field Scientists	<ul style="list-style-type: none"><li>• Install Aethalometer/LASX</li><li>• Instruct RTI/Sierra personnel on operation of instruments</li></ul>
ARB Personnel	<ul style="list-style-type: none"><li>• Assist in operating the Ambient site</li></ul>

**TABLE 3-2. Design of the Pilot Study**

Trip	Date	Roadway Type	Ventilation Setting	Time	Roadway Monitoring
1	2/27	Freeway rush	mid	AM	no
2	2/26	Freeway rush	mid	PM	no
3	2/27	Freeway rush	high	AM	yes
4	2/27	Freeway rush	high	PM	yes
5	2/28	Freeway rush	low	PM	yes
6	3/1	Rural <sup>a</sup>	low	mid-day	no
7	3/3	Freeway	high	PM	yes

<sup>a</sup> A second rural trip was not conducted based on consultation and approval of ARB personnel in the field.

**TABLE 3-3. Distances for Vehicle Drives**

Commute	Location	Total Minutes	Total Miles	Average Speed (mph)
2/26 am	Freeway	135	56.7	25.2
2/26 pm	Freeway	138	85.6	37.2
2/27 am	Freeway	118	84.2	42.8
2/27 pm	Freeway	171	56.4	19.8
2/28 pm	Freeway	120	78.7	39.3
3/1 am	Rural	135	107	47.6
3/3 am	Freeway	116	88.7	45.9
Means:		133.3	79.6	36.8

Driving protocols were developed by Sierra Research and approved by ARB prior to the Pilot Study. The protocol for “freeway-congested-heavy duty influence” was as follows:

- 1) follow the pre-selected route and position behind a target vehicle whenever possible; the target vehicle was defined as a heavy duty vehicle with diesel exhaust or other obvious emissions;
- 2) drive the right hand lane, except when changing lanes to follow or acquire a target vehicle;
- 3) break off target vehicle pursuit if target vehicle turns off route, can't be followed, drives erratically or unsafely, or appears to modify behavior due to following;
- 4) change target vehicle if a vehicle with higher exhaust emissions becomes available;
- 5) drive with normal following distances (like other nearby cars) but not further than about 100 feet behind target vehicle.

The protocol for “rural” driving was to drive at the posted speed limit and simply note any target vehicles that were on the road. No attempt was made to either acquire or avoid target vehicles.

During vehicle runs, monitoring data were collected from inside the passenger compartment of the vehicle, from the exterior of the vehicle, along the roadways traveled, and at an ambient monitoring station close to the route traveled. Information on the pollutants monitored and the sampling and analysis methods used is summarized in Table 3-4. Information on supplemental data collection is given in Table 3-5. The number and location of samples collected for each drive is given in Table 3-6. Summaries of the total integrated and continuous data collections were given previously in Tables 1-3 and 1-4. A schematic that shows the vehicle and fixed-site monitoring is given in Figure 3-1.

In-vehicle samples were collected at a location representative of the driver and passenger's breathing zone. This was accomplished by mounting the sampling lines/cartridges in a specially constructed rack positioned in the rear seat. The interior sampling lines/cartridges were positioned at shoulder height just behind the passenger seat near the center of the car. Exterior car samples were collected from a glass manifold connected to tubing which extended through an aluminum plate at the car's rear passenger window and extended to the front grill of the car. The inlet of the tubing was secured to the hood ornament of the car. Exterior air was pulled through the tubing and into the glass manifold by an air pump mounted in the car's trunk and by the internal pumps supplying air to the individual monitors. The sampling lines and cartridges for the exterior samples were mounted directly to the glass manifold using appropriate stainless or Teflon fittings.

Most of the sampling systems operated simultaneously, collecting from both the inside and outside manifold. The high flowrate in the sampling line and manifold provided transport times from the front of the vehicle that were less than a few seconds. Since only single LAS-X and Aethalometer units were available, electronic 3-way valving units operating on a one minute cycle were used to allow sequential inside and outside sampling. This was reasonable for all scenarios except those with durations less than 1 minute (e.g. following behind a target vehicle for only 50 seconds). In these cases, an equilibrium inside reading might be obtained with an associated outside reading that was much lower (did not reach equilibrium - or vice versa).

**TABLE 3-4. Pollutant Sample Collection and Analysis Method Summaries**

Pollutant	Sample Collection	Sample Analysis
PM <sub>10</sub> Particles (integrated)	MSP 200 2.0 LPM PM <sub>10</sub> inlets, particle on 37 mm, 3.0 Tm Gelman Teflo filters	Gravimetric, on a modified Mettler AT20 microbalance, with computer control
PM <sub>2.5</sub> Particles (integrated)	MSP 200 4.0 LPM PM <sub>2.5</sub> inlets, particle on 37 mm, 3.0 Tm Gelman Teflo filters	Gravimetric, on a modified Mettler AT20 microbalance, with computer control
Particle Size Distribution	Particle Measurement Systems (PMS) Model LASX multi-channel analyzer	Computer data collection and size distribution analyses
Black Carbon	McGee Scientific Aethalometer	5 LPM on quartz fiber tape readings by optical absorption
VOCs	SUMMA passivated 6 liter evacuated canisters, sample rate of 25 cc/min; Multisorbent tubes	GC/MS with SIM enhancement
Formaldehyde	DNPH cartridges	Electron with acetonitrile, HPLC analysis Thermal desorption GC/MS, full scan
CO	Draeger Model 190, diffusion sensing (not pumped)	electro-chemical
NO <sub>2</sub>	OSHA Model ID-109, sampling rate of 100 cc/min through molec. sieve tubes	Extraction with TEA, analysis by polarography
Metals in PM <sub>10</sub> /PM <sub>2.5</sub> particles	PM <sub>10</sub> /PM <sub>2.5</sub> Teflon filters	X-Ray Fluorescence (XRF), energy dispersive, or  Ion-Coupled Plasma Mass Spectrometry (ICP/MS)
PAH	Particle phase (only) on 37 mm, 3.0 Tm Gelman Teflo filters at 8.0 LPM	Gas Chromatography/Mass Spectrometry

**TABLE 3-5. Supplemental Measurement Method Summaries**

Measurement	Sensor	Data Collection/Media
Sedan 1 Traffic speed	Digital speedometer, mph	Computer, real time, trip averaged
Sedan 1 Level of Congestion (traffic density)	Navigator categorical judgment, manual input	Computer storage of binary data
Sedan 1 <u>Additional Switchbox Categories</u> : Air Exchange Rate Category, Roadway Type, Apparent Vehicle Influence, Target Type	Navigator categorical judgment, manual input	Computer storage of binary data
Sedan 1 Lead car spacing	Laser distance meter in grill	Computer, real time, trip averaged
Air Exchange Rate	Draeger CO monitor (method of Ott & Willits, 1981)	Internal logger/computer
Meteorology - wind speed, wind direction, relative humidity, and temperature	Obtained from nearest weather station	Computer file, hourly
Commute Routes, characterization	Trip narrative prepared by navigator to supplement video	video; computer file
Unusual Events	Trip narrative prepared by navigator	video; computer file

**TABLE 3-6. Sample Collection Schedule for Each Drive**

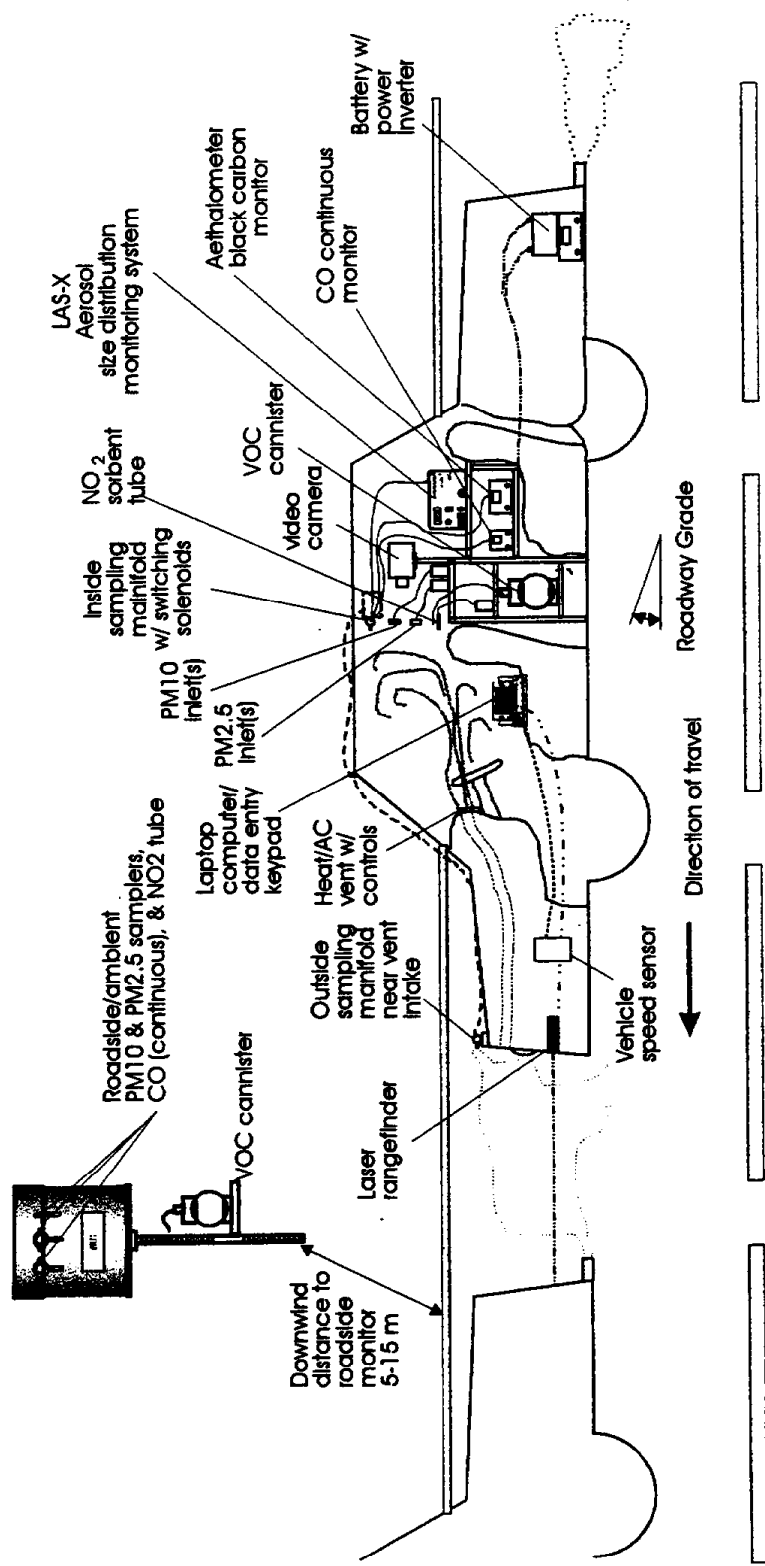
Sample Type	Inside Car	Outside Car	Ambient	Roadside 1 <sup>a</sup>	Roadside 2	Roadside 3	Roadside 4	Total
VOCs (multisorb)	1							1
VOCs (canister)	1	1	1	1	1	1	1	7
Aldehydes (DNPH)	1							1
PAHs (quartz filter)	1	1	1			1		4
CO (Draeger) <sup>b</sup>	1	1	1	1	1	1	1	7
NO <sub>2</sub> mol. sieve	2	2	2	2	2	2	2	14
Particles (PM <sub>2.5</sub> )	1	1	1	1	1	1	1	7
Particles (PM <sub>10</sub> )	1		1	1	1	1	1	6
Particles (LAS-X)	1	1						2
Carbon Black <sup>b</sup>	1	1						2
Temp/% Rh <sup>b</sup>	1							1

<sup>a</sup> Roadside sample collection schedule for four test drives.

<sup>b</sup> Continuous measurements.



Figure 3-1  
**Schematic Diagram of In-Vehicle and Roadside Sampling Components for ARB Pilot Study**



C. Rodes, RTI, 5/97

For four of the vehicle runs, monitoring was conducted at four roadway sites. These sites were selected in consultation and with final approval by the ARB. Encroachment permits were obtained from the California Department of Transportation. Roadway sites are described in Appendix F. Also provided is the CalTrans encroachment permit information to conduct the Roadside sampling. Criteria for selecting these sites included a proximal location to the roadside with no more than a 5-foot elevation difference with the roadway surface, easy access from the freeway, a secure location, and a minimum of obstructions, including walls and trees. Monitoring equipment at each site was located 15 to 30 feet from the roadway. Sampling during freeway commutes was also conducted at one ambient monitoring station located at the ARB ambient monitoring station at 13th and T Streets in Sacramento.

In conjunction with the chemical monitoring data, the ancillary data shown in Table 3-5 was also collected. Information was collected on meteorological conditions, vehicle speed, and traffic conditions. Topographical or environmental conditions that might effect roadway pollutant concentrations were recorded via the switchbox. Drives were video taped. In addition, air exchange rates were measured during separate rural drives for the test vehicle under the three operating conditions.

All vehicle runs were nominally two hours. Either one or two runs were made per day. Vehicle runs were made on 2/26, 2/27, 2/28, 3/1, and 3/3. A detailed schedule of activities for all field monitoring activities is given in Appendix C.

After samples for formaldehyde, NO<sub>2</sub>, PAHs, and VOCs (multisorbent tubes) were collected, they were stored sealed in clean steel cans at 40 °C. VOC canisters were stored in a cool, clean area. All samples were shipped within seven days of collection to RTI via overnight carrier. Particulate filters were equilibrated at temperatures in the work room. An air conditioner in the room was the only source of temperature and humidity control. Filters were pre-weighed before samples were collected and then again within 24 hours after collection. Exposed, weighed filters were placed in labeled Gelman Analyslide petri dishes. All filter samples were hand-carried within seven days of collection to RTI on the return flight from California to Research Triangle Park.

For VOC and formaldehyde monitoring, several types of quality control samples were used throughout the study. Sampling media (cartridges or canister) equivalent to approximately 5% (or minimum of two) of the field samples were set aside as field blanks and were used to assess contamination and/or interferences of field samples. These samples traveled to the field site, returned to the laboratory and analyzed along with the field samples. Field controls were used to assess analyte recovery. Cartridges/canisters equivalent to approximately 5% of the field samples were spiked with known amounts of target analytes. As with the field blanks, these samples were shipped to the field, returned, and analyzed along with the field samples. Five percent of the samples were collected and analyzed in duplicate to evaluate precision.

For particles, metals, PAHs and NO<sub>2</sub>, field blanks each equivalent to 5% of the samples were deployed to assess background contamination. Field duplicates equivalent to 5% of the samples were collected to evaluate precision, respectively.

Since CO was measured using real-time monitoring methods, different QC procedures were used. In the field, an initial calibration was prepared on each monitor upon arrival in California using 0, 2, 10 and 22 ppm standards to assure proper operation prior to use. Analytical accuracy was checked by analyzing zero and span (22 ppm CO) gas standards at the beginning and end of each vehicle run. Precision was evaluated by deploying duplicate monitors.

Table 3-7 presents information on the number of samples scheduled, collected, and analyzed. These data are provided for both the field and the QC samples.

**TABLE 3-7. Total Numbers of Field and Quality Control Samples**

Pollutant	Field Samples <sup>b</sup>	Duplicates	Field Blanks	Field Controls
VOCs (multisorbent)	8/7/7	2/2/1	2/2/2	2/3/3
VOCs (canister)	41/38/38	2/2/2	2/2/2	2/2/2
Formaldehyde	8/7/7	2/2/2	2/2/2	2/2/2
PAHs	12/15/15	2/0/0	2/2/1	<sup>c</sup>
CO	40/37/36	2/2/2	-	-
NO <sub>2</sub>	80/74/74	4/4/4	4/4/4	-
PM <sub>2.5</sub> Particles <sup>d</sup>	40/37/37	2/2/2	2/2/2	-
PM <sub>10</sub> Particles <sup>d</sup>	32/30/32	2/2/2	2/2/2	-
Particles (LAS-X)	16/14/-	-	-	-
Carbon Black	16/14/-	-	-	-

<sup>a</sup> Originally 8 test runs were scheduled; however, only 7 test runs were conducted. One rural test run was canceled.

<sup>b</sup> Scheduled/collected/analyzed.

<sup>c</sup> Not applicable to method.

<sup>d</sup> Approximately one-half of the collected filter samples were analyzed for metals.

Strict sample custody procedures were followed throughout the collection and analysis activities. Each sample was given a unique code to link that sample to the study participant and household, sample type, and collection regime, etc. As part of our quality control procedures, sampling protocol/chain-of-custody forms were prepared for each sample collected. This form was used to track each sample from the time it is prepared until the data have been reduced and reported. Back-up diskettes of all real time data files were prepared to lessen chances of losing electronic data.

### 3.2 GENERAL FIELD MONITORING EVALUATION

Overall, the field monitoring methodologies employed in the Pilot Study were successful, but several very significant and time consuming problems occurred that required resolution. All of these problems have currently been addressed and corrective actions taken to prepare for the Main Study. Several problems were experienced with the monitoring methods proposed only for the Pilot Study. These included the performance of the in-vehicle power system's ability to operate the real-time monitors for particles and carbon black, and the integrated monitoring

pumps for PAH's. A complete evaluation (accomplishments and problem areas) for the Pilot Study is provided in Appendix G. The following is a summary of the most important aspects of the study.

- The technical skills of research field personnel from RTI, Sierra Research, and Aerosol Dynamics were suitable to meet the routine and unexpected demands of the field sampling.
- The number of personnel assigned to this field monitoring effort for the Pilot Study were adequate to complete the planned field monitoring, given the extended hours each day required to resolve technical problems. This includes the (gratefully acknowledged) assistance of ARB personnel to assist in servicing the Ambient site. Careful planning and preparations will be required to eliminate large, time-consuming problems during the Main Study.
- Several unplanned events related to pollutant monitoring that were unique to the Pilot Study methods substantially taxed the field monitoring staff. These included (a) the initial failures of the on-board vehicle system to provide power to the continuous monitors and the PAH pumps, (b) the decision to assign separate individuals to set out the four Roadway and Ambient sites.
- The route selection process met the study objectives, providing (a) a freeway commute route that highlighted heavy traffic densities in the Sacramento area for the AM and PM commutes, (b) a rural commute that substantially taxed the minimum detection limits of the methods resulting from the very low pollutant levels.
- Monitoring at roadway sites was difficult and had a substantial impact on the burden and cost of the field monitoring effort. Obtaining CalTrans permits required more time and was, therefore, more costly than anticipated. Access to roadway sites was difficult during freeway rush hour. The use of four roadway sites placed a heavy burden on equipment requirements which impacted acquisition, testing, shipping, calibration, and set up costs. Finally, there was some initial concern for the security of the expensive monitoring equipment at the Roadway sites. This concern appeared to be unfounded with reasonable care (security cables).
- The 1991 Caprice sampling platform with a driver and navigator worked as planned to collect vehicle spacing data, traffic density, periodic driving diaries, and video records of each commute.
- The initially-installed, on-board power system in the car proved inadequate to handle the power requirements of the sampling equipment and provide sufficiently filtered power to operate the optical particle counter. These problems were corrected prior to the start of the 2/28 commute in a temporary manner that permitted completion of the Pilot Study continuous monitoring. The excessive power drain of this corrective "fix" drained the

batteries rapidly and would be unsuitable for the Main Study. A new power system has been ordered by Sierra Research for the test sedan.

- An insurance liability issue concerning the overnight parking location and the personnel authorized to drive the Caprice complicated the logistics of preparing the vehicle for sampling. A coverage arrangement between RTI and Sierra Research is currently being developed.

### **3.3 SPECIFIC FIELD MONITORING RECOMMENDATIONS**

- The number and skills of field personnel proposed for the Main Study will be sufficient for conduction both AM and PM vehicles runs if: (a) there are no on-board power or logistical problems with the 1991 Caprice or the other test vehicles, (b) Roadside monitoring is limited to no more than 1 site per commute and at an easily accessibly location, and (c) NO<sub>2</sub> tube sampling is deleted. Actions are currently in progress to address all items (a) thru (c).
- All field operations should be streamlined to be as efficient as possible and to distribute the work load evenly between all of the field staff members. Careful consideration must be given to the logistical problems of monitoring in both Sacramento and Los Angeles during the Main Study.
- For the Main Study, several local field technicians/drivers will be hired. Adequate time must be allowed to train these field staff member prior to the start of sampling.
- The same routes should be used in the Sacramento area. Routes in Los Angeles should be chosen using similar criteria. Routes should be selected that allow easy access to the work room and minimize the amount of travel time for setting up/taking down equipment.
- The data/information collected in Sedan 1 (Sierra Caprice) during each commute for the Main Study should be revised. Switchbox data other than Level of Congestion should be deleted. Data to be collected in the Main Study in Sedan 1 should be only (a) vehicle speed, (b) vehicle spacing, (c) Level of Congestion, (d) video recording, and (e) a commute diary.
- If continuous particle monitoring is included as an addition to the Main Study, a more robust power system with a highly filtered 120 VAC output must be obtained.
- An agreement between parties covering the liability insurance concerns for the 1991 Caprice is currently being arranged. All test vehicles must remain at the work room sites overnight.

## 4.0 MONITORING METHODS

This section provides more detailed discussion of the integrated sample and continuous monitoring methods used in the Pilot Study. Specific recommendations for applying the methods in the Main Study are also provided.

### 4.1 Integrated Measurement

#### 4.1.1 Particles (PM<sub>2.5</sub> and PM<sub>10</sub>)

*Method Description* - The filter collection and weighing methods for gravimetrically-based PM<sub>10</sub> and PM<sub>2.5</sub> particles measurements are based on methods that have been used previously at RTI. The methods have been validated during the past three years on two large-scale exposure studies conducted for the U.S. EPA and a commercial client.

A summary of the specifications for the RTI PM<sub>10</sub> and PM<sub>2.5</sub> particle exposure monitoring systems is shown in Table 4-1. The MSP model 200 Personal Exposure Monitor (PEM) inlets for PM<sub>10</sub> and PM<sub>2.5</sub> are based on standard impactor theory, and demonstrate excellent cut point sharpness. Although PM<sub>2.5</sub> cut point impactors can exhibit substrate overloading during extended use, the combination of an additional "scalping" stage, and the short duration of sampling proposed in this study eliminated this concern. The MSP inlets are relatively wind speed insensitive, but the turbulence outside a moving vehicle is undoubtedly too harsh an environment for accurate coarse particle sampling. Thus, the inlets were not used external to a moving vehicle. Outside PM<sub>10</sub> measurements were not made. PM<sub>2.5</sub> inlets collected particles off of the manifold after air was drawn in from the outside.

As shown in Figure 4-1 the inlets incorporate a 5-jet inlet cover (10 holes for a 4 LPM version) that directs the inlet flow toward an oil-coated, sintered metal impactor ring. After impaction to achieve the design cut point, the remaining particles are drawn to the membrane filter substrate located in the inlet base. The oiled surface is clean and replenished prior to each sampling event. The inlets are placed in Ziplok bags after preparation to prevent stray particles from entering through the jet holes.

During monitoring, an electronically flow-controlled battery operated pump (modified BGI model AFC123) was used to sample air through the portable impactors. The impactor contained a 37-mm diameter Teflon filter having a 3- $\mu$ m pore size. For the PM<sub>10</sub> impactor, a constant flow rate of 2.0 L/min was used. For the PM<sub>2.5</sub> impactor, a constant flow rate of 4.0 L/min was used.

Flow rate checks were performed with a specially-designed orifice that seals over the MSP inlet. The pressure drop across the orifice is monitored with a Magnehelic gauge. The pressure drop versus flow rate calibration for the orifice is established against a NIST-traceable Gilibrator bubble flow meter.

Filters were weighed both before and after sample collection using a Mettler AT20 balance with a  $\pm 2$   $\mu$ g weighing precision in a single measurement. The balance was connected to a microcomputer with weighing software developed for gravimetric analysis of filters. All weighings were conducted in the field in the work room. Filters were equilibrated in the work room for at least 12 hours before weighing. Once tared, all filters were inspected for holes or other imperfections prior to use and were kept in a barcode-labeled Petri dish.

A set of ten filters was weighed as follows.

**TABLE 4-1. RTI PM<sub>10</sub> and PM<sub>2.5</sub> Particle Monitoring System Performance**

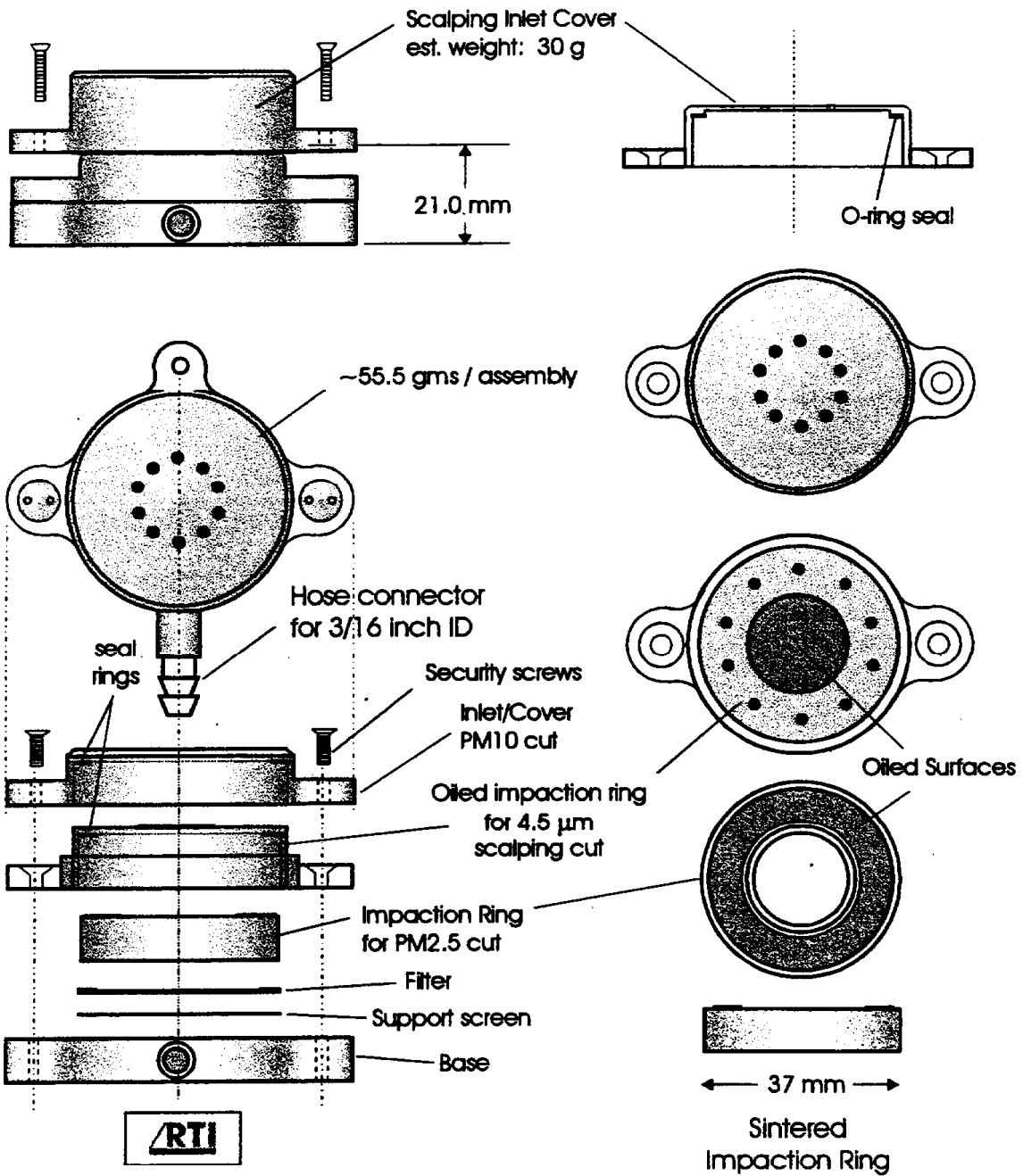
Parameter	Specification
<b>Inlet</b>	
Inlet type	MSP, Corp. model 200
Aerodynamic Cutpoints (D <sub>50</sub> )	PM <sub>10</sub> & PM <sub>2.5</sub>
Cutpoint accuracy	+/- 0.2 Tm
Impactor coatings	Silicone oil or stopcock grease
<b>Filter</b>	
Filter type	Gelman 37 mm, 3.0 Tm porosity Teflon
<b>Pump</b>	
Source	modified BGI model AFC123 with integral feedback flow control
Flowrate	PM <sub>10</sub> - 2.0 liters/min; PM <sub>2.5</sub> - 4.0 liters/min
Flowrate stability	+/- 5% up to 25 inches of H <sub>2</sub> O
<b>Batteries</b>	
Type	4 alkaline AA
Battery life, continuous	-30 hrs at 70°F

Samples were collected over the nominal 2-hour driving period.

1. The balance was zeroed and the calibration checked using a NIST-traceable weight (200 mg). If the zero check was within  $\pm 0.004$  mg and the 200 mg weight within  $\pm 0.002$  mg then the balance was "in control" and filters were weighed. If these specifications were not met the balance was recalibrated.
2. Each filter was weighed and the weight recorded once the computer recognized a stable reading (1-2 min).
3. After each set of 10 filters was weighed, the zero was checked to within  $\pm 0.004$  mg and a 200 mg weight to within  $\pm 0.002$  mg. If either the zero or the 200 mg weighing failed their test, then the zero/calibration was repeated and the previous set of filters was reweighed.

QC checks included multiple weighing tests with a dedicated filter, and spot checks (reweighing 1 in 20) of filter weights.

Figure 4-1  
**PM<sub>2.5</sub> and PM<sub>10</sub> Aerosol Sampling Inlets**  
**(MSP Model 200) Used in**  
**ARB In-Vehicle Pilot Study**





*Method Evaluation* - Performance of the method for particle mass is summarized in Table 4-2. Overall, the method performed adequately. Key element to method performance may be highlighted as follows:

**TABLE 4-2. Summary of Method Performance Data for Particle Mass Samples (PM<sub>10</sub> and PM<sub>2.5</sub>)**

% of samples collected within flowrate specifications (external flow into inlets)	PM <sub>10</sub> - 100.0% PM <sub>2.5</sub> - 94.1%
% of samples collected under acceptable conditions	PM <sub>10</sub> - 100.0% PM <sub>2.5</sub> - 94.1%
% of sample weighed with "in control" calibration	100%
Precision of check samples - Standard filter - Reweighing of field sample filters	s = 2.0 µg = 2.5 µg, s = 3.4 µg
% RSD of duplicate field samples above MQL	PM <sub>10</sub> - 34.4% PM <sub>2.5</sub> - 20.7%
Mass on field blanks	Mean Loss: 3.0 µg <sup>a</sup>
Estimated Method Quantitation Limits (MQL's) <sup>b</sup> in µg/m <sup>3</sup>	PM <sub>10</sub> - 49.8 PM <sub>2.5</sub> - 24.9
% of samples with concentrations greater than MQL	PM <sub>10</sub> - 66.7% PM <sub>2.5</sub> - 63.9%

<sup>a</sup> 2/25/97 TO 3/3/97 [see text]

<sup>b</sup> 3 times MDL

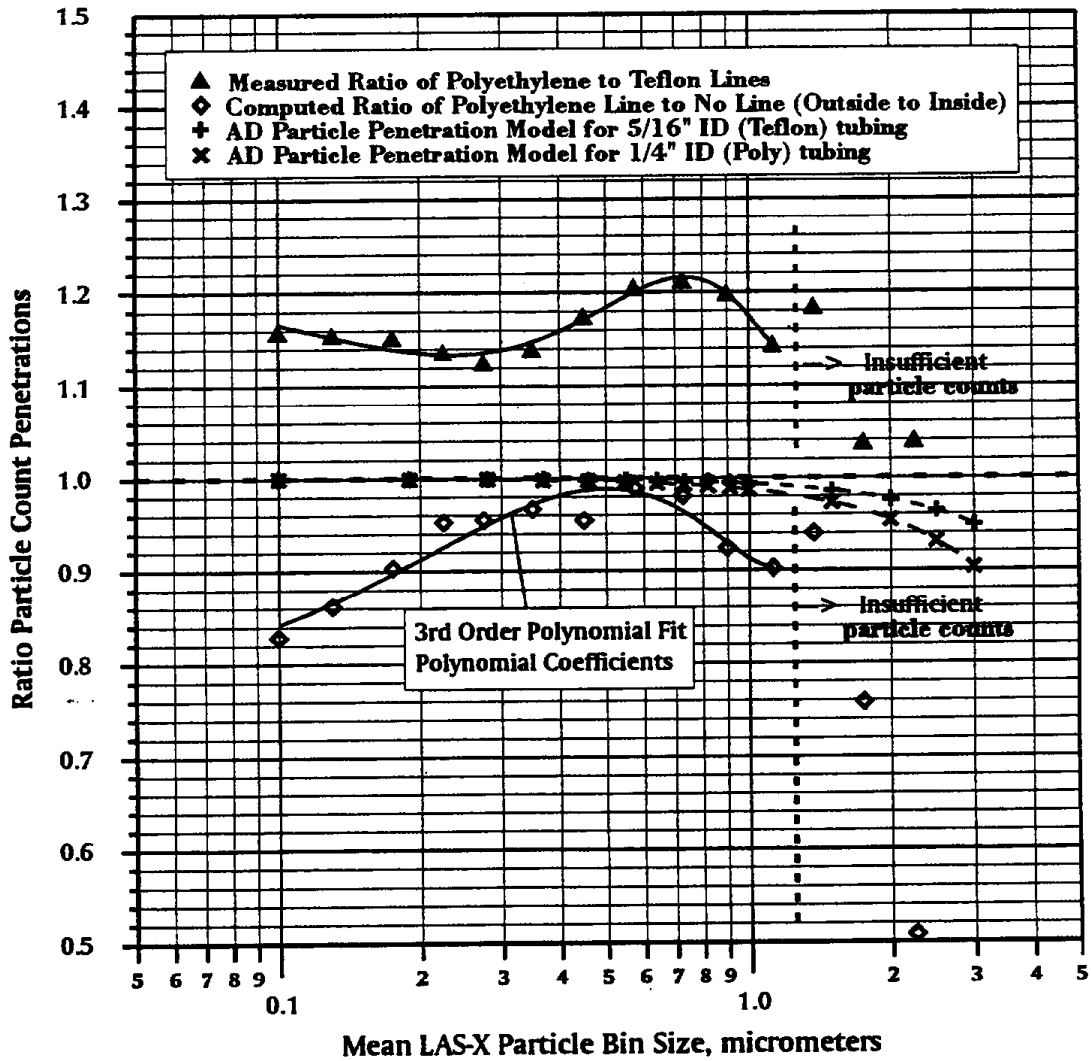
- The flow control systems used for 2 and 4 LPM integrated sampling met specifications.
- Defective internal sealing rings in several of the PM<sub>2.5</sub> inlet impactors produced random leaks that were not identified properly with the existing leak tests. The number that were leaking is uncertain, but was assumed to be the four concentrations below 10 µg/m<sup>3</sup> (see summary table in Appendix H). The hardware problems (manufacturing QC and design) with the MSP inlets were identified and corrected by the manufacturer after Pilot Study sampling had been conducted. The current leak test procedure was inadequate to detect this problem and is being revised (by RTI). The corrected PM<sub>2.5</sub> inlets will be operated (by RTI) briefly in side-by-side testing with ambient PM<sub>2.5</sub> monitors to validate the corrections. Since identification of particle concentration levels is a critical component of this research, every reasonable attempt to optimize the PM<sub>2.5</sub> and PM<sub>10</sub> measurements for the Main Study will be made. The modified PM<sub>2.5</sub> MSP inlets are expected to be fully satisfactory for the Main Study]

- Weighing the Teflon filters in an air conditioned (but otherwise uncontrolled for temperature and relative humidity) space in the motel work room generally proved adequate to meet the expected detection limit of 2.0  $\mu\text{g}$ , based primarily on the precision of successive weighings of the same filter. This limit inexplicably increased, however, to 3.4  $\mu\text{g}$  during the post-weighing period, significantly increasing the MQL for both  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  samples over a 2-hour commute. A summary of the particle concentration data exceeding the MQL's is given in Appendix H. This small increase proved significant, since the low ambient concentrations and small particle mass collections during the 2-hour commutes in the Pilot Study severely taxed the limits of the gravimetric analyses. The median mass collections per filter for all samples in the Pilot Study was only 11  $\mu\text{g}$  for  $\text{PM}_{2.5}$ , and 18  $\mu\text{g}$  for  $\text{PM}_{10}$ . In order to reduce the MQL as much as possible for the Main Study, every effort must be made to optimize the balance performance. A pre- and post-weighing location with a more temperature controlled and less draft-prone balance environment will be sought for both Sacramento and Los Angeles.
- The  $\text{PM}_{10}$  MSP sampling inlets functioned acceptably to collect integrated particle samples, except that the flowrate (2.0 LPM) was too low to provide an adequate sample volume and a reasonable MQL in a 2-hour commute. The low  $\text{PM}_{10}$  concentrations during the Pilot Study were generally at or below the method detection limits. Higher flowrate (4.0 LPM) inlets will be provided (by RTI) to double the collected volume and halve the MQL for  $\text{PM}_{10}$  in the Main Study. Increasing the inside sampling flowrates above 2 LPM had been avoided for the Pilot Study, since the air exchange rates in the test car were assumed to be significantly lower than was measured. Note that although  $\text{PM}_{2.5}$  is a subset of  $\text{PM}_{10}$ , the significantly higher MQL for the  $\text{PM}_{10}$  increased the probability that a  $\text{PM}_{2.5}$  value would occasionally be higher than a paired  $\text{PM}_{10}$ . This was also complicated by random internal leaks in the  $\text{PM}_{2.5}$  inlets.
- Outside the vehicle samples were collected through a sampling line run to the front of the car that operated at a flowrate of approximately 24 LPM. The line was originally PTFE Teflon, but was switched to polyethylene prior to the start of the Pilot Study. Testing with the LAS-X to evaluate ambient particle losses as a function of particle size showed that polyethylene material had significantly fewer losses. This was attributed to the larger static charging capacity of Teflon. The LAS-X testing showed that the size-specific LAS-X count measurements should be corrected when comparing inside and outside measurements using the sampling line (see Figure 4-2). Particle loss calculations using a theoretical model supplied by Aerosol Dynamics had not suggested particle sizes less than 2.5  $\mu\text{m}$  to be significantly affected by the sampling line. This model is not really appropriate, since it provides no compensation for particle diffusive losses. Mass losses based on these counts were estimated to be less than 5% for integrated  $\text{PM}_{2.5}$  samples. Note that the subsequently reported LAS-X outside data in this report are loss-corrected, while the integrated  $\text{PM}_{2.5}$  data are not. The experimental nature of the count-to-mass computation using the LAS-X is experimental, and currently not proven enough to warrant correcting gravimetric data. A table of estimated mass loss corrections will be provided in the Main Study report

Figure 4-2

**Ratio of Teflon to Polyethylene Sampling Line Particle Penetration and  
Ratio of Polyethylene Sampling Line (Outside Car) Penetration to  
No Line Inside Car) Compared to AD Penetration Model  
for Two Different Inside Tubing Diameters**

Teflon and Polyethylene Line lengths: 16 feet  
 OD's: 3/8"  
 ID's: Teflon: 5/16", Polyethylene: 1/4"  
 Flowrate: 6.5 lpm  
 Integration Period: 60 seconds



that will permit a semi-quantitative assessment of the potential gravimetric losses. Also, it was observed that the location of the outside line inlet at the center of the grill, did not always represent the air that was entering the vehicle through the open car windows during the high air exchange rate commutes. Moving the intake to the base of the windshield for the Main Study will significantly reduce the sampling line length, and more importantly, place the intake adjacent to the car vent system intake.

- The Gelman Teflo® filters lab blanks all lost a small, but measurable, 3 µg (mean of 4 filters) in weight from the pre-weighing until the post-weighing. The reason for this loss is not clear, but may be a plasticizer vaporization loss from the plastic support rings. All reported gravimetric data were corrected for this 3 µg loss. This potential for tare weight change will also be monitored in the Main Study.

*Recommendations-* The particle mass measurements should be performed in the Main Study using the same general procedures as for the Pilot Study with the following recommendations. The PM<sub>10</sub> inlet caps should be replaced with 4 LPM versions to double the total collected sample volume and thus reduce the MQL by a factor of 2.

- The faulty PM<sub>2.5</sub> inlets will be returned to the manufacturer for replacement of the sealing rings (already completed). The modified units will be evaluated prior to the Main Study.
- A revised leak test procedure will be developed and evaluated for the particle inlets that will identify internal leaks.
- Filter weighing should be conducted in a more closely temperature-controlled environment, if at all possible. This should improve the precision of the resulting measurements.
- The outside vehicle sampling line loss testing should be repeated immediately prior to the start of sampling in the Main Study.

#### 4.1.2 Metals (Elements)

*Method Description* - The 37 mm Teflon membrane filter samples for the analysis of elements and ionic species were digested using a modification of U.S. EPA SW 846 Method 3052. Metals were analyzed by graphite furnace atomic absorption (GFAA), inductively coupled plasma emission mass spectrometry (ICP/MS) and ion chromatography (IC).

Filter samples were first extracted with 0.1 M HClO<sub>4</sub> in an ultraclean cuvette and an exact volume (2 or 3 mL) removed for the IC measurement. The remaining extract was freeze-dried and digested with 50% nitric acid (1 mL) and a few drops of hydrofluoric acid until the digestate began to boil. The digest was cooled then diluted to the desired volume and analyzed. After samples were digested/extracted, they were transferred to the measurement laboratory in a sealed clean container to minimize contamination from room dust. Prior to ICP/MS analysis, samples were placed in an autosampler that was covered by a class 100 hood glove box enclosure to further avoid room dust contamination during measurement. ICP/MS measurement of the digestates/extract solutions were performed using U.S. EPA SW 846 Method 6020. Similar "clean" techniques were employed for GFAA determinations.

For the pilot study analysis, QC materials such as filter SRM's were not available. Instead, replicate reagent controls (blank spikes) were carried through the entire procedure. Recoveries for these spikes for Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sr, and Zn exceeded 80% without correcting for sample acid matrix suppression on the analytical signal, thereby validating the digestion technique. All preparation operations were carried out in Class 100 clean room conditions. Reagent blank contamination levels were within a factor of 2 of the instrument detection limits.

For the pilot study, several key elements were analyzed using GFAA due to some temporary problems with the ICP/MS which have since been resolved. These elements included lead, cadmium, manganese, and nickel. The remaining metals were determined later by ICP/MS. Sulfate, phosphate, and chloride were analyzed by IC.

*Method Evaluation* - Table 4-3, provides information on instrumental method detection limits (MDL's) and instrumental method quantitation limits (MQL's) for digests of both PM<sub>10</sub> and PM<sub>2.5</sub> filter samples. These are instrumental MDL's based on 3 times the standard deviation of blank samples; MQL's are 3 times the MDL's. The percentage of sample digests that had metal levels above the MQL's are also shown in the table. For some elements, levels on the field blank filters were as high as levels on the samples filters. In these cases, background corrected sample concentrations were reported as not detected even though levels in the digests were measurable.

Results of method controls and method blanks suggested that the proposed method could be used to analyze for elements on filter samples. However, instrumental sensitivity of the method was not sufficiently low to give high percent measurables for many of the elements including lead, cadmium, nickel, phosphorus, potassium, iron, and bromine. For other elements, the field blank samples showed significant and variable background levels which further decreased the percent measurable values for field samples. This was the case for calcium, chlorine, copper, potassium, phosphorus, silicon, strontium, titanium, and zinc. The magnitude of the variable-background problem is currently unclear, and will be addressed by more extensive blank evaluation testing prior to the Main Study.

*Recommendations* - Analyses for the Main Study will focus on the target elements (Pb, S, Cd, Cr, Mn, and Ni) and the additional metals originally proposed, using XRF as the analysis method. Although not as sensitive as ICP/MS, XRF will provide a greater range of elements at a significantly reduced cost/analysis. Additional work should also be performed to minimize contamination for the field blanks. The secondary elements should not be included in the main study since none of these elements gave high percent measurable values during the pilot study. For the main study, additional QC samples including filter SRM's should be included. A rigorous evaluation of method detection limits should also be conducted.

**TABLE 4-3. Method Performance Data for Elemental Analyses**

Analyte	Method	PM <sub>10</sub>			PM <sub>2.5</sub>			Field Blanks (ng/sample)
		MDL (µg/m <sup>3</sup> )	MQL (µg/m <sup>3</sup> )	%>MQL	MDL (µg/m <sup>3</sup> )	MQL (µg/m <sup>3</sup> )	%>MQL	
<b>Primary Elements</b>								
Pb	GFAA	10	30	8.3	5.0	15	22	2.1, 2.1
Cd	GFAA	1.2	3.6	0	0.60	1.8	5.6	0.32, 0.59
Cr	ICP/MS	4.0	12	100	2.0	6.0	100	3.1, 4.8
Mn	GFAA	3.6	11	92	1.8	5.4	89	2.1, 2.1
Ni	GFAA	46	140	0	23	69	5.6	9.5, 9.5
S	IC	520	1600	100	260	780	94	120, 123
<b>Secondary Elements</b>								
P	IC	1000	3000	0	520	1600	0	105, 698
Si	ICP/MS	5000	15000	100 (0) <sup>a</sup>	2500	7500	100 (0) <sup>a</sup>	21000, 21900
K	ICP/MS	1300	3900	0	630	1900	0	653, 2620
Ca	ICP/MS	2800	8400	100 (5)	1400	4200	78 (5)	2470, 5490
Ti	ICP/MS	13	39	100 (0)	6.3	19	100 (0)	7, 26
Fe	ICP/MS	1300	3900	0	630	1900	0	na
Zn	ICP/MS	260	780	100 (0)	130	390	100 (0)	131, 524
Cu	ICP/MS	13	39	83 (10)	6.3	19	94 (15)	12, 26
Sr	ICP/MS	2.6	7.8	100 (0)	1.3	3.9	94 (0)	3.0, 5.0
Br	ICP/MS	1600	4800	0	800	2400	0	26, 105
Cl	IC	320	960	42 (25)	160	480	56 (15)	250, 250

<sup>a</sup> For background corrected samples.

### 4.1.3 VOC's

#### 4.1.3.1 Canister VOC Collection

*Method Description* - Air samples for monitoring the target VOCs (see Table 4-4) were collected in 6 L SUMMA passivated stainless steel canisters. Restrictive orifices were used to control air flow into the canisters at ~25 mL/min during the 2-hour sampling period. Canister samples were returned to the laboratory. Canister samples were analyzed within 8 weeks of collection.

Prior to use, canisters were cleaned by heating to 130 °C in an oven for 4 hours while connected to a vacuum manifold. Canisters were then evacuated to 0.05 mm Hg vacuum. Restrictive orifices constructed and calibrated at RTI were attached to each canister in the field. During sample collection, a rotameter was used to measure air flow rates.

VOCs in canister samples were cryofocused then analyzed by gas chromatography/ mass spectrometry (GC/MS). Selected ion monitoring (SIM) was used to enhance method sensitivity. Analytical conditions are shown in Table 4-4. During analysis, a portion (200 mL) of the sample plus a known concentration of the external quantitation standard were cryogenically trapped then injected into the GC column for separation and analysis.

VOC identifications were based on chromatographic retention times relative to the external quantitation standard and relative abundance's of the selected ion fragments shown in Table 4-5. Ion fragments were selected based on previous project work with the target chemicals. Quantitation was performed using chromatographic peak areas derived from the selected ion profiles. Specifically, relative response factors (RRF's), or first order linear regression, for each target compound were generated from injections of canister standards prepared at 5 different concentrations (~0.5 to 50 ng/L). For each injection, the RRFs was calculated as:

$$RRF_T = \frac{A_T C_{QS} \text{ (ng / L)}}{A_{QA} C_T \text{ (ng / L)}} \quad (1)$$

where  $A_T$  is the peak area of the quantitation ion for the target compound and  $A_{QA}$  the peak area for the quantitation ion of the external quantitation standard.  $C_T$  is the concentration of the target compound in the standard canister and  $C_{QS}$  is the concentration of the external standard canister.

Mean values and standard deviations of the RRFs were calculated for each target VOC. The calibration curve was considered acceptable if the standard deviation for each relative response factor was less than 25%. During each day of analysis, an additional medium level calibration standard was analyzed. If the RRF values for this standard was within  $\pm 25\%$  of the average RRF, the GC/MS system was considered "in control" and the mean RRFs was used to calculate the concentration of the target VOCs in a sample ( $C_{TS}$ ):

$$C_{TS} \text{ (ng / L or } \mu\text{g / m}^3\text{)} = \frac{A_T C_{QS} \text{ (ng / L)}}{A_{QA} RRF_T} \quad (2)$$

**TABLE 4-4. GC/MS Operating Conditions for Analyses of VOC's**

Parameter	Setting
<b>THERMAL DESORPTION<sup>a</sup></b>	
Trap Type	1 = Glass beads, 2 = Tenax TA, 3 = Open
<b>CARTRIDGE DESORPTION<sup>a</sup></b>	
Temperature	2400C
Carrier Gas Flow Rate	25 mL/min
Time	8 min
<b>TRAP 1<sup>b</sup></b>	
Initial Temperature	~1500C
Desorption Temperature	200C
Desorption Carrier Gas Flow Rate	10 mL/min
Desorption Time	4 min
<b>TRAP 2</b>	
Initial Temperature	~100C
Desorption Temperature	1800C
Desorption Carrier Gas Flow Rate	10 mL/min
Desorption Time	35 min
<b>TRAP 3</b>	
Initial Temperature	~1500C
Desorption Temperature	1000C
Inject Time	5 min
<b>GAS CHROMATOGRAPH</b>	
Instrument	Hewlett-Packard 5890
Column	DB-624 widebore fused silica capillary column
Temperature Program	350C (5 min) to 2000C (1 min) at 50C/min
Carrier Gas Flow Rate	1.8 mL/min
<b>MASS SPECTROMETER</b>	
Instrument	Hewlett Packard, Model 5988A
Ionization Mode	Electron Ionization Scan 35-350 m/z
Emission Current	0.3 mA
Source Temperature	2000C
Electron Multiplier	2000 volts <sup>c</sup>

<sup>a</sup> For multi-sorb tube analysis, <sup>b</sup> For canister sample, air sample metered into trap 1.

<sup>c</sup> Typical value.



**TABLE 4-5. Target VOCs**

Target VOCs	Ion Fragments for GC/MS Analysis
Methyl <i>t</i> -butyl ether	73, 57
Ethyl <i>t</i> -butyl ether	57, 87
Benzene	78, 77
Toluene	91, 92
<i>m,p</i> -Xylene	91, 106
<i>o</i> -Xylene	91, 106
1,3-Butadiene	54, 53, 39

During this pilot study, the following quality control (QC) samples were prepared and analyzed to demonstrate method performance.

- Field controls (FC) are used to evaluate method recovery. These are canisters spiked with target VOCs at known concentrations. These samples are shipped to the field and handled exactly as field samples except that the valves are not opened.
- Field blanks (FB) are used to evaluate background contamination. These are unspiked canisters that are prepared by filling clean evacuated canisters with a volume of approximately 4.5 liters of VOC-free humidified nitrogen. These canisters are shipped to the field and handled exactly as field samples except that the valves are not opened.
- Field duplicates are field samples collected side-by-side to assess sampling precision.

Method quantitation limits have been set to the concentration of the lowest calibration standard.

*Method Evaluation* - Table 4-6 summarizes results for performance evaluation samples analyzed as part of the field monitoring effort on this Pilot Study. Although spiked into method controls and calibration standards, benzene was inadvertently left out off the list of target analytes. Since the analyses were conducted by GC/MS, the benzene results could not be retrieved from the sample analysis data. Overall, the method showed good performance for the target VOC's. Recoveries for 1,3 butadiene and methyl *t*-butyl ether (MTBE) were slightly low which may have been due to prolonged storage of the samples prior to analysis. Method quantitation limits were sufficiently low to provide high percent measurables for all targets except ethyl *t*-butyl ether (ETBE). Presumably, ETBE was not in use as a gasoline additive at the time of field monitoring and was, therefore, not present in air samples.

*Recommendations* - It is recommended that the canister method for VOC analysis be used in the Main Study without modification. Benzene will be a target analyte for the Main Study. During the Main Study, rapid turnaround will be required for the canister samples in order to send the canister back to the field for additional collections. Under these conditions, it is anticipated that storage times will be less than 7 days for all samples, and losses of VOC's due to

storage will be minimized. Additional target VOCs may be added to the list of analytes; this list of analytes should be finalized by the ARB.

**TABLE 4-6. Method Performance Data for VOC Canister Samples**

Analyte	Method Quantitation Limit ( $\mu\text{g}/\text{m}^3$ )	Field Blank Concentration ( $\mu\text{g}/\text{m}^3$ ) (n=2)	Field Control % Recovery (n = 2)	% RSD Duplicate Samples
1,3-Butadiene	0.22	0.1	76	0
MTBE	0.65	0.2	78	0
ETBE	0.65	0.0	83	ND <sup>a</sup>
Toluene	0.75	2.0	90	8.6
<i>o</i> -Xylene	0.77	0.3	91	2.0
<i>m,p</i> -Xylene	0.74	0.7	83	1.8
Benzene	NA <sup>b</sup>	NA <sup>b</sup>	NA <sup>b</sup>	NA <sup>b</sup>

<sup>a</sup> Not detected in duplicate samples. <sup>b</sup> Not analyzed

#### 4.1.3.2 Multisorbent Tube VOC Collection

*Method Description* - VOCs in in-vehicle air samples were also collected and analyzed using a multisorbent cartridge technique. Multisorbent cartridge samples were collected for two reasons. First, it was felt that the cartridge techniques were more practical for field operations. Second, the exposed cartridges were analyzed by GC/MS in the full scan mode which allowed additional VOC's that were present in the automobile air samples to be identified (see Appendix I).

For this method, VOCs were collected by passing air through multisorbent cartridges containing Tenax TA and Carbonex 1000 (Supelco, Inc., Pittsburgh, PA). Air samples were collected at a flow rate of approximately 50 mL/min over a 2-hour period to give a nominal sampling volume of 6 L. Exposed cartridges were sealed in stainless steel cans at 4 °C in the field. Samples were shipped via overnight carrier to RTI within 7 days of collection. At RTI samples were stored at -20 °C until analysis. All samples were analyzed within 6 weeks of collection.

VOCs on exposed cartridges were thermally desorbed, focused, then analyzed by GC/MS using the conditions shown in Table 4-5. For quantitative analysis, VOC identifications were based on chromatographic retention times relative to the external quantitation standard and relative abundance's of the selected ion fragments shown in Table 4-4. Quantitation was performed using chromatographic peak areas derived from the selected ion profiles. Specifically, relative response factors (RRFs), or first order linear regression, for each target compound were

generated from injections of standard cartridges prepared at 5 different levels (~10 to 500 ng/cartridge). For each injection, the RRFs was calculated as:

$$RRF_T = \frac{A_T C_{QS} \text{ (ng/L)}}{A_{QA} C_T \text{ (ng/L)}} \quad (3)$$

where  $A_T$  is the peak area of the quantitation ion for the target compound and  $A_{QA}$  the peak area for the quantitation ion of the external quantitation standard.  $C_T$  is the amount of the target compound on the standard cartridge and  $C_{QS}$  is the amount of the external standard canister.

Mean values and standard deviations of the Rf's were calculated for each target VOC. The calibration curve was considered acceptable if the standard deviation for each relative response factor was less than 25%. During each day of analysis, an additional medium level calibration standard will be analyzed. If the RRF values for this standard was within  $\pm 25\%$  of the average RRF, the GC/MS system was considered "in control" and the mean RRFs was used to calculate the amount of the target VOCs in a sample ( $M_{TS}$ ):

$$C_{TS} \text{ (ng/L or mg/m}^3\text{)} = \frac{A_T C_{QS} \text{ (ng/L)}}{A_{QA} R_{FT}} \quad (4)$$

Sample concentrations were calculated by dividing the sample amount by the collected volume.

Identification of non-target VOCs was performed using an electronic search of the NIH/EPA/MSDC Mass Spectral Data Base (NBS library) and the Registry of Mass Spectral Library (Wiley library).

*Method Evaluation* - Quality control samples included field blanks, field controls, and duplicate samples. Method quantitation limits were set equal to sample concentration that would be equal to one-half of the lowest calibration level.

Results for these analyses are given in Table 4-7. Data indicate that recoveries of 1,3-Butadiene from field controls was low. Additional work with the multisorbent tubes showed that during sample collection, MTBE was concentrated on the Carbonex 1000 trap but was not desorbed efficiently. Side-by-side comparisons of the results for multisorbent and canister samples (Table 6-1) showed a negative bias for the multisorbent method for 1,3-Butadiene and MTBE. Comparative data for the other target compounds showed good agreement between the two methods.

*Recommendation* - Based on the results for the pilot study, the multisorbent method is not recommended for the Main Study.

**TABLE 4-7. Method Performance for VOCs and Multisorbent Samples**

Analyte	Method Quantitation Limit ( $\mu\text{g}/\text{m}^3$ )	Field Blank Concentration ( $\mu\text{g}/\text{m}^3$ )	Field Control % Recovery	% RSD Duplicate Samples
1,3-Butadiene	0.22	ND	31 $\pm$ 7.3	ND <sup>a</sup>
MTBE	0.75	ND	101 $\pm$ 24	3.0
ETBE	0.75	ND	108 $\pm$ 9.8	ND
Toluene	0.75	ND	106 $\pm$ 3.5	9.7
<i>o</i> -Xylene	0.75	ND	103 $\pm$ 5.0	7.1
<i>m,p</i> -Xylene	0.75	ND	104 $\pm$ 4.5	9.0
Benzene	0.75	ND	100 $\pm$ 3.1	4.5

<sup>a</sup> Not detected in duplicate pairs.

#### 4.1.4 Nitrogen Dioxide (NO<sub>2</sub>)

##### *Method Description --*

Nitrogen Dioxide in air samples was monitored using OSHA Method ID-109. Using this method, air samples were passed through SKC sorbent cartridges containing molecular sieve impregnated with triethanolamine (TEA). NO<sub>2</sub> in the air sample reacts with the TEA and is collected on the cartridge material. Samples were collected over 1-hour period at a flow rate of approximately 0.1 L/min for a nominal sample volume of approximately 6 L. Flow rates at the cartridge inlet were measured before and after sample collection using calibrated rotameters with a fixed-orifice bypass tube.

The nitrogen dioxide trapped on the sorbent tube was extracted with an aqueous TEA solution. An aliquot of the extract was treated with a solution containing diphenylamine, thiocyanate, and hydrochloric acid. The resulting nitrite ion was measured polarographically. Quantitation was accomplished using by the external standard method using calibration standards prepared in the range of 0.01 to 10 ppm nitrite solution.

*Method Evaluation* - Method performance data generated during the Pilot Study are given in Table 4-8. Results indicate that the method was not sufficiently sensitive to reliably measure nitrogen dioxide in air samples at the low levels found in the ambient air and in automobile samples.

*Recommendations* - Due to its limited sensitivity it is recommended that NO<sub>2</sub> monitoring not be conducted during the Main Study. Alternatively, work should be conducted to improve method sensitivity. Sensitivity could potentially be improved by increasing the sample volume. If this approach were taken, then a study of acceptable breakthrough volume would be required prior to field monitoring for the Main Study.

**TABLE 4-8. Method Performance Results for NO<sub>x</sub> Samples**

Method Quantitation Limit -- based on lowest calibration standard	25 ppm	
Method Detection Limit -- based on 3X standard deviation of field blanks	47 ppm	
% of Samples above MDL	46%	
Field Blanks	0 ± 15.7 ppm	
Duplicate Sample Pairs	Concentration (ppm)	%RSD
1	55, 46	13
2	57, 79	23
3	31, 0	— <sup>a</sup>
4	75, 15	94

<sup>a</sup> Not calculated; both samples below the MDL.

#### 4.1.5 PAH's

*Method Description* - Particle-bound PAHs were measured on a limited set of particle filters. The 5-, 6-, and 7-ringed PAHs targeted for monitoring are given in Table 4-9. This group of PAHs include benzo[a]pyrene (BaP) which is a known human carcinogen; BaP is also within the group of chemicals known as polycyclic organic matter and was identified along with other federal hazardous air pollutants as a toxic air contaminant. PAHs were monitored using a method developed at RTI and applied to more than 1000 air samples as part of ARB funded studies to investigate PAH levels in indoor air.

**TABLE 4-9. PAH's For Analysis**

Structure	Compounds
5 rings	benzo{a}pyrene, benzofluoranthenes, benzo[e]pyrene
6 rings	indeno[1, 2, 3-cd]pyrene, benzo[ghi]perylene
7 rings	coronene

Particle-bound PAHs were collected by passing air through a sampling cartridge containing a 21 mm quartz fiber filter using an AC medium-volume constant flow pump (Esoteric, Model Sp-2511). For samples collected inside and outside of the car, the pumps were operated off the power inverter in the car. A gel cell battery was used to power the pumps at the roadway and ambient sites. Samples were collected during the 2-hour driving period at a flow rate of 8 L/min to provide a nominal sample volume of approximately 1 m<sup>3</sup>. Flow rates at the cartridge inlet were measured before and after sample collection using calibrated rotameters with a fixed-orifice bypass tube.

PAHs were recovered from the filter by sonication extraction with methylene chloride for a 30-minute period, soaking overnight, then sonic extraction for an additional 30 minutes. The solvent extract was separated from the cartridge material by filtering through silanized glass wool. The filtered extract was solvent exchanged into toluene and concentrated to 0.2 mL.

Deuterated surrogate standards were added to samples immediately prior to extraction to monitor overall method performance. External quantitation standards were added to sample extracts immediately prior to final concentration and analysis. Chrysene-d<sub>12</sub>, and benzo[e]pyrene-d<sub>12</sub> were used as surrogate standards. 1,2,3,4-Tetrachloronaphthylene and perylene-d<sub>12</sub> were used as external quantitation standards.

Sample extracts were analyzed by direct liquid injection capillary GC/MS. A 1 µL aliquot of the sample extract was injected using a split/splitless injection technique. Analytes separated on the GC column were introduced to a quadrupole mass spectrometer operating with electron ionization in the selected ion monitoring (SIM) mode. Sample constituents are characterized and quantitated by measuring ions characteristic of the target chemicals. Instrumental operating parameters are described in Table 4-10. Prior to analysis, the GC/MS system was calibrated by analyzing five calibration standards ranging in concentration from 5 to 500 ng/mL. For PAHs with no other chemical substituents, the M<sup>+</sup> ion is used as the primary quantitation ion because it is usually the ion with the greatest relative abundance for PAHs. The M+1 ion is included to verify compound identification.

**TABLE 4-10. GC/MS Operating Parameters for Analysis of PAHs**

Column Type:	30 m, DB-5, 0.25 mm i.d., 0.1 µm film
Run Type:	Electron ionization; selected ion monitoring
Injection Type:	Splitless/Split (0.5 min)
Injection Temperature:	3000C
Interface Temperature:	3000C
Source Temperature:	2000C
GC Program:	Initial temperature = 1000C
	Initial program rate = 30C/min
	Final temperature = 3000C
	Final hold time = 20 minutes
Instrument:	Hewlett Packard 5988A
Multiplier Voltage:	2000 <sup>a</sup>
Emission Current:	300 mA <sup>a</sup>
Dwell Time:	75-250 msec

<sup>a</sup>A typical value.

Results of individual calibration analysis are used to generate relative response factors (RRF) using the following equation:

$$RRF_t = \frac{A_t / C_{std}}{A_{std} / C_t} \quad (5)$$

where:

$A_t$	=	system response (integrated peak area)
$C$	=	concentration in calibration standard (ng/mL)
$t$	=	analyte
$std$	=	external quantitation standard.

Average RRFs are then calculated using results from each calibration standard. Instrumental calibration is considered acceptable if the percent relative standard deviation of the average RRF value was less than 25 for each of the target PAHs.

During sample analysis, two performance checks are made on the analytical system at the start of each day. First, the tune compound, perfluorotributylamine, is introduced into the mass spectrometer ionization source. All characteristic fragment ions were required to be present in the correct relative abundance before proceeding with any further analyses. Second, a mid-level calibration standard is analyzed and RRF values calculated for each target PAH. The calibration is considered "in control" if the RRF values calculated for the primary ions or the target PAHs are within  $\pm 25\%$  of the mean RRFs. Analyte amounts in sample extracts (T) are calculated as:

$$T \text{ (ng)} = \frac{A_t C_{std} V_e}{A_{std} RRF_t} \quad (6)$$

where  $V_e$  is the final extract volume (mL). The concentration of PAHs in air samples is calculated by dividing the sample amounts by the sample volume.

Performance of the monitoring method has been thoroughly evaluated in several ARB-sponsored field monitoring studies. For this study, method performance was evaluated using method blanks, method controls, filters spiked with NIST dust, duplicate samples, and the recovery of surrogate standards from field samples. The method quantitation limits are calculated based on the sample concentration that would give an extract concentration at one-half the level of the lowest calibration standard.

*Method Evaluation* - Method performance data are summarized in Table 4-11. Recoveries of target PAHs from method controls and NIST SRMs were good. In addition, recoveries of surrogate standard in all filter samples was acceptable. Levels of PAHs in the single field blank were either very low or not detectable. Unfortunately, PAHs were not measured in any of the samples at concentrations higher than the MQL. Method sensitivity

could be increased by a factor of two by increasing the flow rates for the sampling pumps. Alternatively, RTI is acquiring a new GC/MS system that will have much lower detection limits (~0.1 pg/μL) compared to the systems currently in use (5 pg/μL). The feasibility of using this system for analyzing PAH samples could be evaluated. It should be noted however, that the MQLs report for this pilot study (1.0 ng/m<sup>3</sup>) are similar to the 0.9 ng/m<sup>3</sup> level that the California Office of Environmental Health Hazard Assessment suggests is required to cause 10<sup>-6</sup> excess cancer risk over a 70-year exposure period.

**TABLE 4-11. Method Performance for PAH Samples**

Estimated Method Quantitation Limit	1.0 ng/m <sup>3</sup> for all PAHs
% of Samples with PAH levels > MQL	0%
% Recovery of Surrogate Standards (n=14)	Chrysene-D12 -- 97 ± 9.4% Benzo[e]pyrene-D12 -- 93 ± 13%
% Recovery from NIST SRM (n=3)	Benzo[a]anthracene -- 73 ± 19% Benzo[a]pyrene -- 83 ± 12% Indeno[1,2,3-cd]pyrene -- 95 ± 4% Benzo[ghi]perylene -- 79 ± 8%
Recovery from Method Controls (n=6)	Benzo[b]fluoranthene -- 96 ± 7% Benzp[k]fluoranthene -- 100 ± 5% Benzo[a]pyrene -- 91 ± 11% Indeno[1,2,3-cd]pyrene -- 82 ± 18% Benzo[ghi]perylene -- 78 ± 16%
Amount on Field Blank	All not detected except Benzo[b]fluoranthene -- 0.08 μg/m <sup>3</sup> Benzp[ghi]perylene -- 0.06 μg/m <sup>3</sup>
% RSD of Duplicate samples	No duplicates collected

*Recommendations -m* Currently, PAH monitoring is not proposed for the Main Study. If additional monitoring is requested by the ARB then both the need for and the feasibility of improving method quantitation limits should be investigated.

#### 4.1.6 Formaldehyde

*Method Description* - Formaldehyde was monitored inside the car during each test drive. Formaldehyde in air samples were collected by passing air through DNPH-coated Sep-Pak cartridges (Water Associates, Milford, MA). Samples were collected at a flow rate of approximately 300 mL/min using a battery-powered low volume pump. Samples were collected for a 2-hour period to give a nominal volume of 36 L. Flow rates at the cartridge inlet were measured before and after sample collection using calibrated rotameters with a fixed-orifice bypass tube.



DNPH/formaldehyde derivatives on sample cartridges were extracted by eluting each cartridge with 5 mL of HPLC grade acetonitrile into a 5 mL volumetric flask. The final volume is adjusted to 5.0 mL and the sample aliquoted for analysis.

DNPH/formaldehyde derivative in sample extracts were analyzed by HPLC with UV detection. Certified solutions of the DNPH/formaldehyde derivative were used to prepare the calibration solutions. DNPH/formaldehyde derivatives in sample extracts were identified by comparison of their chromatographic retention times with those of the purified standards. Quantitation was accomplished by the external standard method using calibration standards prepared in the range of 0.02 to 15 ng/ $\mu$ l of the derivative. Standards were analyzed singly for the formaldehyde/DNPH derivative and a calibration curve calculated by linear regression of the concentration and chromatographic response data. To be acceptable the calibration curve needed to give an  $R^2$  greater than 0.998.

To demonstrate on-going analytical performance, a calibration standard was analyzed each day prior to the analysis of any sample and after every 10 samples. The calibration was considered "in control" if the measured concentration of the formaldehyde derivative in the standard was 85 to 115% of the prepared concentration.

*Method Evaluation* - Method performance was evaluated using field blanks, field controls, and duplicate samples. The method quantitation limit was calculated based on the sample concentration that would give an extract concentration at the level of the lowest calibration standard.

Method performance data are summarized in Table 4-12. Results indicated that the method should provide sufficient accuracy, precision, and sensitivity to measure formaldehyde in automobile air samples.

*Recommendations* - It is recommended that the method be used without modification in the Main Study.

**TABLE 4-12. Method Performance for Formaldehyde Samples**

Estimated Method Quantitation Limit	1.4 $\mu$ g/ $m^3$
% of Samples with formaldehyde levels > MQL	0%
% Recovery from Field Controls (n=2)	99 $\pm$ 0%
Amount on Field Blanks (n=2)	36 ng/samples, 1.5 $\mu$ g/ $m^3$ for a 24 L sample
% RSD of Duplicate samples (n=2)	2.5%, 5.5%

## 4.2 Continuous Measurements

### 4.2.1 Carbon Monoxide (CO)

*Method Description* - Carbon monoxide was measured inside of the vehicles, outside of the vehicles, and at the roadside sites using Draeger Model 190 carbon monoxide monitors/data

loggers with extended memory. The monitors are pocket size, sensing and logging devices with accuracy reported by the manufacturer as  $\pm 2$  ppm CO. The monitors are powered by a single 9 V alkaline battery. The monitors utilize a three-electrode electrochemical sensor for continuous measurement of CO. A scrubber containing charcoal and Purafil is used on the monitor inlet to reduce interferences. An integral data logger records sensor measurements 120 times per minute. These values are averaged by the monitor and 1 minute average values are stored by the monitor data logger. Stored values are downloaded at the end of the monitoring period via an RS-232 interface to a portable computer using software supplied by National Draeger, Inc.. Results will be reported as one hour average and peak CO concentrations.

Two CO monitors were used for each vehicle to monitor inside and outside CO concentrations; Teflon sampling lines were used to draw air sequentially, first near the driver's breathing zone, and then from the vehicle exterior via a sampling manifold. A computer controller electronic timer was used to switch solenoid positions between the interior and exterior sample line every 5 minutes. Fixed site CO monitors were placed in "weather tight", insulated sampling boxes to minimize effects due to ambient outdoor temperatures and moisture.

Prior to initial use in the field, each CO monitor was calibrated using certified carbon monoxide gas standards at concentrations of 0, 2, 10 and 21.5 ppm. In addition to the weekly checks, a zero and span (21.5 ppm) check was performed at the start and the end of each test drive. At the start of the test drive, the zero and span of the monitor was adjusted to give readings of zero and 21.5, respectively. At the end of the test drive, no adjustments were made for the zero and span, rather readings were recorded on log sheets prepared for this purpose.

*Method Evaluation* - Performance of the CO monitors was evaluated based on the calibration checks and the deployment of duplicate monitors. For each test drive, performance of the CO monitor was considered "in control" if there was less than a 2 ppm drift in either the zero or the span reading. This criterion was met for all monitors with one exception. On day one, the zero reading for one monitor drifted to 3 ppm. Method quantitation limits were set at 2 ppm based on information from the instrument manufacturer. Results for duplicate monitors showed agreement in 1-hour average readings within the 2 ppm specifications.

*Recommendations* - The CO monitors worked well throughout the study. Although many of the readings especially at the ambient and roadway sites were at or below the MQL, the monitors are acceptable for measuring CO levels that are below the California ambient air monitoring standard of 9 ppm. It is recommended that the method for monitoring CO be used without modification during the Main Study.

#### **4.2.2 Particle Size and Mass Distributions**

*Method Description*- The size distribution and volume of fine particles both inside and outside of the vehicle were measured continuously in the size range from 0.1 to 3  $\mu\text{m}$ . Measurements were made using the LAS-X optical particle counter (Particle Measuring Systems, Boulder, Colorado). Prior to the study, the instrument was calibrated in the laboratory at Aerosol Dynamics Inc. The individual optical channel calibrations were performed using a differential mobility optical particle size spectrometer (DMOPSS) system, which was developed and deployed for two atmospheric visibility studies to provide *in-situ* calibration of optical counters for precise size distribution measurement (Stolzenburg et al., 1995) with ambient Berkeley, CA aerosols and with dioctyl sebacate aerosols. Calibrations were conducted using both dioctyl

sebacate, an aerosol with a refractive index of 1.45, with size-classified ambient Berkeley aerosols, and size-classified California vehicular aerosols from a local Berkeley tunnel study. The details of these calibrations were provided to the ARB project officer as part of the final subcontract report prepared by Aerosol Dynamics.

During the study, fine particle measurements were made by sampling with a single LAS-X optical counter both inside and outside the vehicle. Data were collected with 15 s time resolution, then combined into 1 min averages. The data were reduced using both calibrations, to yield the volume of aerosol as a function of particle diameter inside and outside of the vehicle. Size distribution data was averaged over longer periods to obtain the mean ratio of inside to outside particle volume as a function of particle diameter. Size distributions were also integrated to give fine particle volumes inside and outside the vehicle as a function of time. The instrument was operated off of the power inverter that was located in the trunk of the test vehicle. Mass distributions were computed by applying density calibrations from "real" California ambient and vehicular aerosols and integrated to produce  $PM_{2.5}$  concentrations. In order to apply the densities of vehicular and ambient aerosol, a composite estimate must be made of the fractional contribution of each source to the aerosol measured during commuting. This was accomplished by first developing a composite density that included a fractional contribution term from each source. The  $PM_{2.5}$  inside and outside concentrations for all commutes were then computed from the LAS-X data, over a range of these fractional contributions. By minimizing the differences between the measured (the concentration  $<10 \mu\text{g}/\text{m}^3$  for the 3/3 AM commute was not used) and computed values, it was determined that the best agreement occurred when the fraction of vehicular aerosol was 24 % (i.e. the ambient fraction was 76 %). A graph of the influence of fractional source contribution of the mean differences between computed and measured  $PM_{2.5}$  concentrations is shown in Figure 4-3. The relationship of the measured and computed  $PM_{2.5}$  concentrations for all commutes using the 24 % vehicular contribution factor is shown in Figure 4-4.

*Method Evaluation-* Overall the LAS-X particle counter worked well and provided valuable information on real-time particle counts and concentrations. Method performance is highlighted as follows:

- When the on-board power system was functioning properly in the car, the LAS-X operated smoothly, requiring little attention during sampling and no unplanned maintenance.
- The prior calibration of the LAS-X with real California ambient and vehicular aerosols substantially improved the ability to correlate the  $PM_{2.5}$  concentrations computed from optical measurements with the integrated gravimetric data.
- The LAS-X 1 minute particle count averages correlated strongly with the Aethalometer black carbon analyzer (see example Figure 4-5) when the car was following a vehicle (gasoline or diesel) with a smoking exhaust.
- The LAS-X 1 minute computed  $PM_{2.5}$  mass concentrations provided greater detail during the commute of the actual exposure levels, as compared to the total commute gravimetric, integrated average (see example Figure 4-5).

Figure 4-3

Composite Mean Difference Between Measured and Computed LAS-X  
PM2.5 Concentrations as a Function of the Fraction of Ambient Air Input  
Into the Particle Size and Particle Density Computations

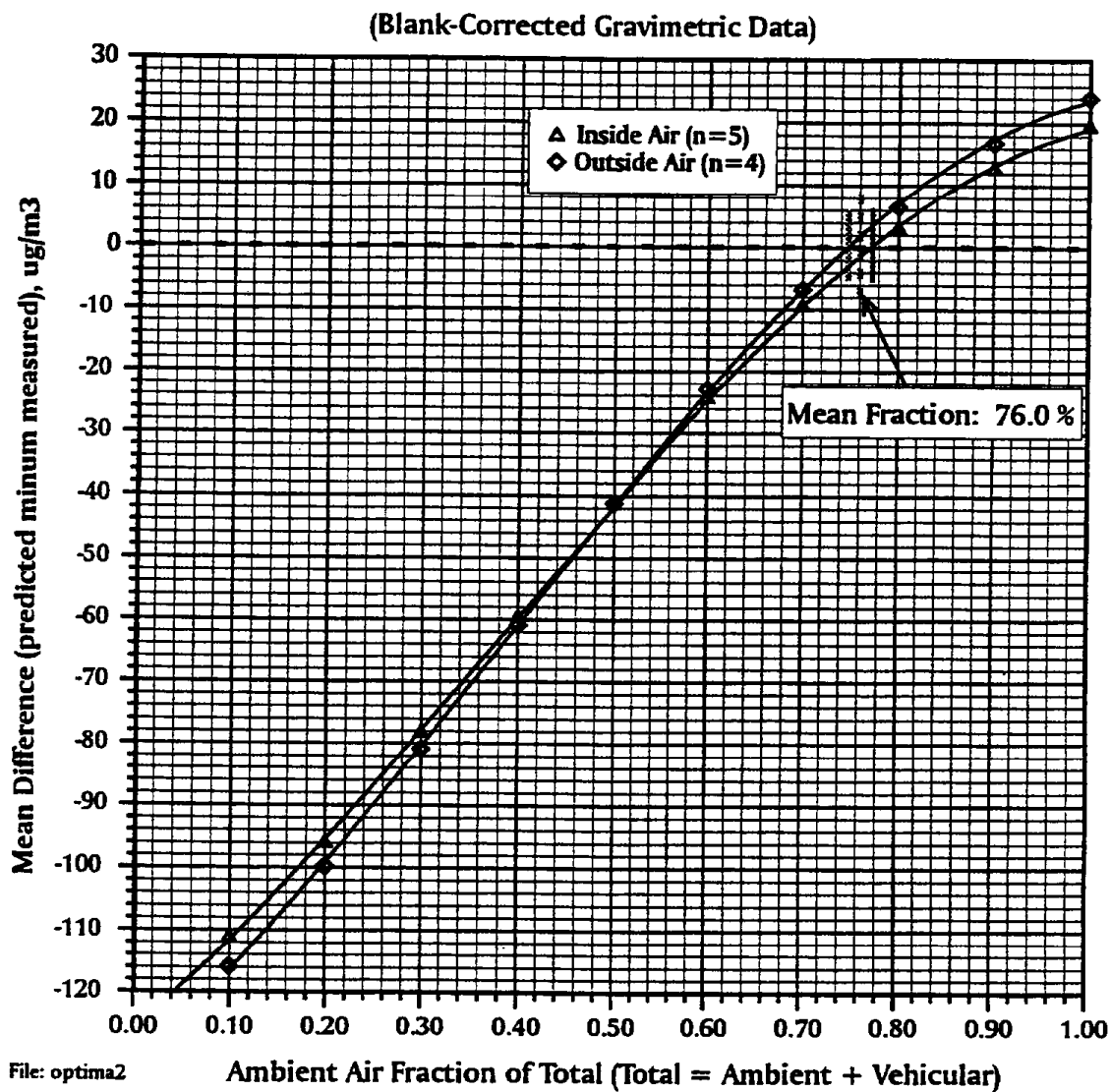


Figure 4-4

### PM2.5 Gravimetric Mass Concentrations as Predicted by Computed Concentrations from LAS-X Data

Blank-Corrected gravimetric data;  
Error bars are 1 sigma MDL's based on weighing precision only;  
LAS-X concentrations computed using Aerosol Dynamics' particle density  
and optical size calibration data for California ambient and vehicular aerosols.

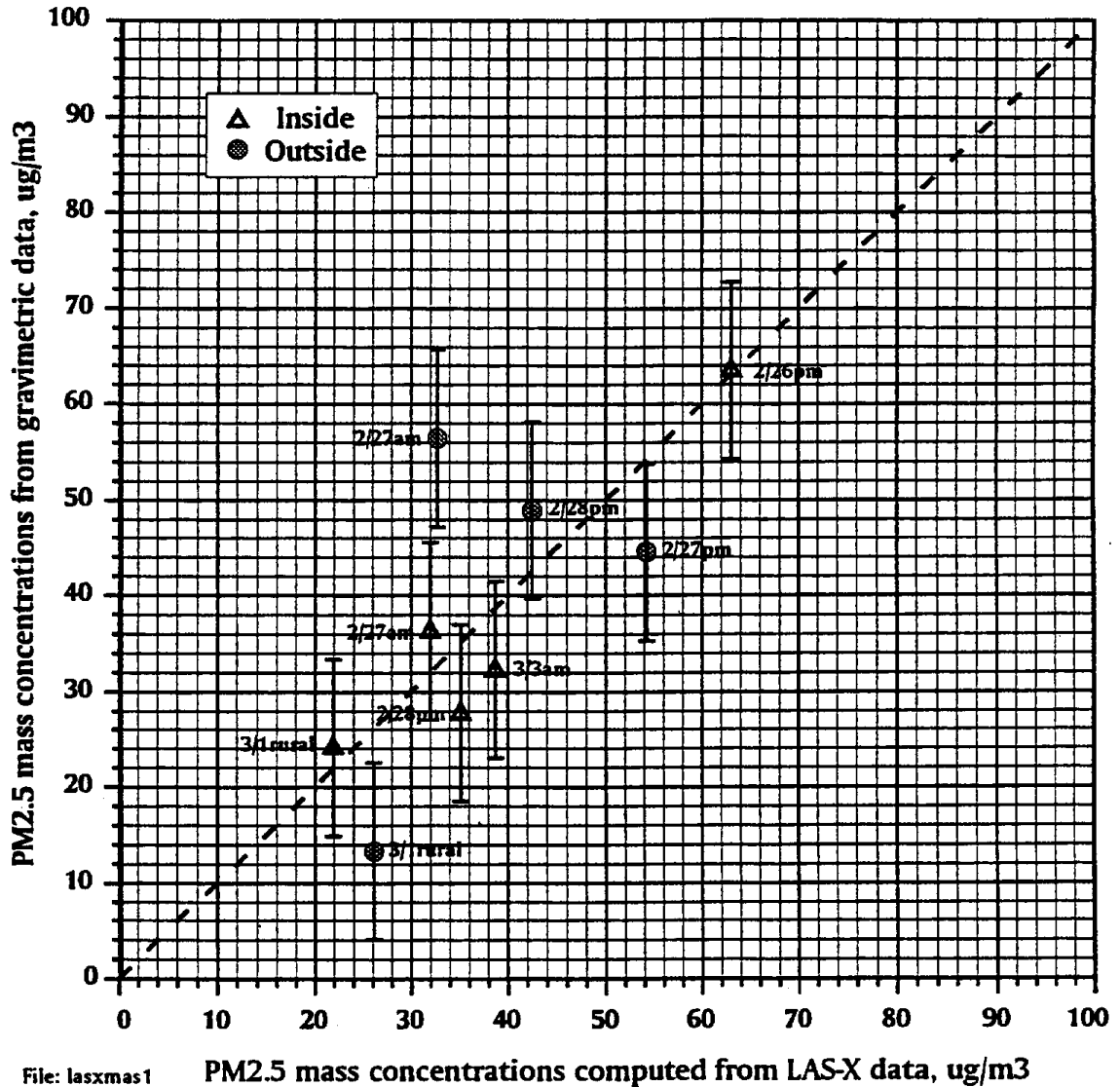
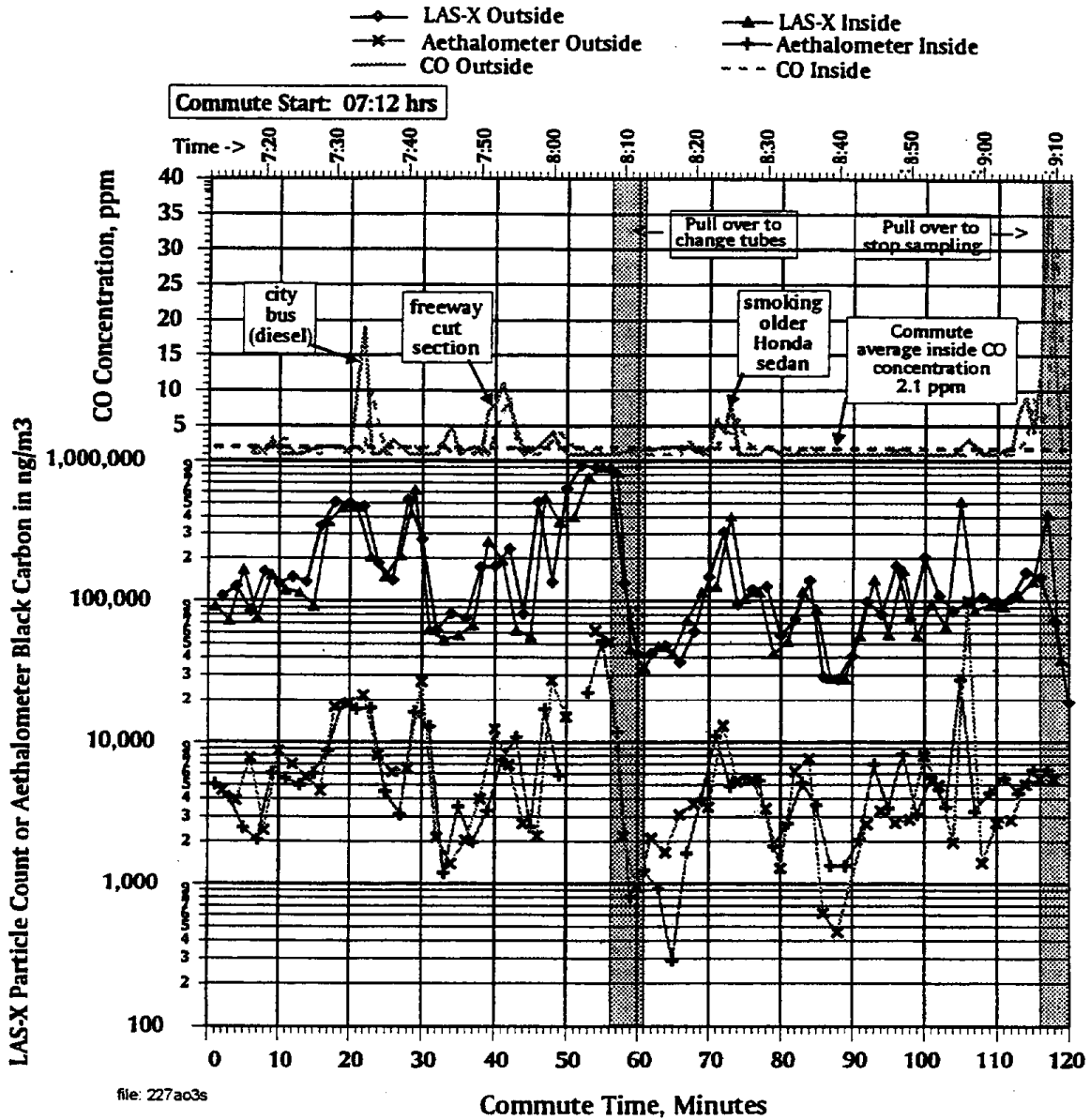


Figure 4-5

### LAS-X Particle Counts, Aethalometer Black Carbon and Carbon Monoxide (CO) Outside and Inside Test Car

2/27/97 AM

Particle Size Bin TOTAL



*Recommendations-* It is recommended that the LAS-X particle counter be used during the Main Study to collect real-time particle data. This can be done with a minimum of cost and effort with the equipment that is currently available. The calibration that was generated during the Pilot Study would still be applied. These data would be archived and provided to the ARB for future analysis.

#### **4.3.3 Black (Elemental) Carbon**

The concentration of elemental, or "black" carbon was measured semi-continuously using an Aethalometer (Magee Scientific, Berkeley, CA). This is a commercial instrument that examines the blackness of a filter as the sample is collected. A prototype developed at Lawrence Berkeley Laboratories was used in the 1986 ARB-sponsored Carbon Species Method Comparison Study, and was able to resolve single diesel trucks in the parking lot next to the sampling site. The instrument was operated using the manufacturer's calibration. Measurements were taken with a 1 min time resolution. Measurements were made inside and outside of the vehicle to give the inside/outside ratios as a function of time and vehicle driving conditions. Outside air was drawn through the sampling manifold. The instrument was operated off of the power inverter that was located in the trunk of the test vehicle.

*Method Evaluation-* Method performance for the Aethalometer black carbon measurements may be highlighted as follows:

- When the on-board power system was functioning properly in the car, the Aethalometer operated smoothly, requiring little attention during sampling and no unplanned maintenance.
- The expected correlation of the LAS-X and Aethalometer was observed when 1 min averages were compared, but the expected correlation with PAH integrated levels could not be determined because of the low PAH concentrations.
- The Aethalometer readily indicated the presence of smoking gasoline and diesel exhausts (as did the LAS-X), when the Caprice was behind these vehicles.

*Recommendations-* Although the Aethalometer potentially can provide useful information relative to identifying diesel vehicle influence on vehicular exposure levels, the additional cost of the monthly lease (unplanned) does not appear to be a warranted expense for the Main Study.

#### **4.3 Air Exchange Rate (AER)**

Air exchange rates for the test car under the three ventilation settings were measured using a modification of the CO decay method of Ott and Willits (1981). The procedure was implemented as follows:

- travel to an isolated location with minimal traffic ;
- set the selected ventilation setting in the test car and begin to drive the car at the desired speed (0 to 45 mph);
- release CO into the cabin of the automobile to a concentration of approximately 100 ppm;
- maintain the desired speed of the car (0 or 45 mph);
- monitor CO concentrations in the cabin of the car with the Draeger CO monitor; and
- compute the AER [air changes / hour], as

$$\text{AER} = (1/t) \ln (C_i / C_f) \quad (7)$$

where  $t$  = decay time (h), ,  
 $C_i$ ,  $C_f$  is the initial, final concentration of CO in ppm.

*Method Evaluation* - Air exchange rates for the test vehicle were made on the rural route. Measurements of the three air exchange rate took approximately 2 hours. There were no logistical problems with implementing this procedure. There was, however, no way to assess the accuracy of the method, other than to cite the expected accuracy of the Draeger CO monitor (see Section 4.2.1). The main drawback to this method is that only a representative air exchange rate is obtained for the ventilation settings. Measurements of AER are not made during the test runs thus the AER during the test run could be substantially different that that was measured.

*Recommendations* - Despite this limitation, the method is recommended for the Main Study. Tests should be performed at the outset of the Main Study to characterize Sedan 1, Sedan 2, the sport/utility vehicle, and the school bus. If Sedan 2 and the SUV have the same range of air exchange rates as Sedan 1, the emphasis for the Main Study should be the high AER ventilation settings, which tend to maximize inside concentrations. If the additional vehicle AER data are significantly lower than Sedan 1, the emphasis should be balanced.

#### 4.4 TRAFFIC DATA

##### 4.4.1 In-Vehicle Data

###### *Method Description--*

Vehicle speed was recorded using a digital sender mounted on the drive-shaft for Sedan 1 and custom signal-conditioning circuitry. The signal from the OEM speed sender was also recorded as a backup. A grill-mounted laser range finder made to custom order for Sierra Research by Laser Atlanta, measured following distance from the car ahead. Accuracy of the measurement is approximately two feet. Lateral and longitudinal accelerometers were used to record total acceleration. All data were recorded once per second.

During on-road data collection, the test vehicle was driven by a two-member team that is familiar with the on-board equipment and drive protocols. The principal responsibility of the driver was, of course, to drive safely. The second technician served as a navigator and "observer," and uses a data entry switch box to log information of the selected parameters. These parameters were selected in consultation and final approval by the ARB. When necessary, the navigator kept a manual record of unusual events during each test drive. All drives were videotaped for later examination of any unusual events or to ascertain additional information about the test drive. Available data were obtained from CalTrans on roadway traffic counts relative to the selected commute route.

*Method Evaluation-* The collection of data for Level of Congestion and the Additional Parameter given in Table 3-5 using the-vehicle switch box was cumbersome and time consuming for the navigator. The utility of the Addition Parameter data was also not apparent during data analysis. The videotape of the drives provide excellent information on roadway conditions and target vehicles. CalTrans data are not always available for test runs and although it can provide good information for route selection, it does not appear to be useful for data analysis. For the freeway drives following distances were uniform throughout and therefore would not be a useful variable for data analysis.



*Recommendations-* The data/information collected during each commute for the Main Study should be revised to be (a) vehicle speed, (b) vehicle spacing, (c) Level of Congestion (traffic density), (d) video recording, and (e) a commute diary. This revisions will minimize the burden placed on the driver and navigator in collecting the data. It will also reduce the effort associated with reducing these data and relating it to measurement parameters.

## 5.0 DATA TABULATIONS

### 5.1 Data Tables

A compilation of the individual pollutant monitoring data for VOCs, formaldehyde, particle mass, black carbon, PAHs, carbon monoxide, and nitrogen dioxide is given in Tables 5-1A thru 5-1D by monitoring trip. These data represent 6 freeway commutes and 1 rural commute, all in the Sacramento area. Starred (\*) data are below the method MQL. A similar compilation for the primary elements (metals) is given in Tables 5-2A thru 5-2E. The commute-average data are based on the commute times (minutes) given in Table 3-3. The CO and NO<sub>2</sub> hourly data are nominally: (a) Hour 1 - first 60 minutes, and (b) Hour 2 - next 60 minutes [truncated if the commute was less than 120 minutes]. A table summarizing the PM<sub>2.5</sub> and PM<sub>10</sub> data separately is provided in Appendix H.

It should be noted that the Pilot Study data represent only a limited six-day monitoring period in Sacramento from February 26 to March 3, 1997. The meteorological conditions during that period resulted in a relatively "clean" ambient air setting compared to what might normally be expected in the winter in Sacramento or in the Summer/Fall (proposed time period for the Main Study) in either Los Angeles or Sacramento. The limited scope of the data suggests that only limited conclusions can be drawn, especially considering the low concentrations and the associated limits of detection for the respective methods.

We have based our conclusions on these monitoring data. However, it should be understood that some of the conclusion from the Pilot Study may not be directly applicable to a more polluted setting such as that anticipated for the Main Study later this year in Sacramento and Los Angeles. This becomes a very important consideration when evaluating the sensitivity of various monitoring methods. Methods that appear to be marginally suitable based on sensitivity may, in fact, be acceptable if the Main Study is conducted under more highly polluted conditions.

### 5.2 Data Interpretations

The data collected during the Pilot Study have been evaluated to answer several questions that address basic study design elements of the Main Study. These include:

**1. Are the measurement methods sufficiently sensitive to measure pollutant air concentrations during 2-hour driving periods?**

Results in Tables 5-1 and 5-2 provide information on air concentrations regardless of whether they are below the reported MQL. Data that are below the estimated MDL of MQLs are highlighted in the tables. The percentage of sample measurements that are above the reporting level are summarized in Table 5-3. In general, methods for VOCs, formaldehyde, continuous measures of PM<sub>2.5</sub>, continuous measures of carbon black, and peak measures for CO provided higher percent measurable values. Methods for PM<sub>2.5</sub> mass, PM<sub>10</sub> mass, NO<sub>2</sub>, and 1-h average CO provided measurement data that were in the range of the MQL or MDL values. Methods for the metals were typically near the MQL, but the results were dependent upon the specific metal measured. PAHs gave concentrations well below the MQL values.

It should be reiterated that although several methods appear to provide only marginal sensitivity for this Pilot Study. They may, in fact, provide acceptable sensitivity if the Main Study is conducted under more highly polluted conditions.

**TABLE 5-1A. IN-TRAFFIC DATA**

Analyte	Concentration						
	Ambient	Out-Car	In-Car <sup>a</sup>	Road-1	Road-2	Road-3	Road-4
<b>Day 1 (2/26), AM, Freeway Rush – Vent 2; medium air exchange rate:( 98 hr<sup>-1</sup> @ 55 mph)</b>							
VOCs (µg/m <sup>3</sup> )							
1,3-Butadiene	0.5	1.9	2.7 (ND) <sup>b</sup>	-- <sup>c</sup>	--	--	--
MTBE	5.7	10	12 (7.2)	--	--	--	--
ETBE	ND <sup>d*</sup>	ND <sup>*</sup>	ND <sup>*</sup>	--	--	--	--
Benzene	--	--	(1.7)	--	--	--	--
Toluene	20	27	37 (34)	--	--	--	--
<i>m,p</i> -Xylene	5.3	12	21 (21)	--	--	--	--
<i>o</i> -Xylene	2.1	4.8	8.1 (7.2)	--	--	--	--
Formaldehyde (µg/m <sup>3</sup> )	--	--	11	--	--	--	--
PM <sub>10</sub> (µg/m <sup>3</sup> )	46 <sup>*</sup>	--	63	--	--	--	--
PM <sub>2.5</sub> (µg/m <sup>3</sup> )	58	53 (–)	35 (–)	--	--	--	--
Carbon Black (µg/m <sup>3</sup> )	--	--	--	--	--	--	--
CO average (ppm)	0, 0 <sup>e</sup>	1.3, 1.1	--	--	--	--	--
CO peak value (ppm)	1, 0	10	--	--	--	--	--
NO <sub>2</sub> (ppb) <sup>e</sup>	48, 37	36, 67	45, 48	--	--	--	--
<b>Day 1 (2/26), PM, Freeway Rush – Vent 2; medium air exchange rate:( 98 hr<sup>-1</sup> @ 55 mph)</b>							
VOCs (µg/m <sup>3</sup> )							
1,3-Butadiene	0.6	2.9	3.1 (7.5)	--	--	--	--
MTBE	4.5	17	19 (12)	--	--	--	--
ETBE	ND <sup>*</sup>	ND <sup>*</sup>	ND <sup>*</sup>	--	--	--	--
Benzene	--	--	(1.8)	--	--	--	--
Toluene	12	30	32 (31)	--	--	--	--
<i>m,p</i> -Xylene	4.6	17	19 (19)	--	--	--	--
<i>o</i> -Xylene	2.0	7.0	7.7 (6.7)	--	--	--	--
Formaldehyde	--	--	--	--	--	--	--
PAHs (ng/m <sup>3</sup> )							
Benzo[b]fluoranthene	0.2 <sup>*</sup>	0.6 <sup>*</sup>	0.3 <sup>*</sup>	--	--	0.4 <sup>*</sup>	--
Benzo[k]fluoranthene	0.1 <sup>*</sup>	0.2 <sup>*</sup>	0.2 <sup>*</sup>	--	--	0.1 <sup>*</sup>	--
Benzo[e]pyrene	ND <sup>*</sup>	0.4 <sup>*</sup>	0.2 <sup>*</sup>	--	--	0.2 <sup>*</sup>	--
Benzo[a]pyrene	ND <sup>*</sup>	0.4 <sup>*</sup>	0.2 <sup>*</sup>	--	--	0.1 <sup>*</sup>	--
Indeno[1,2,3-cd]pyrene	0.2 <sup>*</sup>	0.6 <sup>*</sup>	0.3 <sup>*</sup>	--	--	0.3 <sup>*</sup>	--
Benzo[ghi]perylene	0.2 <sup>*</sup>	1.1 <sup>*</sup>	0.4 <sup>*</sup>	--	--	0.5 <sup>*</sup>	--
PM <sub>10</sub> (µg/m <sup>3</sup> )	238	--	76	--	--	--	--
PM <sub>2.5</sub> (µg/m <sup>3</sup> )	34 <sup>*</sup>	24 <sup>*</sup> (70)	64 (63)	--	--	--	--
Carbon Black (µg/m <sup>3</sup> )	--	7.2	6.6	--	--	--	--
CO average (ppm)	0,0	3.6, 3.9	--	--	--	--	--
CO peak value (ppm)	0,0	33	--	--	--	--	--
NO <sub>2</sub> (ppb)	22 <sup>*</sup> , 42 <sup>*</sup>	59, 22	144, 108	--	--	--	--

<sup>a</sup> For VOC in-car number in parentheses is multisorbent tube date.

<sup>b</sup> Starred (\*) values are below the reported limit.

<sup>c</sup> No sample. <sup>d</sup> Not detected. <sup>e</sup> For CO and NO<sub>2</sub>, two one-hour average values are reported.

TABLE 5-1B. IN-TRAFFIC DATA (continued)

Analyte	Concentration						
	Ambient	Out-Car	In-Car	Road-1	Road-2	Road-3	Road-4
<b>Day 2 (2/27), AM, Freeway Rush -- Vent 3; high air exchange rate: ( 160 hr<sup>-1</sup> @ 55 mph)</b>							
VOCs (µg/m <sup>3</sup> )							
1,3-Butadiene	0.3	3.7	3.0 (ND*)	0.9	1.9	1.4	1.5
MTBE	3.5	18	17 (9.8)	4.7	9.1	8.0	7.7
ETBE	ND*	ND*	ND*	ND*	ND*	ND*	ND*
Benzene	--	--	(1.8)	--	--	--	--
Toluene	6.1	26	27 (32)	13	26	19	18
<i>m,p</i> -Xylene	2.9	18	18 (21)	4.3	11	8.6	9.2
<i>o</i> -Xylene	1.3	7.2	7.1 (7.3)	2.0	4.3	3.5	3.7
Formaldehyde	--	--	6.2	--	--	--	--
PM <sub>10</sub> (µg/m <sup>3</sup> )	75	NS	71	53	62	71	78
PM <sub>2.5</sub> (µg/m <sup>3</sup> )	6.0*	56 (38)	36 (32)	15	15	44	35
Carbon Black (µg/m <sup>3</sup> )	--	9.7	7.2	--	--	--	--
CO average (ppm)	0*, 0*	1.6*, 2.3	1.9*, 2.3	0*, 0*	--, --	1.5*, 0.7	0.1*, 0.1*
CO peak value (ppm)	ND	40	31	1.0	--	3.0	2.0
NO <sub>2</sub> (ppb)	61, 38	64, 9	65, 59	9.0*, 17*	69, 60	50, 43	108, 24
<b>Day 2 (2/27), PM, Freeway Rush --Vent 3; high air exchange rate: ( 160 hr<sup>-1</sup> @ 55 mph)</b>							
VOCs (µg/m <sup>3</sup> )							
1,3-butadiene	0.4	1.5	1.4 (ND*)	1.4	1.7	1.1	2.0
MTBE	ND*	ND*	8.9 (3.8)	9.1	10	7.9	10
ETBE	ND*	ND*	ND*	ND*	ND*	ND*	ND*
Benzene	--	--	(4.6)	--	--	--	--
Toluene	5.9	15	15 (12)	14	22	13	19
<i>m,p</i> -Xylene	3.2	10	10 (7.8)	8.6	12	7.5	12
<i>o</i> -Xylene	1.2	4.0	4.3(2.7)	3.5	4.9	3.0	4.8
Formaldehyde	--	--	4.3	--	--	--	--
PAHs (ng/m <sup>3</sup> )							
Benzo[b]fluoranthene	0.2*	0.1*	ND*	--	--	0.3*	--
Benzo[k]fluoranthene	0.1*	0.03*	ND*	--	--	0.1*	--
Benzo[e]pyrene	0.1*	0.02*	ND*	--	--	0.2*	--
Benzo[a]pyrene	0.1*	ND*	0.2*	--	--	0.2*	--
Indeno[1,2,3-cd]pyrene	0.1*	0.1*	0.2*	--	--	0.3*	--
Benzo[ghi]perylene	0.2*	0.1*	1.0*	--	--	0.4*	--
PM <sub>10</sub> (µg/m <sup>3</sup> )	49	--	33*	113	73	21	79
PM <sub>2.5</sub> (µg/m <sup>3</sup> )	56	44 (50)	16* (54)	15*	15*	44	35
Carbon Black (µg/m <sup>3</sup> )	--	4.9	4.4	--	--	--	--
CO average (ppm)	ND, ND	2.0, 1.0*	1.2*, 0.5*	0.7*, 0.4*	0.2*, 0.1*	1.1*, 1.1	0.6*, 0.1*
CO peak value (ppm)	1.0*	5.0	3.0	4.0	2.0	3.0	2.0
NO <sub>2</sub> (ppb)	37*, 40*	84, 26	42*, 20*	55, 41	50, 57	47, 76	127, 46

<sup>a</sup> For VOC in-car number in parentheses is multisorbent tube date.

<sup>b</sup> Starred (\*) values are below the reported limit.

<sup>c</sup> No sample. <sup>d</sup> Not detected. <sup>e</sup> For CO and NO<sub>2</sub>, two one-hour average values are reported.

**TABLE 5-1C. IN-TRAFFIC DATA (continued)**

Analyte	Concentration						
	Ambient	Out-Car	In-Car	Road-1	Road-2	Road-3	Road-4
<b>Day 3 (2/28), PM, Freeway Rush -- Vent 1; low air exchange rate: ( 39 hr<sup>-1</sup> @ 55 mph)</b>							
VOCs (µg/m <sup>3</sup> )							
1,3-Butadiene	0.6	2.8	2.4 (ND*)	1.3	2.2	0.5	1.3
MTBE	1.9	18	13(9.4)	8.4	11	2.5	8.2
ETBE	ND*	ND*	ND*	ND*	ND*	ND*	ND*
Benzene	--	--	(1.9)	--	--	--	--
Toluene	6.0	24	24(29)	13	20	6.1	13
<i>m,p</i> -Xylene	3.3	18	17(20)	8.3	11	0.9	8.2
<i>o</i> -Xylene	1.5	7.0	6.9(7.1)	3.5	4.5	--	3.5
Formaldehyde	--	--	18	--	--	--	--
PAHs (ng/m <sup>3</sup> )							
Benzo[b]fluoranthene	0.2*	.07*	0.4*	--	--	0.7*	--
Benzo[k]fluoranthene	0.1*	0.2*	0.2*	--	--	0.2*	--
Benzo[e]pyrene	0.1*	0.4*	0.4*	--	--	0.4*	--
Benzo[a]pyrene	0.1*	0.4*	0.5*	--	--	0.3*	--
Indeno[1,2,3-cd]pyrene	0.2*	0.6*	0.9*	--	--	0.3*	--
Benzo[ghi]perylene	0.2*	1.2*	1.7*	--	--	0.9*	--
PM <sub>10</sub> (µg/m <sup>3</sup> )	18*	--	54	101	62	78	61
PM <sub>2.5</sub> (µg/m <sup>3</sup> )	9.3*	49 (43)	28 (35)	43	40	23	51
Carbon Black (µg/m <sup>3</sup> )	--	--	7.4	--	--	--	--
CO average (ppm)	0.2*, 0.4*	2.8, 4.0	1.9*, 2.3	0.1*, 0.4	0.4*, 0.6*	0.8*, 1.0	0.6*, 1.2*
CO peak value (ppm)	13	34	5.0	2.0	2.0	2.0	3.0
NO <sub>2</sub> (ppb)	1.0, 44	44, 82	92, 128	48, 50	16, 45	54, 39	61

<sup>a</sup> For VOC in-car number in parentheses is multisorbent tube date.

<sup>b</sup> Starred (\*) values are below the reported limit.

<sup>c</sup> No sample. <sup>d</sup> Not detected. <sup>e</sup> For CO and NO<sub>2</sub>, two one-hour average values are reported.

**TABLE 5-1D. IN-TRAFFIC DATA (continued)**

Analyte	Concentration						
	Ambient	Out-Car	In-Car	Road-1	Road-2	Road-3	Road-4
Day 4 (3/1), AM, Rural – Vent 1; low air exchange rate: ( 39 hr <sup>-1</sup> @ 55 mph)							
VOCs (µg/m <sup>3</sup> )							
1,3-Butadiene	ND <sup>a</sup>	ND <sup>a</sup>	ND <sup>a</sup> (ND <sup>a</sup> )	--	--	--	--
MTBE	1.0	1.4	1.6 (ND <sup>a</sup> )	--	--	--	--
ETBE	ND <sup>a</sup>	ND <sup>a</sup>	ND <sup>a</sup>	ND <sup>a</sup>	ND <sup>a</sup>	ND <sup>a</sup>	ND <sup>a</sup>
Benzene	--	--	(0.3)	--	--	--	--
Toluene	3.2	4.6	5.8 (5.0)	--	--	--	--
<i>m,p</i> -Xylene	1.5	1.8	3.4 (3.3)	--	--	--	--
<i>o</i> -Xylene	0.8	0.9	1.5 (ND <sup>a</sup> )	--	--	--	--
Formaldehyde	--	--	9.6	--	--	--	--
PAHs (ng/m <sup>3</sup> )							
Benzo[b]fluoranthene	0.1 <sup>a</sup>	0.3 <sup>a</sup>	ND <sup>a</sup>	--	--	--	--
Benzo[k]fluoranthene	0.1 <sup>a</sup>	0.2 <sup>a</sup>	ND <sup>a</sup>	--	--	--	--
Benzo[e]pyrene	ND <sup>a</sup>	ND <sup>a</sup>	ND <sup>a</sup>	--	--	--	--
Benzo[a]pyrene	0.1 <sup>a</sup>	0.1 <sup>a</sup>	0.1 <sup>a</sup>	--	--	--	--
Indeno[1,2,3-cd]pyrene	ND <sup>a</sup>	0.2 <sup>a</sup>	0.1 <sup>a</sup>	--	--	--	--
Benzo[ghi]perylene	ND <sup>a</sup>	0.2 <sup>a</sup>	ND <sup>a</sup>	--	--	--	--
PM <sub>10</sub> (µg/m <sup>3</sup> )	28 <sup>a</sup>	--	18	--	--	--	--
PM <sub>2.5</sub> (µg/m <sup>3</sup> )	31	13 <sup>a</sup> (26 <sup>a</sup> )	24 <sup>a</sup> (22 <sup>a</sup> )	--	--	--	--
Carbon Black (µg/m <sup>3</sup> )	--	--	1.3	--	--	--	--
CO average (ppm)	0 <sup>a</sup> , 0 <sup>a</sup>	0 <sup>a</sup> , 0 <sup>a</sup>	0.6 <sup>a</sup> , 1.7 <sup>a</sup>				
CO peak value (ppm)	0 <sup>a</sup> , 0 <sup>a</sup>	0 <sup>a</sup> , 0 <sup>a</sup>	1, 7 <sup>a</sup>				
NO <sub>2</sub> (ppb)	9.0 <sup>a</sup> , 5.0 <sup>a</sup>	1.0 <sup>a</sup> , 1.0 <sup>a</sup>	ND <sup>a</sup> , 29 <sup>a</sup>	--	--	--	--

<sup>a</sup> For VOC in-car number in parentheses is multisorbent tube date.

<sup>b</sup> Starred (\*) values are below the reported limit.

<sup>c</sup> No sample. <sup>d</sup> Not detected. <sup>e</sup> For CO and NO<sub>2</sub>, two one-hour average values are reported.

**TABLE 5-1E. IN-TRAFFIC DATA (continued)**

Analyte	Concentration						
	Ambient	Out-Car	In-Car	Road-1	Road-2	Road-3	Road-4
Day 6 (3/3), Am, Freeway Rush -- Vent 3; high air exchange rate: ( 160 hr <sup>-1</sup> @ 55 mph)							
VOCs (µg/m <sup>3</sup> )							
1,3-Butadiene	0.8	3.0	2.8 (0.9)	0.8	0.7	0.3	0.7
MTBE	8.0	15	14 (12)	5.0	4.2	6.2	3.5
ETBE	ND*	ND*	ND*	ND*	ND*	ND*	ND*
Benzene	--	--	2.5	--	--	--	--
Toluene	11	23	23 (41)	9.8	8.4	8.6	11
<i>m,p</i> -Xylene	7.0	17	16 (23)	5.8	5.3	5.7	4.2
<i>o</i> -Xylene	3.0	6.7	6.5 (7.8)	2.4	2.3	2.6	1.9
Formaldehyde	--	--	7.8	--	--	--	--
PM <sub>10</sub> (µg/m <sup>3</sup> )	27	--	84	20	20	63	96
PM <sub>2.5</sub> (µg/m <sup>3</sup> )	55	9.4 (44)	32 (39)	26	35	--	31
Carbon Black (µg/m <sup>3</sup> )	--	8.0	9.8	--	--	--	--
CO average (ppm)	0.5*, ND*	4.7, 2.2	3.8, 1.8	ND*, ND*	ND*, ND*	0.1, 0.1	0.4, ND
CO peak value (ppm)	1.0*	23	20	1.0*	1.0*	1.0*	2.0
NO <sub>2</sub> (ppb)	84, 27	80, 40	83, 68	46*, 35*	9*, 45	ND*,	48, ND

<sup>a</sup> For VOC in-car number in parentheses is multisorbent tube date.

<sup>b</sup> Starred (\*) values are below the reported limit.

<sup>c</sup> No sample. <sup>d</sup> Not detected. <sup>e</sup> For CO and NO<sub>2</sub>, two one-hour average values are reported.

**TABLE 5-2A. IN-TRAFFIC DATA FOR ELEMENTS**

Analyte	Concentration						
	Ambient	Out-Car	In-Car	Road-1	Road-2	Road-3	Road-4
<b>Day 1 (2/26), AM, Freeway Rush Air exchange rate (mid 98 1/h)</b>							
<b>PM<sub>2.5</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	0.01	0.05	0.03	--	--	--	--
Chromium	105	106	87	--	--	--	--
Manganese	2.3	2.5	2.5	--	--	--	--
Nickel	ND	ND	ND	--	--	--	--
Lead	6.6	8.4	12	--	--	--	--
Sulfur	343	269	575	--	--	--	--
<b>PM<sub>10</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	--	--	0.86	--	--	--	--
Chromium	--	--	9.5	--	--	--	--
Manganese	--	--	ND	--	--	--	--
Nickel	--	--	ND	--	--	--	--
Lead	--	--	11	--	--	--	--
Sulfur	--	--	265	--	--	--	--
<b>Day 1 (2/26), PM, Freeway Rush Air exchange rate (mid 98 1/h)</b>							
<b>PM<sub>2.5</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	0.24	--	0.11	--	--	--	--
Chromium	113	--	107	--	--	--	--
Manganese	1.4	--	6.8	--	--	--	--
Nickel	ND	--	25	--	--	--	--
Lead	6.9	--	11	--	--	--	--
Sulfur	237	--	269	--	--	--	--
<b>PM<sub>10</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	0.69	--	0.37	--	--	--	--
Chromium	200	--	192	--	--	--	--
Manganese	6.9	--	9.3	--	--	--	--
Nickel	53	--	28	--	--	--	--
Lead	8.5	--	13	--	--	--	--
Sulfur	345	--	465	--	--	--	--



**TABLE 5-2B. IN-TRAFFIC DATA FOR ELEMENTS (continued)**

Day 2 (2/27), AM, Freeway Rush Air exchange rate (high 160 1/h)							
	Ambient	Out-Car	In-Car	Road-1	Road-2	Road-3	Road-4
<b>PM<sub>2.5</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	--	ND	0.12(0.12)	--	--	0.15	0.03
Chromium	--	104	109(122)	--	--	112	115
Manganese	--	4.6	16(6.1)	--	--	0.17	1.3
Nickel	--	ND	ND(ND)	--	--	ND	17
Lead	--	4.6	24(7.8)	--	--	5.7	6.7
Sulfur	--	310	293(274)	--	--	314	183
<b>PM<sub>10</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	ND	--	ND(0.26)	--	--	0.24	ND
Chromium	218	--	239(251)	--	--	2.2	203
Manganese	7.0	--	25(21)	--	--	ND	2.3
Nickel	ND	--	ND(11)	--	--	ND	ND
Lead	7.8	--	14(8.3)	--	--	ND	9.1
Sulfur	547	--	639(660)	--	--	106	407
Day 2 (2/27), PM, Freeway Rush Air exchange rate ( high 160 1/h))							
<b>PM<sub>2.5</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	--	0.04	--	--	--	--	--
Chromium	--	73	--	--	--	--	--
Manganese	--	5.4	--	--	--	--	--
Nickel	--	3.5	--	--	--	--	--
Lead	--	3.5	--	--	--	--	--
Sulfur	--	182	--	--	--	--	--
<b>PM<sub>10</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	ND	--	--	--	ND	--	ND
Chromium	221	--	--	--	239	--	197
Manganese	63	--	--	--	46	--	28
Nickel	ND	--	--	--	ND	--	ND
Lead	19	--	--	--	11	--	9.5
Sulfur	453	--	--	--	507	--	326

**TABLE 5-2C. IN-TRAFFIC DATA FOR ELEMENTS (continued)**

Day 3 (2/28), PM, Freeway Rush Air exchange rate (low 39 1/h)							
	Ambient	Out-Car	In-Car	Road-1	Road-2	Road-3	Road-4
<b>PM<sub>2.5</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	--	0.40	--	ND	0.46	--	1.1
Chromium	--	110	--	114	114	--	112
Manganese	--	8.6	--	2.7	4.0	--	3.5
Nickel	--	ND	--	5.3	6.9	--	70
Lead	--	6.7	--	3.1	9.0	--	3.7
Sulfur	--	443	--	324	392	--	283
<b>PM<sub>10</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	ND	--	--	--	--	ND	--
Chromium	209	--	--	--	--	201	--
Manganese	20	--	--	--	--	7.5	--
Nickel	ND	--	--	--	--	ND	--
Lead	16	--	--	--	--	1.9	--
Sulfur	520	--	--	--	--	447	--

**TABLE 5-2D. IN-TRAFFIC DATA FOR ELEMENTS (continued)**

Day 4 (3/1), AM, Rural Air exchange rate (low 39 1/h)							
	Ambient	Out-Car	In-Car	Road-1	Road-2	Road-3	Road-4
<b>PM<sub>2.5</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	ND	--	--	--	--	--	--
Chromium	ND	--	--	--	--	--	--
Manganese	ND	--	--	--	--	--	--
Nickel	ND	--	--	--	--	--	--
Lead	ND	--	--	--	--	--	--
Sulfur	93	--	--	--	--	--	--
<b>PM<sub>10</sub> (ng/m<sup>3</sup>)</b>							
Cadmium	--	--	--	--	--	--	--
Chromium	--	--	--	--	--	--	--
Manganese	--	--	--	--	--	--	--
Nickel	--	--	--	--	--	--	--
Lead	--	--	--	--	--	--	--
Sulfur	--	--	--	--	--	--	--

**TABLE 5-2E. IN-TRAFFIC DATA FOR ELEMENTS (continued)**

Day 6 (3/3), Am, Freeway Rush Air exchange rate (high 160 1/h)							
	Ambient	Out-Car	In-Car	Road-1	Road-2	Road-3	Road-4
PM <sub>2.5</sub> (ng/m <sup>3</sup> )							
Cadmium	0.24	--	ND	--	ND	--	ND
Chromium	93	--	2.7	--	102	--	2.6
Manganese	40	--	0.25	--	ND	--	ND
Nickel	ND	--	ND	--	ND	--	ND
Lead	14	--	ND	--	ND	--	ND
Sulfur	300	--	231	--	261	--	32
PM <sub>10</sub> (ng/m <sup>3</sup> )							
Cadmium	--	--	ND	--	--	ND	1.5
Chromium	--	--	203	--	--	ND	243
Manganese	--	--	22	--	--	ND	21
Nickel	--	--	ND	--	--	ND	ND
Lead	--	--	12	--	--	1.5	24
Sulfur	--	--	543	--	--	215	537

**TABLE 5-3. Percentage of Samples Above the Reporting Levels**

Analyte	% Above Reporting Level	Reporting Level
VOCs -- Canister		MQL estimated from concentration of lowest standard
1,3-Butadiene	92	
MTBE	100	
ETBE	0	
Toluene	100	
Xylenes	100	
Formaldehyde	100	MQL estimated from concentration of lowest standard
PAHs	0	MQL estimated from concentration of lowest standard
PM <sub>10</sub>	67	MQL based on precision of filter re-weighing
PM <sub>2.5</sub>	64 (100)*	MQL based on precision of filter re-weighing
CO 1-h average	20	MQL based on manufacturers specifications
CO peak	95	MQL based on manufacturers specifications
NO <sub>2</sub>	46	MDL based on precision of field blanks
Primary Elements		MQL based instrumental measurement precision of reagent water liquids
Pb	PM <sub>10</sub> - 8.3, PM <sub>2.5</sub> - 22	
Cd	PM <sub>10</sub> - 0, PM <sub>2.5</sub> - 5.6	
Cr	PM <sub>10</sub> - 100, PM <sub>2.5</sub> - 100	
Mn	PM <sub>10</sub> - 92, PM <sub>2.5</sub> - 89	
Ni	PM <sub>10</sub> - 0, PM <sub>2.5</sub> - 5.6	
S	PM <sub>10</sub> - 100, PM <sub>2.5</sub> - 94	

**2. What is the effect of Air Exchange Rate on inside and outside-vehicle pollutant concentrations?**

Figure 5-1 shows the relationship between the Inside/Outside concentration ratios and Air Exchange Rate for several selected measurements. Data are shown for CO, PM<sub>2.5</sub> (computed from the LAS-X), methyl *t*-butyl ether (MTBE), and toluene. Data for CO and PM<sub>2.5</sub> particles suggest that for the low AER the outside concentrations may be somewhat higher than the inside concentrations (inside/outside concentration ratios less than 1.0). No distinguishable trend is apparent for MTBE or toluene. Overall, the data suggest that as the air exchange rate increases, the ratio approaches unity and the inside and outside concentrations are essentially the same.

The indication that the inside concentrations were lower at the 39 air change per hour rate is perhaps an artifact of a driving protocol that emphasizes closely following smoking diesel and gasoline vehicles when the opportunity existed. The short duration (typically a few minutes or less) of these trailing events highlighted the modest "insulating" affect of a lower air exchange rate. More realistic commutes, however, could be expected to show little difference between inside and outside over the range of air exchange rates encountered.

\* Integrated measurement.

**3. What was the relationship between outside vehicle, roadside, and ambient site pollution concentrations ?**

Figure 5-2 shows the 1-minute concentrations of real time CO and PM<sub>2.5</sub> mass (computed from LAS-X data) measured inside and outside the car. Overall results suggest that there are significant relationships for both particle and gas-phase pollutant concentrations inside and outside of the test vehicle. Note, however, that certain vehicles may emit significant quantities of only one of the two pollutants. Figure 5-3 shows the outside CO concentrations compared with the (measurable) data from the ambient site and all four roadway sites during a typical test run. It is apparent that a significant decrease (dilution) in CO concentration is occurring over the limited distance between the vehicles and the roadside. The ambient site and roadway concentration are very low (mostly below the detection limit), precluding development of a relationship between these locations and the outside vehicle monitoring data.

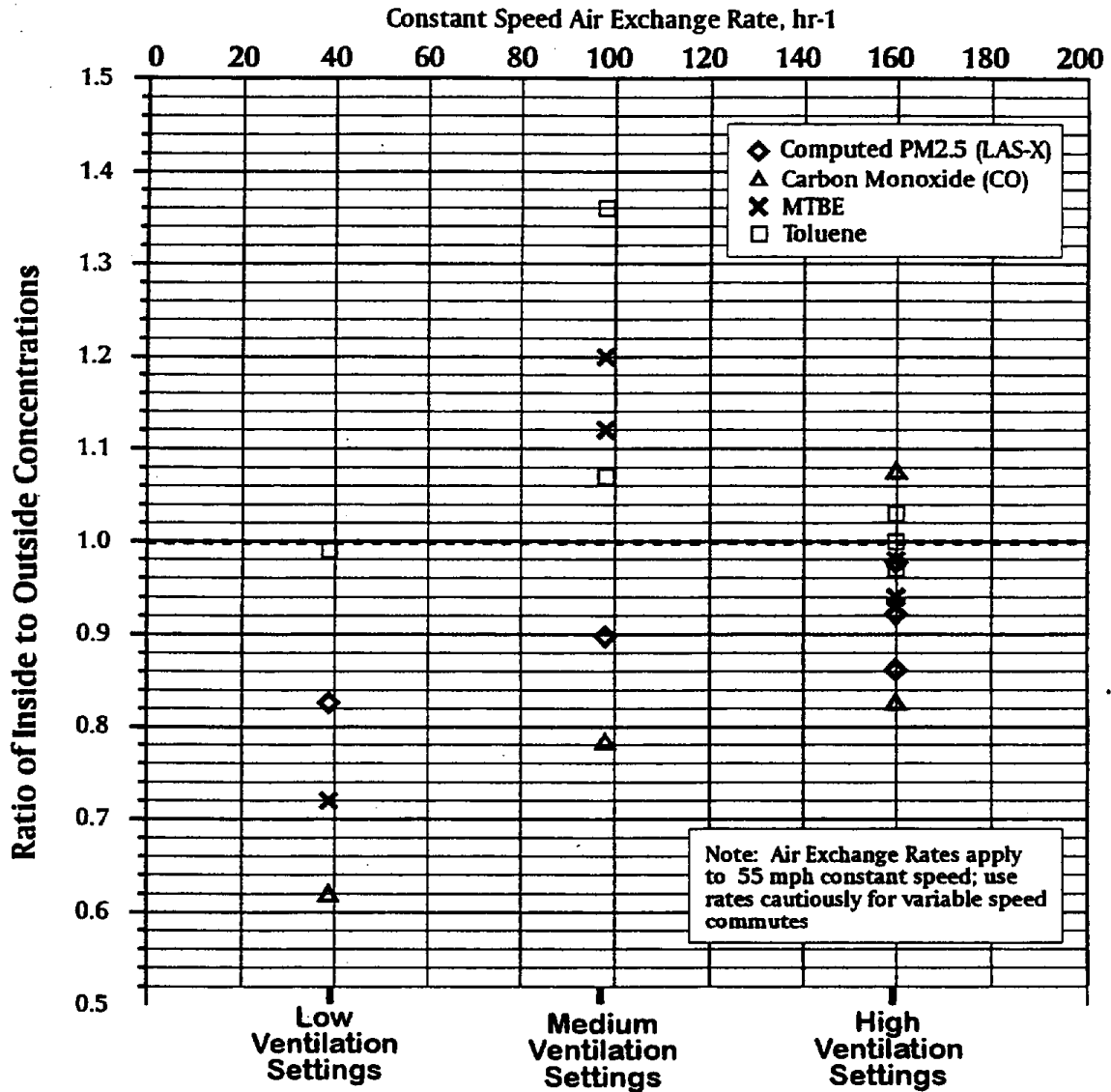
Examination of the integrated sample data in Table 5-4 for VOCs (e.g., methyl *t*-butyl ether and toluene) also demonstrates a lack of clear relationships between the vehicle concentrations and the roadway or ambient monitoring data. In general, the vehicle concentrations (continuous and integrated) are higher than the roadside concentrations, which are higher than the ambient site concentrations.

**4. Can the monitoring data determine differences in roadway sources and conditions?**

Extreme differences in roadway conditions (e.g. between the freeway and rural drives) can be detected by both the integrated and real time monitoring methods for all of the pollutants. Less dramatic differences in roadway conditions (e.g., small changes in hour-to-hour traffic volume, a different mix of target vehicles, proximity to target vehicles to the test car) could not be detected using the integrated monitoring methods. Real time measurements (CO, LAS-X particle count, Aethalometer black carbon) were required to evaluate these effects.

Figure 5-1

**Relationships of Constant Speed Air Exchange Rate to the Ratios of Inside to Outside Concentrations During Freeway Commutes for Computed PM2.5 (LAS-X data), Carbon Monoxide (CO), Toluene, and MTBE**



file: aeriassx1

See text for vent setting definitions

Figure 5-2  
 Computed PM2.5 (LAS-X) Outside and Inside vs  
 CO Concentration

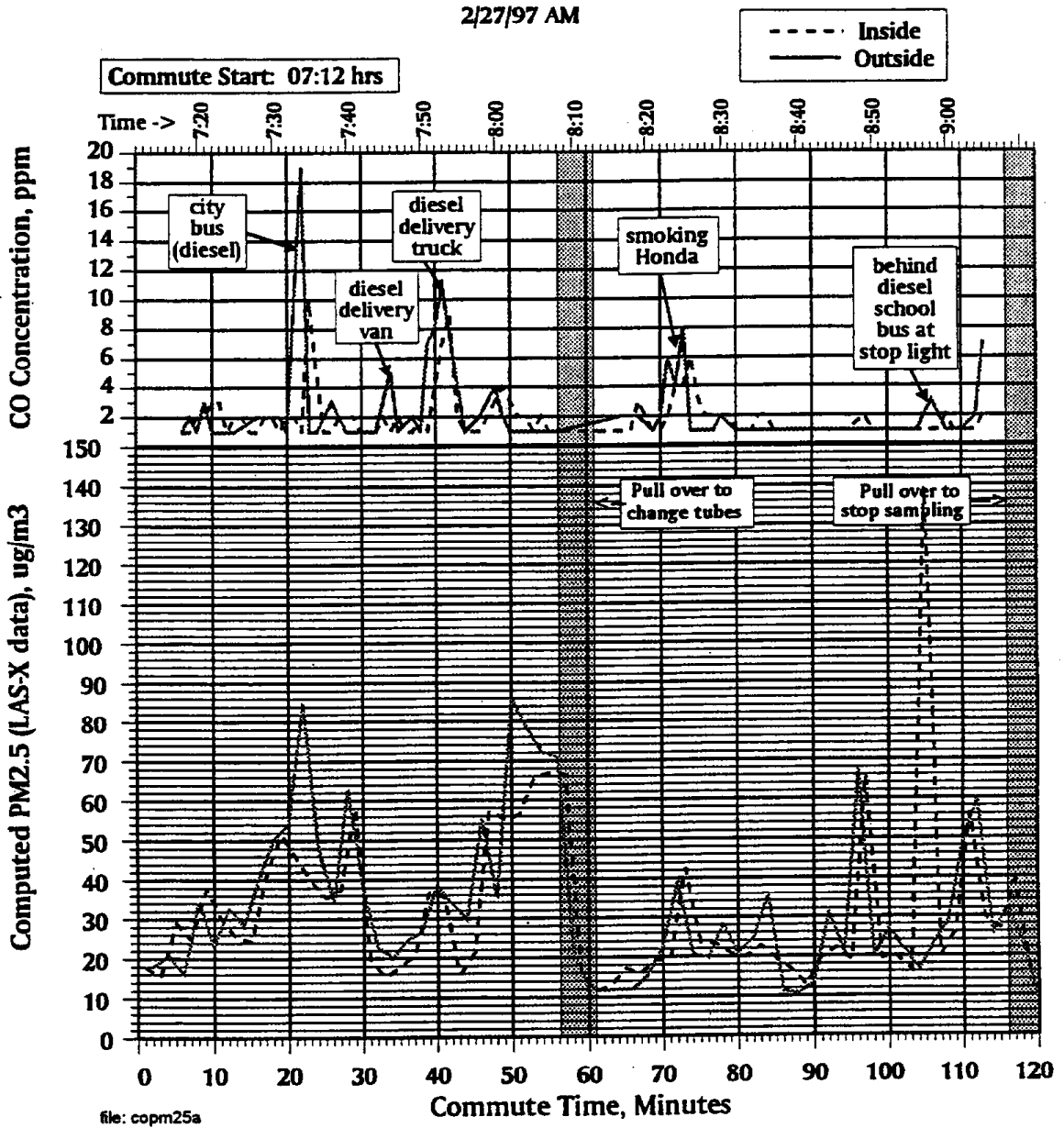
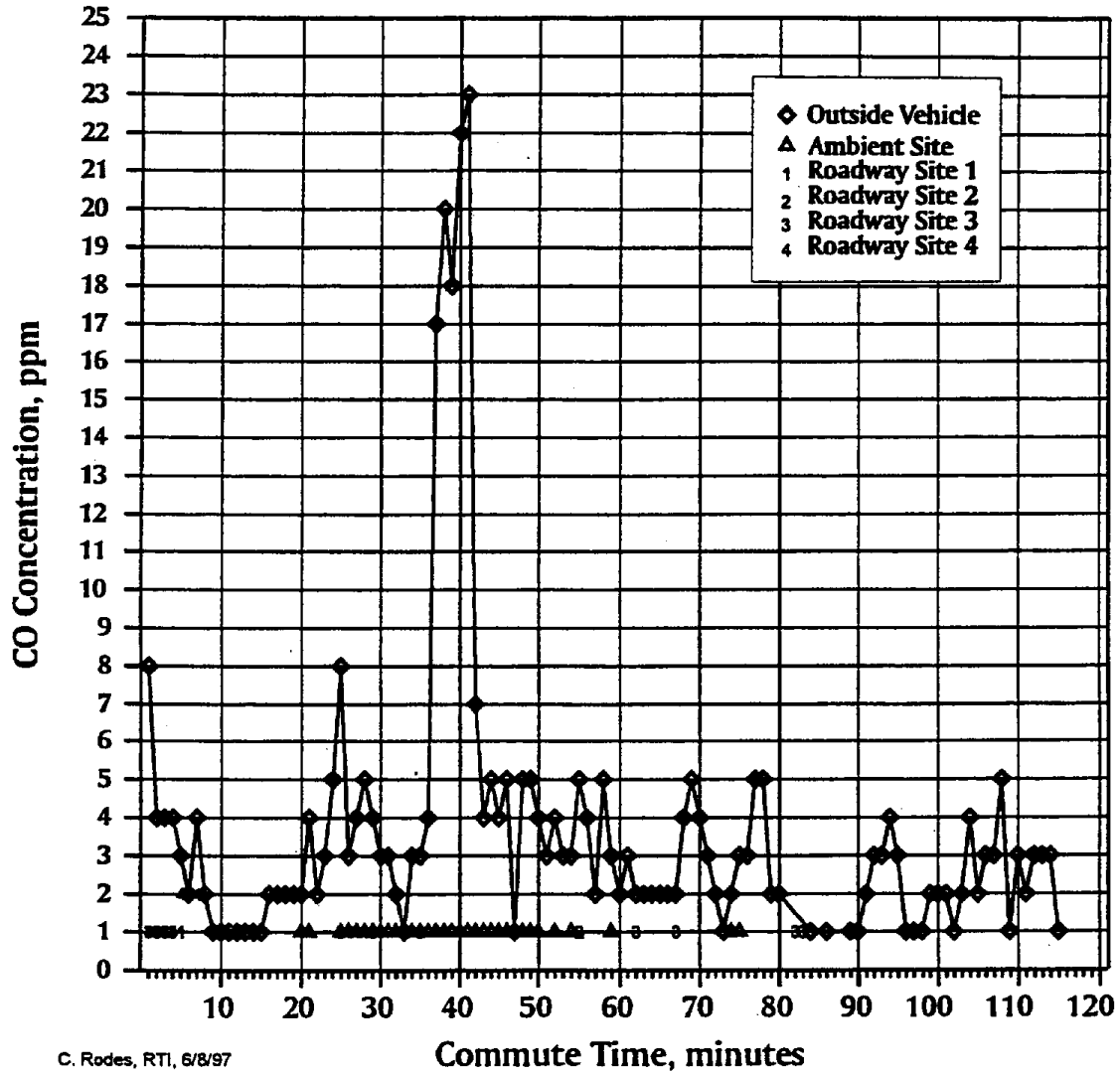


Figure 5-3

### Relationship of Carbon Monoxide Outside Vehicle with Ambient Site and Four Roadway Site Concentrations

3/3/97 AM commute



C. Rodas, RTI, 6/8/97



TABLE 5-4. VOC Concentrations at Freeway Sites

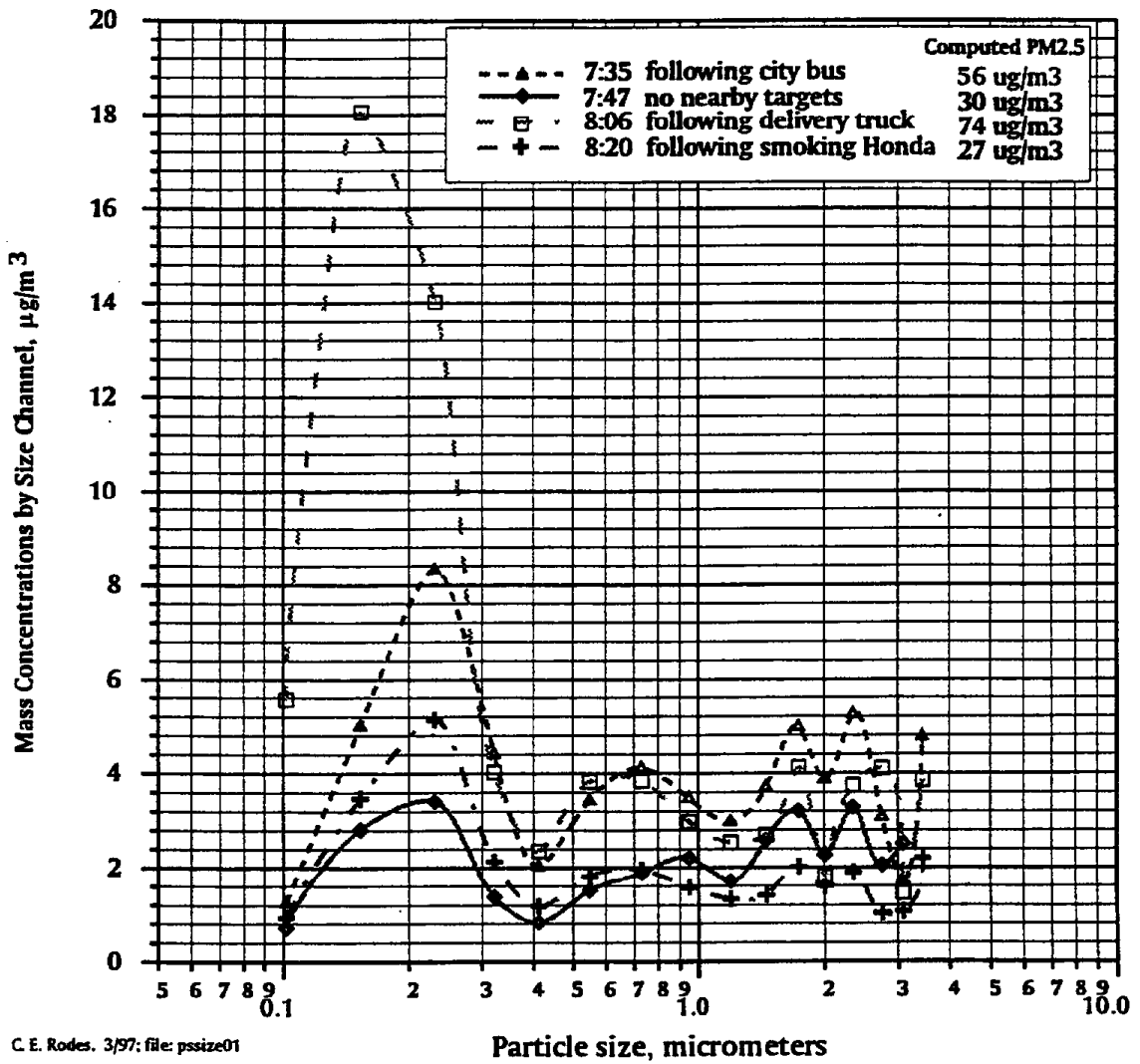
Commute	Ambient	Out	In	Road 1	Road 2	Road 3	Road 4	Avg. road	%RSD
1,2/26, am	5.7	10	12						
2, 2/26, pm	4.5	17	19						
3,2/27, am	3.5	18	17	4.7	9.1	8	7.7	7.4	20
4,2/27, pm	2.5	9.1	8.9	9.1	10	7.9	10	9.3	8
5,2/28, pm	1.9	18	13	8.4	11	2.5	8.2	7.5	37
7,3/3, am	8	15	14	5.2	4.2	6.2	3.5	4.8	19
	Avg	4.4	15	6.9	8.6	6.2	7.4	6.1	15
	%RSD	47	25	28	30	36	32	26	
Toluene									
Trip	Ambient	Out	In	Road 1	Road 2	Road 3	Road 4	Avg road	%RSD
1,2/26, am	20	27	37						
2, 2/26, pm	12	30	32						
3,2/27, am	6.1	26	27	13	26	19	18	19	22
4,2/27, pm	5.9	15	15	14	22	13	19	17	19
5,2/28, pm	6	24	24	13	20	6.1	13	13	34
7,3/3, am	11	23	23	9.8	8.4	8.6	11	9.5	10
	Avg	10	24	12	19	12	15	12	22
	%RSD	50	19	13	34	42	22	30	

Several additional observations were made based on the real time CO, LAS-X particle monitoring data, video tapes, and traffic data. These include:

- The particle count data from the LAS-X readily demonstrated the influence of individual, high-emitting particle vehicles immediately in front of the car.
- The short-term particle count size distribution data showed almost no differences between the shapes of the size distributions for several vehicle types (see Figure 5-4). The differences between distributions were mostly in the size of the particle mode below 0.3  $\mu\text{m}$ . This is consistent with internal combustion engine particle emissions that are significantly less than 0.1  $\mu\text{m}$  in diameter.
- The Aethalometer readily detected the particle emissions when following diesel (or visibly smoking gasoline-powered) vehicles, as did the LAS-X. Both measurements tracked correlated closely (see Figure 5-5). A determination as to whether the Aethalometer black carbon levels could be used to predict PAH levels could not be made, due to the below detection level concentrations measured for the PAHs.
- Limited data following poorly tuned vehicles (visible assessment of the exhaust plumes) suggest that closely following these vehicles for periods of more than a few minutes may add significantly to the total commute-average exposures for particles and CO.
- The rapidity of particle and CO concentration changes on the freeway from following individual vehicles, demonstrated the importance of careful time synchronization between all the continuous measurements. This proved to be more difficult than expected with the Aethalometer and video camera because of their time setting sequences.
- Reduction of all continuous measurements to the same integration average (e.g., 1 minute) was very time consuming after the study because of the inconsistent time synchronizations.
- The video camera was extremely informative as to the sources and scenarios that produced elevated exposure levels. Reviewing each tape to record these events, however, is very time consuming.
- A more refined time synchronization procedure among real-time measurements must be devised to provide a clearer indication of single events and make it cost-effective to reduce the continuous monitoring data.
- Reduction of the vehicle switchbox data that describe the driving scenarios (including traffic density) were difficult to incorporate into a data analysis, given the low concentrations encountered, suggesting that only traffic density (level of congestion) may be worth retaining for the Main Study.

Figure 5-4  
 Selected PM2.5 Outside Particle Mass Size Distributions  
 Computed from LAS-X Particle Counts and AD Densities

2/27/97 AM Commute  
 Composite means of 3 consecutive 1 minute distributions



- Hourly traffic count data were obtained (by Sierra Research) from CalTrans for the locations most relevant to the Sacramento freeway commuting route. Concurrent count data for only a few periods over-lapping the Pilot Study commutes were available. These data were obtained, plotted and are given in Appendix J. They indicated that the selected morning and evening sampling windows for the Pilot Study (7 to 9 AM, and 4 to 6 PM) correctly targeted the periods of highest traffic densities. These same windows will be used in the Main Study.

## TABLE OF APPENDICIES

### Appendix

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- A. Milestone Schedule for Corrective Action (prior to Main Study) -----
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**APPENDIX A**

# RTI Milestone Schedule for the ARB In-Vehicle Exposure Study (Post Pilot Study)

C. Rodas, 6/6/97 (revised DRAFT)

Item #	Milestone Category	Item	Start Date	End or Critical Date	Lead/Assisting Org.	
					Output / Next Step / Result / Comment	Lead/Assisting Org.
1	Field Measurements	Pilot Study	26-Feb	1-Mar	exposure samples & data [Done]	RTI
2	Report	Accomplishments/Problem Area Report	5-Mar	15-Mar	draft report for ARB review [Done]	RTI
3	Chemical Analyses	Pilot Study integrated samples	1-Apr	23-May	data [Done]	RTI
4	Data Analysis	Analyze data / prepare summaries for Pilot Study report	26-May	6-Jun	graphs / tables / summaries	RTI
5	Report	Pilot Study summary	26-May	13-Jun	draft report for ARB review	RTI
6	Agreement Document	Operational agreement between RTI & Sierra concerning test car usage	18-Jun	18-Jun	Clarify RTI insurance provisions relative to SR Caprice	RTI/SR
7	Hardware Modification	Order 4 lpm PM10 caps	na	18-Jun	process requisition	RTI
8	Procurement	Order remainder of substrates/supplies for Main Study	na	18-Jun		RTI
9	Hardware Modification	Send PM2.5 caps to MSP for leak fix	na	18-Jun	replace all gaskets	RTI
10	Study Design Element	Select Main Study Routes	20-Jun	27-Jun	submit to ARB for review	SR
11	Decision Point	Inclusion of Aethalometer in Main Study	na	30-Jun	contingent on decision; Arrange for 30 day lease	RTI
12	Decision Point	Inclusion of LAS-X in Main Study	na	30-Jun	make sure LAS-X will be available in August; prepare LAS-X for Main Study	RTI
13	Decision Point	Increase PM10 flow to 4 lpm	na	30-Jun	prepare additional pumps for tandem operation / order additional 4 lpm inlet caps	RTI
14	Decision Point	Proportion of sampling days in Sacramento vs LA	na	30-Jun	Set field schedule	RTI/SR
15	Decision Point	Provide temperature-controlled weighing facility in Los Angeles	na	11-Jul	not required, but desirable; find facility and make arrangements with facility owner (e.g. SCAPCD)	RTI

RTI Milestone Schedule for the ARB In-Vehicle Exposure Study (Post Pilot Study)

C. Rodas, 6/6/97 (revised DRAFT)

Item #	Milestone Category	Item	Start Date	End or Critical Date	Output / Next Step / Result / Comment	Lead/Assisting Org.
16	Hardware Modification	Add external switches to particle sampler pumps	na	18-Jul	may require ordering some components	RTI
17	Hardware Modification	Add tandem 2 lpm pump to existing PM10 systems	na	18-Jul	make sure the additional equipment will be available in August	RTI
18	Hardware Modification	Add vibration damping to video and LAS-X platform	na	18-Jul	may require ordering some components; coordinate w/ Sierra	SR/RTI
19	Hardware Modification	Automate NO2 tube switching	na	18-Jul	add solenoids / remote switch / or timer	RTI
20	Hardware Modification	Build 4 lpm flow check orifice	na	18-Jul	may require ordering some	RTI
21	Hardware Preparation	Checkout samplers and prepare/clean substrates	na	18-Jul		RTI
22	Test Procedure	Upgrade inlet leak test procedure	na	18-Jul	Procedure / checklist	RTI
23	Hardware Modification	Upgrade power system in car for continuous monitors - if monitors are used in Main Study	na	18-Jul	Contingent on (a) decision to use continuous monitors, and (b) what power system would cost project	SR
24	Document Modification	Revise Field Operations Manual to reflect changes made during and since Pilot Study	na	18-Jul	send to ARB for review	RTI
25	Personnel Action	Identify additional vehicle drivers (including schoolbus) for Sacramento & LA	na	18-Jul	[list of potential sedan/SUV drivers already identified]	SR
26	Agreement Document	Prepare CalTrans request for encroachment permits for Sacramento & LA	na	18-Jul	Contact CalTrans as soon as roadside sites are identified	RTI/SR
27	Study Design Element	Select Ambient monitoring sites for Sacramento and LA	na	18-Jul	Make requests for permission to access	RTI
28	Study Design Element	Select Roadside monitoring sites for Sacramento and LA	na	18-Jul	Make requests for permission to access	RTI/SR
29	Hardware Modification	Redefine needed switchbox settings based on correlations with pollutant levels from Pilot Study	na	18-Jul	Delete several settings & add navigator observation diary?	RTI/SR
30	Study Design Element	Define driving protocols for the Main Study	na	18-Jul	Review & revise Pilot Study version	SR/RTI



RTI Milestone Schedule for the ARB In-Vehicle Exposure Study (Post Pilot Study)

C. Rodas, 6/6/97 (revised DRAFT)

Item #	Milestone Category	Item	Start Date	End or Critical Date	Output / Next Step / Result / Comment	Lead/Assisting Org.
31	Presentation	Pilot Study summary	8-Jul	29-Jul	meeting in Sacramento	RTI/SR/AD
32	Study Design Element	Select and make arrangements for additional sedan, SUV and schoolbus	18-Jul	1-Aug	Bus by 18-Jul; cars by 1-Aug	SR
33	Analysis Tool Modification	Upgrade GC/MS system to improve PAH detection limits	na	1-Aug	New system to be installed (no cost to contract)	RTI
34	Analysis Tool Modification	Upgrade ICP/MS system to improve metals' detection limits	na	1-Aug	New sample atomizer to be installed (no cost to contract)	RTI
35	Study Design Element	Finalize study design	18-Jul	1-Aug	Major elements by 18-Jul; Conference call with ARB to discuss last minute items on 1-Aug	RTI/SR
36	Shipping Date	Ship all components for Main Study to Sacramento	na	5-Aug	ship out by FedEx; return ship by surface freight	RTI
37	Study Design Element	Field staff training; assignment identifications	9-Aug	10-Aug	On-site meeting with key personnel	RTI/SR
38	Field Measurements	Main Study	11-Aug	29-Aug	exposure samples & data	RTI/SR
39	Chemical Analyses	Main Study integrated samples	5-Sep	3-Oct	data	RTI
40	Data Analysis	Analyze data / prepare summaries for Main Study report	6-Oct	17-Oct	graphs / tables / summaries	RTI/SR
41	Report	Main Study summary	20-Oct	7-Nov	draft report for ARB review	RTI/SR
42	Presentation	Main Study summary	17-Nov	17-Nov	meeting in Sacramento	RTI/SR

## APPENDIX B

## **Caprice Switchbox Settings Used by Sierra Navigator to Characterize Traffic in Pilot Study**

### **Switch 1 [ Ventilation Settings ]**

- 0 - Vent OFF
- 1 - MAX AC (no outside air)
- 2 - NORM AC (allows outside air)
- 3 - Heat
- 4 - Vent open

### **Switch 2 [ not used ]**

### **Switch 3 [ Roadway Type ]**

- 0 - Other (parking, etc.)
- 1 - Rural lane
- 2 - Arterial
- 3 - ON or OFF ramp
- 4 - Freeway slow (right) lane
- 5 - Freeway (other lanes except right or carpool)
- 6 - Freeway carpool

### **Switch 4 [ Level of Congestion ]**

- 0 - Other
- 1 - Level A (free flow)
- 2 - Level B
- 3 - Level C
- 4 - Level D
- 5 - Level E
- 6 - Level F (highly congested)

### **Switch 5 [ not used ]**

### **Switch 6 [ Target Type ]**

- 0 - Other
- 1 - Light Duty Vehicle (normal operation)
- 2 - Light Duty Vehicle (obvious exhaust emission, smoking)
- 3 - Heavy Duty (non-diesel)
- 4 - Light Duty Diesel (cars and delivery trucks) [identification sometimes uncertain]
- 5 - Heavy Duty Diesel Buses [and other buses if identification was uncertain]
- 6 - Heavy Duty Diesel truck

## APPENDIX C

2/20/97 Final

## ARB In-Vehicle Exposure Study Pilot Study Schedule of Activities

### Sunday, PM, 2/23/97

- \* Charles Rodes (hand-carrying study laptop computer), Don Whitaker and Mike Roberds (hand-carrying Mettler AT-20 balance) to arrive in Sacramento (Charles at 5:16 pm, Don and Mike at 9 pm)
- \* Charles to pick up station wagon rental
- \* Charles will call Steve Hui at home to confirm arrival.
- \* Charles will call Frank DiGenova at home to confirm arrival and arrange to pickup air freight shipment of equipment at Sierra
- \* Charles will call Susanne Hering at home to confirm meeting time on Monday PM for installation of LAS-X and Aethalometer and operator training.
- \* Don and Mike will pick up cell phones and rental sedan.
- \* Charles and Mike will set up computer and balance, and temperature/humidity sensor and check balance for proper operation and begin recording temperature and humidity fluctuations.

### Monday, AM, 2/24

- \* Charles and Don will meet Frank at Sierra to install the rack, position the rear window panel and locate the Teflon sampling line to the front of the SR car [the Sierra driver and the Sierra navigator will not be needed on 2/24]
- \* Mike will begin equipment setup and pump calibrations
- \* After installation of the rack (should require < 1 hr), Charles, Don, and Frank will take the car to the motel staging area for attachment of the outside switching manifold and the other sampling equipment to the rack.

### Monday, PM, 2/24

- \* LAS-X and Aethalometer will be installed in car by Susan, tested for proper operation, and Susan will train Mike, Don and Frank on their operational settings.
- \* LAS-X will be attached to the laptop computer by Don and the data output and logging functions checked
- \* Aethalometer internal data logger (with its own floppy drive) will be checked by Susan
- \* Paper tape sealing requirements of the Aethalometer will be reviewed by Susan along with tape loading and archiving procedures
- \* All CO monitors will be calibrated by Don and Mike and the internal data loggers checked
- \* All particle monitoring pumps and associated data loggers will be checked by Mike and Charles and pre-set to the correct flowrate (2.0 lpm), including checking batteries.
- \*\* All participants to meet (prior to and at dinner) to discuss responsibilities, logistics and problem areas

Monday, evening, 2/24

- \* Car will be returned to Sierra garage for overnight parking (every night)
- \* All filters will be numbered, pre-weighed, and loaded into petri dishes by Mike Roberds - if the temperature and humidity are within  $20 \pm 5$  °C and 30 to 70 % Rh (should not be a problem if room HVAC is functional). If outside humidity is extremely high and inside humidity cannot be brought below 70%, a dehumidifier will be obtained and the filters weighed on 2/25 PM.

Tuesday, AM, 2/25

- \* PM<sub>2.5</sub> and PM<sub>10</sub> inlets will be cleaned, oiled (as needed), loaded with a filter, sealed, and leak-tested.
- \* The in-vehicle continuous monitors - CO, LAS-X, and Aethalometer - will be turned ON each morning (at Sierra garage) and allowed to warm up for 1 hour.
- \* At the staging area, the CO data logger will be checked, the Aethalometer data logger will be checked, and the RTI laptop connected to the LAS-X and checked.
- \* The 3 continuous monitors will be put into the data collection modes.
- \* The computer system in the car will be checked and data collection initiated for laser, switch setting, and speed logging.
- \* The video camera will be loaded, clock time checked, and camera started.
- \* The Sierra driver and Sierra navigator will proceed to the start of the rush hour commute route and drive the route for 1-2 hours (time of day irrelevant) to (a) become familiar with the route, and (b) become familiar with the switch panel settings.

Tuesday, PM, 2/25

- \* Continuous monitors powered up for the duration of the sampling (thru 3/3)
- \* PM<sub>2.5</sub> and PM<sub>10</sub> inlets will be cleaned, oiled (as needed), loaded with a filter, sealed, leak-tested and placed into Ziplok bags.
- \* Fresh batteries will be installed as needed (batteries will be changed twice - initially and Friday PM) in all particle sampling pumps (4 AA alkalines/pump), NO<sub>2</sub> pumps, VOC multi-sorb pumps, and CO monitors (9V)
- \* The tripod for the Ambient site and the ground stakes for the 4 Roadside sites should be located and installed for the subsequent sampling days. *CalTrans must be notified so they can inspect.*
- \* After the car returns the CO, LAS-X, and Aethalometer data will be retrieved for evening review by Charles.
- \* The car computer data and video will be retrieved by Sierra, reviewed for reasonableness, and given to Charles for subsequent evening review.
- \* All particle sampling pumps, NO<sub>2</sub> tube pumps, PAH pumps, PAH inverter/battery systems will be checked for functionality.
- \* The operation of the in-vehicle integrated samplers, the switching manifold, and laptop data logging system will be demonstrated to the Sierra driver and navigator by Don.

Tuesday, evening, 2/25

- \* All filters will be pre-weighed, if not already weighed on 2/24

- \* Data forms/spreadsheets will be initiated for each sample collection,
- \* Rechargeable batteries for the PAH sampling and aldehyde sampling will be placed on charge
- \* Particle sampler data loggers will be reset to operate unattended (without mid-sampling data review) for the 4 sampling days - unless a final flow is more than 10% different than an initial flow.

**Wednesday, AM, 2/26 [Sampling Day 1: Freeway/Low AER/no Roadside Monitoring]**

- \* All monitor and data systems internal clocks will be set and synchronized
- \* **AM General Commute Preparations [5:30 to 6:45 AM]**
  - + All clocks (samplers, data loggers, video camera) will be checked for synchronization
  - + The car will be fueled and the windows cleaned.
  - + A fugitive leak test for CO and NO<sub>2</sub> will be conducted by Sierra under the hood and along the exhaust system under the car, while the (warmed) car is idling.
- \* **In-Vehicle Sample/Data Collection Preparation [5:30 to 6:45 AM]**
  - + The particle sampling inlets (PM<sub>2.5</sub> and PM<sub>10</sub>) will be installed for inside and outside (no PM<sub>10</sub> outside), the pumps checked and set for initial flowrate, and the data sheets completed with the sampling start time.
  - + The NO<sub>2</sub> tubes will be installed (1 for each hourly value), the pumps checked and set for initial flowrate, and the data sheets completed
  - + The aldehyde pump and cartridge will be installed (Inside sampling only) and the data sheet completed.
  - + The VOC canisters will be installed and the data sheets completed.
  - + The VOC multi-sorb tube (Inside sampling only) will be prepared
  - + The CO monitor will be zeroed and span checked, the data logger checked.
  - + The LAS-X will be checked, along with the laptop computer data collection system
  - + The Aethalometer will be checked, along with its internal data collection system.
  - + Video camera to be prepared (1 video tape per day - AM & PM commutes)
  - + On-board computer system initiated and laser distance finder checked
- \* **Ambient Sample/Data Collection Preparation [6:00 to 6:30 AM]**

At the motel staging area:

  - + The particle sampling inlets (PM<sub>2.5</sub> and PM<sub>10</sub>) will be installed, the pumps checked and set for initial flowrate, and data sheets updated.
  - + The NO<sub>2</sub> tubes will be installed (1 for each hourly value), the pumps checked and set for initial flowrate using a dummy tube [the pumps left ON - tubes will be connected at the roadside], and the data sheets updated.
  - + The VOC canisters will be prepared and the caps removed.
  - + The CO monitor will be zeroed and span checked, and the data logger checked.

- \* Ambient Site Sampling Initiation [6:40 to 6:45 AM]
  - + The route will be driven by Mike and Steve to set out, secure, start the sampler, and note arrival/departure times for the Ambient site station only.
  - + After the placement and initiation of the ambient sampler, Mike will make a phone call to the Sierra driver to begin the 2 hour commuting run [may only be required on first sampling day].
  
- \* Commute Initiation [6:45 AM]
  - + All in-vehicle sampling pumps (particles, NO<sub>2</sub>, PAH, VOC, and aldehydes) and data logging (as required) will be started by Sierra navigator after the signal is received upon setup of the last roadside sample
  - + The commute drive route (see attached maps) will start at the motel staging area, proceed to the I Street on ramp of I5, proceed South to Rte 99, proceed East to Bus. 80, proceed North past the I80 merge, and turn around at Madison Ave., re-enter South on I80 and re-trace the route continuously for the 120 minute period.
  - + The study driving protocol, including data entry via switch panel will be followed.
  - + The front windows of the car will be lowered 1/3 open for the first 2 minutes of each commute that are on the freeway (Wed, Thur, and Fri) or rural route (Sat) to provide an initial in-traffic purge and then returned to the required position for the balance of the commute.
  - + Sierra navigator to monitor signal light on dash for proper activation of outside manifold solenoid switching - if light flash ceases, LAS-X/solenoid switching laptop computer must be re-initiated.
  - + After 120 minutes, the Sierra navigator will suspend all sampling pumps, VOC's, and data logging (as required).
  
- \* Mid-Commute [7:40 to 7:45 AM]
  - + The route will be driven to switch the NO<sub>2</sub> samplers from Hour 1 tubes to Hour 2 tubes at the Ambient site and each of the four roadside sites
  - + The Sierra navigator will switch the in-vehicle NO<sub>2</sub> samplers from Hour 1 tubes to Hour 2 tubes
  
- \* Commute Completion [8:45 AM]
  - + Car returns to staging area (motel)
  - + Mike will conduct final flow checks at the motel on each sampler, complete the data sheets, and secure the collected samples.
  
- \* Ambient Site Sampling Completion [8:40 to 8:45 AM]
  - + The route will be driven by Steve and Mike to stop the sampling and retrieve the sampling systems for the Ambient site station
  
- \* Sample Retrieval/Archival/Data Collection [9:00 to 11:00 AM]
  - + All sampling filters, cartridges, tubes, and canisters will be removed and placed in their respective storage/shipping containers



+ The particle inlets will be unloaded, the filters moved to the proper petri dish, and any unusual deposits noted in the filter log book

- \* Particle Inlet Preparation [12:30 to 1:30 PM]
  - + PM<sub>2.5</sub> and PM<sub>10</sub> inlets will be cleaned, oiled (as needed), loaded with a tared filter, sealed, leak-tested and placed into Ziplok bags.

Wednesday, PM, 2/26

- \* In-Vehicle Sample/Data Collection Preparation [3:00 to 4:00 PM]
  - + Prepare PAH filter cartridge and pump system
- \* Ambient Sample/Data Collection Preparation [3:00 to 3:50 PM]
  - + Prepare PAH filter cartridge and pump system
- \* Ambient Site Sampling Initiation [3:50 to 4:00 PM]
- \* Commute Initiation [4:00 PM]
- \* Mid-Commute [4:50 to 5:00 PM]
- \* Commute Completion [6:00 PM]
- \* Ambient Site Sampling Completion [5:50 to 6:00 PM]
- \* Sample Retrieval/Archival/Data Collection [6:00 to 8:00 PM]
  - + Includes floppy disk backup of data files collected during the day
  - + Recharge PAH batteries and Aldehyde sampler pump battery

Wednesday, evening, 2/26

- \* The inside PM<sub>2.5</sub> and PM<sub>10</sub> particle filters will be post-weighed (and repeated each evening until the final post-weighing) to estimate whether volatilization losses may be occurring.
- \* PAH, VOC multi-sorb, aldehyde and NO<sub>2</sub> samples will be stored in a refrigerator (35-40 °F) after collection until shipment to RTP for analysis. Particle sample filters will not be refrigerated.

Thursday, AM, 2/27 [Sampling Day 2: Freeway/Med. AER/Roadside Monitoring]

- \* AM General Commute Preparations [5:15 to 6:45 AM]
- \* In-Vehicle Sample/Data Collection Preparation [6:00 to 6:45 AM]
- \* Roadside/Ambient Sample/Data Collection Preparation [5:15 to 6:45 AM]
- \* Roadside/Ambient Site Sampling Initiation [6:40 to 6:50 AM]
  - + Steve to place samplers at the ambient site, Mike to place samplers at Roadside sites 1 & 2, Don to place samplers at Roadside sites 3 & 4
- \* Commute Initiation [6:45 AM]
- \* Mid-Commute [7:40 to 7:50 AM]
  - + Steve to switch NO<sub>2</sub> tubes at the ambient site, Mike to switch NO<sub>2</sub> tubes at Roadside sites 1 & 2, Don to switch NO<sub>2</sub> tubes at Roadside sites 3 & 4
- \* Commute Completion [8:45 AM]
- \* Roadside/Ambient Site Sampling Completion [8:35 to 8:55 AM]
  - + Steve to stop samplers at the ambient site, Mike to stop samplers at Roadside sites 1 & 2, Don to stop samplers at Roadside sites 3 & 4
- \* Sample Retrieval/Archival/Data Collection [9:15 to 11:15 AM]

**Thursday, PM, 2/27**

- \* In-Vehicle Sample/Data Collection Preparation [2:30 to 4:00 PM]
- \* Roadside/Ambient Sample/Data Collection Preparation [2:30 to 3:50 PM]
- \* Roadside/Ambient Site Sampling Initiation [3:50 to 4:10 PM]
- \* Commute Initiation [4:00 PM]
- \* Mid-Commute [4:50 to 5:10 PM]
- \* Commute Completion [6:00 PM]
- \* Roadside/Ambient Site Sampling Completion [5:50 to 6:10 PM]
- \* Sample Retrieval/Archival/Data Collection [6:30 to 8:30 PM]
- \* Charles to leave Sacramento

**Friday, AM, 2/28 [Sampling Day 3: Freeway/High AER/Roadside Monitoring]**

Repeat Thursday, AM, 2/27, w/ Roadside Monitoring:

- + Change all batteries in particle sampling pumps prior to sampling

**Friday, PM, 2/28**

Repeat Thursday, PM, 2/27 w/ Roadside Monitoring:

**Saturday, AM, 3/1 [Sampling Day 4: Rural Commutes/Low AER/no Roadside Monitoring]**

Repeat Wednesday, AM, 2/26, w/o Roadside Monitoring; start time not critical. A staging area (starting point where car can be parked and samplers serviced) must be identified.

- \* Add an in-vehicle VOC sample collection with the car standing and OFF to determine if out-gassing from unidentified sources are affecting the inside collections.
- \* Conduct AER measurements (Low, Medium, and High vent settings) after first commute.
- \* Set-up ambient station at ARB location identified by Steve.:

**Saturday, PM, 3/1**

Repeat Wednesday, PM, 2/26 w/o Roadside Monitoring:

- \* Steve, Charles, Don, Mike and Frank will decide whether sample collections have been "successful" and determine whether an additional AM sampling commute run will be needed on Monday.

**Sunday, 3/2**

A day of rest

**Monday, AM/PM, 3/3 [Special Sampling Day]**

- \* Collect Samples to Replace Lost Samples Days 1 to 4 [6:30 AM to 10:00 AM]

- + Replacement samples (no VOC's will be repeated) will only be collected if more than 50% of samples are lost on a previous commute simultaneously (i.e. the expected data capture rate for integrated samples in the Pilot Study is 7 out of 8 samples - only in a case of catastrophic simultaneous failure will a re-run be made)
- \* Steve, Charles, Don, Mike, Frank, and Linda by phone (and Susanne if available) will meet to discuss the special sampling scenarios to be examined during the Continuous Monitor driving.
- \* Collect Continuous Monitor Data [? to 3:30 ]  
Proposed sampling:
  - + Operate only CO, LAS-X, and Aethalometer with Don in backseat to collect data and direct driving scenarios to study typical and max/min exposure situations
  - + Driving location 1: Primarily between the truck station at Antelope and the Madison interchange (~4 miles), following Heavy Duty Diesel Truck (HDDT) - investigating concentrations/size distributions for various situations, e.g.:
    - Immediately behind HDDT during accel vs speed limit cruise,
    - Influence of trailing distance during accel and cruise,
    - Influence of 1 or more intervening cars,
    - Immediately behind to changing to adjacent lane - both left and right
  - + Driving location 2: Moderately congested route with carpool lane:
    - Determine levels/size distributions in lane 1 (HDDT influence) vs middle lanes vs carpool lane
- \* Susanne to conduct final PM check of operating conditions of Aethalometer and LAS-X and retrieve Aethalometer

#### Monday, evening, 3/3

- \* All filters will be post-weighed, returned to the petri dishes, and archived for return to RTI for chemical analysis. If the outside humidity is extremely high and inside humidity cannot be brought below 70%, a dehumidifier will be obtained and the filters weighed on 3/4 PM.

#### Tuesday, AM, 3/4

- \* All samples (except VOC canisters) to be hand carried, along with Mettler balance and laptop computers by Don and Mike back to NC
- \* All equipment and supplies to be boxed and prepared for return shipment to NC (including LAS-X)

#### Tuesday, PM, 3/4

- \* Project operational debriefing (primarily % data capture; preliminary estimates of data quality by category) for Steve by Don and Mike

#### Wednesday, AM, 3/5

- \* Don and Mike to leave Sacramento

**APPENDIX D**

# Inspection of Sedan 1 Prior to the Pilot Study

Sierra Research  
February 20, 1997

## Summary Description of Sedan 1

The test vehicle for the pilot study, Sedan 1, is a 1991 Chevrolet Caprice that is dedicated by Sierra to service as an instrumented vehicle. The base vehicle is a full-size, six passenger sedan with V8 engine and automatic transmission. The interior has leather bench seats both front and rear, power windows, power door locks and power seats.

Several modifications have been made to the vehicle prior to and as part of the current study. One of the most unique aspects of the vehicle is a front-grille-mounted laser range finder (Laser Atlanta, model Atlas 1000) that is used to measure distance to the vehicle ahead. The vehicle has been equipped with a 110 VAC power system based on an isolated 12 volt DC deep-cycle marine battery and a 1200 watt frequency compensated inverter (Triplite Model 1200FC), all of which is mounted in the trunk. Also mounted in the trunk is a 486/66 computer with ROMdisk (Curtiss, Inc.).

An LCD display and keyboard are mounted in the passenger compartment. A six-switch rotary switch box is provided for operator data entry and an accelerometer package has been installed on the rear deck for longitudinal and lateral acceleration. A video camcorder (Sony model CCD-V701/NTSC) is installed in the center rear part of the passenger compartment to record view out the front window.

Additional equipment, installed by RTI after removal of the rear seat bench for the pilot study, is described elsewhere.

## Vehicle Inspection Prior to Pilot Study

The Caprice has been subjected to numerous emissions tests, both as part of California's Smog Check program (it has always passed) and for special mass emissions and fugitive emissions testing programs. However, to ensure that the vehicle did not have undue fugitive emissions either under-hood or in the passenger compartment, three additional tests were performed on February 19, 1997, just prior to the commencement of the pilot program.

First, under-hood emissions were measured at the Sierra Research Vehicle Testing Laboratory. Insofar as there is not yet a standardized test procedure for determining

under-hood fugitive emissions, a modified FID-based CVS sampling system\* was used together with a custom-made stainless steel dilution funnel to sample under-hood air for fugitive leaks, as described previously.\*\* No dilute concentrations in excess of 20 ppmC were observed, which is considered by EPA to be maximum allowable hydrocarbon concentration in "background" air for IM240, i.e., CVS-type testing.\*\*\*

Second, to check for potential fugitive hydrocarbon sources in the passenger compartment, a NDIR-type portable exhaust gas analyzer was used as a "sniffer." No measurable concentrations of hydrocarbons above background levels were detected.

Finally, the vehicle was visually checked for fugitive leaks by an automotive engineer and Qualified Environmental Professional from Sierra. No leaks were found.

### Conclusion

Based on the observations described above and previous test results, it was concluded that Sedan 1 was unlikely to have significant fugitive hydrocarbon leaks that might unduly influence inside or outside sampling.

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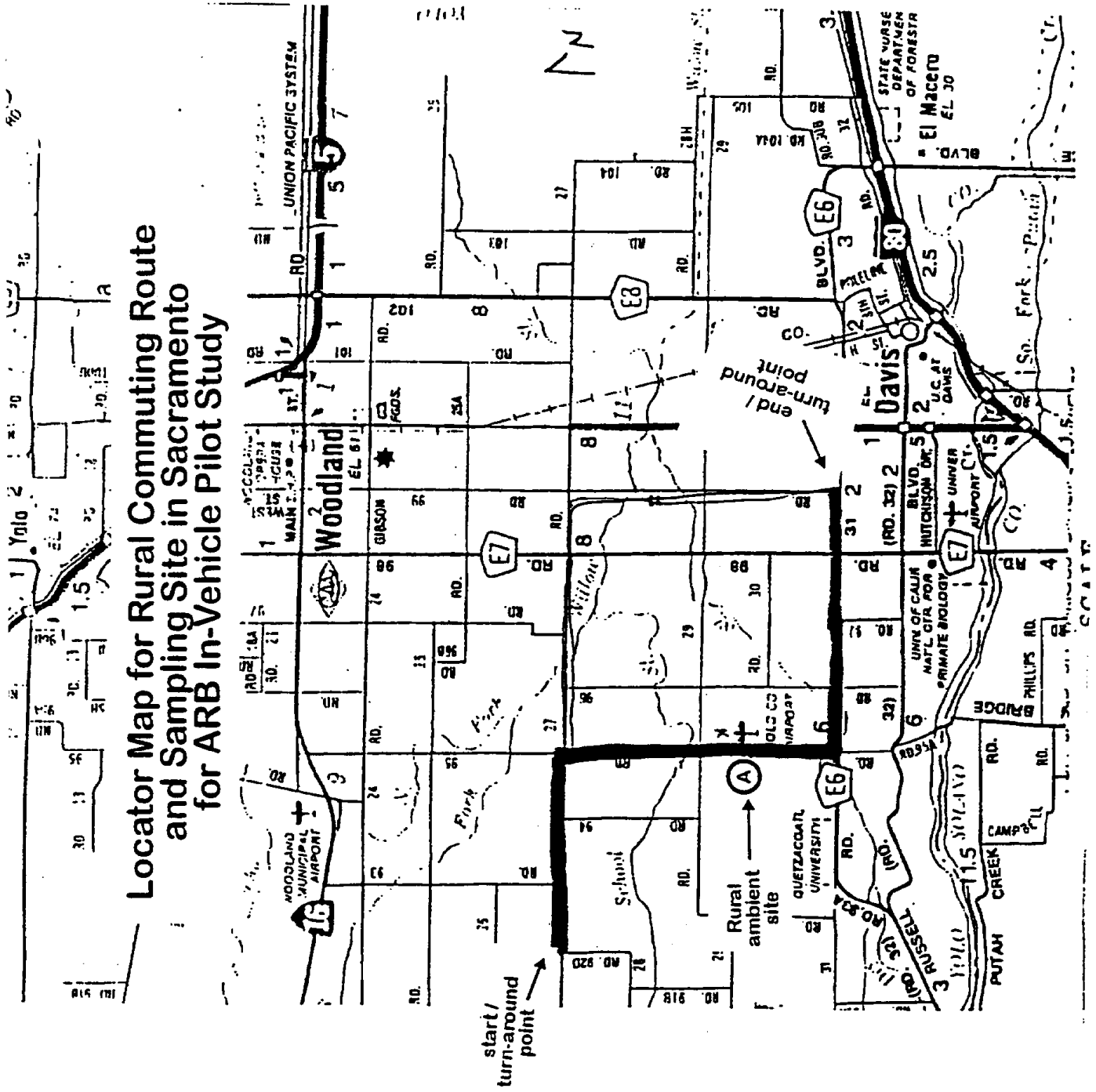
\* Di Genova, Frank, et al., "The Potential Significance of Motor Vehicle Crankcase Emissions on the Mobile Source Emissions Inventory," presented at the 6th Coordinating Research Council Emissions Workshop, San Diego, CA, March 18-20, 1996.

\*\* Di Genova, Frank, et al., "Alternative Techniques for Detecting Excessive Evaporative Emissions During I/M Tests," SAE Paper No. 962093.

\*\*\* "High-Tech I/M Test Procedures, Emission Standards, Quality Control Requirements, and Equipment Specifications: IM240 and Functional Evaporative System Tests," Revised Technical Guidance, DRAFT, USEPA-AA-RSPD-IM-96-1, June 1996.

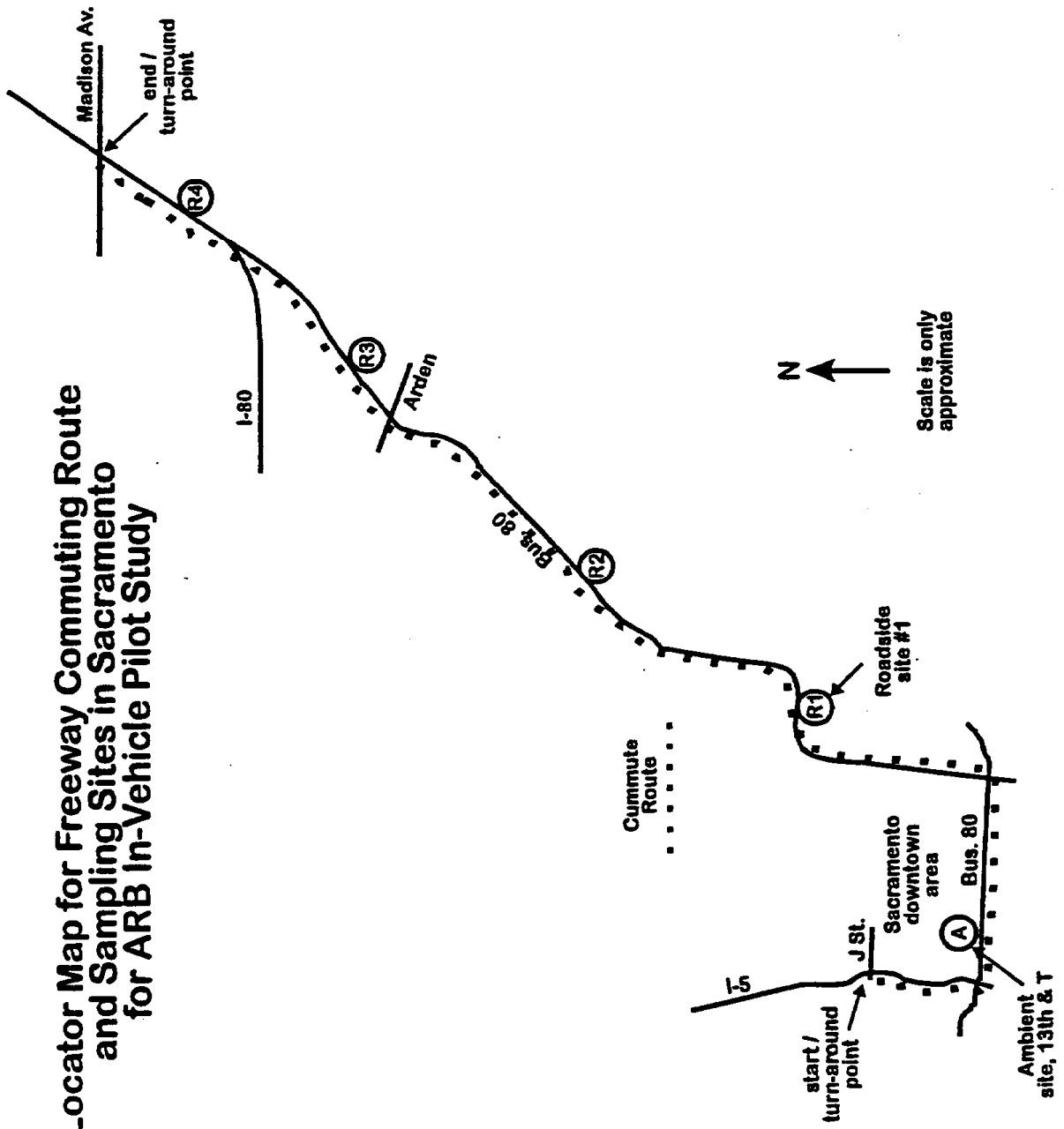
**APPENDIX E**

# Locator Map for Rural Commuting Route and Sampling Site in Sacramento for ARB In-Vehicle Pilot Study





# Locator Map for Freeway Commuting Route and Sampling Sites in Sacramento for ARB In-Vehicle Pilot Study



**APPENDIX F**



sierra  
research

1801 J Street  
Sacramento, CA 95811  
(916) 444-6666  
Fax: (916) 444-837

February 18, 1997

**Memo To:** Alicia Beyer, Encroachment Permit Engineer  
Caltrans District 3 Encroachment Permits

**From:** Frank Di Genova 

**Subject:** Site Locations for RTI Encroachment Permit Application of 2/6/97

This memorandum provides specific locations for four portable air samplers in support of RTI's February 6, 1997 application for encroachment permits. This air sampling is needed for an inside-vehicle air pollution research study sponsored by the California Air Resources Board.

RECEIVED PERMIT  
FEB 17 1997

Three site locations are along Route 51 (Business 80) between the junction with Highway 50 (milepost 0.00) and junction 80 west (milepost 8.86). The fourth location is on Highway 80, just north of the junction with Route 51. All samplers will be located to the right (east) of the shoulder of the northbound lanes, between approximately 15 and 25 feet from the edge of the rightmost lane. Additional details about the samplers are contained in the application filed on February 6, 1997, by RTI.

- Location #1: milepost 2.4, next to the call box (call box number SA-51-22), which is located immediately north of the highway sign indicating 1 mile to the Cal Expo exit. The sampler will be located to the north of the sign and thus will not obstruct view of it.
- Location #2: milepost 4.3, approximately halfway between Arden Way interchange (milepost 4.06) and El Camino Avenue interchange (milepost 4.74), which is approximately adjacent to a large "CINEMA" sign to the east of the right of way.
- Location #3: milepost 5.85, approximately halfway between the Auburn Blvd. connection (milepost 5.78) and the Howe Avenue connection (milepost 5.96). Because of the limited space at the shoulder, it is anticipated that this site will be accessed from Auburn Blvd rather than from Route 51.
- Location #4: milepost 11.4, immediately east of the I-80/highway 51 split but west of the eastbound I-80 onramp from route 244, in the vicinity of call box number SA-80-114.

February 18, 1997

The approximate locations of the four sampling sites are shown on the attached map. If you have any questions about the sampling locations, please call me. If you have questions about other aspects of the permit application or the project, please call Dr. Rodes at RTI or Mr. Hui at ARB.

cc. Charles Rodes, RTI  
Steve Hui, ARB  
Tira McCann, Caltrans

**ENCROACHMENT PERMIT**  
TR-0120 (NEW 9/91)

Permit No. <b>0397-NSV0152</b>	
Dist/Co/Rte/PM <b>03-SAC-51-2.4/5.96</b> <b>03-SAC-80-R11.55</b>	
Date <b>February 20, 1997</b>	
Fee Paid <b>\$ EXEMPT</b>	Deposit <b>\$ N/A</b>
Performance Bond Amount (1) <b>\$ N/A</b>	Payment Bond Amount (2) <b>\$ N/A</b>
Bond Company	
Bond Number (1)	Bond Number (2)

In compliance with (check one):

Your application of **February 18, 1997**

Utility Notice No. \_\_\_\_\_ of \_\_\_\_\_

Agreement No. \_\_\_\_\_ of \_\_\_\_\_

R/W Contract No. \_\_\_\_\_ of \_\_\_\_\_

TO:

Research Triangle Institute  
P.O. Box 12194  
Research Triangle Park, NC 27709-2194

ATTN: Charles E. Rodes  
PHONE: (919) 541-6749

, PERMITTEE

and subject to the following, PERMISSION IS HEREBY GRANTED to:

Install four (4) temporary air monitoring stations, three (3) along State Highway 51 (Bus. 80) and one on State Highway 80. Specific locations described on memo dated February 18, 1997.

**MEMO ATTACHED**

Permittee shall contact State Inspector Tara McCann, telephone (916) 227-7008, two working days prior commencing work, to arrange a pre-job meeting, in accordance with Provision 6 of the attached General Provisions. The 24 hour notification before restarting work, provided by Provision 6, shall be strictly adhered to. All work shall be conducted and completed to the satisfaction of Caltrans representative listed below. Immediately following completion of the work permitted herein, the Permittee shall fill out a mail the Notice of Completion attached to this permit.

The following attachments are also included as part of this permit. (Check applicable):			In addition to fee the permittee will be bill actual costs for:		
<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No	General Provisions	<input type="checkbox"/> Yes	<input checked="" type="checkbox"/> No	Review
<input type="checkbox"/> Yes	<input checked="" type="checkbox"/> No	Utility Maintenance Provisions	<input type="checkbox"/> Yes	<input checked="" type="checkbox"/> No	Inspection
<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No	Special Provisions <b>TRAFFIC CONTROL</b>	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No	Field Work
<input type="checkbox"/> Yes	<input checked="" type="checkbox"/> No	A Cal-OSHA permit required prior to beginning work; <b># PLAN and MEMO ATTACHED</b>	(If any Caltrans effort expended)		
<input type="checkbox"/> Yes	<input checked="" type="checkbox"/> No	The information in the environmental documentation has been reviewed and considered prior to approval of this permit.			

This permit is void unless the work is completed before **May 1, 1997**

This permit is to be strictly construed and no other work other than specifically mentioned is hereby authorized.

No project work shall be commenced until all other necessary permits and environmental clearances have been obtained.

Tara McCann, Permits  
5900 Folsom Boulevard  
Sacramento, CA 95919  
(916) 227-7008, Cellular 755-7371

APPROVED:

Irene J. Itamura, District Director

BY:

*Richard W. Jones*  
Richard W. Jones, Chief - Office of Encroachment Permits

cc Peter Azevedo, Sunrise Region

## Attachment

### California Department of Transportation Standard Encroachment Permit Application

#### Items 1, 2, 3, 4, 6, 7, and 8

The exact locations of the four encroachment locations on the Highway 51 (I-80 business) freeway from the downtown Sacramento J street intersection to the Auburn Boulevard interchange on I-80 (towards Roseville) have not been determined. They are proposed to be approximately equally spaced over this route. These locations will be used to place portable air pollution monitors temporarily for a study under contract to the California Air Resources Board (see Item 22). The exact locations will be selected by February 12, 1997, and provided to the CalTrans encroachment engineer immediately.

#### Item 22.

##### Roadside Air Sampling by the Research Triangle Institute for the California ARB

###### 1. Introduction:

The Research Triangle Institute<sup>1</sup> and its subcontractors, Sierra Research<sup>2</sup>, and Aerosol Dynamics<sup>3</sup> have been awarded a contract by the California Air Resources Board (ARB) in Sacramento, California (contract ARB 95-339, project officer: Steve Hui, ph 916-323-1530) to conduct vehicle occupant air pollution exposure studies while commuting on California freeways. The California Health and Safety Code (HSC) Section 39660.5 requires the ARB to assess human exposure to toxic pollutants. The ARB is also required to identify the relative contribution of indoor concentrations to total exposure, taking into account both ambient and indoor air environments. In order to assess a population's actual exposure to a pollutant, it is necessary to account for exposure in all microenvironments where people spend their time. This requires information on how much time people spend in specific microenvironments and the corresponding air concentration of toxic pollutants in those microenvironments. Although the ARB has representative data on Californian's activity patterns (Wiley et al., 1991a, 1991b), very little pollutant concentration data are available for many microenvironments including vehicle passenger compartments.

The purpose of this study is to measure concentrations of a number of pollutants inside vehicles while they are being driven on California roadways. The results of this study will be used by ARB to determine the need for, and feasibility of, additional in-vehicle pollutant measurements in future studies.

---

<sup>1</sup> A not-for-profit research organization established in conjunction with North Carolina State University, Duke University, and the University of North Carolina, comprising approximately 1500 employees and conducting research studies in a broad variety of disciplines. mailing address: contact: Charles E. Rodes, PhD, ph. 919-541-6749, FAX 919-541-6749; P. O. Box 12194, Research Triangle Park, NC 27709.

<sup>2</sup> Sacramento, CA, contact: Frank DiGenova, ph. 916-444-6666

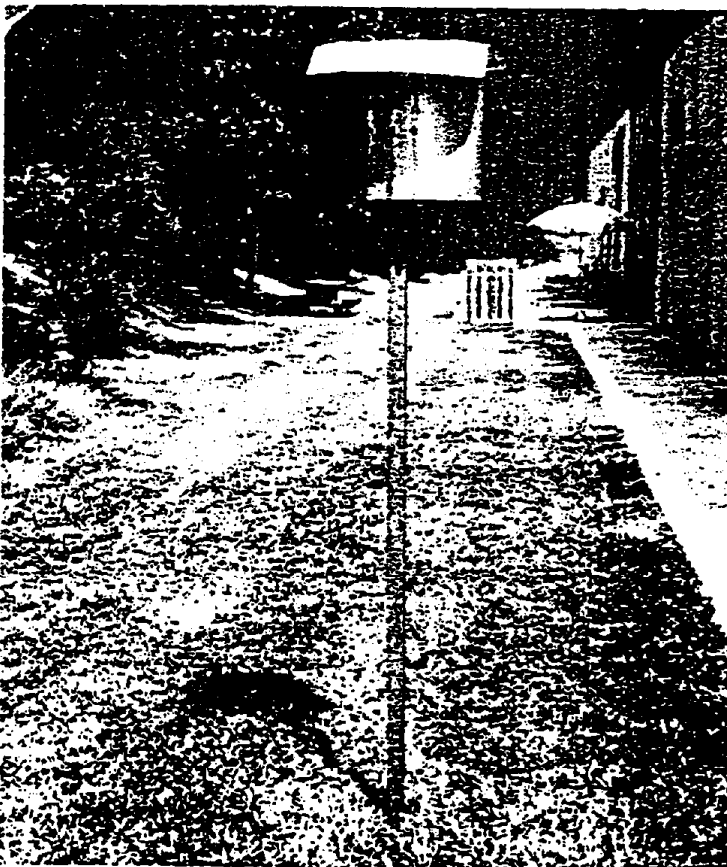
<sup>3</sup> Berkeley, CA, contact Susanne Hering, PhD, ph. 510-649-9360

The results of this project will also be used by the ARB to improve estimates of Californian's current in-vehicle exposures to selected pollutants, and to assess the relative contribution of in-vehicle exposure to total air exposure for these pollutants. In addition, the results may be used to identify actions that driver and passengers may take to reduce their in-vehicle exposures to air pollutants.

## 2. Experimental Plan

The aspect of this study specifically relevant to this encroachment application is the need to collect roadside measurements simultaneously with the in-vehicle measurements during typical 2 hour commutes. ARB would like to determine if fixed-location roadside measurements can be used as reasonably accurate predictors of in-vehicle exposures, to simplify routine monitoring. The study plan proposes a Pilot Study conducted in the Sacramento area on a selected heavily traveled freeway. A total of 4 commuting trips would be conducted over a 3 day period, consisting of 2 morning and 2 evening rush hour periods. The route would each be approximately 20 miles in length and driven repeatedly by a single heavily instrumented test sedan in both directions for 120 minutes (2 hours) to represent a commute trip. The tentatively selected route begins at the downtown Sacramento J street intersection of Highway 51 and proceeds to the Auburn Boulevard interchange on I-80 near Roseville.

During these 2 hour commuting periods we will need to set out 4 air monitoring stations on the southeast side (most probable downwind side) in the Hwy 51/I-80 right-of-way,



approximately equally spaced along the entire route. The monitor roadside locations need to be within approximately 25 feet of the edge of the outermost traffic lane. The basic aluminum monitoring shelters (see photo) are attached to 1 inch square (Unistrut) steel posts, approximately 8 feet long, that are driven into the ground up to 2 feet for support. This leaves 6 feet of the support post above the ground, to which the shelter is fastened by tightening a single bolt. The aluminum shelters are approximately 16 inches high by 16 inches wide by 8 inches deep and weigh approximately 20 pounds with the monitors. The air pollution monitors inside the shelter require no external power. The proposed pollutants will be particles, nitrogen dioxide, carbon monoxide, and volatile organic compounds. The latter organic

compounds will require that a special 12 inch in diameter spherical canister (not shown in photo) be suspended just below one side of each shelter.

The experimental plan would consist of selecting the four roadside sites prior to the actual sampling, and the steel posts located and driven into the ground. Just prior to each 2 hour commuting run by the test vehicle, a technician would travel by car to each roadside location, attach an aluminum shelter with operational samplers to each post, start the samplers manually, and signal by cellular phone to begin the 2 hour commute by the test sedan. The technician is expected to be at each right-of-way location (time required to park, attach the shelter to the post, and start the samplers) less than 10 minutes per location. At the conclusion of each commute, the technician would return to each roadside location to remove the aluminum shelter, leaving the steel post for the next commute. The posts would be removed following the fourth commute.

The physical requirements of the four roadside sites are: (1) locations where Highway 51 and I-80 are proceeding in a northeasterly direction, (2) locations that are relatively unobstructed by nearby trees, (3) locations where the samplers can be within 10 to 25 feet of the roadway, and (4) locations where there is adequate space for the technician to safely pull off and park the service vehicle (rental compact sedan). The exact locations of the four roadside sites are currently being determined. Mr. Frank DiGenova of Sierra Research (916-444-6666) will provide the map copies of the four proposed roadside sampling locations to the CalTrans Encroachment Permit Engineer (Ms. Alicia Beyer; ph. 916-741-4408) to complete this application no later than February 12, 1997.

Minimal damage to the ground cover or other flora should occur as a result of the service vehicle pull off's, driving the posts into the ground, or servicing the samplers during the testing. No modifications to the roadside locations are required and no excavations will be performed.

### 3. Sampling Schedule

The proposed sampling schedule for the four Hwy 51/I-80 commutes would be on two selected days during the period from February 26, 1997 thru March 4, 1997. The morning 2 hr commutes would occur sometime during the interval of 6:30 to 10 AM, while the evening 2 hr commutes would occur between 3:30 and 7 PM.

#### Items 25,26,27,28, and 29

Charles E. Rodes, PhD, project engineer  
Research Triangle Institute  
P. O. Box 12194  
Research Triangle Park, NC 27709  
ph. 919-541-6749  
FAX 919-541-6936



**APPENDIX G**

**Accomplishments and Problem Areas for the Field Sampling Portion of the ARB In-Vehicle Exposure Pilot Study Conducted in Sacramento**

Prepared by C. Rodes, D. Whitaker, M. Roberds, and L. Sheldon  
Research Triangle Institute  
Research Triangle Park, NC 27709  
Revised 4/11/97

**1. Pre-Trip Preparations (RTP)**

**a. Lead-Time for Equipment Design/Procedures Documentation**

Successes

- All specialized equipment was designed, tested and shipped on schedule.

Problem Area

• ARB would like to see procedures/schedules/assignments prepared in more detail and one to three weeks before field sampling starts so they can review and comment.

Comment: We agree that careful planning improves both the data capture rate and the overall data quality. In some cases, however, it is not cost effective to prepare detailed documentation. Additionally, it is sometimes impossible to prepare documentation one to three weeks ahead of time. We will make every attempt to provide these documents in a timely manner for the Main Study.

**b. Manpower Requirements**

Successes

- The individuals and skills identified for design and testing were correct.

Problem Area

• Significantly more man-hours were required to prepare than were budgeted to modify and test the sampling hardware to maximize the probability of success.

Comment: This was partly due to (a) the request by ARB for substantial pre-field documentation that had not been budgeted, (b) discarding the originally planned ball valve Inside/Outside switching arrangement for the manifold as too cumbersome and costly, (c) re-designing the glass manifold to minimize losses, (d) the difficulty in finding an available Chevrolet Caprice matching the subcontractor's vehicle for design purposes, and (e) an underestimation of the amount of logistical pre-planning required for a study with this many elements.

**2. Shipping/Receiving**

Successes

- All equipment arrived intact and on time in Sacramento.
- Very few subsequent FedEx shipments were required to deliver omitted items.

This was a substantial accomplishment, considering the total number of items shipped.

### Problem Area

- The shipping costs appear to be much greater than was allotted.

Comment: This is attributed to two factors. To maximize the probability of successful data collection during the Pilot Study, we opted to send more spare and support items (e.g. 2 glass manifolds, extra sampling pumps) and items that would minimize down-time (e.g. extra tools). Additionally, the equipment was all 2-day FedEx to Sacramento to assure that everything would arrive on time with minimal damage. Aerosol Dynamics had determined that the fragile equipment (primarily the LAS-X required 2-day FedEx delivery to and from the field in special shipping crates (we purchased from the manufacturer) to minimize rough handling during shipment. The balance of the equipment could possibly have been returned to RTP by (cheaper) conventional freight, but it would have added an additional field day to arrange.

## 3. General Logistics

### a. Field Manpower Requirements

#### Successes

- In general the allocated manpower was adequate to reach the percent sample capture goal (7 out of 8), although the on-site personnel worked long hours to make the Pilot Study sampling successful.

#### Problem Areas

- The sampling days were far longer (14 to 16) than the expected hours (12 to 14) on the days with both morning and evening commutes.
- The assistance of ARB personnel (Steve and Peggy) were used to assist in collection of the Ambient site samples.

Comment: The number of RTI personnel on-site was adequate to cover the study - if very few problems had arisen. The problems encountered with (a) accessing the subcontractor's car for setup, (b) dealing with the inadequate power problems in the car, and (c) requiring very close start and end times for all the roadside sites required substantially more time than had been allotted each day. Although most of the hardware and procedures have now been defined, the ability to do both morning and an evening commutes with such a full schedule of sample and data collection in the Main Study with only 2 full time site operators must be reviewed.

### b. Interfacing with Subcontractors

#### Successes

- In general the on-site personnel (RTI, Sierra and AD) worked well together, with everyone demonstrating the initiative and dedication required to produce a successful field effort.

#### Problem Areas

- Access to the Sierra car proved problematical since it could not be left on-site (at the motel) in the evening and could not be driven by RTI personnel.

Comment: The access of RTI personnel (driving, if necessary, and overnight access) should have been a requirement. These items must be addressed for the Main Study.

- Sierra personnel who brought over car were sometimes stranded at the motel.

Comment: The utility/training of the Sierra personnel (driver & navigator) during setup and takedown should be reviewed prior to the Main Study to determine how best to use their time.

- Orientation and training of the Sierra personnel to assist in some of the setup/takedown activities was very limited, since the key RTI personnel were diverted to solving unexpected logistical and power problems.

Comment: A sufficient amount of time must be allotted prior to the Main Study for study participant orientations and training.

- Training of the Sierra personnel to assist in some of the setup/takedown activities was complicated because two different teams were used.

Comment: The number of study participants must be defined prior to the Main Study and the training requirements identified.

#### c. Schedules/Assignments (Daily and Project)

##### Successes

- In general the sampling schedules were comprehensive, such that no samples were lost due to omissions or assignment problems.

##### Problem Area

- Daily routine (morning and evening rush hour sampling in same day was too time consuming with the complex Pilot Study sampling scheme and total number of samples collected.

Comment: The desire to collect data (e.g. relate roadside sampling) at the same time that the methods were being tested and revised proved to be overwhelming. It would have been preferable to have had a lighter AM commute, followed by an intensive PM commute.

#### d. Ambient Site Sampling

##### Successes

- After-hours access to the ARB monitoring site was successfully arranged by Steve Hui and Peggy Jenkins.

##### Problem Area

- The duplicate PAH pumps failed to operate in both attempts. The reasons are still not clear, but appear to be associated with the pump timer.

### e. Roadside Sampling

#### Successes

- The team of 2 persons doing setup/takedown of the sampler provide acceptable start- and end-time windows, as compared to the Inside car samplers.

#### Problem Areas

- The added burden of two persons leaving the starting point early (to meet the  $\pm 10$  minute set-out window) to set up these sites instead of one, placed an added burden on the setup process.

Comment: This Roadside monitoring sample collection scheme should be reviewed to determine how it could have been optimized.

- The requirement to return to the Roadside and Ambient sites after 1 hour to switch the NO<sub>2</sub> tubes was very time consuming.

Comment: A timer and switching valve will be devised for the Main Study to remove the requirement for a mid-sampling return visit.

### f. Inside/Outside Car Sampling

#### Successes

- The equipment rack fit well and the outside sampling manifold and computer-controlled switching valves worked well.

#### Problem Areas

- Testing showed that the Teflon line planned for outside sampling produced significant particle losses as compared to a polyethylene line.

Comment: The Teflon line was replaced with a polyethylene line prior to the start of sampling to accommodate the particle loss findings. The potential impact on NO<sub>2</sub> losses was not defined.

- The myriad of sampling lines inside the car required careful attention (and slowed the pace) to assure that the correct samples and pumps were connected.

Comment: Sampling connections should have been modular quick-connects to speed setup and minimize mix-ups.

- The current design of the rack system makes simultaneous access by two operators impossible.

Comment: If the continuous monitors are to be used in the Main Study (a strong possibility) the rack should be redesigned so that the continuous monitors can be setup simultaneously with the integrated samplers.

- The video camera and some of the sampling inlets vibrated significantly on their rack mounts.

Comment: Vibration damping must be added to the rack support points prior to the Main Study.

### g. Time Synchronization

#### Successes

- The LAS-X data system recording flags of 0 (inside) and 1 (outside) during data collection greatly simplified the identification of sampling modes.

#### Problem Areas

- The Aethalometer data proved cumbersome to match with the LAS-X data, since its results were recorded on a separate data system.

Comment: Consideration should have been given to merging the Aethalometer output into the LAS-X data system..

- The synchronization of Roadside and Ambient sampling with the In-Vehicle sampling proved difficult.

Comment: It is still not clear how closely these sampling time windows should coincide.

- The synchronization of video with the In-Vehicle sampling proved difficult.

Comment: The video clock and the on-board computer clock should be made to agree within 10 seconds.

### h. Communications

#### Successes

- The communications between operators and with the Sierra car (in-transit) worked well with the cellular phones.

#### Problem Areas

- The planned sit-down all-hands meeting was never held so that major sampling problems could be resolved within the demanding time schedule.

Comment: This meeting should definitely be scheduled for the Main Study in both locations to make sure that the important elements of logistics and training are understood by all participants.

- The ability to contact the Sierra driver and navigator was problematical when a decision was made late in the evening concerning a revisions of the sampling schedule for the morning commute.

Comment: Home phone numbers should have been collected.

## 4. Work Spaces

### a. Motel

#### Successes

- The location of the motel at the end of the commute run was time efficient.

- The large room used as a set/drylab/storage area worked well for both sampling preparation and filter weighing.

Problem Area

- The added expense of a third room for the entire 10 days (Charles used the room for only 5 days) was not budgeted.

Comment: In order to maximize the probability of the filter weighing providing the desired MDL, we opted to keep the larger room because of its lack of drafts and apparent temperature and humidity control.

- [Potential Problem] If rain had occurred, the In-Vehicle setup would have been very difficult without.

**b. Inside Car**

Problem Areas

- The accessibility of the back-seat rack for setup and takedown for both the ambient and continuous samples and data was inadequate.

Comment: Almost nothing on the rack was accessible from the front seat and the backseat access was very limited.

**5. Filter Weighing**

**a. Temperature/Humidity/Stability**

Successes

- The temperature and humidity control provided by the room HVAC system was completely adequate for the weighing process.

Problem Areas

- The drafts caused by the cold air leaking in through the sliding glass door affected the zero stability of the balance.

Comment: The drafts required that a 3-sided box be built around the balance (from a cardboard box).

**b. Time Requirements**

Successes

- The pre-weighing and post-weighing were accomplished completely on their individual days.

Problem Area

- The addition of the zero recheck in the balance software to assure that the room conditions were adequately dealt with by the balance, significantly extended the total pre- and post-weighing periods.

Comment: At least 1/3 of the weighings had to be repeated. It's isn't clear why the balance worked well the other 2/3's of the time, but the re-weighings undoubtedly improved the overall weighing precision.

## 6. Particle Inlet Preparation

### a. Work Space Requirements

#### Successes

- The inlet loadings and unloadings were readily accommodated on the small table in the motel room.

#### Problem Areas

- none

### b. Time Requirements

#### Problem Area

- The PM<sub>10</sub> inlet clamp that was shipped to Sacramento would not readily accommodate the taller PM<sub>2.5</sub> inlets.

Comment: A replacement clamp was FedExed overnight from RTP.

### c. Leaks

#### Problem Area

- The leak problems caused by improperly located sealing rings inside the PM<sub>2.5</sub> caps caused intermittent leak test problems.

Comment: Typically 2 out of 8 of the PM<sub>2.5</sub> inlets required reloading after the leak testing. Attempts to re-position the gaskets in the field were only partially successful. The intermittent leaks caused some erratic flow checks (took longer to setup/takedown) and some samples to be seriously under-collected.

### d. Filter Numbering System

#### Problem Area

- The number system adopted to readily identify field blanks and duplicates was too complicated for such an intensive study.

Comment: Correction of missed-assignments added time to the setup that was unnecessary.

## 7. Calibrations/Checks

### a. Particle Sampler Flows

#### Successes

- Pumps maintained the flowrate within limits, except for one marginal case that appears to be attributed to a leaking inlet rather than a pump problem.

- In general the samplers and flow controllers worked as expected, with battery consumption being low and requiring to changes during the Pilot Study.



Problem Areas

- The flow adjustment on the pumps proved impossible to access on the units in the car.

Comment: An external adjustment is being considered.

- A 4 lpm orifice should be developed for the PM<sub>2.5</sub> units.

Comment: The available 2 lpm orifice took twice as long to check the parallel pumps used for PM<sub>2.5</sub>.

b. **NO<sub>2</sub> Tube Flows**Successes

- Pumps maintained the flowrate within limits.

Problem Area

- Unable to check or switch tubes in the car during a commute.

Comment: Either a timer or a remote solenoid switching system are needed for the car, Roadside and Ambient sites.

c. **PAH Sampler Flows**Successes

- Pumps maintained the flowrate within limits.

Problem Areas

- The current design makes it impossible to check the flows with the cartridges in place.

Comment: A redesign is being considered.

- The Ambient site duplicate pumps inexplicably did not function in either run.

d. **Multi-sorb tube pumps**Successes

- Pumps maintained the flowrate within limits.

Problem Areas

- The pumps used were at the lower extreme of their capability.

e. **CO Zeros/Spans**Successes

- The units calibrated within limits.

Problem Areas

- none

#### f. In-Car Manifold Loss Testing

##### Successes

- The losses in the Teflon line were evaluated as compared to a polyethylene line and no line (simulating the Inside sampling).

##### Problem Area

- This was an unplanned test that was conducted after a group discussion on the potential for excessive static charge losses in the Teflon material.

Comment: The losses for the Aethalometer were inadvertently not determined at the same time. The use of polyethylene may have been somewhat detrimental to NO<sub>2</sub> collection.

### 8. Battery Charging

#### a. NO<sub>2</sub> pumps

##### Successes

- The batteries charged as planned.

##### Problem Areas

- None

#### b. PAH pumps

##### Successes

- The battery inverter/charger system worked well.

##### Problem Areas

- None

#### c. Multi-sorb tube pumps

##### Successes

- The batteries charged as planned.

##### Problem Areas

- None

#### d. Aldehyde pumps

##### Successes

- The batteries charged as planned.

##### Problem Area

- Only one pump stopped prematurely, when it was discovered that the charger had be set in the wrong (trickle) mode.

## 8. Data Collections

### a. LAS-X

#### Successes

- After the power problems were resolved, the LAS-X appeared to work well.

#### Problem Area

- The LAS-X requires a much more stable inverter output than was available.

Comment: Several inverters were tested at RTP on a different LAS-X before one was found (and shipped FedEx overnight) that would successfully operate the unit in the car.

- The training time on both the LAS-X and (especially) the Aethalometer were too short, and start-up/shut-down check lists should have been available in writing to streamline the processes (although no data appears to have been lost due to improper operations).

### b. Aethalometer

#### Successes

- The Aethalometer appeared to work well and review of a data file sent by Steve Hui to the manufacturer showed no problems.

#### Problem Areas

- The setup menu to start the sampling was very cumbersome..

Comment: If the Aethalometer is to be used in the Main Study, it would be very helpful if a "quick-start" menu option could be added.

- The collected data file did not have an entry for each minute.

Comment: This made it very difficult to match with the LAS-X. When the tape advances (or for any other non-sampling reason) the data logger should store 9999 or some other code to indicate no data available.

### c. Temperature/Humidity (Car & Weighing)

#### Successes

- The loggers worked well.

#### Problem Areas

- The weighing logger was read by inadvertently not dumped after the initial weighings.

Comment: The operating protocol needs revision.

### d. Air Exchange Rate (AER)

#### Successes

- The CO release method worked reasonably well.

Problem Areas

- The higher than expected AER values for the car required using higher than would have been desired initial CO concentrations to stay within the lower limit (1 ppm) of the CO monitor and collect enough points to construct a decay curve.

- The CO release method does not provide integrated AER data representing the composite AER existing for each 120 minute commute.

e. **Manual Data Entry (Forms)**

Successes

- The prepared forms worked well in identifying what was to be collected and when.

Problem Areas

- Some streamlining is needed to clean up the spreadsheets (e.g. no PM<sub>10</sub> was collected Outside).

- The sheer volume of forms to be completed and checked significantly increased the length of the day (evenings).

f. **Data File Backups**

Successes

- All hard drive data files were backed by floppy drive copies.

Problem Areas

- none

9. **Sample Collections**

a. **PM2.5/PM10 Particles**

Successes

- No samples appear to have been lost due to sampling problems.

b. **VOC canisters**

Successes

- No samples appear to have been lost due to sampling problems.

Problem Area

- The inherent flow drop due to reduced vacuum at the end of each sampling period may prove difficult to address.

Comment: An alternative orifice may be needed for the Main Study.

**c. Multi-Sorb Tubes**Successes

- No samples appear to have been lost due to sampling problems.

Problem Areas

- A special tube holder inside the car is needed to keep them in place during the commutes.

**d. NO<sub>2</sub> Tubes**Successes

- No samples appear to have been lost due to sampling problems.

Problem Areas

- The procedure for switching tubes after 1 hour must be addressed.

**e. Aldehyde Tubes**Successes

- No samples appear to have been lost due to sampling problems.

Problem Areas

- 

**f. PAH filters**Successes

- No regular samples appear to have been lost due to sampling problems

Problem Areas

- The two duplicate samples were lost due to pump timer failures.

**10. Sample Storage/Transfer**Successes

- All samples were stored according to their protocols (refrigerator/freezers were available in the motel rooms).
- All samples were successfully hand-carried back to RTP following a chain-of-custody procedure.

Problem Areas

- None

**11. Samplers/Hardware Maintenance/Repairs**Successes

- Only minor problems occurred and all were resolved immediately.

Problem Areas

- None

**APPENDIX H**

Inside, Outside, Roadside & Ambient Site Mass Concentrations

PM2.5 (blank corrected)								
Date	Run	R1	R2	R3	R4	A	I	O
2/26	1	na	na	na	na	58.5	35.4	52.5
2/26	2	na	na	na	na	34.1	63.5	23.8
2/27	1	14.6	14.9	44.3	35.2	6.0	36.3	56.4
2/27	2	27.8	23.4	18.6	6.2	56.4	15.9	44.5
2/28	1	42.9	39.5	22.6	51.1	9.3	27.7	48.9
3/1	1	na	na	na	na	30.6	24.1	13.3
3/3	1	25.7	34.6	void	31.1	54.5	32.3	9.4

Shaded cells indicate that an internal leak was suspected

PM10 (blank corrected)								
Date	Run	R1	R2	R3	R4	A	I	O
2/26	1	na	na	na	na	45.6	63.0	na
2/26	2	na	na	na	na	237.7	76.0	na
2/27	1	53.3	61.8	70.6	78.5	75.1	70.7	na
2/27	2	112.7	72.8	20.9	78.8	48.7	32.8	na
2/28	1	101.2	61.5	78.2	61.3	-18.4	53.6	na
3/1	1	na	na	na	na	28.0	18.4	na
3/3	1	19.5	19.8	62.7	96.2	27.4	84.1	na

Testing that PM2.5 is < PM10								
Date	Run	R1	R2	R3	R4	A	I	O
2/26	AM	--	--	--	--	<10 MQL	ok	--
2/26	PM	--	--	--	--	ok	ok	<2.5 MQL
2/27	AM	<2.5 MQL	<2.5 MQL	ok	ok	<2.5 MQL	ok	--
2/27	PM	ok	<2.5 MQL	<2.5 MQL	<2.5 MQL	<10 MQL	<2.5 MQL	--
2/28	AM	ok	ok	<2.5 MQL	ok	<2.5 MQL	ok	--
3/1	midday	--	--	--	--	<10 MQL	<2.5 MQL	<2.5 MQL
3/3	AM	<10 MQL	<10 MQL	>	ok	<10 MQL	ok	<2.5 MQL

Shaded cell indicates PM2.5 is greater than PM10 and both values are above the MQL's



**APPENDIX I**

**Background VOCs in Sedan 1**  
**"Grab" Sample - Pilot Study - Sacramento**

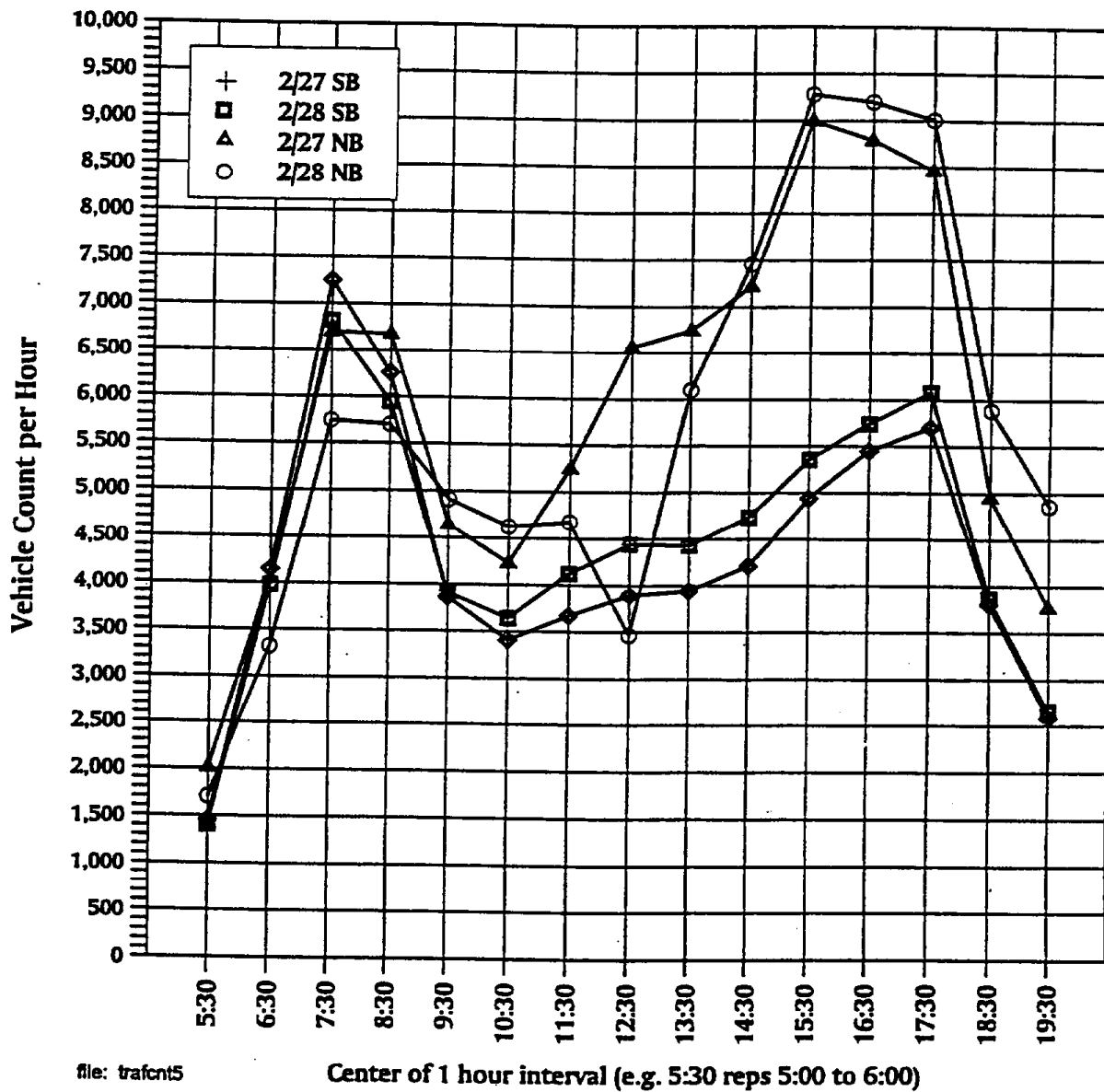
Analyte	Concentration ( $\mu\text{g}/\text{m}^3$ )
1,3-Butadiene	BDL <sup>a</sup>
MTBE	BDL
ETBE	BDL
Toluene	4.4
o-Xylene	1.1
m,p-Xylene	2.6
Benzene	NA <sup>b</sup>

<sup>a</sup>BDL = below detection limit

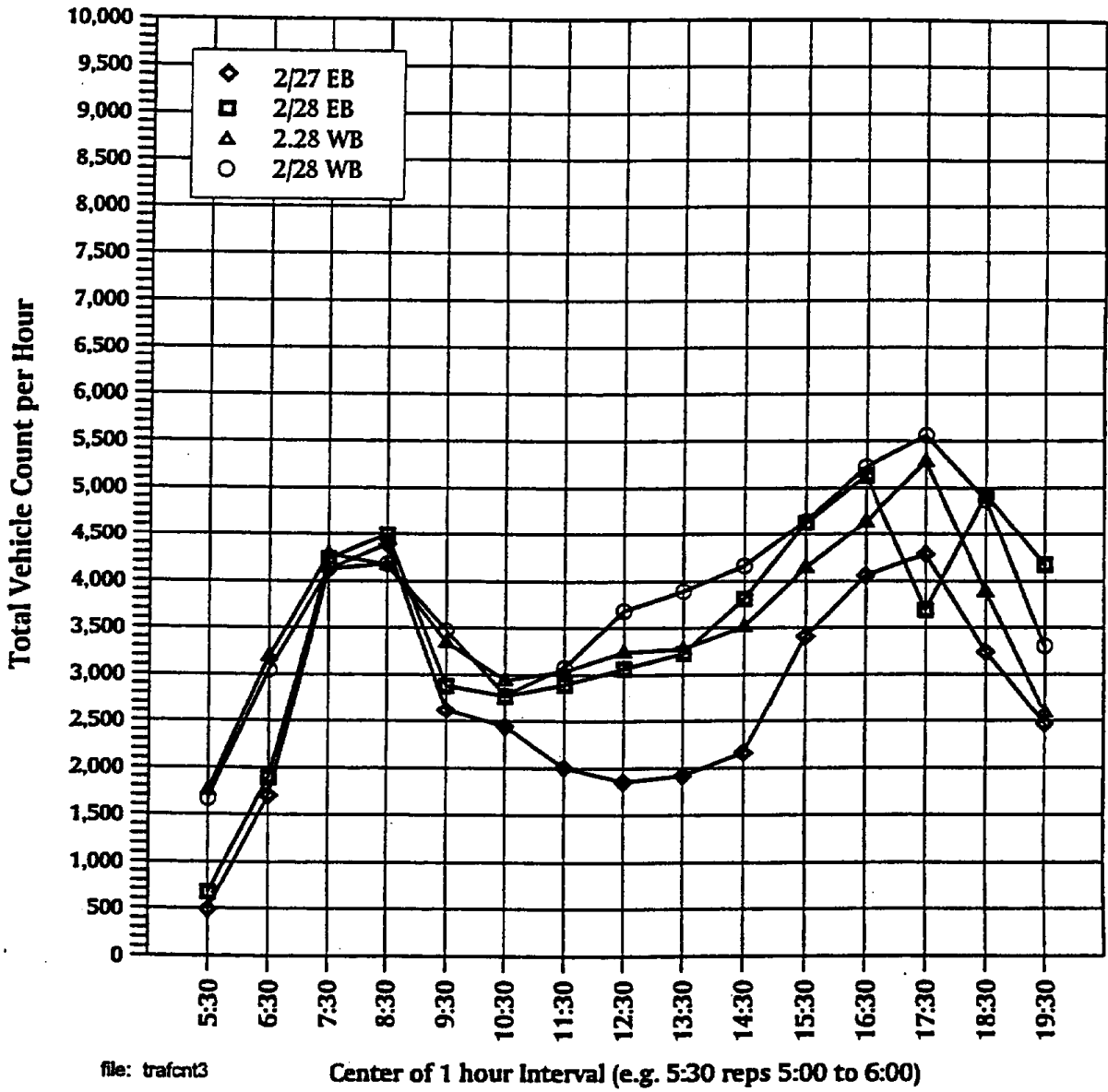
<sup>b</sup> Not Analyzed

**APPENDIX J**

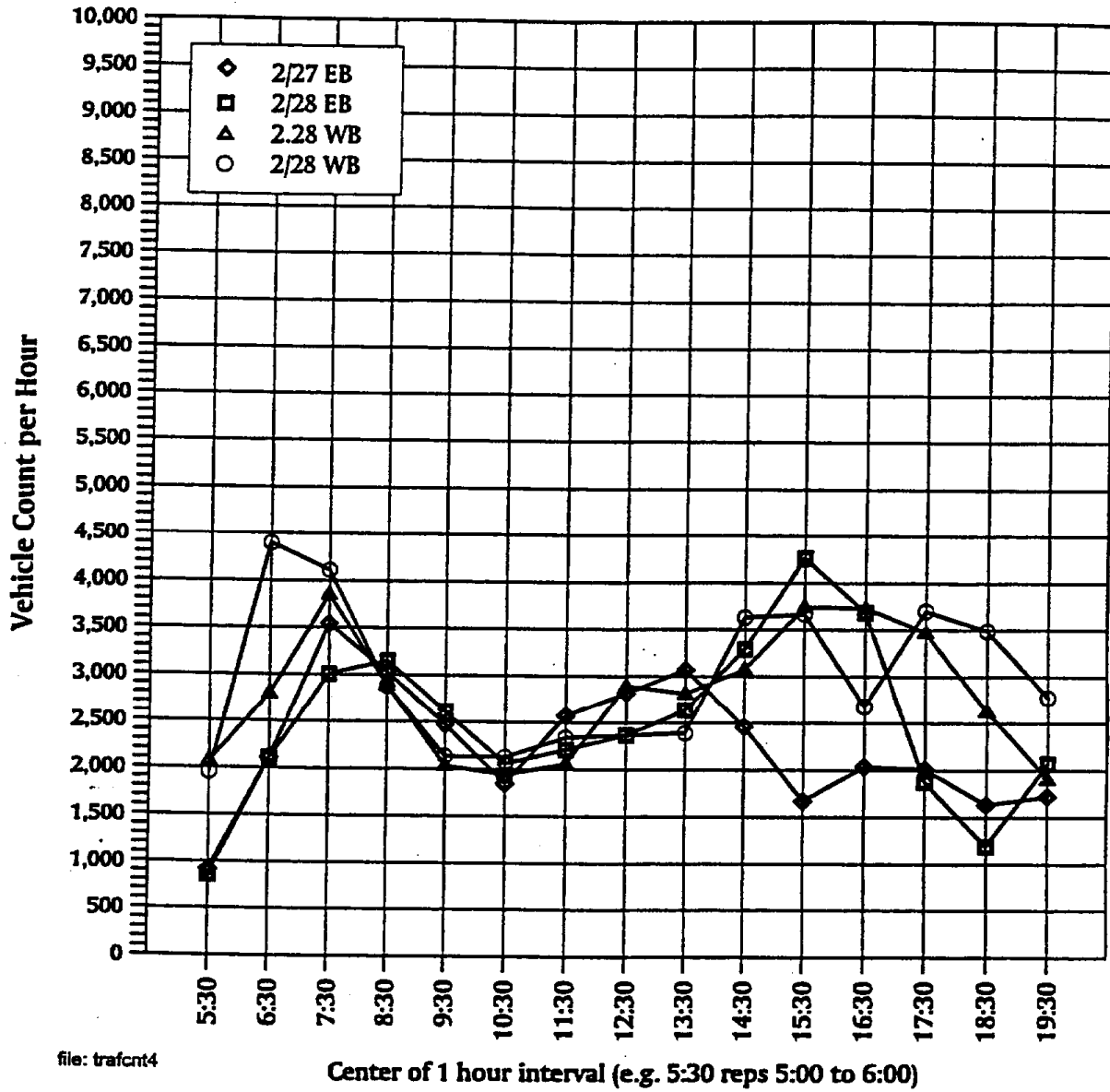
## I 5 at I-Street East and Westbound Traffic Count



## Bus. 80 at Junction w/ Highway 50 East and Westbound Traffic Count

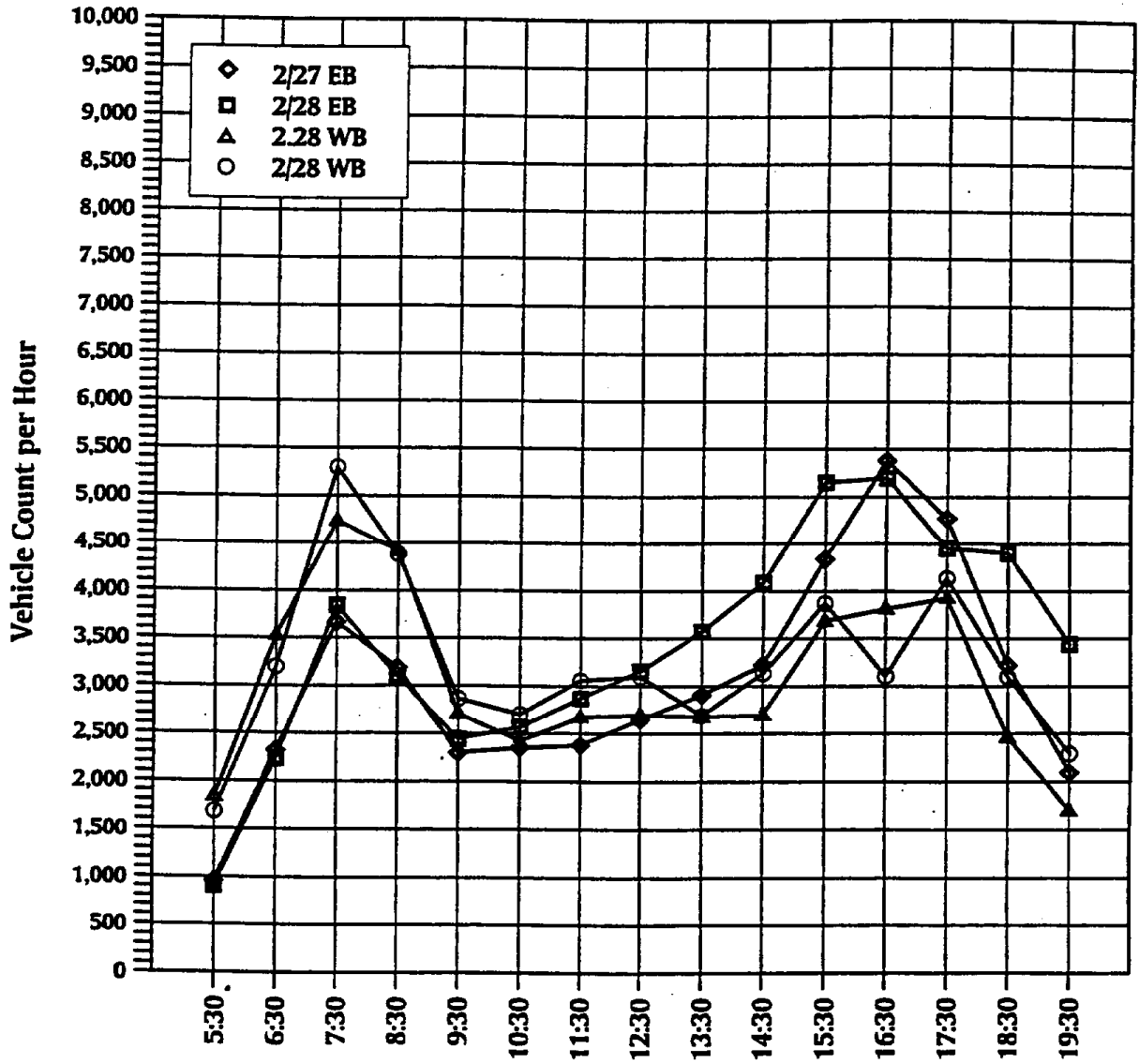


## I 80 at Raley Blvd. East and Westbound Traffic Count



file: trafcnt4

## I80 at Junction w/ Rte 5 East and Westbound Traffic Count



file: trafcnt2

Center of 1 hour interval (e.g. 5:30 reps 5:00 to 6:00)

**Appendix B**

**ARB Fuel Analysis Results**





## Appendix B : Fuel Analysis Results

During the main study, field staff collected samples of the gasoline that they used to refuel the test vehicles. The purpose of the sample collection was to find out whether the content of the important oxygenate and aromatics in the gasoline were in normal concentration ranges. The samples were sent to the Air Resources Board for chemical analysis. The analysis was performed for four chemicals: MTBE, benzene, toluene, and *m,p*-xylene. The results of the analysis are listed in the table below. Based on the results, the mass percentage of these fuel chemicals in all the samples were within the normal range. Therefore, the fuel used to power the test vehicles for this study should not have an above-normal impact on the air measurements of these chemicals inside or just outside the vehicles.

Test Vehicle Fuel Content Analysis  
(Mass %)

City	Vehicle	Sample date	MTBE	Benzene	Toluene	<i>m,p</i> -Xylene
Sacramento	Caprice	9/8/1997	11.39	0.74	6.51	6.43
	Caprice	9/10/1997	10.18	0.73	7.12	5.10
	Caprice	9/12/1997	10.98	0.78	5.87	5.87
	Caprice	9/13/1997	10.65	0.76	8.46	5.91
	Taurus	9/10/1997	10.14	0.73	7.13	5.09
	Taurus	9/12/1997	10.95	0.77	5.88	5.88
	Taurus	9/13/1997	10.64	0.76	8.48	5.80
Los Angeles	Caprice	9/24/1997	11.51	0.80	6.27	6.06
	Caprice	9/26/1997	11.28	0.67	3.41	4.12
	Caprice	9/28/1997	11.28	0.66	3.45	3.94
	Caprice	9/30/1997	11.35	0.67	3.41	4.24
	Caprice	10/1/1997	11.28	0.68	3.42	4.14
	Explorer	9/26/1997	11.23	0.68	3.41	4.02
	Explorer	9/28/1997	11.30	0.67	3.44	4.19
	Explorer	9/29/1997	11.32	0.67	3.41	4.18
	Explorer	10/1/1997	11.25	0.66	3.31	4.04



## **Appendix C**

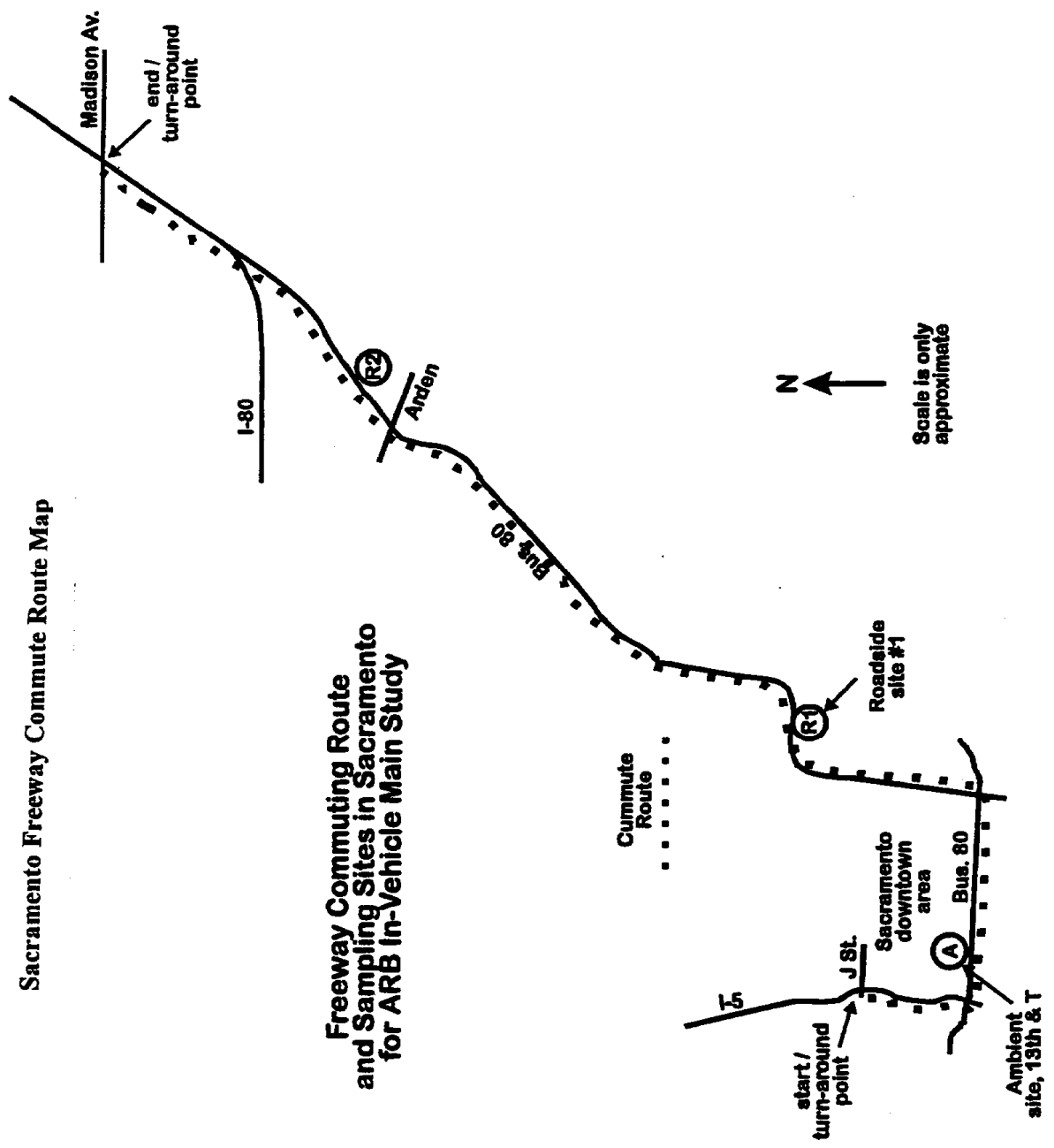
### **Commute Routes; Roadside and Ambient Site Locations**

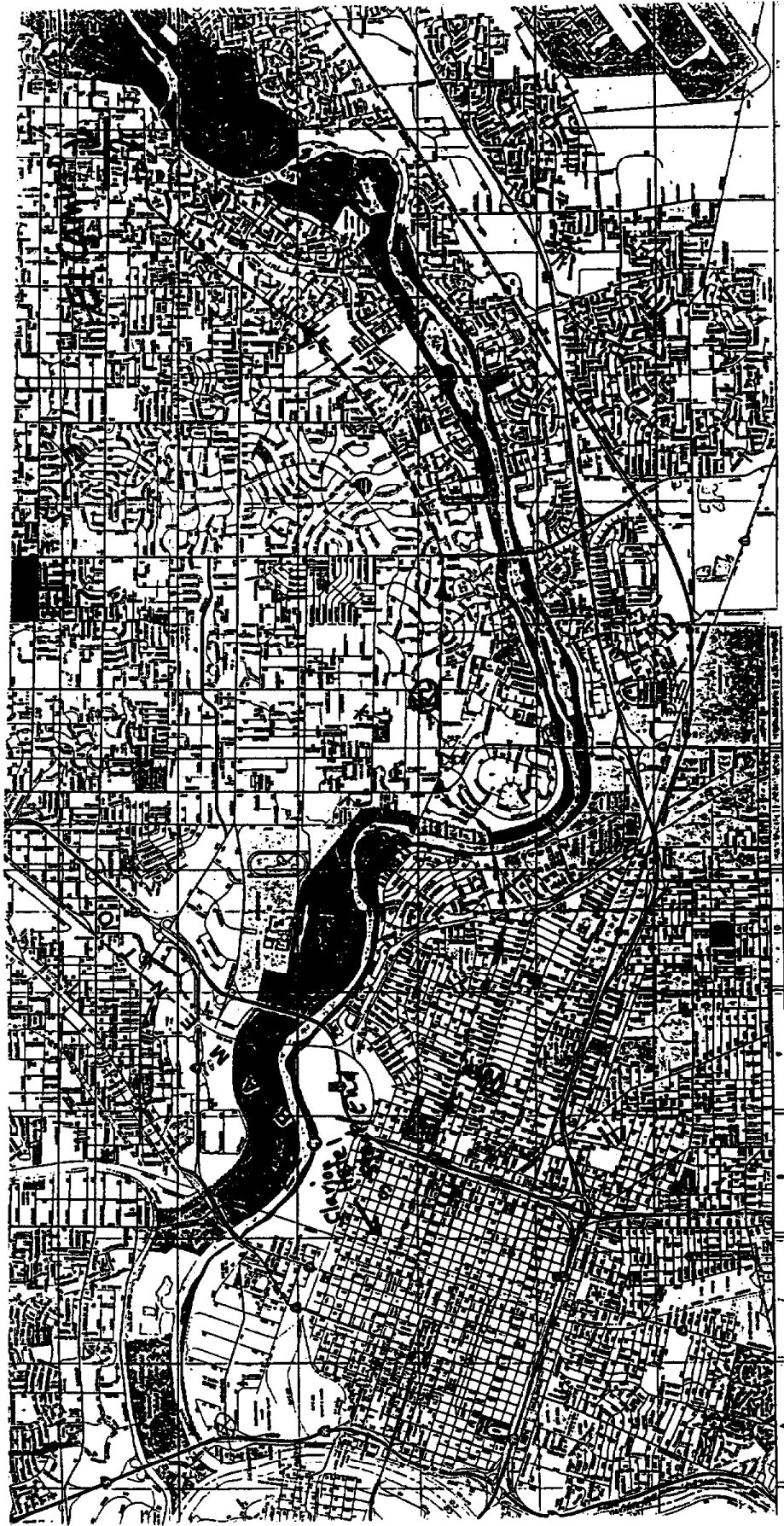
- Sacramento Freeway Commute Route Map
- Sacramento Arterial Commute Route Map
- Sacramento Rural Commute Route Map
  
- Los Angeles Freeway Commute Routes Map
- Los Angeles Arterial Commute Routes Map
  
- Roadside and Ambient Site Locations for Sacramento and Los Angeles



**Sacramento Freeway Commute Route Map**

**Freeway Commuting Route  
and Sampling Sites in Sacramento  
for ARB In-Vehicle Main Study**

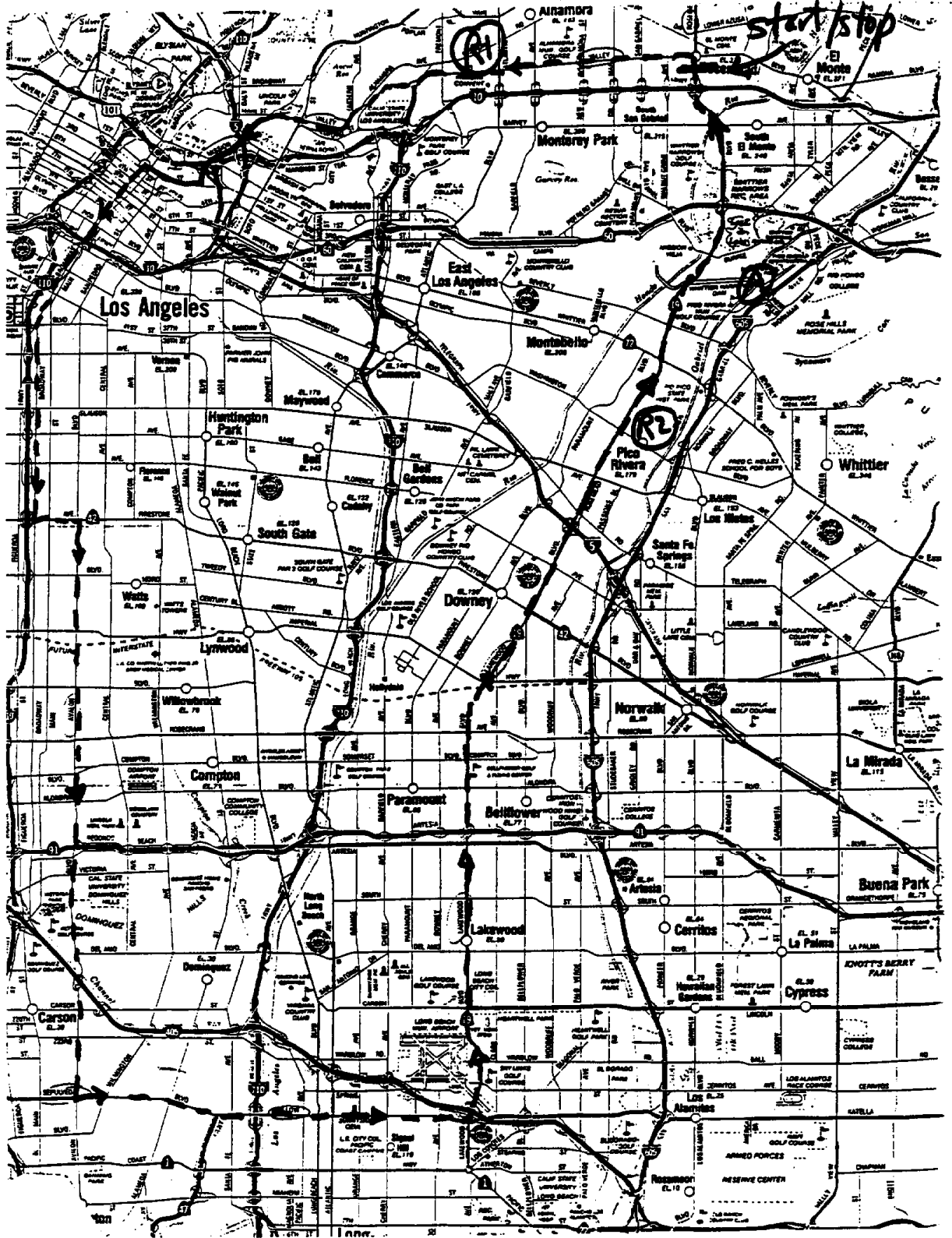




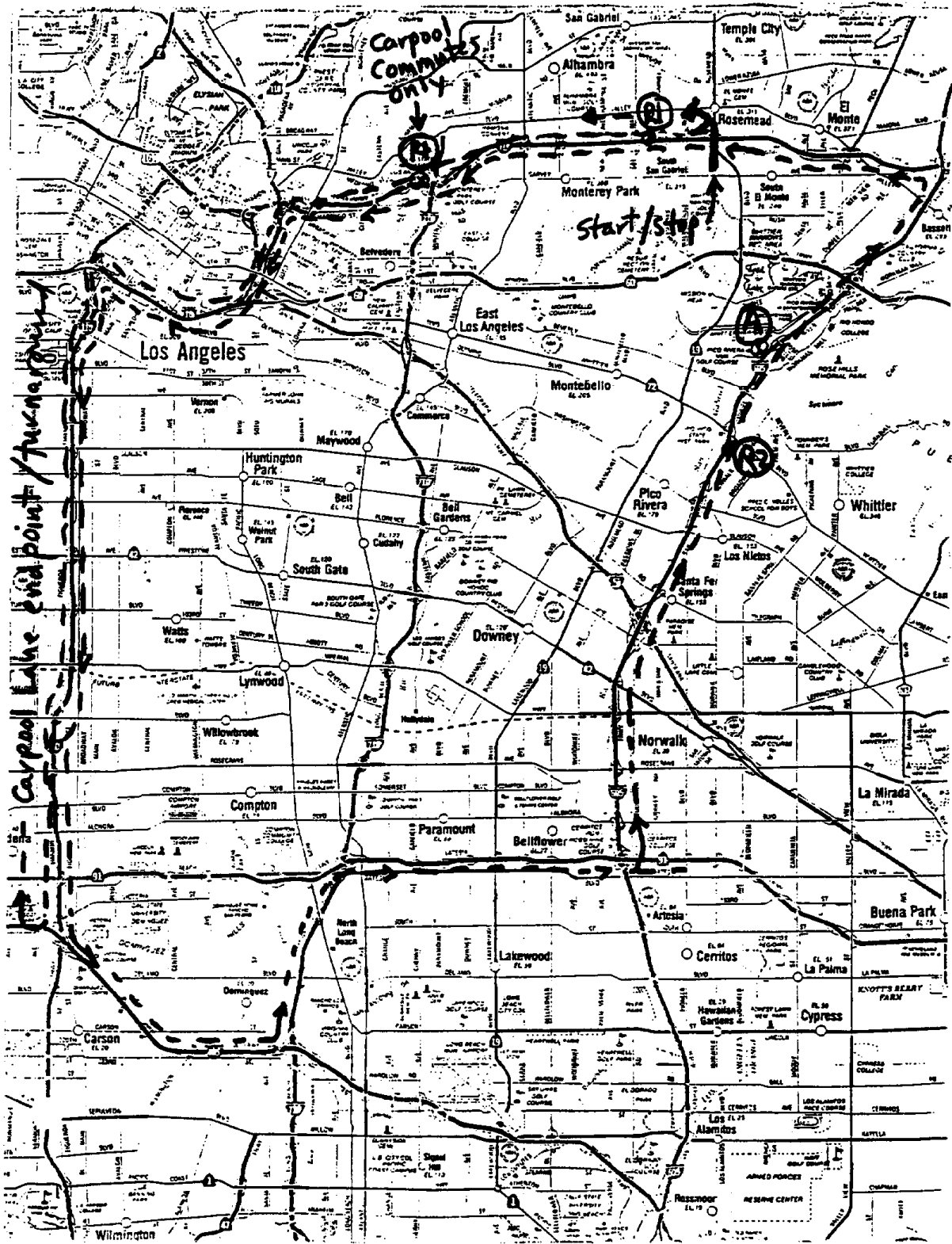
Sacramento Arterial Commute Route Map







Los Angeles Arterial Commute Routes Map



PM direction  
shown

Los Angeles Freeway Commute Routes Map

**ROADWAY and AMBIENT SAMPLING SITE LOCATIONS FOR EACH COMMUTING ROUTE**

**Sacramento - Freeway Roadside sites:**

1. R1- (same as Pilot Study R1) located on the south side of Bus. 80 freeway, approx. 2/3's of the distance northbound from the A St. overpass to the railroad bridge overpass, approx. 15 feet from the edge of the roadway.
2. R2- (same as Pilot Study R3) located on the south side of Bus. 80 freeway, between Auburn Ave. and the freeway, approx. 2/3's of the distance northbound from the Marconi overpass to the (non-connecting) intersection of Howe Ave. and Bus. 80, approx. 15 feet from the edge of the roadway.

**Sacramento - Arterial Roadside sites:**

1. R1- Located at 38<sup>th</sup> and J Street. In front of NOVA Care Medical Building - 3800 J Street. Approximately 2 ft from street on south side.
2. R2- Located in the 2300 block of Fair Oaks Blvd. across from Kaiser Permanente Medical Offices sign. Located on traffic island approximately 4 ft from road on north side..

**Sacramento (Davis) - Rural Roadside sites:**

1. R1 - Located on east side of SR 95 at fire station, approximately 15 ft from road.
2. R2 - Located on west side of SR 98 approximately 1/4 to 1/3 mile south of SR 29, approximately 15 ft from road.

**Sacramento - Ambient Site (same for arterial, school bus and freeway tests):**

ARB 13th and T St. monitoring site (A on map)

**Los Angeles- Freeway tests - Roadway sites:**

1. R1- On I-10 W Between San Gabriel Blvd. and Delmar Av. Adjacent to call box 10-257
2. R2- On I-605 N at Whittier Blvd. , just past the exit ramp off of I-605 N to Whittier Blvd.

**Los Angeles Carpool tests - Roadway sites:**

1. R1- Same as above.
2. R2- On I-10 W just past the I-710 exit, adjacent to call box 10-213.

**Los Angeles Arterial tests - Roadway sites:**

1. R1 - Located at 1749 Valley Blvd. near intersection of Valley and Campbell. Approximately 3 ft from road between sidewalk and street on north side of Valley Blvd.
2. R2- Located at 7246 Rosemead Blvd., in Pico Rivera, in front of Colonial Gardens Nursing Home, approximately 8 ft from street on east side of Rosemead Blvd.

**Los Angeles - Ambient Site (same for arterial, carpool and freeway tests):**

Pico Rivera South Coast monitoring site (A on map) - 3713 San Gabriel River Parkway.

## **Appendix D**

### **Comparison of Study PM<sub>2.5</sub> Samplers with EPA Reference Method**

- Comparison Study Report
- Graphical Comparison of RTI vs EPA FRM PM<sub>2.5</sub> Sampler Data
- RTI PM<sub>2.5</sub> Inlet Comparison with EPA PM<sub>2.5</sub> Federal Reference Method Requirements



August 29, 1997

Peggy Jenkins, Manager  
Indoor Exposure Assessment Section  
Research Division  
California Air Resources Board  
2020 L Street  
Sacramento, CA 95814  
ph. 916-323-1504  
FAX 916-322-4357

Peggy,

Attached is the data and a brief summary report for the leak test/field evaluation of the eight refurbished PM<sub>2.5</sub> inlets that were used in the Pilot Study. We revised the manual leak test procedure, showed that all inlets passed the test, and (more importantly) demonstrated an excellent collocated precision and accuracy under field conditions.

The revised leak test procedure uses a modified pump that applies a maximum of 12 inches of water across the inlet (rather than running the pump uncontrolled at ~3 inches of Hg). The normal pressure drop across the filter is only 2 to 3 inches of water. Adding too much vacuum potentially can distort the internal seals and was not a realistic test. The procedure has been added to the Field Operations manual.

We followed the experimental plan FAXed earlier, using collocated field exposures for 4 and 8 hour periods. The results are described in the summary. The test also demonstrated the performance of the new 4 LPM pumps and flow controllers to be used in the Main Study.

Sincerely,



Charles E. Rodes, PhD  
Senior Research Environmental Engineer  
Center for Engineering and Environmental Technology

cc: Steve Hui, ARB  
Linda Sheldon, RTI

## Summary of Results PM<sub>2.5</sub> MSP Inlet Leak Tests Prior to the ARB In-Vehicle Main Study

The sample flow and concentration results for the leak test field evaluation of the eight 4 LPM PM<sub>2.5</sub> MSP inlets are summarized in the attached tables. The first table summarizes the results of the (revised) leak tests and the flow control during the 4 hour and 8 hour test periods. The second table describes the filter collections and mass concentrations, and provide comparison data showing collocated PM<sub>2.5</sub> reference impactors operated simultaneously for the same period using EPA samplers. Salient Observations and Recommendations for the Main Study follow:

### Flowrate Data

- Observation: All inlets were observed to have visibly appropriate sealing surfaces and subsequently *all passed the leak test* procedure applied to every inlet prior to being used in the field sampling.

Recommendation: The inlets seal adequately and the revised leak test is acceptable.

- Observation: All mean flowrates were well within 5% of the nominal 4.0 LPM inlet flowrate.

Recommendation: Flow control was acceptable.

- Observation: The pump stopped pre-maturely on 1 of 16 samples, traced to an internal set-screw loosening on the motor shaft.

Recommendation: Check the internal set-screws on all Main Study pumps prior to shipment {Done}

### Mass Collection Data

- Observations: For the 6 acceptable filter samples for the 4-hour collocated inlet field comparison, the mean concentration was 10.9  $\mu\text{g}/\text{m}^3$ , the standard deviation was  $\pm 2.3 \mu\text{g}/\text{m}^3$ , and the coefficient of variation was 21.0 %. For the 3 EPA samplers operating at the same time, the mean concentration was 12.8  $\mu\text{g}/\text{m}^3$ , the standard deviation was  $\pm 1.3 \mu\text{g}/\text{m}^3$ , and the coefficient of variation was 10.0 %. The EPA sampler operated at 16.67 LPM. The MSP results are excellent, considering the extremely low ambient concentration level encountered during the testing (even lower than was observed in Sacramento during the Pilot Study). The MSP standard deviation was only 1  $\mu\text{g}/\text{m}^3$  poorer than the much higher flowrate EPA samplers. Assuming the EPA samplers were correct, the MSP accuracies were excellent.

Recommendation: The modified MSP inlets are acceptable for use in the Main Study.

- Observation: Two of the sampled filters (and one of the field blanks) were visibly contaminated with large black fibers on the back sides of the filters. This suggested that the filters picked up material from contact with other surfaces. The most obvious source of the fibers was the Mettler balance brush used to sweep clean debris from the balance pan prior to weighings.

Recommendation: Clean room pressurized air canisters will be used during weighings and inlet preparation to blow (clean) the balance pan and the inlet filter support screens to minimize contact contamination.

- Observation: For the 7 acceptable filter samples for the 8-hour collocated inlet comparison, the mean concentration was  $16.3 \mu\text{g}/\text{m}^3$ , the standard deviation was  $\pm 1.5 \mu\text{g}/\text{m}^3$ , and the coefficient of variation was 9.0 %. For the 2 EPA samplers operating at the same time (one failed to operate properly), the mean concentration was  $15.2 \mu\text{g}/\text{m}^3$ , the standard deviation was  $\pm 1.0 \mu\text{g}/\text{m}^3$ , and the coefficient of variation was 6.6 %. The larger total collection averaging  $31 \mu\text{g}$  significantly improved the precision. The MSP standard deviation was only  $0.5 \mu\text{g}/\text{m}^3$  poorer than the much higher flowrate EPA samplers. Assuming the EPA samplers were correct, the MSP accuracies were excellent.

Recommendation: The modified MSP inlets are acceptable for use in the Main Study.

- Observation: Incorporating the filter blank weight changes appeared to bring the MSP concentration data almost exactly in agreement with the EPA reference samplers.

Recommendation: The mean field blank changes should be incorporated into a correction of the filter tare weights (as applied during the Pilot Study), if the corrections are greater than  $2 \mu\text{g}$ .

C. Rodes, RTI, 8/25/97

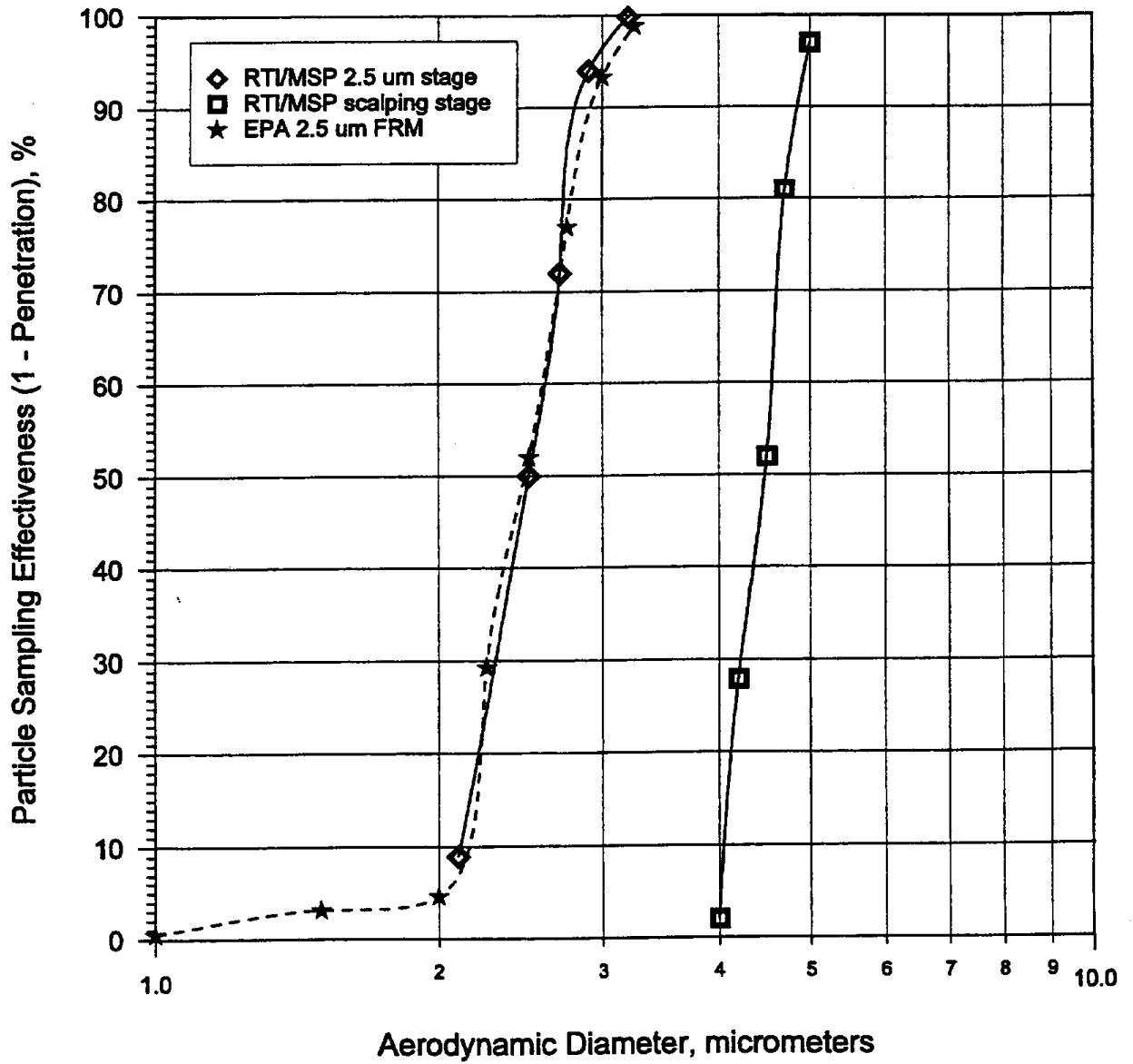


ARB In-Vehicle Exposure Study												Flowrate Data			
Leak Test - Reproducibility Evaluation of 4.0 LPM MSP PM2.5 Inlets															
8/22/97															
Date	Nominal Test	Inlet ID#	Filter ID#	Passed Leak Test?	Logger ID#	Start Time	End Time	Elapsed Time, min.	Start Magn.	Start Flow, LPM	End Magn.	End Flow, LPM	Mean Flow, LPM	Sampled Volume, M3	Comments
1	18-Aug 4 hr	1	ES01	YES	32688	11:46	13:50	244	4.85	4.01	4.45	3.83	3.92	0.956	Flow OK
2	18-Aug 4 hr	2	ES02	YES	28111	11:46	13:50	244	4.85	4.01	4.45	3.83	3.92	0.956	Flow OK
3	18-Aug 4 hr	3	ES03	YES	32739	11:46	13:50	244	4.85	4.01	4.75	3.96	3.99	0.972	Flow OK
4	18-Aug 4 hr	4	ES04	YES	28747	11:46	13:50	244	4.85	4.01	4.65	3.92	3.97	0.967	Flow OK
5	18-Aug 4 hr	5	ES05	YES	32664	11:46	13:50	244	4.85	4.01	4.70	3.94	3.98	0.970	Flow OK
6	18-Aug 4 hr	6	ES06	YES	28323	11:46	13:50	244	4.85	4.01	4.55	3.87	3.94	0.961	Flow OK
7	18-Aug 4 hr	7	ES07	YES	32667	11:46	13:50	244	4.85	4.01	4.80	3.99	4.00	0.976	Flow OK
8	18-Aug 4 hr	8	ES08	YES	28172	11:46	13:50	244	4.85	4.01	4.55	3.87	3.94	0.961	Flow OK
		Fld. blink	ES09	na											
		Fld. blink	ES10	na											
1	19-Aug 8 hr	1	ES11	YES	32688	9:04	5:10	486	4.85	4.01	4.70	3.94	3.98	1.932	Flow OK
2	19-Aug 8 hr	2	ES12	YES	28111	9:04	5:10	486	4.85	4.01	4.50	3.85	3.93	1.910	Flow OK
3	19-Aug 8 hr	3	ES13	YES	32739	9:04	5:10	486	4.85	4.01	4.70	3.94	3.98	1.932	Flow OK
4	19-Aug 8 hr	4	ES14	YES	28747	9:04	5:10	400	4.85	4.01	0.00	0.00	void	void	pump stopped
5	19-Aug 8 hr	5	ES15	YES	32664	9:04	5:10	486	4.85	4.01	4.65	3.92	3.97	1.927	Flow OK
6	19-Aug 8 hr	6	ES16	YES	28323	9:04	5:10	486	4.85	4.01	4.65	3.92	3.97	1.927	Flow OK
7	19-Aug 8 hr	7	ES17	YES	32667	9:04	5:10	486	4.85	4.01	4.65	3.92	3.97	1.927	Flow OK
8	19-Aug 8 hr	8	ES18	YES	28172	9:04	5:10	486	4.85	4.01	4.60	3.90	3.96	1.922	Flow OK
		Fld. blink	ES19	na											
		Fld. blink	ES20	na											
												Tests Conducted by:			
												R. J. Newsome/C.B. Rodas			

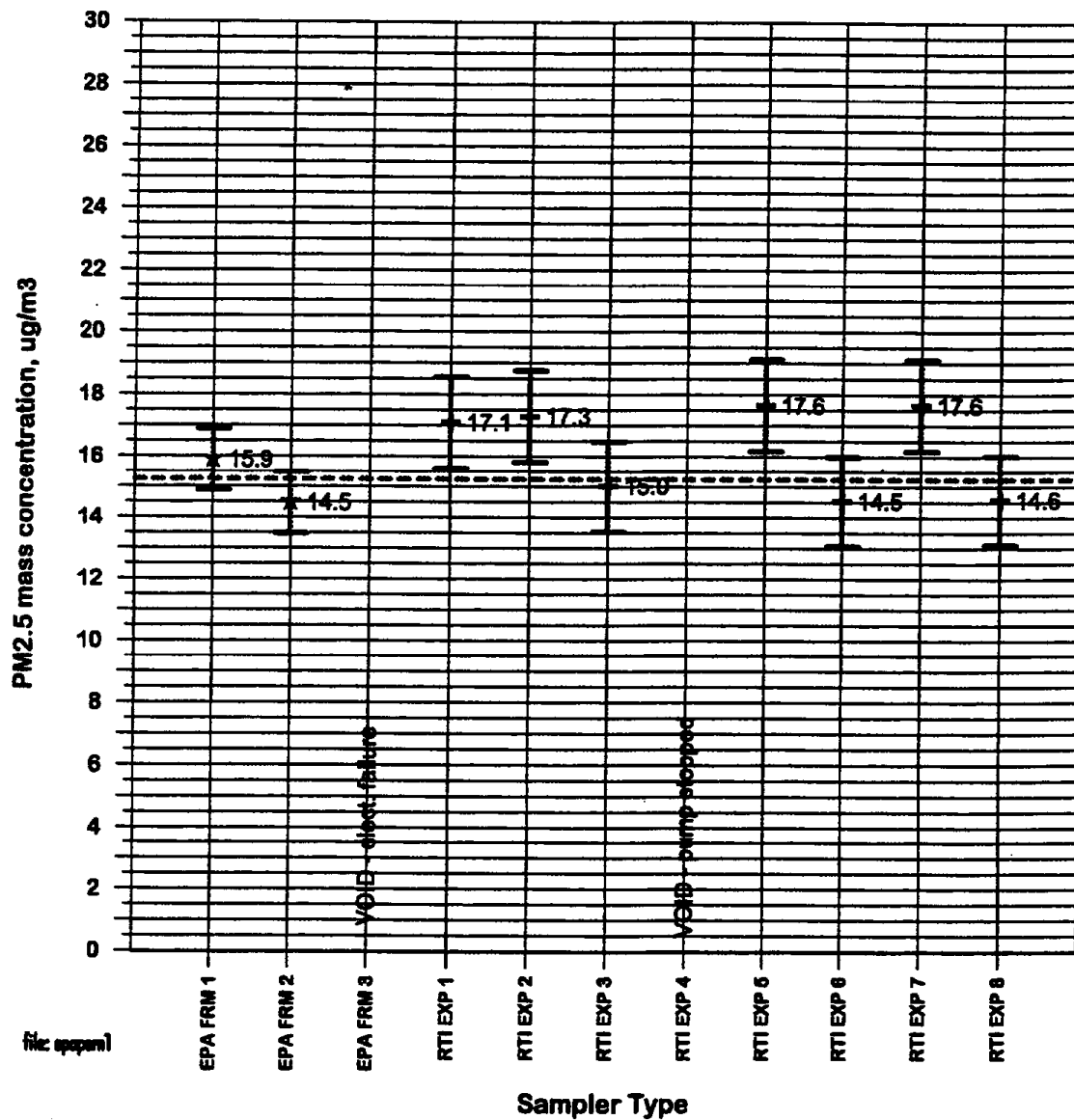
ARB In-Vehicle Exposure Study						Mass collection data			
Leak Test - Reproducibility Evaluation of 4.0 LPM MSP PM2.5 Inlets									
8/22/97									
	Date	Filter ID#	Filter Pre-wt. gm.	Filter Post-wt. gm.	Collection. ug	Sampled Volume. m3	Sampled Conc., ug/m3	Comments	EPA Data. ug/m3
1	18-Aug	ES01	0.110995	0.111008	13	0.956	13.59	Sample OK	14.25
2	18-Aug	ES02	0.105320	0.105330	10	0.956	10.46	Sample OK	11.75
3	18-Aug	ES03	0.112851	0.112863	12	0.972	12.34	Sample OK	12.50
4	18-Aug	ES04	0.112694	0.112702	8	0.967	8.27	Sample OK	
5	18-Aug	ES05	0.104335	0.104356	21	0.970	21.65	fibers on filter back	
6	18-Aug	ES06	0.101605	0.101623	18	0.961	18.72	fibers on filter back	
7	18-Aug	ES07	0.100209	0.100217	8	0.976	8.20	Sample OK	
8	18-Aug	ES08	0.108744	0.108756	12	0.961	12.48	Sample OK	
	18-Aug	ES09	0.110519	0.110529	10		void	fibers on filter back	
	18-Aug	ES10	0.107874	0.107872	-2		-2.07	equiv. collection	
Notes:						n:	6		3
1. Shaded area concentrations VOID: fiber on back of filter						mean:	10.89		12.83
2. Statistics computed w/o VOIDs (ES05 & ES06)						std. dev.:	2.29		1.28
3. EPA impactor operated for same time interval, but at 16.67 LPM						coef. var., %:	21.04		10.00
						max:	13.59		14.25
						min:	8.20		11.75
1	19-Aug	ES11	0.106522	0.106555	33	1.932	17.08	Sample OK	15.88
2	19-Aug	ES12	0.108068	0.108101	33	1.910	17.28	Sample OK	14.47
3	19-Aug	ES13	0.097867	0.097896	29	1.932	15.01	Sample OK	void
4	19-Aug	ES14	0.098262	0.098288	26	void	void	pump stopped	
5	19-Aug	ES15	0.102874	0.102908	34	1.927	17.64	Sample OK	
6	19-Aug	ES16	0.104141	0.104169	28	1.927	14.53	Sample OK	
7	19-Aug	ES17	0.101390	0.101424	34	1.927	17.64	Sample OK	
8	19-Aug	ES18	0.108281	0.108309	28	1.922	14.57	Sample OK	
	19-Aug	ES19	0.114805	0.114807	2		1.04	equiv. collection	
	19-Aug	ES20	0.117463	0.117465	2		1.04	equiv. collection	
						n:	7		2
						mean:	16.25		15.18
						std. dev.:	1.47		1.00
						coef. var., %:	9.04		6.57
						max:	17.64		15.88
						min:	14.53		14.47
Percent Data Capture (2 days): 94 %									

# Particle Sampling PM2.5 Scalper and Primary Impactor Cutpoints for RTI Exposure Sampling Systems

Data for MSP 2.0 lpm PEM w/ Scalping Stage from Univ. of Minnesota, 8/95 - V. Marple



### Comparison of PM2.5 PEM's with EPA FRM PM2.5 Samplers at RTI RTP Field Site





## **Appendix E**


### **Gelman Teflo Filter Background Metals' Analyses**

- RTI Laboratory Report - ICP/MS Analyses for Background Elemental Analyses of ARB Study Gelman Teflo® Filters



Memorandum

To: Dr. Charles Rodes

From: Peter M. Grohse,   
Program Manager, Trace Metals Analyses

Subject: Analyses of Blank Teflo™ Filters

Attached are the trace metal analytical results for 10 blank Teflo™ filters. Procedures conformed to your memorandum accompanying the samples. Please call me if there are any questions at X6897.



## **Elemental Background Levels of Teflo Filters by ICP-MS**

A brief summary of the sample preparation and analysis of the Teflo Filters is summarized below.

### *Sample Preparation*

1. Filters were separated from their outside plastic rings with tweezers provided and placed in acid washed 15 mL centrifuge tubes.
2. 3 mLs of 50 % doubly distilled Ultrex Nitric Acid was added to each centrifuge tube (ten samples, two blanks, two blank spikes)
3. Spikes were added and the samples were mixed and microwaved using the following program: 1 min. 50 % power; 30 sec. at 65 % power and 15 sec. at 75 % power
4. Samples were allowed to cool, Internal Standard added and brought up to 14 mL total volume.

### *Sample Analysis*

5. Calibration standards were prepared by serial dilution of a 10 ppm multi-element standard.
6. Internal standards were added to blanks and all calibration standards. The internal standard level was 5 ng/mL for Sc, Y, In, Bi. The instrument used interpolation to correct for drift.
7. Instrument was tuned and samples analyzed following ICP-MS SOP.

### *Results*

8. Detection limits were calculated as 3 times the standard deviation of 6 blank analyses.
9. Precision and accuracy were calculated by a duplicate analysis of the two blank spikes. Total of N=4 for each element. Total spike amount was 100 ng. All recoveries were between 87% and 92%.

**Analytical Results-Filter Analysis**

<b>Filter #</b>	<b>Cr</b>	<b>Mn</b>	<b>Ni</b>	<b>As</b>	<b>Cd</b>	<b>Pb</b>
1	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng
2	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng
3	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng
4	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng
5	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng
6	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng
7	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng
8	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng
9	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng
10	< 0.4 ng	< 1 ng	< 2 ng	< 0.06 ng	< 0.2 ng	< 0.7 ng

**Detection Limits, QC for Filter Analysis**

	Cr	Mn	Ni	As	Cd	Pb
Detection Limits	0.4 ng 0.008 ng/m <sup>3</sup>	1 ng 0.02 ng/m <sup>3</sup>	2 ng 0.04 ng/m <sup>3</sup>	0.06 ng 0.001 ng/m <sup>3</sup>	0.2 ng 0.003 ng/m <sup>3</sup>	0.7 ng 0.01 ng/m <sup>3</sup>
Blank Spike	0.092 µg +/- 0.001	0.087 µg +/- 0.0004	0.091 µg +/- 0.0003	0.091 µg +/- 0.0005	0.092 µg +/- 0.0004	0.092 µg +/- 0.0006
Spike Amt	0.100 µg	0.100 µg	0.100 µg	0.100 µg	0.100 µg	0.100 µg
% Recovery	92	87	91	91	92	92

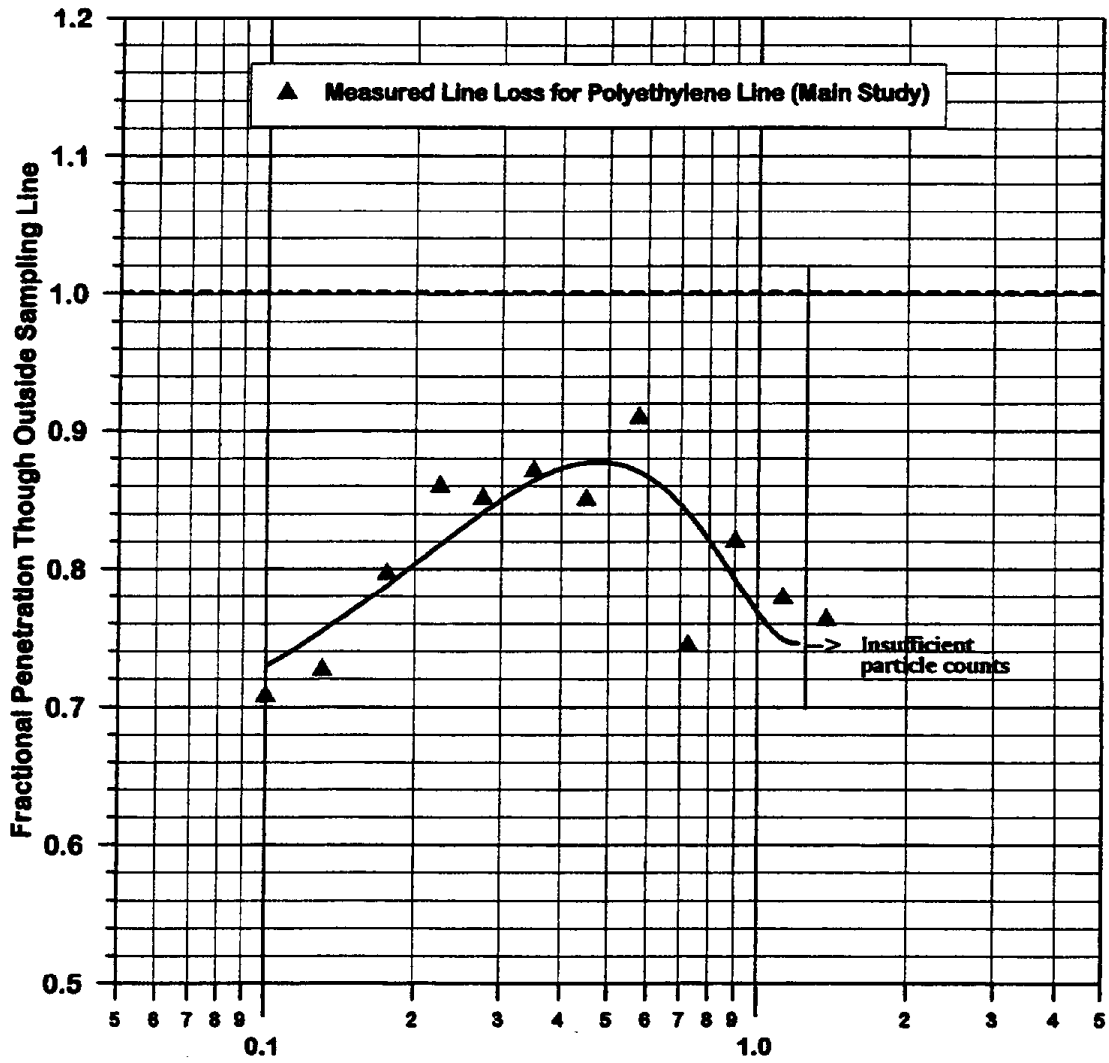
## **Appendix F**

### **Outside Inlet Line Particle Loss Data; LAS-X Calibration Data**

- **Outside Sampling Line Particle Loss LAS-X Data**
- **LAS-X Bin Calibration Data - Aerosol Dynamics**
- **California Ambient and Vehicular Particle Density Data - Aerosol Dynamics**
- **Normalized Number Concentration Version of Figure 4-16**



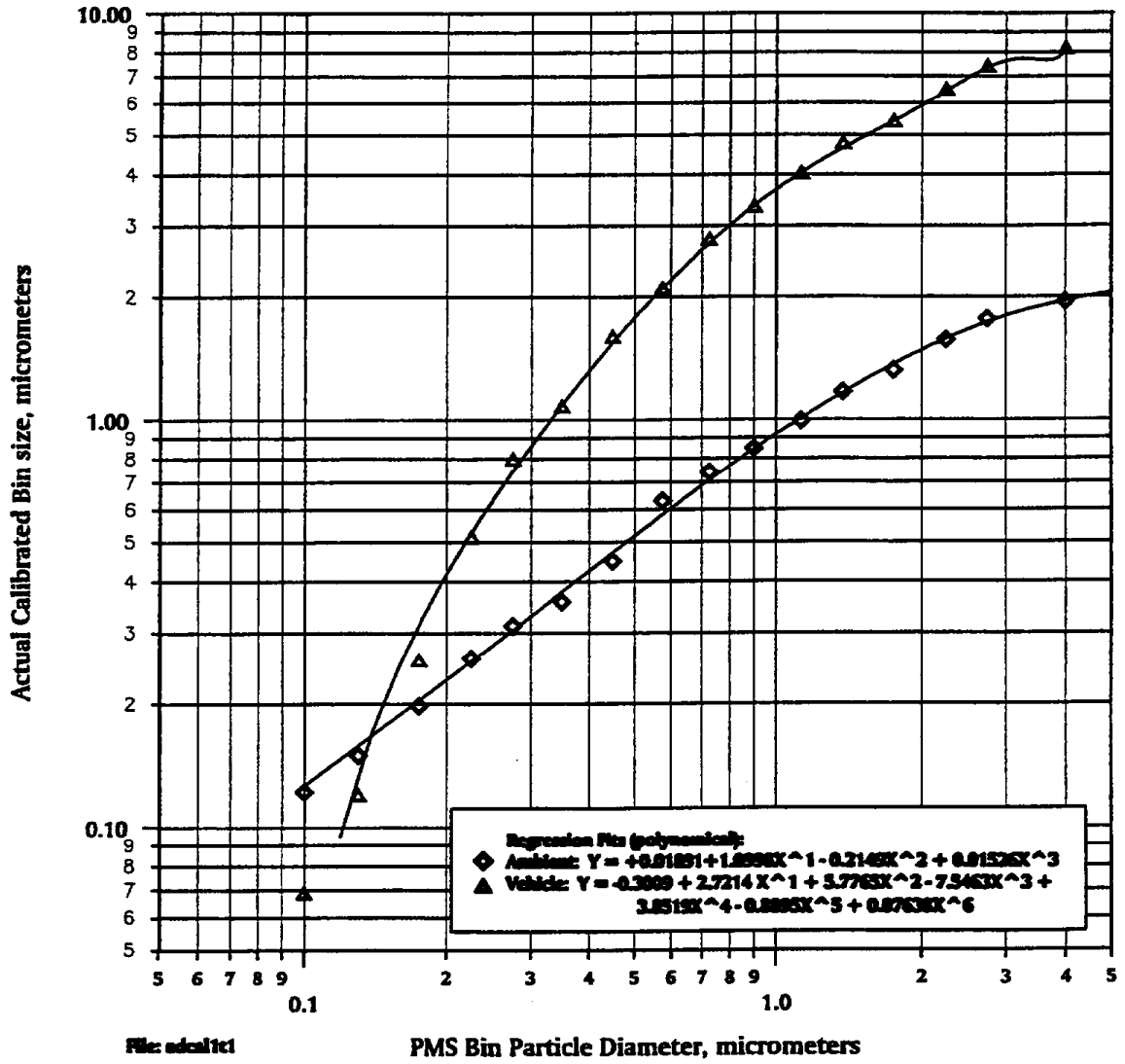
### In-Vehicle Study Outside Sampling Line Penetration by Particle Size



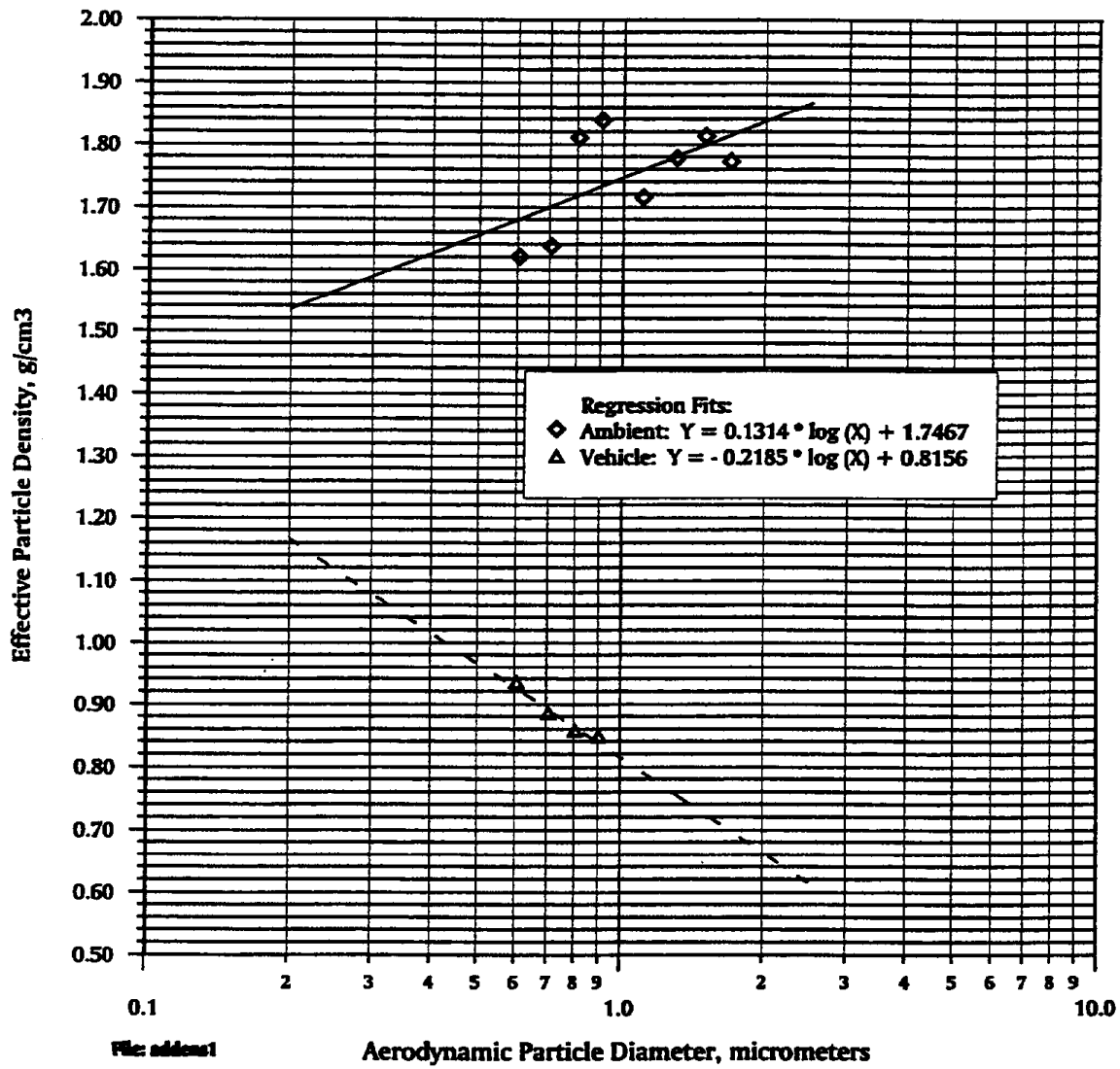
file: msline1

Mean LAS-X Particle Bin Size, micrometers

## Aerosol Dynamics Calibration of RTI LAS-X Using California Ambient and Vehicular Aerosols



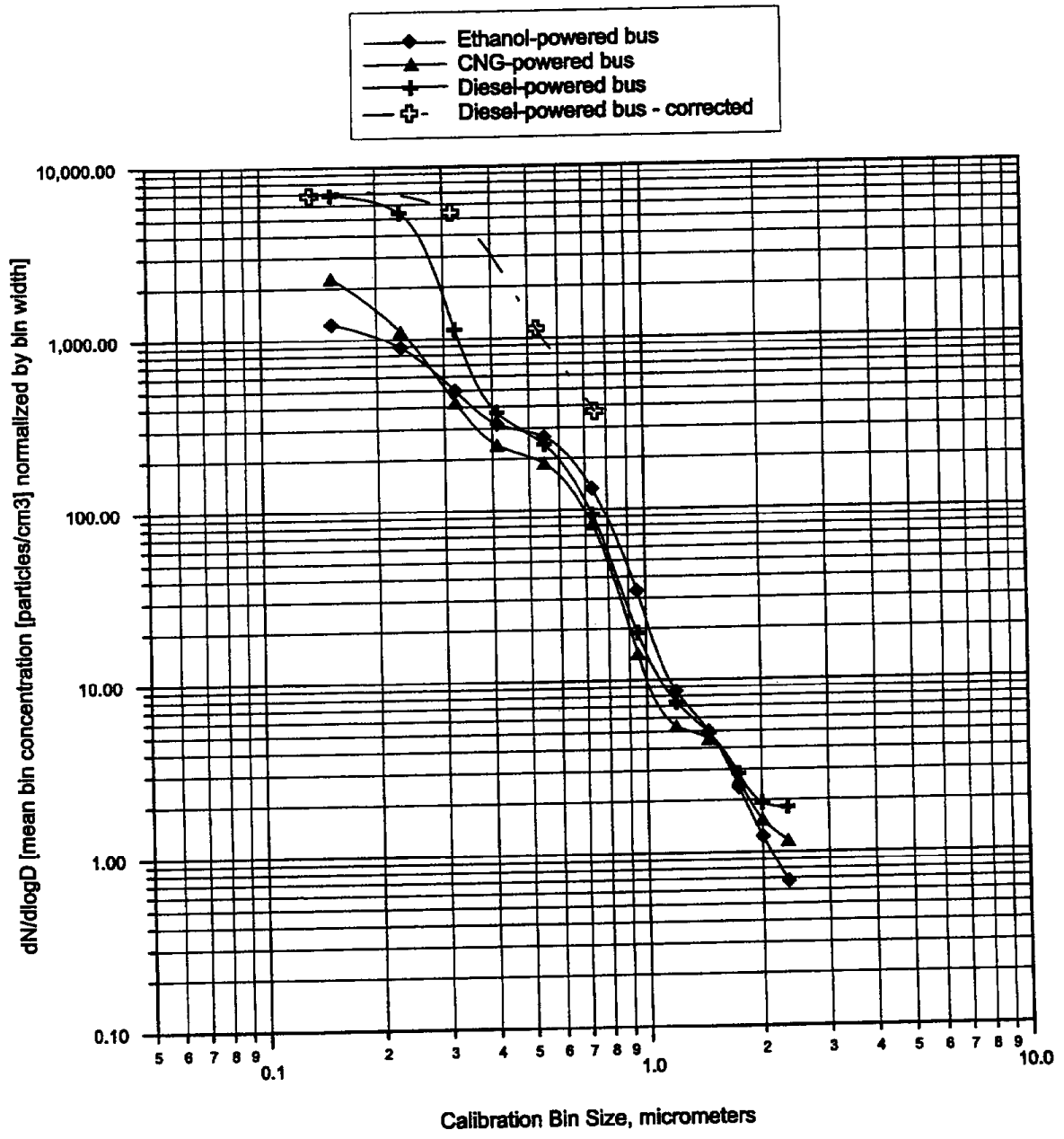
## Aerosol Dynamics Estimation of Particle Densities by Size Using California Ambient and Vehicular Aerosols





# Normalized Version of Figure 4-16: Particle Number Concentration Size Distribution

Commute #17: 9/27/97 PM, ANR



file: szdisn3a

# Sierra Research Notes

## Sacramento Caprice Data

<u>Date</u>	<u>Trip</u>	<u>Filename</u>	<u>Driver</u>	<u>Start</u>	<u>End</u>	<u>Time</u>	<u>Odometer</u>
09/09/97	FNRH	09090.prn	FDG	09:05	56951.2	11:08	57054.5
09/09/97	FNRH	09092.prn	JML	12:05	57058.8	17:00	57161.7
09/10/97	FRH	09102.prn	JML	05:50	57161.7	10:00	57245.0
09/10/97	FRH	09105&6.prn	FDG	15:58	57245.7	18:00	57301.2
09/11/97	FRH	09111.prn	FDG	06:50	57305.0	08:51	57393.0
09/11/97	FRH	09113.prn	JML	15:59	57394.3	16:27	57407.8
inverter dies, park in lot to repair, no lasx or bc data in second file.							
09/11/97	FRH	09114.prn	JML	16:47	57407.8	18:00	57447.7
09/12/97	AR	0912.prn	RLH	05:30	57449.6	09:04	57498.0
09/12/97	AR	091210.prn	FDG	16:00	57541.3	18:00	57590.0
09/13/97	Rural	09133.prn	FDG	14:02	57624.8	16:03	57731.0
09/13/97	AER	09134.prn	FDG	16:30		16:50	
09/15/97	AR	09152.prn	RLH	05:47	57777.4	08:47	57827.4
09/15/97	AR	09155.prn	JML	16:00	57840.6	17:59	57884.9
09/16/97	SB	09161.prn	DM	07:45	57889.5	09:45	57931.5
09/16/97	SB	09165.prn	DM	13:45	57945.2	15:46	57971.9

### Caprice Notes

09/09/97 PM: diesel truck brake lockup ~15:10-15:15.

Odo 57058.8 start - 57153.2 end

09/12/97 Sacto PM AR/hi

#### second description

2614 emergency vehicle

2834 construction dust

5681 emergency vehicle

5914 construction dust

09/13/97 Rural drive by Davis

start 12:51:08 location Clarion odo 57,599.9

end 13:13:17 Davis>, 1st +C odo 57,615.8

15:33 following LDV but marked as HDD - made correction later (right after we turned into Rd 31).

09/15/97

06:15:13 start time

06:16:12

sec 6379 lot of smoke from HDD bus, sampling outside, confined space, 2 lanes each direction, trees on both sides + overhead.

sec 6839 following '40-'50 vintage Plymouth, LDV smoker, blue smoke, smell.

MRP125 lic. , sampling outside, before and after Morse (st?)

09/15/97 Sacto PM AR/lo

second description

217 construction delay - no visible dust  
3193 construction delay - dust visible  
5805 tar/oil smoke  
6519 construction delay - dust visible

**September 16, 1997**

**School Bus Route**

Some average statistics for Urbanized school bus driving patterns based on report by Valley Research titled, 'Study of the Driving Patterns of Transit Buses and School Buses Using Instrumented Chase Cars', April 1995.

37 minutes of idling per 2 hours of driving.  
4 service stops every 30 minutes.  
21 idling events.  
17.5 mph average trip speed.  
4.8 minutes of speed greater than 50 mph per 2 hour drive.

UCD 30' diesel school bus, engine made by International, chasis made by Carpenter height = 11'2", seats 28, automatic transmission, wheel chair lift in rear right side.

Licence E 404006

UC Davis 54102

S1800

Driver: Meredith Armstrong, Feb 95, 2.5 years

3 windows on each side halfway down

Sampler on the fourth row, left side

Sample line out drivers window

AM Caprice

Driver: Dwight

Navigator: John

Start Odometer: 57902.5

Target switch new meanings:

0 = on route

1 = idle by school

2 = Service stop idle

3 = travel from school to begining of route (green highlight)

end odometer: 57931.5

Filename: 09161.prn

AM Bus

Passengers: Randy, Don, Frank, and Steve Hui.

Weather: Clear, cool ~65 deg. F

Caprice leads the bus.

Bus Odometer: 107439.8 @ 7:45 am

07:45 Start sample, bus idling in front of Abe Lincoln School  
07:46 Other bus pulls away.  
07:47 Idle at curb, door open  
07:50 Smell of diesel in front seat area. Vinyl seats, rubber floor mats.  
07:53 advance 50'  
07:55 many students present, increased veh traffic, still idling with door open, two other buses present and both are idling.  
07:56 another bus departs after 4 minutes.  
08:10 level of activity declining, still a few drop offs occurring  
08:13 Start route, south on Glenmore.  
08:14:10 R on Ellenwood  
08:14:52 L on Routier  
08:16:24 R on Old Placerville  
08:18:08 R on Bradshaw  
08:19:33 R on Business Park Dr.  
08:22:14 Stop for 1 minute by Fite Cir.  
08:23:14 Resume drive  
08:24:05 L on Routier  
08:25:00 R on Folsom  
08:26:12 R on Mather Feild Rd.  
08:26:38 R Mills Station  
08:28:00 Stop on Mills Station, Smell diesel  
08:30:19 L on Routier  
08:32:07 R on Lincoln Village Dr.  
08:33:20 L on Asral  
08:33:29 R on Redstone  
08:34:03 L at Lyra  
08:34:44 Stop at Burline  
08:35:40 Resume  
08:35:56 R on Burline  
08:36:25 Stop by Kobias  
08:37:25 Resume  
08:38:16 L on Granby  
08:39:38 R on Old Placerville  
08:41:05 R on Bradshaw  
08:41:58 R on Lincoln Village  
08:44:43 L on Routier  
08:45:51 R on Rockingham  
08:46:30 R on Glenmore  
08:47:30 Stop at school for 5 minutes with door open, little traffic  
08:52:39 Start repeat of route.  
08:53:37 R on Ellenwood  
08:54:34 L on Routier  
08:55:54 R on Old Placerville

08:57:00 R on Bradshaw  
09:00:15 R on Business Park Dr.  
09:01:45 R on Horn  
09:02:51 Stop for 1 minute by Fite Cir.  
09:03:51 Resume drive  
09:04:30 L on Routier  
09:05:40 R on Folsom (very dusty, road construction work)  
09:06:56 R on Mather Feild Rd.  
09:07:20 R Mills Station  
09:08:50 Stop on Mills Station, door open for all stops, strong diesel smell here  
09:09:50 Resume  
09:11:19 L on Routier  
09:13:10 R on Lincoln Village Dr.  
09:14:13 L on Asral  
09:14:26 R on Redstone  
09:14:56 L at Lyra  
09:15:35 Stop at Burline  
09:16:35 Resume  
09:17:00 R on Burline  
09:17:17 Stop by Kobias  
09:18:10 Resume  
09:18:45 L on Granby  
09:20:00 R on Goethe  
09:20:39 R on Bradshaw  
09:21:58 R on Lincoln Village  
09:24:33 L on Routier  
09:25:45 R on Rockingham  
09:26:32 R on Glenmore  
09:27:18 Stop at school  
09:28:18 Resume  
09:29:17 R on Ellenwood  
09:30:16 L on Routier  
09:31:44 R on Old Placerville  
09:33:27 R on Bradshaw (a lot of smoking trucks)  
09:36:10 R onto I50 westbound  
09:40:45 Howe Ave Exit  
09:41:13 South onto Howe  
09:42:27 R on Folsom  
09:43:00 Stop @ 7991 Folsom (Medimer Marble and Granite) idle  
09:45:00 End of data gathering - Bus odometer = 107469.2  
09:52 Start drive back to Sierra

PM Caprice

Driver: Dwight

Navigator: Lori

File: 09165.prm

PM Bus

Passengers: John and Steve Hui.

Weather: Clear, windy ~5-10 mph, ~75-80 deg. F

Caprice follows the bus.

13:45:00 Start at 7991 Folsom near Power Inn Rd.  
13:47:20 Start On Ramp from Power Inn Rd. To I50 east  
13:47:53 Start Freeway I50  
13:52:15 Start Off Ramp I50 to Bradshaw south  
13:53:00 On Bradshaw Rd.  
14:00:40 Stop at School and wait  
14:30:15 Leave School  
14:40:15 Start 1 minute service stop on Horn Rd.  
14:47:45 Start 1 minute service stop on Mills Station Rd.  
14:53:30 Start 1 minute service stop on Lyra St.  
14:55:05 Start 1 minute service stop on Burline St.  
15:05:00 Stop and idle at school  
15:14:30 Leave School  
15:24:50 Start 1 minute service stop on Horn Rd.  
15:30:25 Start 1 minute service stop on Mills Station Rd.  
15:37:15 Start 1 minute service stop on Lyra St.  
15:39:00 Start 1 minute service stop on Burline St.  
15:45:00 End data collection - Bus odometer = 107150.0

RTI In-Vehicle Study  
School Bus Route

**Start near Watt Ave. and Folsom Blvd.**

North Watt Ave.  
Enter Hwy 50 east  
Exit Bradshaw Rd.  
Left Bradshaw Rd.

**Begin Pickup Route**

Right Business Park Dr.  
Right Horn Rd.  
Stop \* 10026 Horn Rd.  
Left Routier Rd.  
Right Folsom Blvd.  
Right Matherfield Rd.  
Right Croydon Way  
Left Mills Station Rd.  
Stop \* Centennial Mobile Home Park  
Left Routier Rd.  
Right Lincoln Village Rd.  
Left Astral Dr.  
Right Redstone Dr.  
Left Lyra St.  
Right Burline St.  
Stop \* Burline St. & Lyra St.  
Cont. Burline St.  
Stop \* Burline St. & Kobias St.  
Left Granby Dr.  
Cross Old Placerville Rd.  
Right Goethe Rd.  
Right Bradshaw Rd.  
Right Lincoln Village Rd.  
Left Routier Rd.  
Right Rockingham Dr.  
Right Smithlee Dr.  
Stop \* Lincoln Elementary School  
Stand-by Idle 15 minutes

**Leave school**

Right Ellenwood Ave.  
Left Routier Rd.  
Right Old Placerville Rd.  
Right Bradshaw Rd.  
**Start pickup loop again**

## **Appendix G**

### **Sierra Navigator's Event Logs for Sacramento and LA Commutes**

- **Sacramento Commute Notes**
- **Los Angeles Commute Notes**
- **Commute Start and Stop Times**





# Sierra Research Event Log

Clock times are specified as PDT. Where shown in seconds, times are from start of data collection.

## 9/24/97 Sacramento to LA drive (DM\*)

- 9:30 leave gas station, odometer 57,988.1, added one quart of oil.
- LASX start at 12:02:28; end at 12:03:27.
- Camcorder 6 seconds ahead of other instruments.
- Zereth data file is 092497a. First file is 092497p. Second file is 092497d (time was wrong). Third file is 092497x. LASX start 14:14:21; end at 14:15:21.

## 9/25/97 am drive (FDG)

(First column shows number of seconds from start of data collection.)

- Laser not reading reliably, apparently due to rain
- 435 Two car accident on I10 just west of I605 SB\*\* turn, brief slowing
- ~600-1000 I605 SB, behind a long line of trucks
- ~723 Two car accident on I605 SB, no slowing
- Note that there is a carpool lane from about Route 72 to Route 91. WB on Route 91 there is a carpool lane.
- 3535 There is a truck scale on I405 WB just east of 110.
- I110 NB, carpool (2 or more) starts at Route 91.
- I10 EB, carpool and bus lane starts near I710

## 9/26/97 am (FDG)

(First column shows number of seconds from start of data collection.)

- Laser range finder was not operable during this run, apparently due to moisture from the previous day

---

\* Observer's initials (DM-Dwight Mitchell, FDG-Frank Di Genova, JML-John Lee, LLW-Lori Williams)

\*\* "SB" means southbound, etc.

- ~3400-4000 10-50 foot following distance behind HDD bus with heavy smoke, CA license CP38953, Bus number 100, Four Seasons Charter, phone 310-542-8834, 8V-92 turbocharged
- 3970-4470 Detour, missed turn for I10 NB segment, took Route 60 EB and then I710 NB to I10 EB.
- 4492 Resumption of driving on route.
- Inadvertantly turned off route near the end; ended the run at approximately 2 hours.

#### 9/26 am supplemental drive

- Performed supplemental return drive to staging area. Started near Griffith and Figueroa, took I110 NB near I405. Videotaped supplemental drive. Set at high air exchange rate.
- 700-900 LASX showing elevated concentration on I110 NB.

#### 9/26/97 pm (DM)

- 16:57 Distances or laser inconsistent during route (noticed at 16:57)
- 17:16 Accident; diamond lane NB I605 before Telegraph Road exit.

#### 9/26/97 pm supplemental

- supplemental run from Adam exit on I110 SB to Vagabond Inn
- Laser returns appeared somewhat sporadic during this run. Problem resolved by replacing damaged skylight filters.

#### 9/27/97 Arterial, nonrush, pm, high AER (JML)

- 14:47-14:53:20 MTA bus number 3617, dirty diesel bus

#### 9/28/97 am (FDG)

- ~760 Start following VERY dirty city bus, sootiest so far, bus number 4471, CA license plate 433957
- 1793-1900 Following old Dodge pickup, no smoke but strong gasoline smell.
- 5000 Missed left turn onto Firestone from Avalon, so turned left on Florence (later determined that the correct turn is called Manchester at Avalon; it becomes Firestone further west).
- 5561 Late in switching from ramp to arterial by about 60 sec.

**9/28/97 supplemental am run**

- Supplemental am run from Elm, EB on Valley; no videotape made due to short drive

**9/28/97 pm (FDG)**

- 5894 Following Oldsmobile burning oil for ~1 minute on I710 NB
- 6730 Following smelly, smoking tanker truck

**9/29/97 Freeway, rush, heavy duty influence, am drive (JML)**

In this drive, the observer noted carefully the locations of starts and ends for carpool lanes and used switch no. 2 to denote these as follows: 0 no carpool lane, 1 2-person minimum carpool lane, 2 3-person minimum carpool lane and 3 2 carpool lanes (one of these may be a bus lane, which was sometimes indistinguishable from a second carpool lane.)

	I605 SB*
6:48:40	@I5, start
6:53:25	turn off at Route 91
	Route 91 WB
6:54:15	Start on Route 91
7:02:00	Transition from Route 91 to I110
	I110 SB
7:17:50	Start carpool
7:38:00	End, left I110 to I10
	I10 EB
7:45:00	Start at I710 off ramp
7:54:00	End past Rosemead Blvd before turnaround at Santa Anita
	I605 SB
8:17:48	Start at I5

**9/29/97 Supplemental am freeway drive (JML)**

---

\* Southbound

8:50:30-8:57:50 Smokey Metro bus.

**9/29/97 Supplemental pm drive**

- Supplemental drive began at 190th St., 1 block west of I110 SB, near I405 interchange.

**9/30/97 Freeway, rush, carpool, am (JML)**

- Entered I10 WB at Rosemead, couldn't get into carpool lane on the first WB leg.
- 7:10 Exit I10 at Peck Road because couldn't move over in time for Santa Anita exit. Took wrong exit at Frazier and back on I10 WB at Frazier on ramp.

**9/30/97 Freeway, rush, carpool, pm (FDG)**

- 17:44:00 Entered carpool lane at Santa Anita but didn't mark that till about 17:44:35
- 17:22:30-17:25:16 stopped for slow freight train at Sepulveda and Alameda in Carson; many HDD trucks on Alameda
- 18:00:45-18:05:03 following HDD truck NB on I110, we were in right truck lane but it was mistakenly marked as ramp in dataset
- 18:06:30-18:10:26 depressed ('cut') section of I110 NB, congestion F
- 18:12:49 There was a staled vehicle and two truck in number 4 lane
- 18:16:57-18:21:50 MTA bus no 8645, Broadway NB@Venice, very dirty on acceleration
- 18:23:35-18:25:20 MTA bus 8706, very dirty

**10/1/97 Arterial, rush, a.m. (FDG)**

7:19:00-50 very dirty HDD truck

**10/1/97 Arterial, rush, p.m. (LLW)**

- 16:18:00-16:23:00 MTA bus 2737, visible emissions on acceleration
- 16:42:49 Left on Broadway, following MTA bus 9089
- 16:45:10 MTA bus 2750, emissions on acceleration
- 16:49:20 MTA bus 8331, very smokey on acceleration
- 16:51:10 MTA bus 9001, smokey on acceleration
- 16:54:05 Right on Adams
- 16:58:40 I110 on ramp at Exposition

17:16:30 MTA bus 1340, ethanol  
 17:27:19 MTA bus 4761, CNG, Route 447  
 17:50 Major congestion on Willow due to road construction @ Redondo

**10/2/97 Arterial, rush, a.m., low air-exchange, CCW (LLW)**

6:39 Switched to "Norm A/C" switch setting. Was incorrectly set to "Max" prior to this.  
 6:53 Target is cement truck, visible emissions on acceleration.  
 6:58 Target is "other diesel." Strong smell, visible emissions on acceleration.  
 7:22 Target is gasoline truck @ stoplight. Right turn (N) onto Avalon Blvd.  
 7:44:00 Target is small diesel delivery vehicle, Chevrolet 6.2L.. Smelly, but no visible emissions.  
 7:55:38 Entering depressed corridor area on 110 freeway N. (@ Slauson Ave.) Trip odom: 37.2 miles.  
 7:59:31 Exiting depressed corridor area on 110 freeway N. (1 exit before Exposition Blvd.) Trip Odom: 38.4 miles.  
 8:07 Missed left turn from Manchester onto Broadway N. Instead, turned left on Main St., left on 25th St., right on Broadway, heading N.  
 8:07:45 Target is CNG powered MTA bus #4629, route #345.  
 8:11:56 Beginning of "downtown corridor" section.  
 8:13:00 Target is ethanol powered MTA bus #1280, route # 30. Slight smoke visible on acceleration.  
 8:16:25 End of "downtown corridor" @ corner of 1st and Broadway. Trip odom: 52.1 miles.  
 8:19:44 Target is Dash Bus #73, visible smoke on acceleration.  
 8:20:36 Target is ethanol powered MTA bus #1280, route #30.  
 8:24:43 Target is diesel powered MTA bus #8624.

**10/2/97, Supplemental am drive, EB on Valley Blvd to Vagabond Inn parking lot**

8:36:20 Target is ethanol powered MTA bus #1470, route #76.

**10/2/97 pm**

- Computer crashed and was restarted during this drive  
 16:12:15-16:12:47 Following MTA bus 2931, diesel with high exhaust on left, light smoke on acceleration

- 16:22:45-16:30:04 @6.6 miles\* from Vagabond on Valley stopped for railroad crossing behind Hino medium duty diesel, very congested intersection (marked as congestion B, but should have been congestion F).
- 16:31:38-16:31:51 medium duty, U-haul
- 16:33:18 @8.6 miles, turn left at Lincoln Park onto Mission St.
- 16:38:50 @10.5 miles, turn right onto First St.
- 16:43-45 @11.6 miles, turn left onto Broadway, follow MTA bus 4637, CNG
- 16:48:12 MTA bus 2823, visible emissions on acceleration, high left exhaust
- 16:50:33 @12.7 miles, crossing Olympic, end downtown street canyon
- 16:54:00 MTA bus 4674, CNG, high left exhaust, bus route 68
- 16:59:00 odometer 59,517.0 miles
- 17:01:13 laser reading incorrectly, stop and restart it
- 17:03:35 resume driving
- 17:06:29 @mile 15.0, entering I110 SB
- 17:09:31 @15.7 miles, entering depressed section, congestion should be E, lane should be right hand truck lane
- 17:12:00 @16.9 miles, exit depressed section
- 17:14:37 @19.0 miles, left turn onto Manchester
- 17:16:47 MTA bus 2468, smokey, high left exhaust; should be marked as arterial, not ramp from about 17:15
- 17:19:37 @20 miles, right turn onto Avalon
- 17:28:14-17:29:27 school bus, 3LAX846, not full size, bus no. 19135, Collins chassis, record as "other diesel"
- 17:35-17:40 MTA bus 2338, light smoke on acceleration
- 17:45:50 @30.7 miles, left onto Sepulveda

#### 10/2/97, supplemental pm drive

- 18:12 @37.5 miles, turn onto Lakewood
- 18:50:00-18:52:16 what is recorded as HDD for about 2 min was actually LDV

#### 10/3/97 "Maximum Concentration" Drive, am

- 7:03:48 parked at gas station by Valley and Rosemead Blvds, positioned at pump #1, three car doors open
- 7:06:56 smell gasoline
- 7:08:48 start refueling, three car doors open, engine off
- 7:11:56 correct recording switch from arterial to other for the period stopped
- 7:13:59 pump shut off
- 7:14:53 start engine

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\* For this drive, the trip mileage counter was used to note various locations from start of route at Vagabond Inn.

7:20:24 windows up, drive away  
7:23 enter I10 WB  
7:27 follow other diesel (we had been following one car behind it for 1-2 miles already)  
7:28:33 corrected switch setting to middle lane from RH truck lane  
7:43 exit I10 at 101, Mission  
7:45 WB at Caesar Chavez  
7:48 following HDD MTA bus 1122, going SW on North High St., very smokey  
7:50 right on Temple  
7:51:12 left onto North Broadway  
7:51:49 (start of street canyon), SB on Broadway  
7:56 (end of street canyon) stop at Olympic  
7:57 (start of 'non street canyon section,' for comparison)  
8:01:52 left onto 30th St.  
8:03:18 left onto Main  
8:03:35 left onto 28th  
8:04:20 right onto Broadway  
8:05 paused near 23rd and Broadway waiting for bus 'target'  
8:06:35 proceeding north on Broadway, no bus targets  
8:10:45 pause for bus target near 12th  
8:11:39 following MTA bus 2083, fast idle  
8:14:53 @8th St.  
8:18:25 following MTA bus 2041, very smokey, CA plate 079241, been on target but forgot to set target switch  
8:20:09 continue, no target  
8:21:30 waiting for bus target  
8:22:11 resume target, MTA bus 2041, late on target switch, left on Sunset Blvd  
~8:24:00-8:24:30 Uphill, following MTA bus 2041, sampling outside, smokey  
8:28:30 Made right turn, then U turn on Elysian Park  
8:29:32 Right onto Marion Blvd, headed for I101  
8:32:28 left on Glendale to I101 SB  
8:34:42 entering I101 SB  
8:36:11 I110 SB  
8:38:14 passing I10 exit  
8:41:20 60-70 feet behind Honda (could not acquire HDD target)  
8:44:46 double distance  
~8:45 turned onto I105 WB  
8:48 exit I105 at Crenshaw Blvd  
8:49:20 EB on I105  
8:50:33 following other diesel  
8:51:51 ramp for I110 S  
8:53 SB on I110  
8:54:00 new target, other diesel, at 40 feet, smells  
8:56 I405 SB  
9:05 I405 SB to I710 NB



9:14:40 Artesia Blvd, 91EB  
 9:21:07 following other diesel  
 9:23:41 following at ~90 feet, lost target  
 9:25:18 "  
 9:26:03-57 end pursuit, can't follow at fixed distance  
 9:30:45 take I605 NB  
 9:32:46 smelly diesel, CA plate 2N38645  
 9:38-9:43:10 very congested section, diesel target, many diesels nearby, noticed that we  
 were recording for ramp but should be middle lane; passed disabled  
 vehicle which was the apparent cause of the slowdown  
 ~9:46-9:49:30 following 80-100 feet behind other diesel  
 9:49:49 ~50 feet behind  
 9:53 break off pursuit

### 10/3/97 "Maximum Concentration" Drive, pm

15:03:30 behind Oldsmobile idling at In and Out Burger, Rosemead and Valley Blvds  
 15:06 restarted laser and data collection after noting suspicious laser readings, now  
 reading normally  
 15:08 car ahead pulls out, target switch should have been on the entire time of our being  
 stopped  
 15:09:40 right onto Mission Drive  
 15:15:00 LDV smoker at 40-50 feet (congestion should have been D on freeway)  
 15:17:27 target at about 100 feet  
 15:20:10 go back to 40-50 feet  
 15:23:03 end pursuit of smoker, target switch got bumped off prematurely  
 15:24:27 left onto Caesar Chavez  
 - left onto Broadway  
 15:28:03 computer error message, end data collection, odometer 59,658.2 miles when  
 noticed  
 15:30:00 north on Broadway and Temple, resume data collection  
 15:31:35 enter Canyon section @odometer 59,658.4 miles  
 15:33 another computer failure, restart  
 15:36:57 restarted NB, looks ok  
 15:37:29 stop at Olympic, end of canyon section and start of comparable non-canyon  
 section  
 15:41:41 right on Adams, end of non-canyon section  
 15:43:20 left onto Flower  
 15:45:39 up ramp  
 15:46:26 begin 'cut' section just south of Exposition, ramp  
 15:47:27 restart PC  
 15:48:54 exiting cut section  
 15:50:37 road type switch was set wrong  
 15:55:30 end of cut section

16:04:11 MTA bus 2089, lost it in red light, smoker  
16:08:17 MTA bus 8442, very smokey on acceleration, left exhaust  
16:21:40 outside sample during bus acceleration, expect very high concentrations  
16:23:27 end 15 min following of bus  
16:29:46 follow cement truck at about 30 feet in slow traffic  
16:32:30 lost target  
16:34:30 same cement truck at about 60 feet, smoking on acceleration  
16:37:38 resume following at 30 feet  
16:41:52 end following of cement truck  
16:43:40 HDD at 30 feet  
16:46:39 begin following at 60 feet  
16:50:34 end following at 60 feet  
16:58:28 idling at drive thru behind Chevy van

# ARB In-Vehicle Exposure Main Study Commute Particle Sampling Start and End Times

SACRAMENTO																				
Commute Day	Date	DOW	Period	Type	Vent	Vehicle 1 (Caprice)			Vehicle 2 (Taurus)			Roadside 1			Roadside 2			Ambient		
						Start Time	End Time	Elapsed Minutes	Start Time	End Time	Elapsed Minutes	Start Time	End Time	Elapsed Minutes	Start Time	End Time	Elapsed Minutes	Start Time	End Time	Elapsed Minutes
1	9-Sep-97	Tu	AM	FNRH	Hi	9:05	11:08	2:03	9:05	11:09	2:04	9:05	11:09	2:04	9:07	11:15	2:08	9:00	11:05	2:05
2	9-Sep-97	Tu	PM	FNRH	Hi	14:05	16:05	2:00	14:05	16:05	2:00	14:05	16:05	2:00	14:05	16:05	2:00	14:05	16:05	2:00
3	10-Sep	We	AM	FRH	Hi	6:50	8:50	2:00	6:49	8:50	2:01	6:45	8:45	2:00	6:45	8:45	2:00	6:50	8:50	2:00
4	10-Sep	We	PM	FRH	Hi	15:59	17:59	2:00	15:59	17:59	2:00	16:00	18:00	2:00	16:00	18:00	2:00	16:00	18:00	2:00
5	11-Sep	Th	AM	FRH	Lo	6:50	8:51	2:01	6:49	8:51	2:02	6:50	8:50	2:00	6:50	8:50	2:00	6:50	8:50	2:00
6	11-Sep	Th	PM	FRH	Lo	15:59	18:00	2:01	15:59	18:01	2:02	16:00	18:00	2:00	16:00	18:00	2:00	16:00	18:00	2:00
7	12-Sep	Fr	AM	AR	Hi	7:04	9:04	2:00	7:04	9:04	2:00	7:05	9:05	2:00	7:05	9:05	2:00	7:05	9:05	2:00
8	12-Sep	Fr	AM	AR	Hi	16:00	18:00	2:00	15:59	18:00	2:01	16:00	18:00	2:00	16:00	18:00	2:00	16:00	18:00	2:00
9	13-Sep	Sa	midday	R	Hi	14:01	16:02	2:01	14:02	16:03	2:01	14:00	16:05	2:05	14:09	16:05	1:56			
10	15-Sep	Mo	AM	AR	Lo	6:45	8:47	2:02	6:44	8:47	2:03							6:45	8:45	2:00
11	15-Sep	Mo	AM	AR	Lo	16:00	17:59	1:59	15:59	18:00	2:01							16:00	18:00	2:00
12	16-Sep	Tu	AM	SB	Hi	7:45	9:45	2:00	7:45	9:45	2:00							7:45	9:45	2:00
13	16-Sep	Tu	AM	SB	Hi	13:45	15:45	2:00	13:45	15:45	2:00							13:44	15:44	2:00
14	25-Sep-97	Th	AM	FNRH	Hi	8:59	11:01	2:02	9:00	11:02	2:02							9:01	11:01	2:00
15	26-Sep	Fr	AM	FRH	Hi	6:31	8:30	1:59	6:29	8:29	2:00							6:30	8:30	2:00
16	26-Sep	Fr	PM	FRH	Hi	15:59	18:02	2:03	15:59	18:02	2:03							16:00	18:00	2:00
17	27-Sep	Sa	PM	ANR	Hi	13:59	16:00	2:01	13:59	16:00	2:01							14:00	16:00	2:00
18	28-Sep	Su	AM	ANR	Hi	8:59	11:00	2:01	8:59	10:59	2:00							9:00	11:00	2:00
19	28-Sep	Su	PM	FNRH	Hi	12:59	15:01	2:02	12:59	15:00	2:01							13:00	15:00	2:00
20	29-Sep	Mo	AM	FRH	Low	6:29	8:29	2:00	6:29	8:30	2:01							6:32	8:32	2:00
21	29-Sep	Mo	PM	FRH	Low	15:59	18:02	2:03	16:03	18:02	1:59							16:00	18:00	2:00
22	30-Sep	Tu	AM	FRC	Hi	6:29	8:35	2:06	6:29	8:29	2:00							6:31	8:31	2:00
23	30-Sep	Tu	PM	FRC	Hi	15:59	18:01	2:02	16:00	18:00	2:00							16:00	18:00	2:00
24	1-Oct	We	AM	AR	Low	6:29	8:30	2:01	6:29	8:29	2:00							6:30	8:30	2:00
25	1-Oct	We	PM	AR	Low	15:59	17:59	2:00	15:59	17:59	2:00							16:00	18:00	2:00
26	2-Oct	Th	AM	AR	Hi	6:29	8:30	2:01	6:29	8:30	2:01							6:30	8:30	2:00
27	2-Oct	Th	PM	AR	Hi	15:59	18:01	2:02	15:59	18:00	2:01							16:00	18:00	2:00
28	3-Oct	Fr	AM	MC	Hi	6:59	9:01	2:02										7:00	9:04	2:04
29	3-Oct	Fr	PM	MC	Hi	14:59	17:04	2:05										15:00	17:00	2:00