

Kansas City PM Characterization Study

Final Report

Appendix DD

Work Plan

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

Sponsors:

National Renewable Energy Laboratory, U.S. Department of Energy
Federal Highway Administration, U.S. Department of Transportation
STAPPA-ALAPCO Emission Inventory Improvement Program
Coordinating Research Council Inc. (Project No. E-69)

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EPA Contract No. GS 10F-0036K

October 27, 2006
Revised April 2008 by EPA staff



United States
Environmental Protection
Agency

EPA420-R-08-009
April 2008

Characterizing Exhaust Emissions from Light-Duty Gasoline Vehicles in the Kansas City Metropolitan Area

Work Plan

Prepared for:

U.S. Environmental Protection Agency

April 14, 2004

ERG No.: 0133.18.000.001

**CHARACTERIZING EXHAUST EMISSIONS FROM LIGHT-DUTY
GASOLINE VEHICLES IN THE KANSAS CITY METROPOLITAN AREA**

WORK PLAN

EPA Contract No. GS-10F-0036K

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April 14, 2004

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CONFLICT OF INTEREST CERTIFICATION

Eastern Research Group, Inc.
EPA Contract No. 68-C-00-112
Work Assignment/Task Order No.: 3-07

In accordance with EPAAR 1552.209-71 (Organizational Conflicts of Interest), EPAAR 1552.209-73 (Notification of Conflicts of Interest Regarding Personnel), and Prime Contract clause (Work Assignment Conflicts of Interest Certification), Eastern Research Group, Inc. makes the following certifications:

ORGANIZATIONAL AND PERSONAL CONFLICTS OF INTEREST:

☒ To the best of our knowledge and belief, no actual or potential organizational conflicts of interest exist. In addition, none of the individuals proposed for work under this Work Assignment/Task Order has any personal conflicts of interest.

OR:

☐ To the best of our knowledge and belief, all actual or potential organizational and personal conflicts of interest have been reported to the EPA Contracting Officer. If applicable, attached is a letter disclosing the conflict of interest.

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Authorized Signature

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Printed Name

Vice President, Mobile Sources

Title

May 14, 2004

Date

1.0 Introduction

The KCMSA PM characterization study requires a contractor team with technical expertise in a number of diverse specialty areas, including QA/QC, vehicle sample selection and stratification, motorist recruitment, emissions/fuel testing and lab analysis, data evaluation, and fleet characterization. In addition, the team must have the managerial expertise to coordinate all of these efforts and integrate the findings for the final product.

The ERG Team has proven capabilities in all of these areas. In addition, many of our team members are also leading experts in the fields of combustion PM formation and PM emissions modeling. Some of our key team members have been actively involved in the peer review and framework development for the MOVES model. We have also been intimately involved with the collection and use of second-by-second emissions and vehicle parameter data for many years. As such, our team members also understand the broader context of the study, regarding the ultimate uses and potential limitations of the study results.

1.1 Background

Recent studies have indicated that gasoline vehicles contribute significantly to ambient PM. PM emissions from gasoline sources have been shown to be predominantly in the PM_{2.5} size range especially for so called "smoker" vehicles.

Review of research led by Steve Cadle (1998), Joe Norbeck (1998), and Kevin Whitney (1998) indicates that gasoline powered vehicles with visible smoke in their exhaust plume emit about 9-times more particulate than non-smoking vehicles. This factor probably varies with model-year, with new smoking vehicles emitting more, and older smoking vehicles emitting less than this amount.

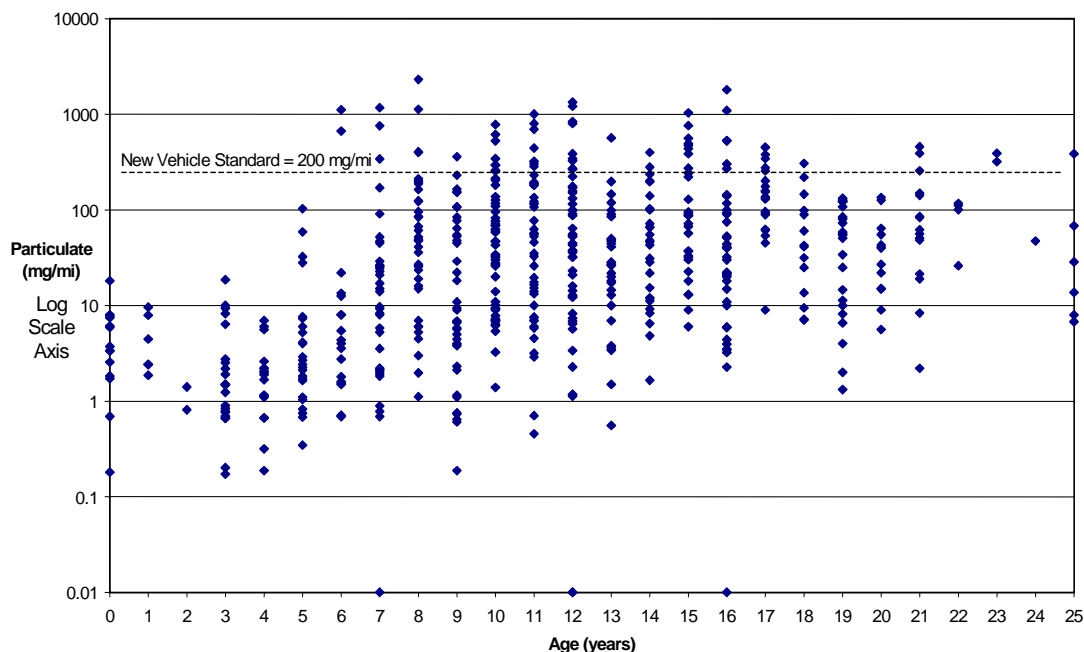
The research by Cadle and Norbeck estimated the incidence of vehicles with visible smoke plumes using roadside surveys. Cadle used both remote sensing and visual surveys in Denver, Colorado and Norbeck used the visual method in Southern California. Their results were somewhat different, but the fleet average incidence was found to be about 1%. Also, ERG has estimated the incidence of smoking vehicles in the Phoenix fleet by analyzing data from the Maricopa County Smoking Vehicle Hotline. Data from the Maricopa County Smoking Vehicle Hotline indicates that the incidence of smoking vehicles that are new is up to 100-times lower than the fleet average, and the incidence of older smoking vehicles is up to 4-times higher than the average, indicating a strong age dependence for smokers.

Many studies have tried to characterize the distribution of PM for a vehicle fleet. One such example is shown in Figure 1-1. We see that this is an age dependence in the data but also that there is a large variance among vehicles. As an example, 10-year-old vehicles can have PM emissions from 1-2 mg/mi to 1,000 mg/mi.

However, study designs have been lacking in their focus to develop random sampling techniques with careful attention to non-responsive behavior. For this research, the Project Sponsors have developed the following goals:

- Characterize gaseous and PM toxics exhaust emissions.
- Characterize the particle size distribution from these vehicles.
- Characterize the fraction of high emitters in the fleet.

Figure 1-1. Example Plot of PM Data from Light-Duty Gasoline Cars and Trucks, Model Year 1994 and Older



Source: Burnette, A.D.; Kishan, S., "PART5-TX1: Update of the PART5 Model For Use In Texas." Final report by ERG for the Texas Natural Resource Conservation Commission (now named Texas Commission on Environmental Quality). Austin, Texas, July 14, 2000.

Note: The data are from in-use vehicles recruited from private owners. The database was compiled from various research sources.

Data obtained from this program will be used to evaluate and update existing and future mobile source emission models. This project will also provide a benchmark to establish various

vehicle recruitment, testing, data collection, and vehicle exhaust emissions analysis protocols which EPA may use in future data collection efforts.

2.0 Technical Approach

Section 2.1 presents an overview of the entire project. Starting in Section 2.2 we present a detailed description of all technical tasks required. Parenthetical references to Section 5 of EPA's SOW are included in the section titles.

2.1 Project Overview

The ERG team will conduct a well-organized and efficient research program to identify, recruit, test, and analyze the exhaust PM emissions from 480 vehicles in the Kansas City area. We have broken the project down into the following major components:

- Vehicle pilot testing;
- Recruitment;
- Testing and Analysis; and
- Reporting

The management and reporting tasks will be ongoing activities throughout the project. Our team will communicate with the Project Officer and the Project Sponsors through:

- Written reports;
- Face-to-face meetings;
- Regular conference calls; and
- Project website.

A kick-off meeting was held in Ann Arbor to initiate the project, and the ERG team is in the process of developing of the quality documents. We has also developed a schedule of bi-weekly conference calls with the project team, and has implemented a password-protected project website, through which the project team can gauge the progress of the project. We will also develop monthly progress reports and all the reports listed in Section 6.0 of the RFP. The final deliverable of the project will be a complete MSOD compatible database with an accompanying final report.

A detailed flowchart covering the first three components is shown in Figures 2-1 through 2-5.

Figure 2-1. Vehicle Pilot Testing

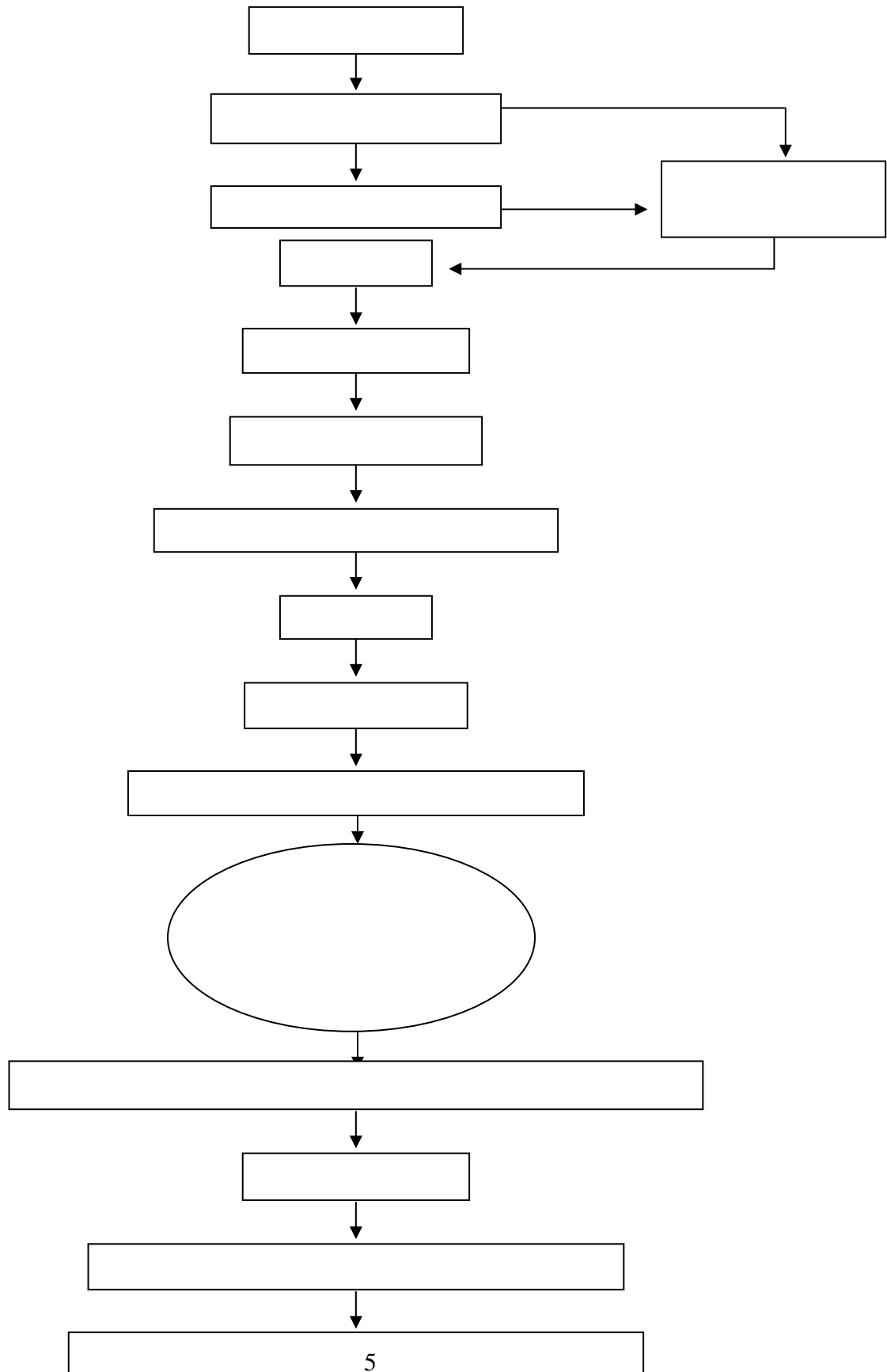


Figure 2-2. Vehicle Recruitment Task (Part 1)

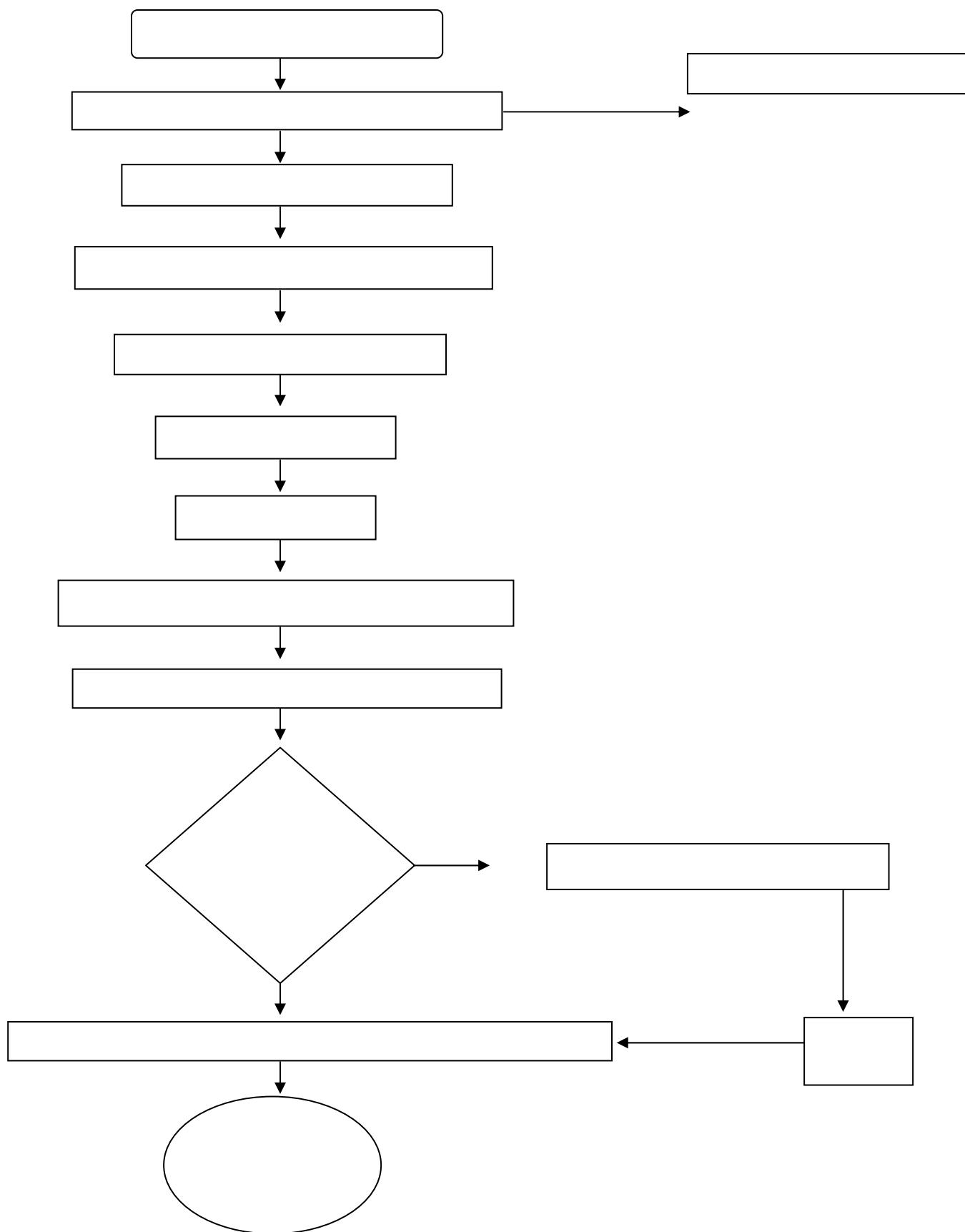


Figure 2-3. Vehicle Recruitment Task (Part 2)

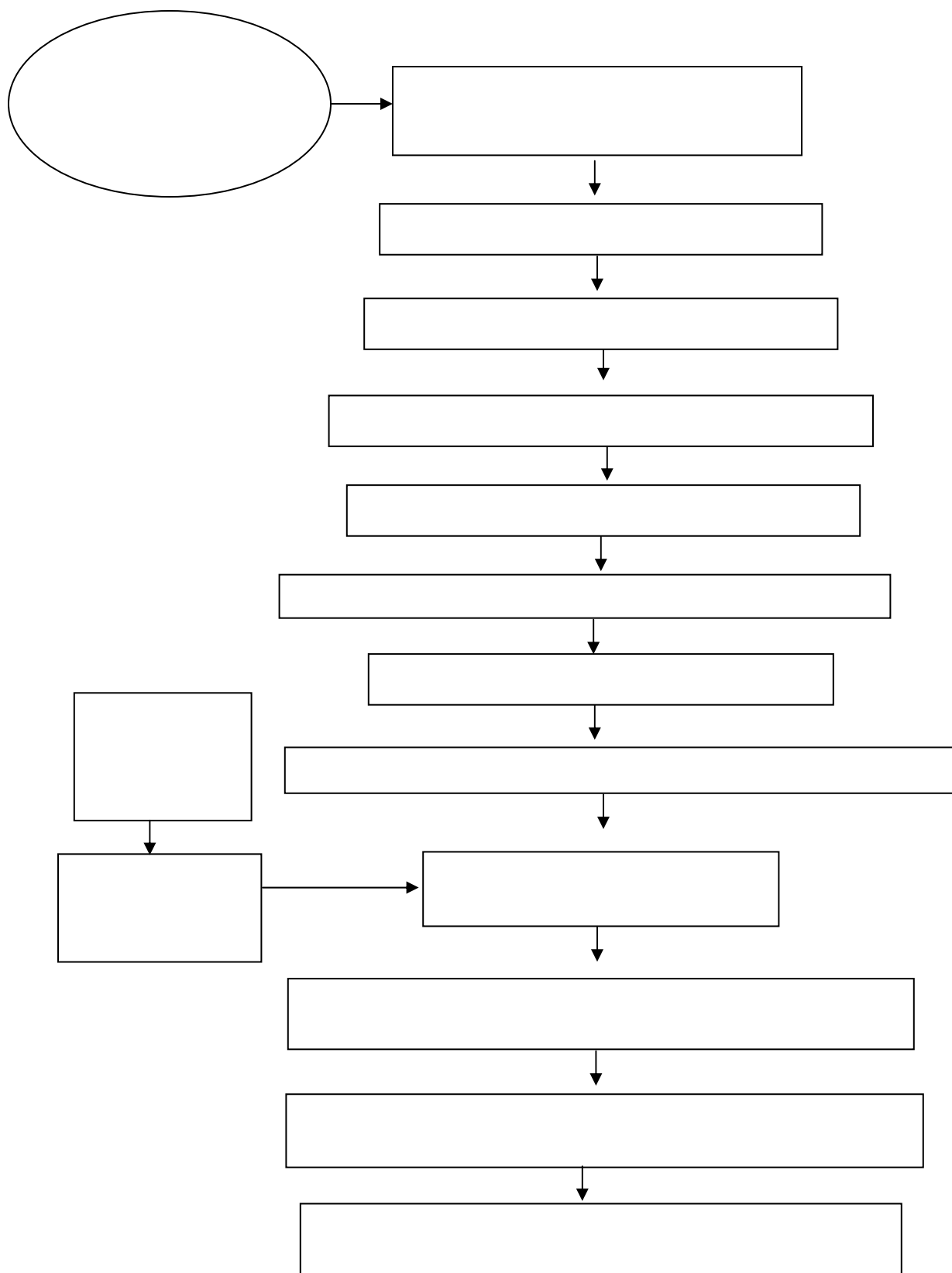


Figure 2-4. Vehicle Testing Task (Rounds 1 and 2)

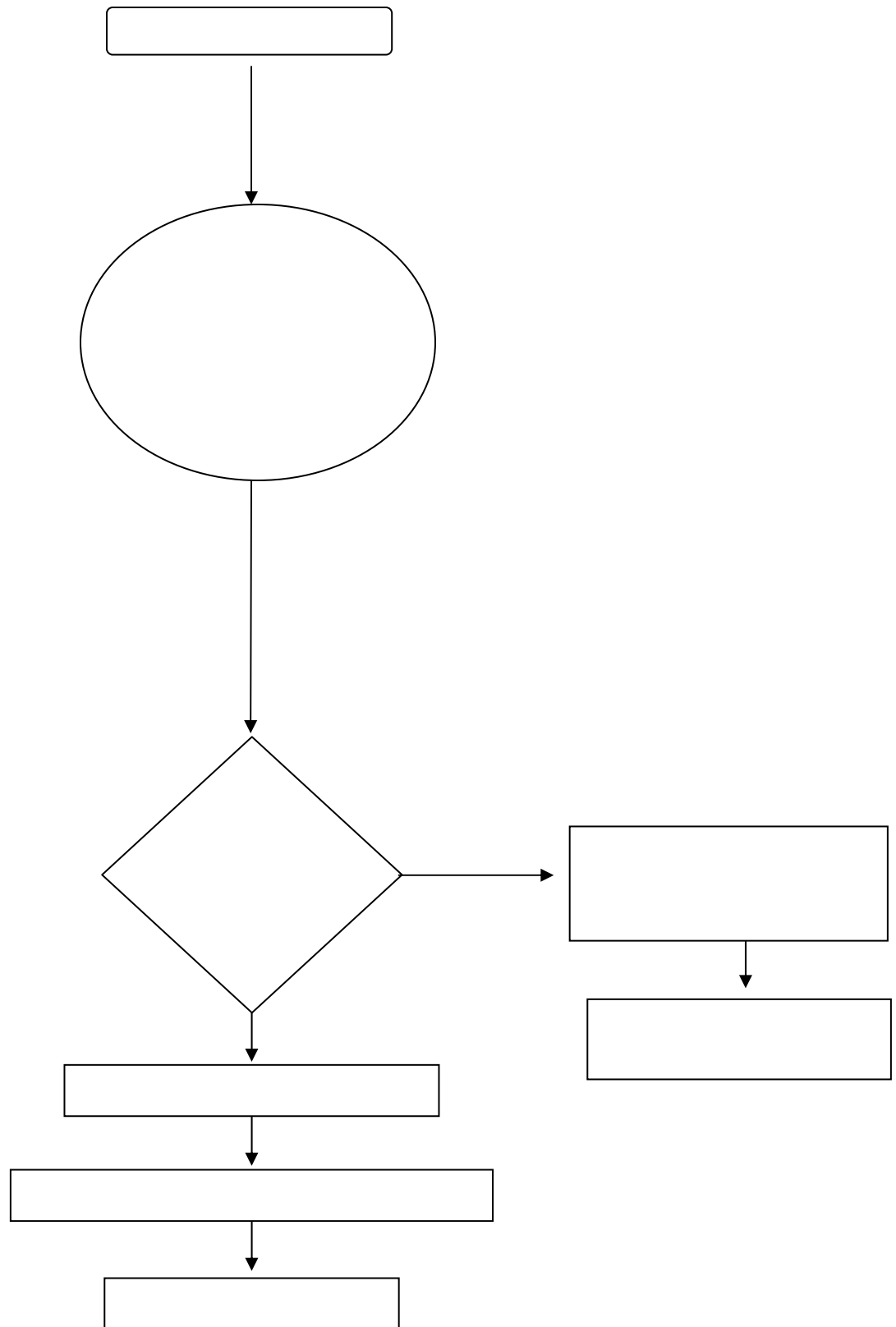
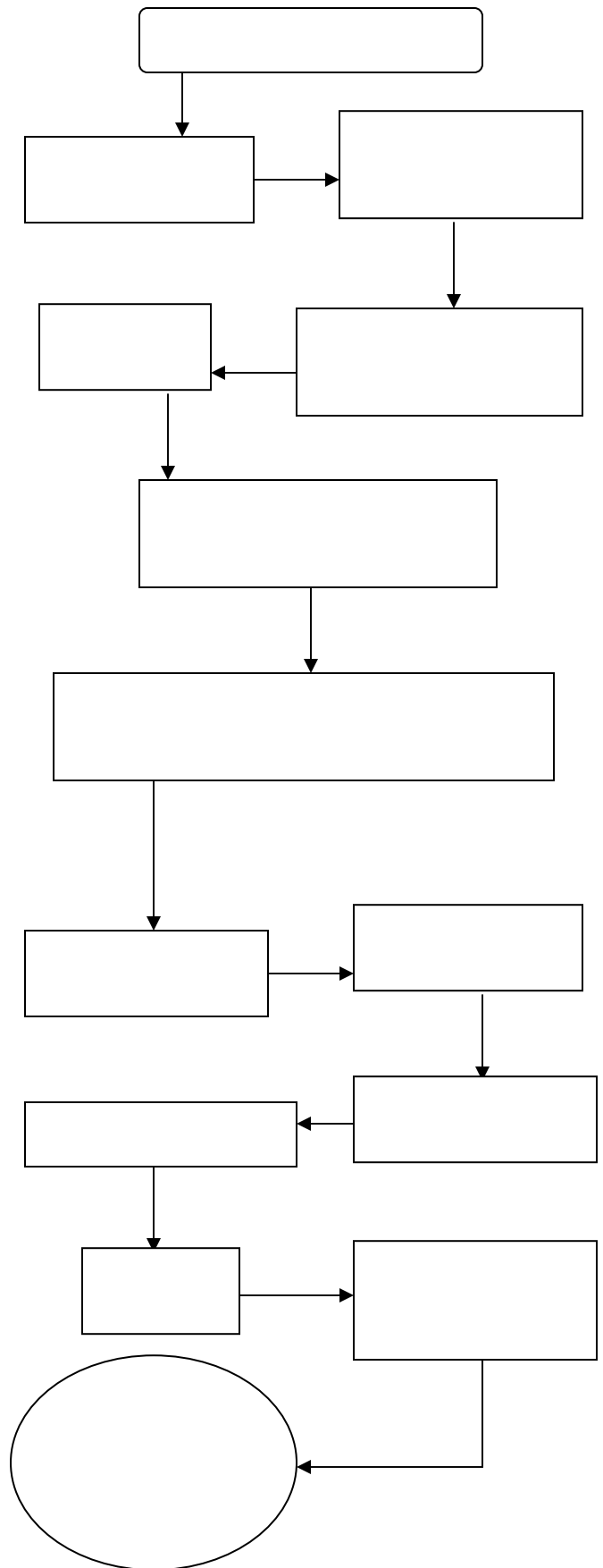
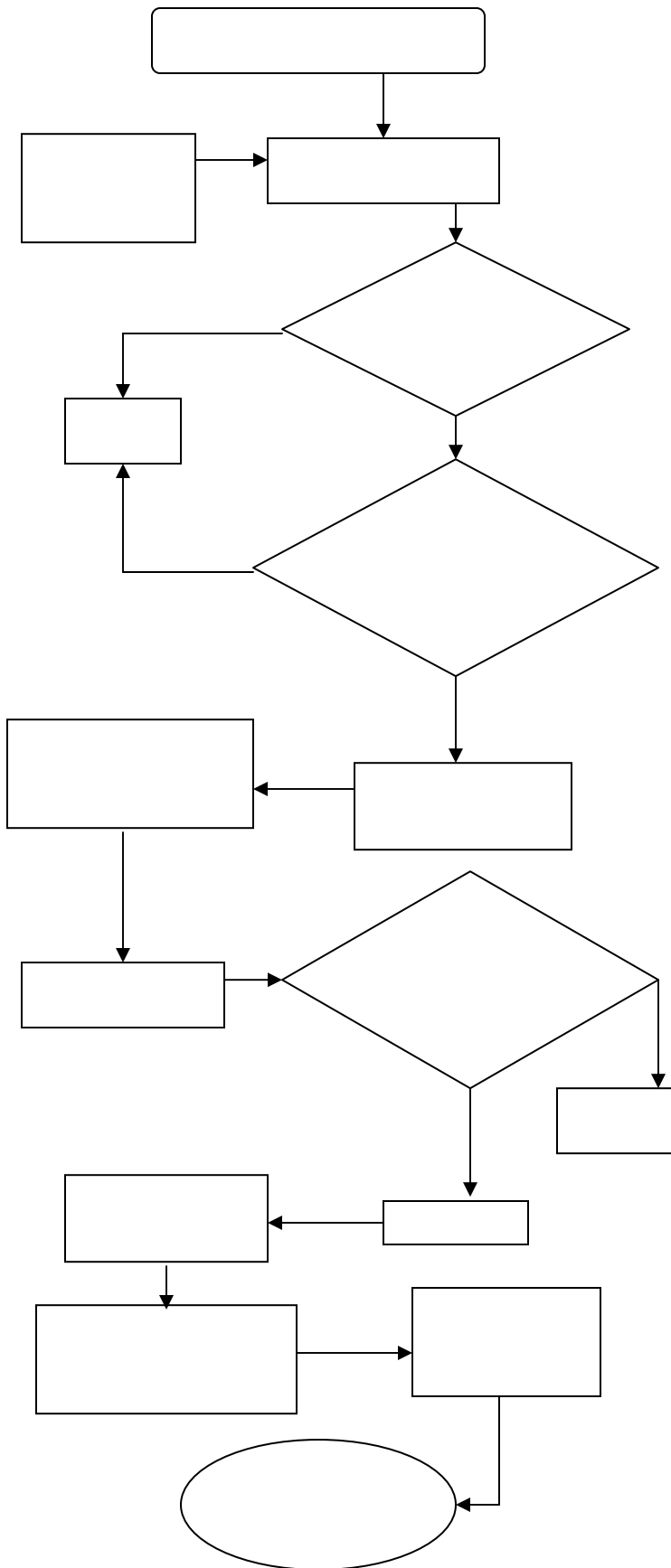


Figure 2-5. Summary of Daily Activities



Draft QAPP and QMP documents will be developed and presented to the Project Officer for approval before beginning the work on site in Kansas City. ERG has an office in Kansas City, which will be used for on-site coordination. We have also identified several options for a suitable warehouse, which could be used for vehicle testing. We have received a market survey from a broker and the location of the testing site will be finalized after a site visit by our vehicle testing contractor, BKI. The pilot phase will then be started by transporting and setting up the equipment in Kansas City. The three vehicles supplied by EPA will be used. The dynamometer and measurement equipment will be made operational and several practice tests will be conducted prior to testing the pilot vehicles. Real time PM evaluation, integrated sample collection system, and the gaseous toxics evaluation will all be made operational. Any derivations and changes from the QAPP will be noted. A pilot vehicle test report will be prepared at the conclusion of the pilot testing.

The ERG Team will conduct the vehicle recruitment task assuring statistically representative sample selection, and effective use of incentives. We believe that a Random Digit Dial (RDD) approach to cohort development offers the most robust approach to sample development, and is preferred over the strategy used to stratify the existing cohort. Therefore a new cohort of at least 2,000 households/4,000 vehicles will be developed using this methodology. Once established, the cohort will be evaluated for non-response bias and compared to the entire registered KC MSA fleet in terms of model year and other discrete variables, as well as RSD emissions data to the extent possible. A geodemographic comparison will also be performed. Based on these comparisons a determination will be made regarding which data set to use for vehicle recruitment.

Preferred vehicle incentive packages to be used for recruitment will be developed under the Vehicle Recruitment Pilot subtask. In this subtask different incentive packages will be evaluated for effectiveness, for both respondents and non-respondents. The preferred incentive package will consider both acceptance rates, as well as recruitment and incentive costs. The selected package will be used in the Round 1 Vehicle Recruitment task, and may be modified if needed for Round 2.

Our subcontractor, BKI, will lead the vehicle testing task. Upon a vehicle's arrival at the testing site an initial inspection and paperwork session will be performed before soaking the vehicle overnight. The vehicle will be scheduled for testing on the dynamometer the next day. DRI will assist the on-site ERG team in collecting the continuous PM measurements and the integrated sample collection for the filter samples. The gaseous samples will also be collected

and analyzed by DRI. Fuel and oil samples will also be collected and stored for all vehicles, with a subset of these oil samples provided to a lab for analysis (fuel samples will be collected, but not analyzed). The PEMS/PAMS deployment will be conducted on selected vehicles after the vehicle testing. RSD measurements will also be conducted on all vehicles tested as well as a portion of the Kansas City fleet. DRI will perform the analysis of the speciation data. The dynamometer emissions data and the continuous PM measurements will be collected in a common database on-site. PEMS/PAMS, PM gravimetric, elements, EC/OC, ions, and gaseous analysis will be added to the dataset later.

2.1.1 Summary of Daily Activities

The Summary of Daily Activities section of the flow chart illustrates how a test vehicle will be processed and tested over a two day period. Vehicles will be over-recruited to ensure that 5 suitable vehicles will be available each day. On day one, vehicles previously scheduled will be received and inspected at the test facility. An initial inspection will determine if the vehicle is suitable for testing (no major repairs required, not too large for the dynamometer, etc.). Repairs that would result in exclusion of a vehicle from the test program include (but are not limited to):

- Replacement of vehicle exhaust system. New exhaust systems would have to be conditioned for quite some time (200- 300 miles) to remove cutting oils. These oils could bias the PM results.
- Replacement of catalyst. Conditioning would be required to age the catalyst (approximately 5000 miles).
- Engine or engine component replacement or rebuild within the last 5000 miles, including heads, valves, block, etc.

Replacement and/or repair of other systems (A/C, steering, brakes, body, tires, transmission, etc.) will generally be considered acceptable. Replacement and/or repair of emission control components (oxygen sensor, EGR valve, etc.) can be considered maintenance actions and are acceptable, but a short break-in period of approximately 100 miles would be necessary before testing.

Upon successful initial inspection of the vehicle, it will be accepted for emissions testing and the vehicle owner will be given a loaner car. The vehicle will next be video taped (to document overall condition), OBD data will be taken, and pertinent vehicle data will be recorded. In the event that minor repairs are needed (exhaust leaks, faulty tires, etc.), the vehicle will be driven to a local repair facility for repairs to ensure valid test results and safety. If the exhaust system requires major repair/replacement the vehicle will not be tested because of the

lengthy preconditioning required for exhaust systems. If only the tailpipe section has a problem, it will be removed, and the exhaust transfer tube will be connected directly to the exhaust system underneath the vehicle. Processing will continue with installation of PEMS and driving of the vehicle over a prescribed conditioning route. If the vehicle performance is satisfactory, a qualitative determination of PM emissions will be made via PM sniffer, as well as visually, in order to rank the vehicle as a low, medium, or high emitter. Low and medium PM emitters will be cued for testing first on the following day. At the conclusion of Day 1, the conditioned vehicles will be soaked overnight at ambient temperatures.

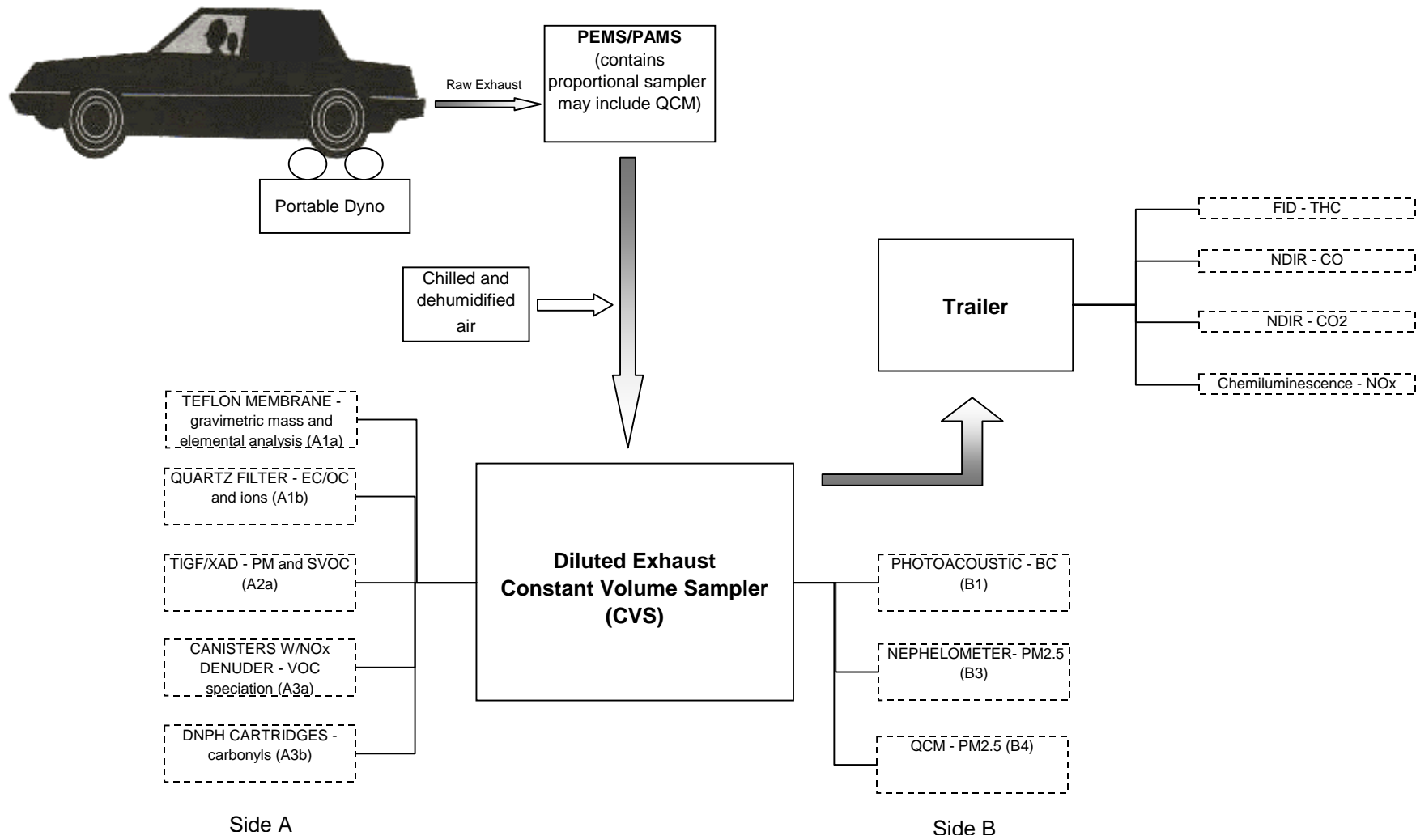
On day two, emissions tests will be performed on the vehicle. The day will start with the dilution tunnel warmup being performed, followed by dynamometer warmup and calibrations. The first test vehicle will then be placed and secured onto the dynamometer for the cold start LA92 driving cycle. All samplers and real time instruments will be readied for testing. A PEMS unit dedicated for use with the dynamometer testing will also be interfaced to the test vehicle. Real time and integrated samples to be collected over the 3 phase test cycle include regulated emissions, PEMS data, real time PM mass and elemental carbon, and integrated PM mass, EC/OC, Ions, SVOC, and gaseous air toxics. At the conclusion of the test cycle, the vehicle exhaust will be disconnected from the dilution tunnel and the dilution tunnel will be purged for at least 30 minutes. During this time, the test vehicle will again undergo a qualitative smoke evaluation, with the exhaust being video taped (if required) against a light background. Following this, the vehicle will be removed from the dynamometer and a PEMS/PAMS unit will be installed on selected vehicles. Tunnel blanks will be collected in the middle of the day during lunch instead of at the beginning of each test day. At the end of each test day the CVS tunnel will be reconditioned by setting the dilution tunnel heater to its highest level and the dilution tunnel will be thoroughly purged.

2.1.2 Summary of Exhaust Measurements

Details of the types of samples and analyses to be performed are shown in Figure 2-6. The PEMS/PAMS system will sample a small portion of the raw exhaust for bag regulated emissions (THC, CO, CO₂, NO_x). The remaining raw exhaust will be directed to the CVS, where it will be diluted with temperature and humidity conditioned air. The remaining samples will then be taken from this diluted mixture. Real time and bag regulated emissions will be determined using instrumentation housed in EPA's transportable dynamometer analytical trailer. Aldehydes and Carbonyls will be collected on DNPH cartridges and subsequently transported to the laboratory for HPLC analysis. VOCs will be collected in canisters and also transported to the laboratory for GC speciation. Real time instrumentation for PM analyses include photoacoustic

(BC), Nephelometer (PM_{2.5}) and QCM (PM_{2.5}) instruments. These instruments will be interfaced to the CVS dilution tunnel via appropriately sized iso-kinetic probes and temperature controlled lines. Additional PM samples will be collected on filter media and transported to the laboratory for analysis. These samples will be collected from an iso-kinetic probe equipped with a 2.5 um cutpoint cyclone. Teflon membrane filters will be used to collect samples for gravimetric mass and elemental analysis. Pre-fired quartz filters will be used to collect samples for EC/OC and ion analysis. TIGF/XAD will be used to collect samples for PM and SVOC analysis.

Figure 2-6. Kansas City Exhaust Measurement Flowchart



2.1.3 Differences Between Proposal and Scope of Work

Several changes to the sampling and analysis protocol were incorporated into this version of the study plan resulting from discussions among the project sponsors and contractors. The changes are summarized below.

Vehicle Sample Selection

- At the kick-off meeting it was clear that this study does not require an overrepresentation of smoking vehicles. They will come into the study according to their prevalence in the area. As such, special protocols will not be required for smoking vehicles. Our recruitment protocols will elicit information about whether or not the subject believes that he/she has a "smoking" vehicle, but we will not be invoking sampling procedures to guarantee a prespecified nominal representation of this vehicle attribute.
- At the kick-off meeting, NuStats provided background on the Kansas City Regional Household Travel Survey. The Travel Survey sample was drawn using list-assisted random digit dialing sampling methodology and in conducting the survey, collected demographic and vehicle information for each participating household. Because of tentative interest by the Mid-American Regional Council (MARC) in this study, NuStats sought and received approval to use the Travel Survey database to draw the sample for the recruitment pilot study. The Study is a rich source of vehicle movement by vehicle type, and NuStats felt it would enhance the analysis and estimate of emissions data in the region. Under this scenario, households that participated in the Kansas City Regional Household Travel Survey would be reviewed and categorized (demographic and fleet characteristics). Using this existing data will enable the Team to conduct the pilot study sooner and focus resources on designing the incentive study questionnaire using a stated preference (SP) survey technique. Note that the Travel Survey data will supplement the sample purchased from Marketing Systems Group.

Vehicle Recruitment

- A stated preference (SP) survey technique will be used in the incentive study. The SP approach relies on an experimental design of various incentive combinations in order to identify the most important attributes of the incentives as well as the best combination to ensure participation for various demographic groups.
- An advance letter will be sent to households prior to recruitment. This letter will focus on study objectives and purpose, provide a contact to verify legitimacy, and be written such that the importance of participating is paramount. Doing so will lend legitimacy to the project and serve to increase participation rates.

Vehicle Sample Analysis

- The Scope of Work and proposal call for comparative analyses and the use of statistical tests (e.g., Chi-square tests, difference of means, etc.) to determine the extent to which differences occur and to measure significance of those differences. Given the straightforwardness of the analysis, these types of tests are unnecessary for phase I sampling, although analysis to answer research questions is still needed.

Protective Covering for Equipment

Locations have been identified in the Kansas City Metropolitan area for protection of the analytical testing equipment and the recruited vehicles. To better protect the analytical equipment and the consumer's vehicles from the elements during a study of this magnitude, an industrial warehouse has been secured. This warehouse exceeds the requirements set forth in the Scope of Work for protective coverings for the testing equipment.

Testing Protocol and Continuous PM Measurements

- PEMS units will be used more extensively in the emissions testing process than was previously proposed. PEMS units will now be installed during the vehicle conditioning run, prior to vehicle placement upon the dynamometer, to gather additional data. A PEMS unit will also be attached *during* dynamometer testing as well. Also note that originally, PEMS units were intended to take measurements of HC, CO, NO_x, and CO₂ using the Semtech-G instrument. PEMS units will now include an additional QCM for PM measurement.
- The dynamometer dilution air will be dehumidified and heated to 47°C +/- 5°C during testing. No residence chamber will be used for integrated samples and sampling streams will be maintained at 47°C +/- 5°C. The photoacoustic instrument is an exception since it is designed to operate at below 35 °C and black carbon concentrations should not be affected by temperature.
- Tunnel blanks will be collected in the middle of the day during lunch instead of at the beginning of each test day. The duration of the tunnel blank sample should be equivalent to the length of the UDC cycle minus the 10-minute soak or some multiple of this duration.
- The dilution tunnel will be purged between tests for at least 30 minutes. Continuous PM measurements will be monitored to ensure that background levels have stabilized after the prescribed purge period. The adequacy of purge time will be evaluated during the pilot study.
- The EPA-supplied TEOM is eliminated. DRI will operate its own TEOM and DustTrak at no cost to the project. However, these measurements will be made as time and resources permit and have lower priority than the QCM, nephelometer and photoacoustic measurements.

- BKI will provide DRI with a time-speed data signal that can be incorporated with the continuous PM database.

Integrated Samples and Compositing

- Vehicles will be brought in for testing randomly. No media composites will be used.
- The back-up quartz filter from the dual quartz filter pack is eliminated. The RFP proposed collecting a second, backup quartz filter behind the primary quartz filter and using the backup as a blank. This backup filter is not an appropriate blank. This approach might be applicable for ambient sampling where relative amounts of SVOC on the aerosol are considerably less than under source sampling conditions. We recommended appropriate numbers of dilution tunnel and field blanks for establishing blank levels and their variability. In addition to collecting quartz blanks during the tunnel blank samples, we are also recommending placing a second quartz filter behind the Teflon (rather than the quartz filter) to characterize the relative importance of SVOC on gravimetric mass. This issue will be evaluated during the pilot study where sampling will be conducted at two temperatures.
- The second quartz filter for ion analysis is eliminated. Each half of the three quartz filters for OC/EC analysis will be extracted together and analyzed for ions.

Chemical Analysis

- After gravimetric analysis of the three Teflon filters for the separate phases of the UDC, the three Teflon filters will be extracted together and the composite sample analyzed for elements by ICP-MS. Table 2-12 compares the elements that are quantified by XRF and ICP-MS and the associated minimum detection limits. Neither method will provide data for all specified elements. We recommend a combination of XRF using DRI protocol A (\$21/sample or \$63/test for three Teflon filters from each phase of the UDC) and ICP-MS for selected elements (e.g., Pb and Hg definitely and possibly As, Zn, Ni, Mn and Cr) at a cost of (\$36 per sample for the first element and \$2 for each additional element assuming combining the extracts from the three Teflon filters). Total cost per test would be comparable to the budget estimate in our original proposal of \$128 per test.
- Because no media compositing will be possible, TIGF filters and XAD cartridges be extracted and analyzed separately for the 1991 to 1995 and 1996 and newer categories. The TIGF filter has a very low background and removing the artifacts from the XAD will improve the detection limits for particulate organic species. Several samples will be composited together based on appropriate sample composite criteria (e.g., emission rate and ratio of photoacoustic black carbon to QCM mass).

- All of the PM/SVOC organic analysis will be shifted from field blanks and some from transportation blanks to dilution tunnel blanks. Analytical blanks will remain unchanged.
- DRI will upgrade the existing gravimetric analysis to a 0.0001 mg balance.

Sampling and Analysis During Pilot Study

- Integrated measurements of gravimetric mass, OC and EC, and volatile and particulate organic compounds speciation will be included during the pilot study.

RSD Testing

- The Scope of Work originally contained methodology to test certain recruited vehicles (in the recruited sample) using RSD. It is ERG's opinion that the most important use of RSD in this project will be to compare the cohort to the Kansas City fleet as a whole. Any available RSD information is a few years old, and our intention is to obtain current RSD information. Thus, in addition to testing selected vehicles in the cohort, RSD systems will be deployed at several sites around Kansas City to allow for collection of this data.

The following describes ERG's technical approach to EPA's scope of work, as per Section 5 of the RFP.

2.2 Quality Assurance Project Plan (QAPP) and Quality Management Plan (QMP) Task (Section 5.1)

As specified in the RFP, the ERG team will provide draft QMP and QAPP documents according to the following schedule.

- A draft QMP and QAPP for each measurement system to the client within 30 days of task order execution.
- A final QAPP within 30 days of the end of the Pilot Study

2.3 Vehicle Recruitment Tasks (Section 5.2)

The vehicle recruitment effort is comprised of 5 tasks that begin with a study to identify the appropriate incentives and conclude with initial recruitment of households to participate in Round 1 activities. The activities involved in performing these tasks are discussed below, along with a summary of the proposed schedule, key dates, and deliverables.

2.3.1 Vehicle Recruitment Pilot Study (Section 5.2.1)

The purpose of this task is to identify the incentives that will be necessary to ensure participation by regional households. The result will be the creation of an effective motorist recruitment incentive package for vehicle testing and instrumentation, as well as providing the best assurance for a high response rate. The task activities cover sampling, survey design and administration, and analysis of results.

Subtask A. Pretest Household Sample Design

The demographic and fleet characteristics of the households that participated in the Kansas City Regional Household Travel Survey will be reviewed and categorized in order to draw a random sample of households for contact in the incentives test. This will be supplemented by a random general population sample, as both are anticipated for inclusion in the full study. The goal for the incentives test is to include a geodemographic representation of Kansas City residents, not necessarily a sample that is representative of the regional vehicle fleet. (The fleet characteristics will be considered for the full study testing. Here, the pilot is concerned with identifying incentives necessary to offer to the vehicle owners for participating in the study.)

Subtask B. Develop Incentive Options

As identified in the proposal, specific incentives (or combinations thereof) that will be investigated include cash (different levels), rental cars (different qualities), gas tank refills, car washes, and guaranteed rides. A matrix of options with varying levels as well as combinations of options will be developed to ensure a thorough testing during the survey.

The issue of whether respondents with smoking vehicles would require different incentives and whether using a different incentive structure would result in a over-representation of these types of vehicles in the data set was raised in the proposal.

Subtask C. Develop Draft Survey Instrument

Once the incentive option matrix has been finalized, a survey will be designed to test respondent reaction to the incentive options for both vehicle testing as well as vehicle instrumentation. The survey will begin with a brief explanation of the project and what is being requested of the respondent in terms of vehicle testing and instrumentation. Then the respondent will be presented with varying levels and combinations of incentives to identify the optimal mix for ensuring high participation rates and minimizing non-response. This survey will be

conducted in English and Spanish, based on the language preference of the respondent. We anticipate about 5% of the interviewers to be in Spanish, based on language prevalence in a current transportation study of the Kansas City region.

The questionnaire will be designed for administration using computer-aided telephone interviewing (CATI) technology. The power of the CATI software will allow for a thorough and random testing of the incentive options. The survey will be designed for an interview that might last up to 20 minutes.

Two approaches will be used in the survey instrument. The first uses a method similar to the contingent evaluation technique, in order to identify the minimum levels for each incentive necessary to induce participation. For those combinations of incentives, a stated preference (SP) survey technique will be utilized. The SP approach relies on an experimental design of various incentive combinations in order to identify the most important attributes of the incentives as well as the best combination to ensure participation for various demographic groups.

Subtask D. Develop Data Collection Protocols

Although the survey will be administered using CATI technology (which implicitly contains the criteria for when particular questions will be asked and how the incentive levels and combinations will be offered), the sample management protocol, interviewer training, and survey administration details will be summarized prior to the start of the pilot. This also includes the timing of the advance mailing as well as identification of the debrief questions regarding the explanation of the vehicle testing concept and the advance mailing.

Subtask E. Develop Survey Materials

Survey research literature contains several citations regarding the positive correlation between the use of advance notification materials and the study response rate. For this study, an advance letter will be designed to inform the randomly selected households of the forthcoming interview and provide contact information to legitimize the study. The letter should be signed by an EPA staff person, preferably someone at the Kansas City office. It should also provide contact information for the EPA project manager and the NuStats manager, in case of questions.

Subtask F. CATI Program and Logic Test

May 4th is the target date for final approval of the pilot survey and materials. This date allows time for the CATI programming and logic check software to be developed and fully

tested. Because the survey will incorporate experimental design elements to support the SP survey, a full week is necessary for testing to ensure the skips and rotations work as specified.

Subtask G. Develop/Test Sample Management System

Supporting the data collection effort is a sample management system. This program provides the status for each piece of sample selected for inclusion in the study throughout the course of the study. It is structured such that the key activities take place in a time-sensitive manner – for example, that the mailing addresses are provided to the staff preparing the advance letters such that the letters are mailed 4 days prior to the survey call. In addition, the status of the sample in terms of call outcomes is tracked carefully as well. Although not an issue for the pilot, this system will be critical for ensuring that respondents recruited for Round 1 testing are reminded in a timely manner.

Subtask H. Recruit and Train Interviewers

A team of experienced interviewers will be assembled to staff the project. Because of the nature of the survey and the importance of the incentives test in laying the foundation for the full study, the study will use more experienced interviewers.

A training manual will be developed that includes the background on the project, the objectives of the study, and a question-by-question guide to what is being asked of the respondents. This includes definitions of the various incentives and the levels being tested. All interviewers will receive a briefing as well as spend 2 hours conducting mock interviews before actually beginning the survey process. All training will be monitored and only those staff that exhibit mastery of the task will be allowed to conduct the survey.

Subtask I. Commence Pretest Recruitment

Approximately 100 households will be interviewed for this study, over the course of a week. During the course of interviewing, the outcomes for all calls will be carefully tracked. Interviewing will take place in two stages:

1. Regular Completes. These are households that are contacted and agree to participate in the incentives test survey. We anticipate 90 out of the 100 households to fall into this category.
2. Soft Refusals. Some households that are contacted may not be interested in participating due to concerns about legitimacy, other time commitments, or a general lack of interest in the study. Those that are adamant about not participating will be coded as “hard refusals”, while others will express

reluctance, but not in a rude manner. These are termed “soft refusals.” Approximately 3 days after the contact that was designated as a soft refusal, an interviewer will make a follow-up call to the household and immediately offer a cash incentive of \$20 to participate in the survey. Upon agreement, the same survey would be administered. The home address would be confirmed to ensure the \$20 incentive reaches the participant, then the incentive would be mailed out the day following the interview, with a short note of thanks.

Subtask J. Process pretest data for analysis

The data from the survey incentives test will be processed into a master file, with flags to identify the regular vs. soft refusal completes, the various geodemographic groups, and any other identifying characteristics of the household that will support the analysis.

Subtask K. Recommendations based on pilot

The results will be analyzed and a document prepared that summarizes the preferred incentives, how those preferences vary across the respondent groups, and the anticipated cost associated with the preferred incentives. The result will be the identification of several recruitment packages with a sensible incentive costs to be offered during the vehicle recruitment phase.

2.3.2 Cohort/Vehicle Analysis (Section 5.2.2)

2.3.2.1 Cohort Frame Analysis (Section 5.2.2.a)

Our proposed approach stipulates that 2,000 households in the Kansas City Metropolitan Statistical Area (KCMSA) will be randomly selected to participate in the study using random digit dialing methodology. The RDD sample will be obtained from a nationally recognized vendor, Marketing System Group. They will provide random numbers to those exchanges that are known to have working residential telephone numbers. This approach presumes that the sampling frame of households with telephones can provide a representative sample of vehicles from the KC area, as well as from individuals who operate these vehicles, since owners often affect the performance of their vehicles (with respect to emissions) through maintenance patterns, driving styles, and driving patterns .

The frame analysis will also take into consideration the desired stratification (socio-demographic and vehicular segments) required for the sample to reflect the KC MSA. This will be assessed using MARC survey data from the ongoing KC travel survey. The data set from that survey can be used to assess the representation of the RDD sample according to population demographics as well as fleet characteristics. Note that the MARC data is being used as a

supplement to the purchased sample from Marketing Systems Group. NuStats believes that relying solely on the MARC sample might introduce bias, because it would likely recruit participants who are already predisposed to participating in surveys. In addition, the MARC sample is limited in terms of number of households available to call. For these reasons, our sampling plan for recruitment of our Cohort Frame combines both MARC data and the purchased sample.

The methodology will be documented in a memorandum that documents the sample design, stratification used, associated costs, and restrictions in use, if any.

2.3.2.2 Cohort Recruitment (Respondent/Non-respondent) Analysis (Section 5.2.2.b)

Participants will be recruited via RDD sampling of the Kansas City (KC) metropolitan area. Such samples are geographically and demographically representative of the KC population. Recruitment will screen respondents on vehicle information (e.g., make, model, year, user) and household demographic information (e.g., age, gender, and other socio-demographic variables). Demographic data is available for the MARC sample, but not the purchased sample. In cases where demographic information is unknown, NuStats will use US Census-based zip code data to impute these key variables for the analysis, rather than directly inquiring of participants. Recruitment will be monitored to watch for stratification quotas, nonresponse, and other issues. Assessments for nonresponse or quota adjustments (to the interview tool) will be made as necessary. The process for recruitment and any necessary adjustments will be documented in a vehicle/cohort recruitment memorandum.

Because we will be recruiting vehicles from participating households of an RDD sample survey, our underlying assumption is that the distribution of recruited vehicles from these households will be highly representative of the KC vehicle fleet. This assumption will be assessed empirically by comparing the pool of cohort sample vehicles with the known distributions of the KC vehicle fleet obtained from extant data.

2.3.3 Cohort/Vehicle Fleet Analysis (Section 5.2.3)

The final cohort sample resulting from the cohort recruitment will be compared to the KCMSA fleet with respect to vehicle distribution patterns by year, model, and make. (Cohort recruitment comparison to the national fleet may be necessary if obtaining registration information proves problematic). The analysis will assess the degree in which the three populations differ to confirm that the cohort sample is representative of the KCMSA fleet as a

whole. This analysis will be documented in a cohort/fleet analysis memorandum including methodology, databases used for KCSMA and national fleets, and analysis approach.

2.3.4 Cohort/Vehicle Emission Analysis (Section 5.2.4)

Upon completion of the vehicle emissions testing, a comparative analysis of the cohort data and the regional Kansas City fleet will be conducted. The methodology, data, and statistical analysis will be described in a memorandum.

2.3.5 Cohort/Vehicle Summary Analysis (Section 5.2.5)

A report summarizing tasks 2.3.1 – 2.3.4 will be prepared that compares the chosen cohort for the testing program with the cohort fleet. Sampling biases and other issues related to using the sampling cohort as the recruitment population will be addressed. The report will provide conclusive judgment on the value of the cohort sample for vehicle recruitment.

2.3.6 Vehicle Recruitment Sample Plan (Section 5.2.6)

Using the cohort sample, the core sample of 480 vehicles to participate in the study will be drawn. For round 1, 170 vehicles will be recruited from the cohort and 80 vehicles from the non-response households. For Round 2 vehicle recruitment, 230 different vehicles from the cohort will be recruited along with 25 vehicles from Round 1 for retesting.

2.3.7 Vehicle Recruitment (Section 5.2.7)

Subtask A. Revise Survey Instrument

Based on the incentives packets and the respondent reactions to the study descriptions provided during the pilot test, the recruitment instrument will be finalized and translated into Spanish. The recruitment interview is anticipated to average 10 minutes in length. It will begin with a description of the program, obtain household address and vehicle information, and secure agreement for testing (in a hypothetical manner). The outcome of each call attempt will be tracked and the sample thoroughly dialed according to industry standards. A “completed” recruitment interview is one in which the household agrees to be scheduled (if selected), provides all key fleet characteristics, and provides/confirms a valid home address. NuStats will use census data for given zip code to impute key demographic variables for the analysis. Sufficient households will be recruited to ensure that 480 vehicles are tested. We estimate that 2,000 households will have to be recruited to ensure that 480 vehicles conforming to the data collection goals are tested in Rounds 1 and 2.

For those households contacted who decide not to participate, the survey will include a few questions about that decision, to be attempted for all refusers. This information will most likely include home address, gender (observed), and household vehicle information.

Subtask B. Finalize Data Collection Protocols

Data collection protocols will be adjusted to accommodate the refocus from incentives testing to household recruitment. Again, the surveys will be administered using CATI technology (which implicitly contains the criteria for when particular questions will be asked and how the recruitment process will be managed). The corresponding sample management protocol, interviewer training, and survey administration details will be summarized prior to the start of recruitment. This also includes the timing of the advance mailing.

Given the requirement that a portion of the vehicles tested must come from households that initially refuse to participate, the treatment of soft refusals will be documented and pre-programmed. This includes details regarding when a callback is made, how the sample will be identified for treatment by specially trained interviewers, and how the refusal-conversion respondents “availability” designation differs from a regular recruit so that progress towards the different testing goals can be monitored.

Subtask C. Finalize Survey Materials

The advance notification mailing will be revised to focus on the key points that the pilot respondents found important. This letter will be signed by an EPA official, preferably one from the Kansas City region, and contain contact information for the EPA project manager as well as the NuStats Project Manager.

Following the recruitment call, households that agree to be scheduled will be mailed a packet containing more details about the vehicle testing program. This might include statistics about the levels of pollutants in the Kansas City region and what that means for the regional residents (we would like to discuss with EPA the possibility of obtaining and using one of their existing brochures for this purpose), what the testing will achieve, how households will be selected and what will be required of participating households. We will also consider other small “tokens of appreciation,” as survey literature indicates that pre-payment of a small incentive has a positive effect on response rates. This follow-up package will only be sent to those households sampled for testing in Round 1 and Round 2, and will be mailed approximately 4 days prior to the scheduling call.

Subtask D. Finalize CATI Program and Test Logic

The CATI recruitment program will be finalized and tested to ensure it conforms to the skip logic.

Subtask E. Finalize Sample Management System

The sample management system will be critical for timely interaction with the recruited households. On any given day, the program will identify households to be mailed the advance notification, those that should be contacted for recruitment, those eligible for scheduling, and those that require reminder calls for upcoming appointments. A portion of the program will be set to receive schedule outcome updates from BKI (so that real time tracking of actual tested vehicles by goals is maintained, as well as the rates of attrition between those that agreed to testing vs. those that actually completed the testing process).

Subtask F. Recruit and Train Interviewers

A team of experienced interviewers will be assembled to staff the project. Because of the nature of the survey and the importance of securing valid agreements for the testing process, the interviewers will focus on obtaining solid commitments and their training will reflect that need to discern respondent reactions.

A training manual will be developed that includes the background on the project, the objectives of the study, and a question-by-question guide on what is being asked of the respondents. It will show the detailed data collection process, from advance mailing to recruitment, scheduling, and reminder calls, as well as how the recruitment feeds into the two rounds of recruitment. This document will also include definitions of the various incentives and the levels being offered, as well as explicit detail regarding how the incentives will be administered and under what circumstances. All interviewers will receive a briefing as well as spend two hours conducting mock interviews before actually beginning the survey process. All training will be monitored and only those staff exhibiting mastery of the task will be allowed to conduct the survey.

Subtask G. Issue Advance Letters to Households

Four days prior to the dialing of specific sample, advance letters will be mailed to households identified as being ready for the recruitment call. As discussed in an earlier task, this letter will focus on study objectives and purpose, provide a contact to verify legitimacy, and be written such that the importance of participating is paramount. It will be signed by an EPA staff

person, preferably one from the Kansas City region and provide contact information for the EPA project manager and the NuStats project manager.

Subtask H. Recruitment Operations/Calling

Recruitment will take place on a daily basis, with households being identified based on the fleet characteristics that will guide the selection of households for scheduling. The best timing of the recruitment call will be adjusted based on respondent reaction and the exact number of days between recruitment, scheduling, and the actual appointments in order to maximize participation levels. Real time progress towards the vehicle testing goals will be monitored using the CATI reporting functions.

Subtask I. Process Recruitment Data

At the conclusion of each shift, the data will be extracted and appended to the master sample management system.

2.3.7.1 Vehicle Recruitment (Round 1) (Section 5.2.7a)

Subtask J. Sample Vehicles for Round 1 Recruiting

The cohort analysis conducted in the previous task will be used to select vehicles for testing from among the fleet represented by the recruited households. Sufficient vehicles will be identified to ensure that the correct distribution of 480 vehicles is obtained. This distribution is shown in Table 2-1, which is derived from Table 1 in the SOW.

Table 2-1. Estimated Sample Sizes by Stratum

Stratum	Vehicle Class	Age Class	Total Vehicles Tested	Regular Responders	Refusers
1	Truck	Pre 1980	50	42	8
2	Truck	1980 – 1990	100	84	16
3	Truck	1991 –1995	70	58	12
4	Truck	1996 and newer	40	33	7
5	Car	Pre 1980	40	33	7
6	Car	1980 – 1990	50	42	8
7	Car	1991 –1995	80	66	14
8	Car	1996 and newer	50	42	8
Total			480	400	80

It is anticipated that 300 households will need to be sampled to result in 80 vehicles tested. For the regular respondents, we anticipate sampling 1,000 to 1,500 households to complete the 400 tests.

For Round 1, the testing will include all 80 refuser vehicles and 170 of the 400 regular responder vehicles, for a total of 250 vehicles tested. In Round 2, the goal will be to retest 25 of the 250 vehicles plus 230 vehicles from the regular responder households. Table 2-2 presents a summary of vehicles recruited and tests performed for each round.

Table 2-2. Estimated Number of Vehicles Recruited and Test Performed

	Different Vehicles	Tests
Round 1		
Positive Respondents from Cohort	170	170
Replicate Vehicle Tests	0	15
Non-respondent from Cohort ^a	80	80
Weekly calibration vehicle test ^b	0	12
Total	250	277
Round 2		
Positive Respondents from Cohort	230	230
Non-respondent from Cohort ^a	0	0
Replicate Vehicle Tests	0	10
Repeat Vehicles from Round 1 ^b	25	25
Weekly calibration vehicle test ^b	0	12
Total	255	277

^a see Section 3.1.3 for description of this activity.

^b see Section 3.2.3 for description of this activity.

Total vehicles includes non-response assessment.

Subtask K. Contact Households and Schedule Appointments

Selected households for the first round will be re-contacted and scheduled for vehicle testing. Prior to the start of scheduling operations, a detailed schedule would be developed that includes all valid testing dates, the appointment “slots” for each date, and a unique identification number for each slot on each day. This production plan is critical for ensuring successful recruitment and scheduling, as it would trigger when the advance letters are mailed as well as ensure the reminder calls be made on a timely basis. Each time slot will have a maximum cap on how many households can be scheduled, to ensure a steady flow of appointments. Once a particular time slot has been filled, households will be directed to the next available time slot (the CATI program will automatically track households in each time slot and “close” each once the maximum is reached). Ultimately, households will be scheduled for the most convenient time slot among those available.

Scheduling will take place at sufficient levels in order to ensure that 250 vehicles are tested in this round. Of the 250 vehicles, 170 will come from households that respond positively to the survey effort and 80 will come from those that initially refused but were “converted” after a follow-up call and using a different incentive (see 2.3.6 above). It will be critical for BKI to report daily on actual testings completed to ensure that scheduling is at the right level (not too many and not too few households) and stratum goals are being fulfilled as planned. Recruitment estimates will be adjusted daily based on feedback from BKI.

Scheduling calls will take place about a week prior to the appointments, and followed-up with reminder calls the day/evening prior to the appointment. Reminder calls will be critical to ensuring the proper flow of vehicles at the testing facility. They will be short (2 minutes) and exclusively for the purpose of reminding the household about their testing appointment and the promised incentive. Reminder calls will be attempted for all scheduled households.

Subtask L. Provide Appointment Schedule to Test Facility

Appointment summaries will be prepared and sent to BKI, along with summary reports tracking participation by key variables. The home address information will be used for delivery of the incentive to the household (some incentives may be provided to BKI for delivery at the time the household keeps the appointment, others may be provided directly to the household through the mail).

In addition, an appointment reminder postcard will be drafted if the pilot respondents indicated it would be useful.

Subtask M. Comparative Analysis of Tested Vehicles

Statistical tests will be used to confirm that there were no differences in the vehicles that were tested vs. those that were sampled for testing.

Subtask N. Develop Analytic Weights

Weights will be developed to compensate for non-response analysis, as well as to adjust the results to represent the overall vehicle fleet in the Kansas City region.

Subtask O. Methodology Report on Round 1

A report documenting the efforts of Round 1 recruitment, scheduling, and impact on the incentives will be prepared and submitted.

2.3.7.2 Vehicle Recruitment (Round 2) (Section 5.2.7b)

Subtask P. Review Vehicle Data of Agreeing Households

The status of data collection at the end of Round 1 will be reviewed against the data collection goals listed in Table 2-1. This will assist in the determination of which households to sample.

Subtask Q. Sample Vehicles for Round 1 Re-testing

The goal is to retest 25 vehicles from Round 1. The purpose of this task is to randomly sample 100 households from Round 1 to recontact for purposes of achieving that goal. Table 2-3 presents the estimated sample sizes for the Round 2 re-testing .

Table 2-3. Estimated Sample Sizes by Stratum for Round 2 Re-Testing

Stratum	Vehicle Class	Age Class	Sample Size (n_h) ¹
1	Truck	Pre 1980	3
2	Truck	1980 – 1990	5
3	Truck	1991 –1995	3
4	Truck	1996 and newer	2
5	Car	Pre 1980	2
6	Car	1980 – 1990	3
7	Car	1991 –1995	4
8	Car	1996 and newer	3
Total			25

1 Number of randomly selected vehicles tested during Round 1 re-tested during Round 2.

Subtask R. Sample vehicles for Round 2 Testing

Sufficient vehicles (and their associated households) will be sampled from the recruited households to ensure that 230 vehicles will be tested during the 2nd round of the study (see 2.3.6 above).

Subtask S. Contact Households and Schedule Appointments

Selected households for the second round will be re-contacted and scheduled for vehicle testing. As with Round 1, prior to the start of scheduling operations, a detailed schedule would be developed that includes all valid testing dates, the appointment “slots” for each date, and a unique identification number for each slot on each day. This production plan is critical for ensuring successful recruitment and scheduling, as it would trigger when the advance letters are mailed as well as ensure the reminder calls be made on a timely basis. Each time slot will have a maximum cap on how many households can be scheduled, to ensure a steady flow of appointments. Once a particular time slot has been filled, households will be directed to the next

available time slot (the CATI program will automatically track households in each time slot and “close” each once the maximum is reached). Ultimately, households will be scheduled for the most convenient time slot among those available.

Scheduling will take place at sufficient levels in order to ensure that 255 vehicles are tested in this round. Of the 255 vehicles, 25 will come from vehicles that underwent testing in Round 1 and the remaining 230 will come from those that were recruited earlier in the year (see 2.3.6 above). Given the passage of time since the initial recruitment, the scheduling interview will be longer, as it will be necessary to confirm the demographic and fleet information for each household.

Again, it will be critical for BKI to report daily on actual testings completed to ensure that scheduling is at the right level (not too many and not too few households) and stratum goals are being fulfilled as planned. Recruitment estimates will be adjusted daily based on feedback from BKI.

Scheduling calls will take place about a week prior to the appointments (or at whatever length was found to work best in Round 1), and followed-up with reminder calls the day/evening prior to the appointment. Reminder calls will be critical to ensuring the proper flow of vehicles at the testing facility. They will be short (2 minutes) and exclusively for the purpose of reminding the household about their testing appointment and the promised incentive. Reminder calls will be attempted for all scheduled households.

Subtask T. Provide Appointment Schedule to Test Facility

Appointment summaries will be prepared and sent to BKI, along with summary reports tracking participation by key variables. The home address information will be used for delivery of the incentive to the household (some incentives may be provided to BKI for delivery at the time the household keeps the appointment, others may be provided directly to the household through the mail).

Subtask U. Comparative Analysis of Tested Vehicles

Statistical tests will be used to confirm that there were no differences in the vehicles that were tested vs. those that were sampled for testing.

Subtask V. Develop Analytic Weights

Weights will be developed to compensate for non-response analysis, as well as to adjust the results to represent the overall vehicle fleet in the Kansas City region.

Subtask W. Methodology Report on Round 2

A report documenting the efforts of Round 2 recruitment, scheduling, and ultimate results of the recruitment effort.

2.3.8 Non-Response Assessment (Section 5.2.8)

A critical component of this study is to determine the presence and extent of bias introduced into the survey by non-response. Using the original survey of respondents, this task will draw approximately 340 non-respondents with the goal of convincing 80 of these households to respond and agree to have their vehicles tested. The number of vehicles to target in each stratum for the non-response analysis will be proportional to the vehicles recruited for the total population - as shown in Table 2-4 below.

Table 2-4. Estimated Sample Sizes by Stratum for Non-Respondent Testing

Stratum	Vehicle Class	Age Class	Sample Size (n_h) ¹
1	Truck	Pre 1980	8
2	Truck	1980 – 1990	16
3	Truck	1991 –1995	12
4	Truck	1996 and newer	7
5	Car	Pre 1980	7
6	Car	1980 – 1990	8
7	Car	1991 –1995	14
8	Car	1996 and newer	8
Total			80

1 Number of randomly selected vehicles tested for the non-response assessment.

A list of non-respondent criteria will be developed (e.g., those classified as a “hard” refusal during the original survey along with those households refusing to answer questions critical for stratification and analysis) and submitted to EPA for approval. In addition, criteria to achieve a high participate rate for non-respondents will also be submitted to EPA for approval.

Vehicles will be recruited to participate in the program, and the results from these 80 respondents will be compared with the 400 respondents to determine the presence of any non-response bias. Findings will be reported in a non-response memorandum at the conclusion of the Phase I study.

2.3.9 Participation Incentives (Section 5.2.9)

The appropriate mix of incentive packages for use in recruiting study participants (for participants and non-respondents) will be identified during the pilot test. Incentives will be disbursed upon participant completion of the necessary paperwork at the test center. On a monthly basis, a memorandum documenting of the incentive disbursements will be submitted to the EPA Project Officer. This report will document the total amounts disbursed for all incentive packages. When 75% of the allotted incentive funds have been paid out, the EPA Project Officer will be notified. Examples of possible incentives are presented in Table 2-5 below.

Table 2-5. Incentives

Type of Incentives	Incentive Cost
Cash	\$200 (if using a rental vehicle) \$275 (for not using a rental vehicle)
Full Tank of Gasoline	\$25
Rental Vehicle	\$75 (for up to three days)
Car Wash (possible)	\$10
PEMS / PAMS Use	\$50
Total	\$360

2.3.10 Post Round 1 Vehicle Analysis (Section 5.2.10)

Following round 1 testing, regulated and PM mass emission results, as well as vehicle data, will be compiled and submitted in a report for review by the EPA Project Officer and Sponsors. This report will also include an evaluation of the data, and document any known problems and concerns that were encountered in round 1, including vehicle processing and conditioning, testing, and emissions sampling and analysis. If problems are identified, suggestions will be offered for improving the affected processes. The goal of this analysis and report are to identify and correct issues related to the quality of data being generated that were not identified before or during the course of round 1.

2.4 Vehicle Testing Task (Section 5.3)

BKI will provide vehicle-testing services to the project for the pilot study and the intensive 2-part field study. Chassis dynamometer vehicle emissions testing will be conducted according to a protocol developed for the transportable dynamometer by EPA/ORD/NERL.

2.4.1 Pilot Vehicle Testing Task (Section 5.3.1)

BKI will provide technical support for the calibration, operation and maintenance of a portable chassis dynamometer, associated driver's aid, constant volume sampler (CVS), analytical bench, and data acquisition/reduction system. This system is used to obtain exhaust emission samples in the field. In addition, BKI will support the calibration, operation, and maintenance of other sampling and measuring equipment as specified in the SOW descriptions. BKI will comply with all EPA health and safety, environmental, waste handling, and other applicable work rules. BKI will also follow proper laboratory, field testing, and vehicle testing practices for all work required by the SOW. BKI will adhere to all applicable standard operating procedures and the QA/QC procedures recommended therein. BKI will notify the ERG Project Manager, the Project Officer, and WAM immediately if it encounters any equipment failures that cannot be readily remedied by the contractor or technical problems that may impact the quality or on-time delivery of deliverables, or if any required equipment or supplies are unavailable to accomplish the required work under this SOW. Specific subtasks for the pilot vehicle testing are described in detail below.

Subtask A. Prepare Work Plan for Pilot Study

The ERG team has prepared a Work Plan (this document) for submittal, describing the tasks and subtasks to be performed. Applicable Quality Assurance Project Plans (QAPPs) and Quality Management Plans (QMPs) will also be submitted as part of this task.

Subtask B. Protective Covering for Equipment and Vehicles, Test Site Selection

BKI and ERG will identify an industrial warehouse in the Kansas City Metropolitan area for the testing of the recruited vehicles. This will also better protect the analytical equipment from the elements and provide stable electrical power. This will allow the analytical equipment to be continually powered up which eliminates warm-up times. The location identified has large drive in doors for ease of equipment setup and for ease of entry for the test vehicles as well as increased ventilation. The test area with all doors open will allow for the overnight soaking of test vehicles at ambient conditions and will allow the background levels to be maintained at ambient levels while testing.

Subtask C. Prepare and Transport Dynamometer and Analytical Trailer

BKI staff will prepare and transport the transportable dynamometer and analytical trailer to the Kansas City test site. Before transport the dynamometer system will be inspected and packed for shipment. All components and analytical equipment will be strapped down and secured for over the road transportation. The transportable test cell includes a Clayton model CTE 50-0 water brake chassis dynamometer mounted on a Freuhauf trailer. The dynamometer is coupled to a Clayton direct drive variable inertia flywheel system allowing vehicle testing at inertia weights of 1750, 2000, 2250, 2500, 2750, 3000, 3500, 4000, 4500, 5000, and 5500 pounds. Vehicle road load (Hp @ 50 MPH) is manually set using the driver's pendant switch.

All utilities necessary for dynamometer operation (compressed air, cooling water, and electrical power distribution) are self-contained on the trailer. A compressor provides compressed air for operation of the dynamometer's roll brake, vehicle lift, and flywheel clutches. Compressed air is also available at each corner of the trailer via quick-disconnect fittings for adjusting test vehicle tire pressure. A closed-loop water system provides the dynamometer's power absorption unit with both cooling and load water. The water system includes a SPA pump, a 12 gallon storage tank, and a liquid to air heat exchanger. The water system is normally filled with a 50/50 mixture of water and antifreeze to prevent freeze damage in colder weather. The air compressor and water system are electrically wired into the test cells electrical power distribution box. Electrical outlets, also wired to the power distribution box, are located underneath the trailer for miscellaneous equipment with either 110 VAC and 220 VAC power requirements.

Subtask D. Transport EPA Correlation Vehicles and Fuel to Kansas City Test Site

BKI will provide for the transportation of the EPA correlation vehicles, fuel, and oil from Ann Arbor, MI. to the Kansas City test site and back to Ann Arbor, MI. after the study concludes. The vehicles will be placed on a motor carrier and delivered after the transportable dynamometer is initially setup. After testing the vehicles will be returned to the EPA Ann Arbor facility.

Subtask E. Off-Load and Setup Dynamometer, Analytical Trailer, and Associated Sampling Equipment

BKI staff will off-load, setup, and calibrate the dynamometer, analytical trailer, and associated sampling equipment on its arrival at the Kansas City test site. A wrecker will be obtained to move both the dynamometer and analytical trailer from the flat-bed trailers and into the industrial warehouse. After positioning both trailers BKI staff will begin removing and

setting up the interconnecting equipment. Electrical service will be connected to both the transportable dynamometer and analytical bench and 3 phase power will be connected to the dilution tunnel heater.

Subtask F: Maintain & Calibrate Dynamometer, Analytical Trailer, and Associated Sampling Equipment

BKI will maintain the transportable dynamometer to make real-world emission measurements in the field and the laboratory. BKI staff will repair the equipment on an as-needed basis. If the system requires modifications, approval by the EPA Project Officer is required beforehand. BKI staff will calibrate the transportable dynamometer, analytical equipment and associated sampling equipment after setup has been completed and all systems prove to be operational. The Positive Displacement Pump-Constant Volume Sampling (PDP-CVS) system used to dilute and transport the vehicle tailpipe exhaust to analyzers during the test will be calibrated as described in the SOP. Coastdowns will be performed on the Clayton dynamometer that is coupled to a direct drive variable inertia flywheel system allowing vehicle testing at inertia weights of 1750, 2000, 2250, 2500, 2750, 3000, 3500, 4000, 4500, 5000, and 5500 pounds. Vehicle road load (Hp @ 50 MPH) is manually set using the driver's pendant switch. The regulated emission analyzers will be calibrated according to the SOP. The dilute THC concentrations will be determined using a heated flame ionization. The detector analyzer calibration curve should cover the range of 0 ppmC to 3,000 ppmC. Likewise, CO concentrations will be determined using non-dispersive infrared (NDIR) analyzers. CO analysis should cover a range of 0 ppm to 10,000 ppm (1.0%). In order to meet this calibration curve, two CO analyzers are typically required - one from 0 to 1000 ppm, and one from 0 to 10,000 ppm (1%) CO. CO₂ concentrations are also determined using a NDIR analyzer. CO₂ analysis should cover a range of 0 ppm to 50,000 ppm (5%). NO_x concentrations will be determined using a chemiluminescence analyzer. The NO_x measurement must include the sum of nitrogen oxide and nitrogen dioxide. This determination can be completed satisfactorily by calibrating and running the chemiluminescence analyzer in NO only mode, and multiplying the result by 1.03. This eliminates the need for the converter and flow balance. The NO_x analysis should cover a range of 0 ppm to 700 ppm.

Subtask G. Interface Study Specific Analytical Equipment

BKI will supply the interface for the study specific equipment used for EPA-AA real time PM samplers and DRI gaseous and PM samplers. These heated dilution tunnel ports and probes will allow isokinetic flows for the continuous and integrated air measurements to be extracted

from the dilution tunnel. BKI staff will also supply the interface for the second-by-second speed time trace for the incorporation into the real-time PM measurements.

Subtask H. Test Dynamometer and Analytical Systems with Control Vehicle

After the analytical systems are setup and flows calibrated, BKI staff will test the dynamometer and analytical equipment using a control vehicle. This will allow the onsite scientists to calculate the delay times and make the correction in their data spreadsheets. When the corrections have been performed the control vehicle will be ran until all systems are performing as required.

Subtask I. Determine and Develop Protocol for Dilution Tunnel to Minimize the Effects of HC Entrainment

BKI will conduct a series of experiments that will determine if 10 hours of tunnel purging is required to achieve a stable dilution tunnel operation. After the designated control vehicle is disconnected from the dilution tunnel transfer tube, the degradation of PM and total hydrocarbon can be monitored on a second by second basis using the real-time PM monitors and the total hydrocarbon instrument. These tests will also be performed on a high emitting vehicle to determine the length of time required to assure that background levels are obtained before testing is resumed.

When this experiment is concluded and results are reviewed, BKI will document and change if necessary, procedures to ensure proper emission measurements for the testing program. BKI will update its SOP to represent any changes in the procedure resulting from the finding.

Subtask J. Test EPA Correlation Vehicles

BKI will test the correlation vehicles provided by EPA at the Kansas City site. Because testing is being performed under ambient conditions (outdoor conditions) all tests will be conducted as close to the Federal Procedure and the previously performed EPA Ann Arbor tests as possible. Also, the same fuel and oil will be used for performing the tests on the correlation vehicles. BKI is expecting at least 3 vehicles ranging from a newer lower mileage vehicle, an intermediate aged and mileage vehicle, and/or an older high emitting vehicle. Test vehicles will be preconditioned on the first day and tested on consecutive days for at least 3 times each. This data will be compared to the results obtained from tests performed in the EPA laboratory in the EPA-AA location. Comparisons will also be performed on tests without heat or humidity control.

Subtask K. Evaluate Test Results and Report Data

Immediately after the correlation vehicles have been tested BKI will begin evaluating the emission data. Within one month after the completion of the correlation vehicle tests the data will be reported. This report will include emission rates obtained for regulated pollutants from any vehicles tested during the pilot study. All documents will be prepared using a version of Microsoft Word or Wordperfect unless otherwise specified in the task order. Electronic media materials will be delivered on 3 ½ “ disks, CD-R, DVD, or hard drive. BKI will develop and maintain files supporting the requirements of each task. This data will be reported to ERG for the inclusion of PM data for the final reporting to EPA’s Project Officer and sponsors for use in their evaluating the results obtained in the pilot study.

Subtask L. Document and Change Procedures and Methods in QAPP

When the Pilot Study portion of the program is concluded and results are reviewed, BKI will document and change, if necessary, procedures and methods, quality assurance and quality control procedures, and data management procedures to be used in the actual in-use vehicle testing project to ensure the proper emission measurements for the testing program.

2.4.2 Vehicle Testing Task (Specialized Sampling and Analytical Needs) (Section 5.3.2)

The project will characterize gaseous and PM exhaust emissions from the test vehicles in accordance with the testing and sample analysis procedures described in Task 5.4. PM continuous and integrated air measurements will be extracted from the BKI dilution tunnel through a low particulate loss 2.5 um cut point pre-classifier. The sample will be isokinetically partitioned among the continuous instruments and integrated air samples using a suitable sample distribution manifold. Continuous measurements include the following instruments to be supplied by the EPA: Brooker Systems Model RPM-101 Quartz Crystal Microbalance (QCM), and Thermo-MIE Inc. DataRam 4000 Nephelometer. In addition, we will supply a DRI photoacoustic instrument for determination of black carbon mass concentrations. Parameters determined from the integrated samples include PM gravimetric mass, elements, elemental and organic carbon, ions, particulate and semi-volatile organic compounds (all compounds in Table 12 of the RFP plus methylated-PAHs and oxy-PAHs, and as an option, nitro-PAHs), volatile organic air toxics (benzene, toluene, xylenes, ethylbenzene, styrene, 1,3-butadiene, n-hexane, naphthalene, formaldehyde, acetaldehyde, acrolein and MTBE. Vehicle testing and sample analysis procedures are described in Task 5.4.

We recognize that not all of the samples specified for collection in Table 7 and 8 of the RFP can be analyzed due to budget limitations. As requested in the RFP, a budget for complete chemical analysis of 50 vehicles is provided. This budget provides for collection of all samples specified in Tables 7 and 8 of the RFP and determination of gravimetric mass for all Teflon filters and analysis of a corresponding proportion (i.e., 50/554) of the blank samples specified in Table 8 of the RFP. In similar sampling programs in the past, various compositing approaches were used to reduced analysis cost without adversely affecting project goals and objectives. These approaches are described in this section.

Recent study such as the U.S. Department of Energy's Gasoline/Diesel PM Split Study and the Northern Front Range Air Quality Study have shown that newer, low mileage gasoline vehicles are low PM emitters. Figure 2-7 shows the distribution of light-duty gasoline vehicle PM_{2.5} mass emission rates by ten model year and mileage categories (Gabele et al, 2003). Figure 2-8 shows the distribution of the same data by ascending mileage accumulation and vehicle age. Of the 57 vehicles tested, all of the 16 vehicles with less than 98K miles and all of the 31 vehicles newer than 11 years had emission rates less than 20 mg/mi. Several vehicles were sampled on the same sampling media for the four cleanest categories in order to improve the signal to blank ratios. We refer to this sampling approach as "media composites" as opposed to a "sample composite", which involves combining several samples by extracting several samples together or by other means prior to chemical analysis. Figure 2-7 also shows that fewer samples were composited for chemical analysis for older, high mileage vehicles. The rationale for compositing approach used in these prior studies reflected budget limitations and limits of analytical sensitivities for various sampling media and analytical methods.

Table 2-6 gives estimate mass loadings for a range of PM mass emission rates by applying suitable parameters for the BKI portable dynamometer, driving cycle, and our various sampling systems. Based upon these estimates, most vehicles newer than ten years and with mileage accumulations less than 100K would yield mass loading well below the optimum target loadings of 200 µg per sample for carbon analysis and 1 mg per sample for all other analyses. Accordingly, we recommend a combination of media and sample composites. Test vehicles were recruited during the Gasoline/Diesel PM Split Study by vehicle category starting with the newest vehicles with low mileage. This was especially important during the first four categories that involved media composites. In these cases, about four vehicles were composited. However, for the present study, vehicles will be brought to the testing facility randomly among the eight vehicle categories and collection of media composites will not be possible. In order to reduce the

effect of media blanks, we propose to extract and analyze the filters and XAD samples (or composites) separately for the two latest model year categories.

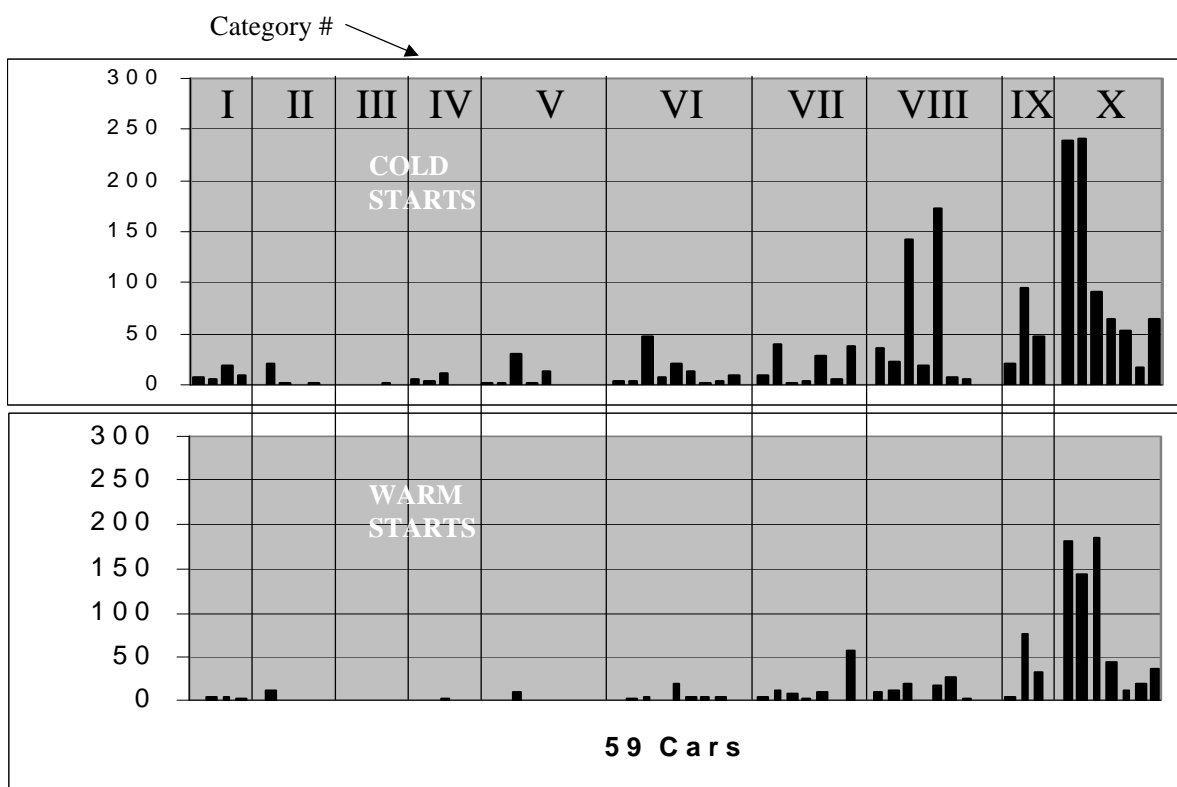


Figure 2-7. Distribution of light-duty gasoline vehicle PM_{2.5} mass emission rates by model year and mileage categories. Preliminary results from the DOE Gasoline/Diesel PM Split Study (Source: Gabele, 2003)

Category	Model Year	Odometer (miles)	Number of Vehicles	Number of Composites
1	1996 and newer	low mileage (< 50,000)	4	1
2	1993-95	low mileage (< 75,000)	4	1
3	1996 and newer	high mileage (> 100,000)	4	1
4	1990-92	lower mileage (< 100,000)	4	1
5	1993-95	higher mileage (> 125,000)	8	2
6	1990-92	> 125,000	9	3
7	1986-89	> 125,000	6	3
8	1981-85	> 125,000	6	3
9	1980 and earlier	> 125,000	6	3
10	Smoker	no model year or odometer criteria	6	6
11	LD Diesel	no model year or odometer criteria	2	2
		Total	59	26

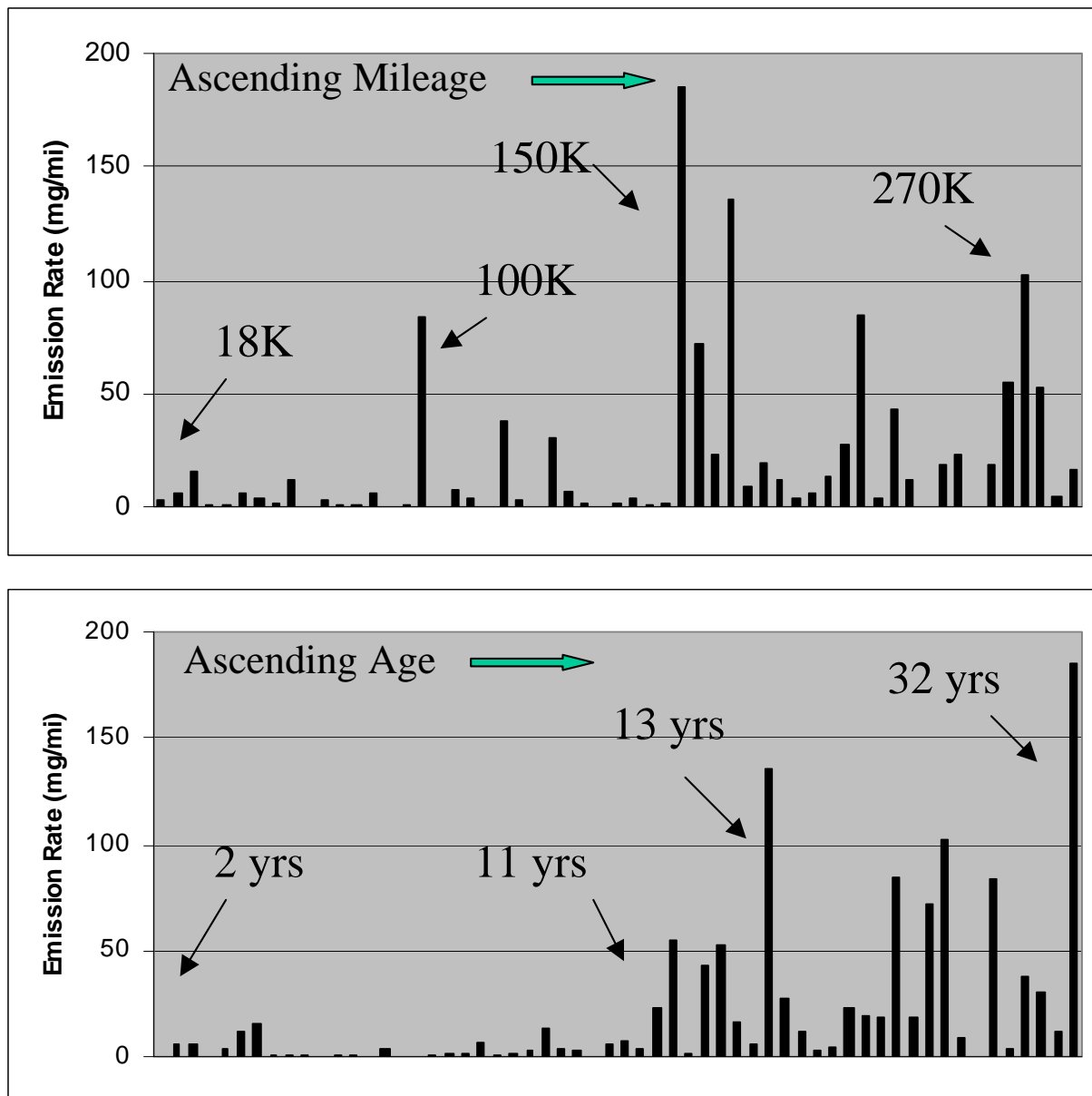


Figure 2-8. Distribution of PM_{2.5} emission rates by ascending mileage accumulation and vehicle age. Preliminary results from the DOE Gasoline/Diesel PM Split Study (Source: Gabele, 2003)

Note that the 16 vehicles with less than 98K miles and 31 vehicles newer than 11 years had emission rates less than 20 mg/mi. (weighted emission rates).

**Table 2-6. Expected PM Mass Loadings for Light-Duty Vehicles
(micrograms per sample)**

Sample	Emission Rate mg/mile	Flow Rate (l/min)	No. of Composites	UC Phase 1 or 3	UC Phase 2	UC Phases 1 plus 2
Teflon and Quartz	5	50	1	20	141	160
	5	50	4	78	562	641
	50	50	1	196	1405	1602
	50	50	2	392	2811	3203
	300	50	1	1177	8433	9609
TIGF/XAD	5	100	1	39	281	320
	5	100	4	157	1124	1281
	50	100	1	392	2811	3203
	50	100	2	784	5622	6406
	300	100	1	2353	16866	19219

^a Target of 1 mg/sample of PM for laboratory analysis except carbon measurements by TOT (200 ug/sample)
DRI will sample at 10 to 50 lpm depending on expected mass loading

Basis for Mass Loading Calculations

Parameters	Symbol	Units	UC Phase 1/3	UC Phase 2	UC Phase 1+2
distance UC P1+P2	d	miles	1.2	8.6	9.8
sample duration UC P1+P2	t	min	5.0	18.9	23.9
total diluted volume UC P1+P2	V _d	m ³	76.5	289.4	365.9
PM emission rate	R	mg/mi		1 to 500	
sample volume	V _s	m ³		$V_s = Q * t * 10^{-3}$	
mass loading	m	ug/sample		$m = R * d * 1000 * V_s / V_d$	
sample volume	V _s	m ³		$V_s = Q * t * 10^{-3}$	
sample flow rate	Q	l/min	10 to 50 for Tef or Qtz, 100 for Organic		
average concentration	C	ug/m ³		m / V_s	

2.4.3 Vehicle Testing Task (Section 5.3.3)

This task includes vehicle check-in and inspections, vehicle conditioning, overnight soak and cold start dynamometer emissions testing over three phases of the LA92 driving cycle with determination of regulated emissions.

2.4.3.1 Protective Covering for Equipment and Test Vehicles (Section 5.3.3.1)

Locations have been identified in the Kansas City Metropolitan area for protection of the analytical testing equipment and the recruited vehicles. To better protect the analytical equipment and the consumer's vehicles from the elements during a study of this magnitude, an industrial warehouse is considered a better choice for testing. The locations identified have drive-in doors for ease of the equipment setup and large loading dock doors that will remain open for continuous ventilation of the area. Large overhead exhaust fans for additional ventilation are also located in the roof of the vehicle test area. The identified areas will maintain the test vehicles at ambient condition during its soak period and allow the background to be maintained at the ambient levels while testing. The testing areas consist of about 10,000 square feet plus additional office space for special analytical equipment setup. Since there could be up to 15 participants' vehicles in the area at any given time, an area of this dimension would allow orderly processing. A big advantage of using a well-ventilated industrial warehouse is the stable source of electrical power available, including 3 phase 480 volt for the dilution tunnel heater. This will allow analytical equipment to be powered up continually, eliminating instrument warm-up time; therefore reducing the time the staff is required to be onsite before vehicle testing can begin.

2.4.3.2 Vehicle Testing and Data Collection (Section 5.3.3.2)

The following subtasks describe procedures that will be undertaken during vehicle testing and data collection.

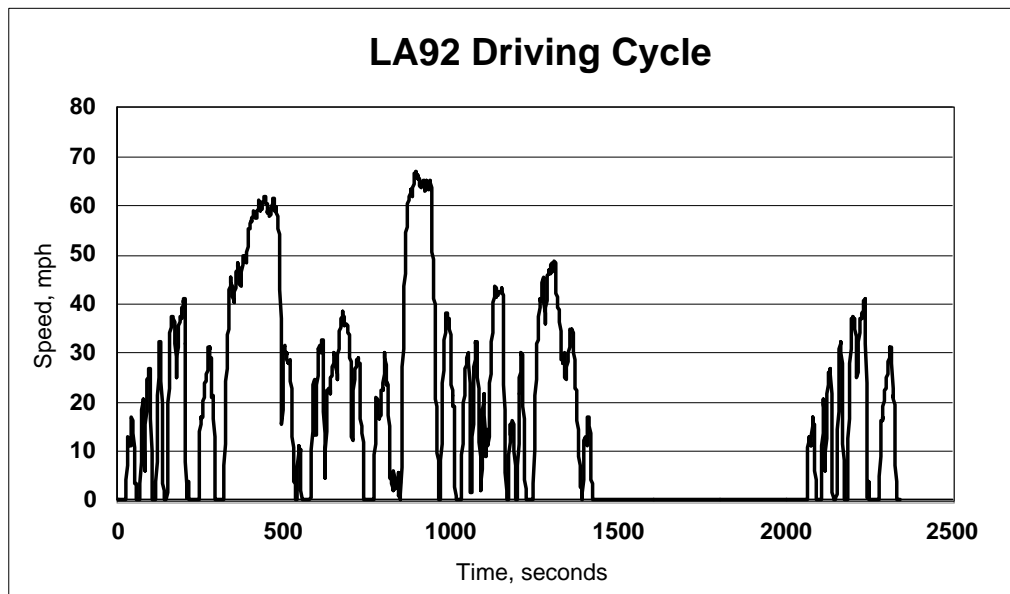
Subtask A. Vehicle Inspections

All vehicles will undergo body and mechanical inspections upon arrival at the test site. These inspections will be performed to reduce to possibility of the owner complaining that the car had been damaged during its testing. After inspections and answering the questionnaire, the agreement and waiver will be signed by the participant and they will receive their incentive and a rental vehicle. After these initial inspections and video, all vehicles with OBD1 and OBD2 systems will be scanned and the results reported along with the type of OBD system on the vehicle. Detailed information on all vehicles will be obtained and recorded on a computerized vehicle information form. Recorded information is not limited to but will include the following:

- Date and time of vehicle procurement
- Date and time of vehicle testing

- Test number
- License plate number
- Make
- Model
- Model year
- Odometer reading
- Vehicle identification number (VIN)
- Engine displacement
- Number of cylinders
- Emission control and catalyst information
- Vehicle registration status
- Fuel and oil information

Subtask B. Vehicle Conditioning



After the vehicle has passed inspections, it will undergo conditioning on a predetermined route. The conditioning route will contain multiple high speed accelerations, a minimum of ten minutes of continuous high speed operation, and low speed operation and idling just prior to the completion of the route. After conditioning, the vehicle will be staged for testing the next day and soaked overnight at ambient conditions. If any abnormalities are found while vehicle

conditioning (smoker, smell) it will be noted in the vehicle folder and entered in to the database and staged for testing last vehicle of the test day.

Subtask C. Vehicle Testing

Vehicle exhaust testing will occur using the EPA Office of Research and Development dynamometer under ambient conditions. Vehicles will be operated over the LA92 Unified Driving Cycle consisting of a cold start Phase 1, (first 310 seconds) a stabilized Phase 2 (311-1427 seconds) a 600 second engine off soak, and a warm start Phase 3 (repeat of Phase 1). A positive displacement pump (PDP-CVS) operating at 540 scfm, will be used to quantitatively dilute exhaust gas from the vehicle operating on the dynamometer through an eight-inch stainless steel dilution tunnel. Dilution air will be dehumidified before it is treated with a charcoal bed followed by a HEPA filter to remove particles prior to being heated $47^{\circ}\text{C} \pm 5^{\circ}\text{C}$ and mixed with vehicle exhaust. Throughout the sample extraction and partition process, the temperature of the sample air at the filter face will be maintained at $47^{\circ}\text{C} \pm 5^{\circ}\text{C}$, and the sample air will be held within the specified humidity range.

As part of the tunnel conditioning process, the CVS and tunnel dilution air heater shall be turned on for a number of hours prior to engine start (as determined during pilot testing) and run to purge the exhaust transfer line and dilution tunnel. Pumps at the analytical bench shall be run at least one hour prior to engine start to purge all sample lines. The CVS, tunnel heater and sample pumps shall be kept running throughout the day and will not be shut down until the conclusion of testing for that day. Testing shall not be started until the temperature in the dilution tunnel has reached a stable value (no increase in temperature over a 3 minute period).

Within two (2) minutes of the start of the initial test of the day, background THC, CO, NO_x , and CO_2 concentrations in the dilution tunnel shall be recorded by the regulated emissions bench operator. These levels shall serve as reference background levels for the tests that immediately follow that day. If prior to the start (within 2 minutes of start) of succeeding tests that day, the background levels measured for that test differ from the reference background by $\pm 15\%$, testing shall be delayed until corrective measures are taken. If the $\pm 15\%$ change in background is due to a change in the ambient background level (not influenced by station exhaust or spillage) and cannot be corrected, the testing may resume with a new set of reference background levels. However, after each test, the ambient background levels shall be monitored by the bench operator so that the reference background levels can be adjusted if ambient levels continue to change.

Background levels of THC from the tunnel filter shall also be monitored by the instrument bench operator for fifteen (15) minutes before the start of a test. If the background level of THC in the dilution tunnel differs by +/- 15% of the background level of THC after the tunnel filter, the test shall be delayed until tunnel levels are adjusted accordingly.

Prior to placing the vehicle on the dynamometer, the proper load and inertia will be set by motoring the dynamometer at 50mph. Vehicle inertia and horsepower loading for each vehicle will be determined by a lookup table developed from the EPA Certified Vehicle Test Reports. After these settings have been applied, the test vehicle will then be winched onto the dynamometer, stabilized, and secured by the restraint system. During this time the CVS will remain on to purge any residual PM and hydrocarbon from the system. The emissions tests will be started when the background levels stabilize. The emission analysis system will sample and record dilute exhaust THC, CO, CO₂, and NO_x concentrations in 1-second intervals during the entire transit driving cycle. Temperature and pressure in the CVS, dynamometer speed, ambient temperature, relative humidity, and barometric pressure will also be recorded in 1-second intervals.

Two hundred and forty vehicles will be tested for each round of this study. Twenty-five vehicles tested during the 1st round will be retested during the 2nd round of testing. These 25 vehicles will be randomly selected from each stratum as required. There will be 15 replicate vehicle tests performed in the Round 1 test phase and 10 replicate tests performed during the Round 2 test phase. Also, there will be a weekly calibration/correlation vehicle tested each week during both Round 1 & 2.

Subtask D. Vehicle Fluid Sampling

BKI will collect fuel and oil samples from all feasible vehicles after the dynamometer tests for analysis. These fuel and oil samples will be transferred to ERG staff onsite and will be maintained for 2 years after the study is complete for possible future analysis.

Subtask E. Maintenance of Emission Equipment

BKI staff will provide for the maintenance, calibration, and operation of the transportable dynamometer and its associated sampling and analytical equipment. Manufacturer's recommendations and SOPs will dictate the types and frequency of routine maintenance performed. Additional maintenance and repairs will also be performed as the need may be indicated through calibrations and other equipment checks. Any malfunctions will be corrected before vehicle testing will continue. Prior to use, all necessary calibrations will be performed.

2.4.3.3 RSD Evaluation (Section 5.3.3.3)

New RSD data can play an important role in verifying that cohort vehicles are tested on the chassis dynamometer in a fully conditioned state and to verify that the vehicle Cohort is indeed representative of the Kansas City fleet at large. It is ERG's opinion that the most important use of RSD in this project will be to compare the Cohort to the Kansas City fleet, especially since many Cohort vehicles will have their emissions tested using a PEMS/PAMS system. (The data from the PEMS/PAMS system can be more readily compared to the chassis dynamometer data than RSD data can. From our research in Arizona we know that knowledge of the last few seconds of how the vehicle was driven is extremely influential on the emissions during a given second of operation. Since RSD systems do not record operating history, RSD data is very difficult to compare to second-by-second dynamometer data.)

It is important that the proper equipment be used to collect RSD data for this project. Environmental Systems Products (ESP) in Tucson, Arizona has developed an opacity measurement process that uses a range of ultraviolet (UV) light to detect exhaust opacity. Because UV radiation has a shorter wavelength than either visible or infrared (IR) light, it is "blocked" and "scattered" by smoke particles that are too small to effect either visible or infrared light. This allows the ESP system to detect opacity that cannot be detected by older RSD equipment (which use only IR light for opacity detection). Therefore, this new system is appropriate for finding smoking vehicles in the fleet. ERG has a contract in place with ESP to provide RSD equipment for this study. This capability may also improve our ability to recruit smoking vehicles for Round 2 testing if we find them to be under-represented during Round 1 testing.

The RSD system will be deployed at several sites near where chassis dynamometer testing is occurring, to allow easy access for Cohort vehicles soon after they are tested. RSD data will also be collected at other sites around Kansas City to ensure that the fleet in general is well represented in the data. From our previous experience with RSD data collection in the Kansas City area, we are familiar with many promising sites for RSD data collection. We are also familiar with the processes required for obtaining encroachment permits for RSD data collection sites. This will allow us to effectively oversee our RSD data provider and to ensure a representative RSD sample. RSD data will be collected during the last month of both Round 1 and Round 2 testing. This will allow us to request participating Cohort vehicles being tested at this time to drive past the RSD equipment (note that only participants whose cars are tested during the last month of each round will have RSD data collected).

2.4.3.4 Vehicle Fluid Sampling (Section 5.3.3.4)

Oil and gasoline samples will be collected from test vehicles when collection does not produce an undue burden on program time and costs. It is anticipated that oil samples will be collected from nearly all, if not all, test vehicles. Approximately 10 ml of oil will be collected and stored for later analysis. Oil sample analyses to be performed are listed in Table 2-7.

Due to gasoline anti-siphoning and evaporative control devices found on most vehicles, only limited collection of gasoline samples from test vehicles is anticipated.

Unused oil and gasoline samples will be stored for a period of 2 years to allow for possible further analysis. At the end of the two-year period, oil and gasoline samples will be recycled.

Table 2-7. Oil Sample Analyses

Test	Method
Sulfur Content	ASTM D4294-90
Viscosity, cST 40°C, kinematic	ASTM D445
Wear Particles, Total Ferrous Particles	ISO 4405
Iron, ppm	Elemental Analysis
Copper, ppm	Elemental Analysis
Tin, ppm	Elemental Analysis
Aluminum, ppm	Elemental Analysis
Boron, ppm	Elemental Analysis
Calcium, ppm	Elemental Analysis
Chloride, ppm	Elemental Analysis
Sulfur, ppm	Elemental Analysis
As, ppm	Elemental Analysis
Cr, ppm	Elemental Analysis
Phosphorous, ppm	Elemental Analysis
Silicon, ppm	Elemental Analysis
Nickel, ppm	Elemental Analysis
Lead, ppm	Elemental Analysis
Magnesium, ppm	Elemental Analysis
Sodium, ppm	Elemental Analysis
Zinc, ppm	Elemental Analysis
Water, % (Karl Fisher)	ASTM D4926
Glycol	Infrared Analysis FT-IR
Total Acid Number, mg KOH/g	ASTM D664
Chromium, ppm	Elemental Analysis

2.4.3.5 PEMS/PAMS Data (Section 5.3.3.5)

Portable emission measurement systems (PEMS) and portable activity measurement systems (PAMS) will be used to collect on-road emissions and driving data on a randomly selected group of vehicles that have been tested on the chassis dynamometer. The purpose of collecting these data is to improve EPA's understanding of "real world" vehicle operations and emissions. The data will also be added to the MSOD database, which EPA will use in the creation of the MOVES model. The data will be ideal for MOVES since it will be collected on a carefully selected set of vehicles from a metropolitan area which does not yet require an I/M program.

EPA will supply at least eight PEMS/PAMS devices and train ERG team personnel on their use. ERG team personnel will install and de-install the equipment on vehicles selected using a method suggested by our team and approved by EPA. Procedures specified in the PEMS/PAMS QAPP will be strictly followed during installation, de-installation, data download, and equipment maintenance. These procedures are described in detail in Appendix A of this document. Whenever possible the installation and de-installation will occur at the dynamometer test site.

ERG proposes to further investigate vehicle selection methods in collaboration with EPA. The strata to be used selecting PEMS/PAMS vehicles do not necessarily need to be the same as those used to select vehicles for dynamometer tests. Since the PEMS/PAMS equipment collects driving information, it may be advantageous to consider vehicle characteristics that help dictate how a vehicle is driven in selecting the strata. For example, vehicles with a low “power-to-weight ratio” are likely to be driven quite differently than vehicles with a high “power-to-weight ratio.” Yet, that ratio will not likely play a prominent role in selecting vehicles for dynamometer testing. If, after consultation with EPA it is decided to capture this or other vehicle characteristics in the sample strata, our team will design a special set of strata for the PEMS/PAMS vehicles.

Owners of the selected vehicles will be instructed on their agreed duties before their vehicles have a PEMS/PAMS unit installed. These owners will agree to drive their vehicles in the manner they normally would (as if the PEMS/PAMS unit were not present on their vehicle). They will also be required to keep a log of significant events during the testing period (e.g., changes in vehicle load, such as passengers entering and leaving the vehicle). PEMS devices will be typically be installed for a period of 1 to 3 days, with each PEMS device installed on about 20 individual vehicles. Similarly, the PAMS devices will be installed for a period of 1 to 7 days, with each PAMS device installed on about 10 to 12 vehicles.

After the device has been present on their vehicle for the prescribed time period, the owner will return to the project data collection location to have the PEMS/PAMS unit removed. The owner will be interviewed at that time to determine various information about their experience and events that occurred during their participation (no demographic information will be solicited during the interview). The questions we propose to ask the drivers are:

- Did you drive any differently than you normally drive while the PEMS/PAMS device was installed on your vehicle?

- Do you feel that having the device on your vehicle caused you to drive any differently than you normally drive?
- Did the device cause your vehicle to behave any differently than it normally does?

In the occasional instance where a vehicle owner is unable to meet at the testing location, ERG will arrange to meet the owner at a more convenient location for de-installation.

After de-installation the collected data will be downloaded and quality assured in accordance with the applicable QAPP. Any necessary equipment maintenance and preparation for the next installation will also occur at that time.

2.4.3.6 Vehicle Testing Reports (Section 5.3.3.6)

Vehicle data, regulated emission results and visible smoke observation results will be provided to ERG. This data will be compiled and provided in Lotus123 format for final reporting to the EPA Project Officer. This data will be provided in a draft report within two months following vehicle testing. The draft report will also include a description of data gathering and testing methods used in the study.

At the conclusion of the project, BKI staff will prepare and transport the transportable dynamometer and analytical trailer back to EPA in RTP NC. Before transport the dynamometer system will be inspected and packed for shipment. All components and analytical equipment will be strapped down and secured for over the road transportation.

2.5 Speciation Tasks (Section 5.4)

In addition to the regulated gas pollutants measured by BKI, DRI will provide continuous measurements of PM mass using an EPA-supplied Brooker Systems Model RPM-101 Quartz Crystal Microbalance (QCM) and Thermo-MIE Inc. DataRam 4000 Nephelometer. Black carbon will be measured continuously with a DRI photoacoustic instrument and integrated samples will be collected and analyzed by DRI for PM gravimetric mass, elements, elemental and organic carbon, ions, particulate and semi-volatile organic compounds (all compounds in Table 12 of the RFP plus methylated-PAHs and oxy-PAHs, and as an option, nitro-PAHs), volatile organic air toxics (benzene, toluene, xylenes, ethylbenzene, styrene, 1,3-butadiene, n-hexane, naphthalene, formaldehyde, acetaldehyde, acrolein and MTBE. Continuous PM and integrated air measurements that will be made during the study are summarized in Table 2-8.

The samples will be extracted from the BKI dilution tunnel through a low particulate loss 2.5 um cut point pre-classifier. The sample will be isokinetically partitioned among the

continuous instruments and integrated air samples using a suitable sample distribution manifold. The proposed sampling configuration is summarized in Table 2-9. Separate Teflon and quartz filters will be collected for each of the three phases of the Unified Driving Cycle (UDC) using a sequential sampler. All other integrated samples will be collected over all three phases of the cycle, excluding the 10-minute soak period between phases 2 and 3. The number of samples collected and analyzed during the pilot study and rounds 1 and 2 of the main study are summarized in Tables 2-6 and 2-7, respectively. The chemical species that will be identified and quantified are listed in Tables 2-8 through 2-12.

The planned oil sample analysis does not include detailed organic speciation. Recent studies have shown that emission rates of high-molecular weight PAHs, which are surrogates for POM (on EPA's HAP list), are correlated with the concentration of these PAHs in lubrication oil. If additional funding is available, a few oil samples from high emitters and smokers should be speciated and compared to their relative abundances in exhaust and compared to the relative abundance of these high-molecular weight PAHs in new unused motor oil.

2.5.1 Pilot Methods Testing Task (Section 5.4.1)

A pilot test will be conducted in the Kansas City area to determine and finalize testing methodologies, quality assurance and quality control procedures and data management procedures. Three vehicles will be tested in triplicate at the Kansas City site. The vehicles will also be tested at the EPA laboratory in Ann Arbor. DRI will measure continuous PM and black carbon during the pilot study in Kansas City. Collection and analysis of the integrated samples are provided as shown on Table 2-10. BKI and DRI will review, document, and change if necessary, all procedures, methods, and sample analyses to ensure proper handling and emission measurements for the testing program. BKI and DRI will update the QAPP to represent any changes in the procedures or methods, resulting from the pilot study.

Because semi-volatile organic compounds are a significant component of emissions from LDGVs relative to emissions of PM, both continuous and integrated PM measurements will vary depending upon the partitioning of organic material between the gaseous and particulate phases. The affect of phase distribution on particulate mass measurements is generally more significant for gasoline-powered vehicles than for diesel-powered vehicles because the fraction of organic aerosol to elemental carbon is typically higher for LDGVs, especially for the high emitters.

2.5.2 Source Testing Equipment Preparation Task (Section 5.4.2)

DRI will provide and prepare sampling equipment and sampling substrates required to the collection of samples listed in Table 2-8. Table 2-9 summarizes the proposed sampling configurations for source characterization measurements. We will pre-test the continuous and integrated sampling equipment prior to installation at the pilot testing site to ensure proper operation and familiarity by field personnel. DRI will provide personnel to operate the samplers and collect and store each sample.

2.5.3 Operating Continuous Measurements of Fine PM Task (Section 5.4.3)

Continuous measurements include the following instruments to be supplied by the EPA: Brooker Systems Model RPM-101 Quartz Crystal Microbalance (QCM) and Thermo-MIE Inc. DataRam 4000 Nephelometer. In addition, we will supply a DRI photoacoustic instrument for determination of black carbon mass concentrations. Additional information on these instruments is provided in Table 2-18. We will also provide measurements of mass and BC concentrations collected during dynamic tunnel blank samples collection to evaluate the condition of the dilution tunnel before conducting tests on the next vehicle. These continuous methods for measurement of fine particulate mass provide several useful data products as well as immediate feedback about the nature of the emissions from vehicles or ambient concentrations. With a time resolution between 0.5 and 5 seconds per update, these methods are ideally suited to identify the portions of a driving cycle where particulate emissions are greatest and least. Rapid time response is also useful for the successful deployment of dilution tunnels to provide knowledge of the state of the tunnel. For example, they are useful in determining if a tunnel has been adequately flushed between measurements. The elemental carbon mass versus total particulate mass can be determined from the use of the photoacoustic instrument to measure elemental carbon and QCM instrument or nephelometer for total particulate emissions. The continuous data may also be time-averaged and accumulated (in real-time) to provide total elemental carbon emission and total particulate emission for use in comparison of the data with that obtained from Thermal Optical Reflectance (TOR) analysis and gravimetric analysis of aerosol accumulation on Teflon or quartz filters. The accumulated particulate mass as a function of time may also be useful in determining the length of a run necessary for accumulating adequate particulate mass for other run-averaged samplers such as those used to differentiate between particle and gas phase polycyclic aromatic hydrocarbons (PAH). DRI will provide estimates of cumulative particulate mass loading for each of the samples collected for subsequent chemical analysis at the conclusion of each run.

The continuous monitors will all sample from a common sampling manifold. They will provide real time graphical output as an aid for judging the best likely sampling strategy for filter samplers. The photoacoustic instrument will be equipped with pressure, temperature, and relative humidity sensors so that the mass concentration can be adjusted to the desired ambient condition of pressure and temperature. Data from the real-time sensors can also be used to evaluate total particulate emissions by accumulating it over the sample period, and can be compared with data from the filter samplers. It is recommended that all personnel agree on a single set of standard conditions, such as 1 atmosphere of pressure and 273 K temperature, and adjust all data so that applies to these conditions.

2.5.3.1 Quartz Crystal Microbalance (QCM) (Section 5.4.3.1)

A Quartz Crystal Microbalance is a thin, usually round, slice of crystalline quartz with an electrode on each side. If the two electrodes are put at different potentials an electric field results across the QCM, i.e. in the "Y direction". Because of the piezoelectric properties of quartz, such an electric field in the "y direction" couples to shear motion "around" the z-axis, and vice versa. The end result is that shear waves in the quartz, in which the mechanical displacement is in the "x" direction, also called the electric axis, are coupled to voltage between the electrodes. QCMs are used as sensitive detectors of mass deposited on them. This added mass decreases the resonant frequency of the QCM. The added mass per unit area on the QCM can be calculated by measuring the decrease in the resonant frequency of the QCM. Because frequency changes can be measured to very high precision, QCMs are very sensitive. They can measure amounts of deposited material with an average thickness of less than a single atomic layer. Hence the "microbalance" part of their name.

QCMs have been used to make "sniffers" for monitoring air pollution. This is done by having an array of QCMs, each topped with a different thin film which absorbs a particular set of chemicals. When these chemicals are present in the environment they are absorbed, increasing the mass of the QCM and decreasing its resonant frequency. The pattern of which sensor's frequency decrease gives information about what chemicals are present in the environment.

2.5.3.2 Tapered Element Oscillating Microbalance (Section 5.4.3.2)

No TEOM instrument will be used during the emissions testing procedures.

2.5.3.3 Nephelometer (Section 5.4.3.3)

Nephelometers measure light scattered by aerosol introduced into their sample chamber. Nephelometers can be fairly simple and compact instruments with excellent sensitivity and time

resolution. However, scattering per unit mass is a strong function of particle size and refractive index. If particle size distributions and refractive indices in exhaust strongly depend on the particular engine and operating condition, this may not be an effective way to measure exhaust particle mass. However, it has been shown that mass scattering efficiencies for both on-road diesel exhaust and ambient fine particles have values around 3 square meters per gram. Mass scattering efficiencies for exhaust sampled from a dilution tunnel may be significantly lower. For this project, Thermo-MIE Data Ram 4000 nephelometer will be used. The MIE data Ram nephelometer measures simultaneously at two wavelengths for the purpose of reducing the uncertainty in the mass scattering coefficient.

2.5.3.4 Photoacoustic Instrument (Section 5.4.3.4)

The photoacoustic instrument has been developed at DRI and has been described in several publications (Arnott, Moosmüller et al. 1999; Arnott, Moosmüller et al. 2000). Briefly, light from a 1047 nm laser is power-modulated at the operating frequency of an acoustical resonator. Sample air is continuously drawn through the resonator at a flow rate of 1 – 3 lpm. Light absorbing aerosol (black carbon) will absorb some of the laser power, slightly heating the aerosol (typically much less than 1 C). The heat transfers very rapidly from the aerosol to the surrounding air, and the local pressure increases, contributing to the standing acoustic wave in the resonator. The acoustic wave is measured with a microphone as a measure of the light absorption. For the operating conditions of the resonator, and the laser wavelength used, the light absorption measurement is linearly proportional to the mass concentration of the black carbon aerosol in the sample air. The constant of proportionality has been inferred from correlations of black carbon measurements with elemental carbon as determined by the TOR method, and an efficiency factor of 5 square meters per gram is used to go from aerosol light absorption to estimated black carbon mass concentration. No filters are needed for the photoacoustic measurement, and the flow rate is not used in the calculation of aerosol mass concentration. The flow rate must only be sufficient to adequately sample the air with minimal particle loss in the instrument and sample lines. The resolution of the instrument for a 3 second averaging time is usually 2.5 inverse Mm for light absorption, corresponding to 0.5 microgram per cubic meter for black carbon mass concentration. The resolution scales as the square root of sampling time, so for example, a resolution of 0.25 micrograms per cubic meter can be obtained for a 9 second averaging time. The photoacoustic measurement does not receive interference from exhaust gases, in our experience so far, and it is a zero-based measurement when no light absorbing aerosols are present.

2.5.4 Integrated Sample Collection and Sample Analyses Task (Section 5.4.4)

DRI will provide and prepare sampling equipment and sampling substrates required for the collection of the samples listed in Table 2-10. The vehicles will be tested on the EPA transportable dynamometer using a Unified Driving Cycle that will be composed of three phases. Separate samples will be collected for each phase of each vehicle for gravimetric mass and OC/EC. DRI will provide a sequential filter sampler with a PM_{2.5} inlet in which two filters (Teflon and quartz) sample concurrently at up to 55 lpm each. The sequential filter sampler has sufficient number of ports to allow for collection of at least three pairs of filter samples without the need for filter changes during the three phases of the Unified Driving Cycle. DRI will also provide a parallel sequential sampler for collection of samples on Teflon-impregnated glass fiber (TIGF) filters with a backup cartridge consisting of XAD-4 resin. DRI will provide personnel to operate the samplers.

DRI will acceptance test the Teflon and quartz filters and pre-weigh Teflon filters. Pre-labeled filter packs will be prepared and shipped to the test site. DRI will also acceptance test TIGF filters and XAD-4 resin packs and prepare and ship TIGF filters and XAD plug-in cartridges to the test site. DRI will post-weigh all Teflon filters for PM_{2.5} mass. DRI will perform chemical analysis as follows: Teflon filters by Inductively Coupled Plasma Mass Spectrometry for elements Na to U; quartz filters by ion chromatography for chloride, nitrate and sulfate ion, quartz filters for elemental and organic carbon by thermal optical reflectance carbon analysis (TOR) using the IMPROVE protocol; TIGF/XAD samples for PAHs, methylated-PAHs, oxy-PAHs, nitro-PAHs (optional), hopanes, steranes, organic acids, cycloalkanes and alkanes (as listed in Table 2-12, 2-14, 2-15 and 2-16) by GC/MS. Each sample collected for mass and EC/OC will be analyzed separately. Whether samples are composited for analysis of other analytes will be decided in consultation with ERG and the EPA project manager after reviewing the continuous mass and black carbon data.

The following substrates are proposed for this program:

- Gelman (Ann Arbor, MI) polymethylpentane ringed, 2.0 mm pore size, 47 mm diameter PTFE Teflon-membrane filters (#RPJ047) for particle mass, elements, and particulate organic acids
- Pallflex (Putnam, CT) 47 mm diameter pre-fired quartz-fiber filters (#2500 QAT-UP) for water soluble chloride, nitrate, sulfate, ammonium, and potassium measurements, and for organic and elemental carbon measurements

- Pallflex (Putnam, CT) TX40HI20-WW 102 mm diameter teflon-impregnated glass fiber filters for the DRI Sequential Fine Particulate/Semi-Volatile Organic Compounds Sampler (PSVOC sampler)
- Polystyrene-divinylbenzene resins, XAD-4 in cartridges for collection of semi-volatile PAH. The Amberlite XAD-4 resin (20-60 mesh) is purchased from Aldrich Chemical Company, Inc.

Filters require treatment and representative chemical analyses before they can be used. Excessive blank levels and filter interferences discovered during or after several important air quality studies have compromised their results. At least two filters from each lot (typically 100 filters) received from the manufacturers will be analyzed for species to verify that pre-established specifications have been met. Lots will be rejected if they do not pass this acceptance test. Each filter will be individually examined over a light table prior to use for discoloration, pinholes, creases, or other defects. In addition to laboratory blanks, 5 to 10% of all filters will be designated as field blanks to follow handling procedures, except for actual sampling.

In addition to acceptance testing, some filters will require pre-treatment before sampling. Quartz-fiber filters may absorb organic vapors with time. Blank quartz-fiber filters will be heated in air for at least three hours at ~900 °C prior to acceptance testing analysis. Sets of filters with levels exceeding 1.5 mg/cm² for organic carbon and 0.5 mg/cm² for elemental carbon will be re-fired or rejected. Pre-fired filters will be sealed and stored in a freezer prior to preparation for field sampling. XAD-4 is placed in a Buchner funnel and rinsed with distilled water three times followed by technical grade methanol 3-4 times, and again three times with distilled water. It is then further cleaned by Soxhlet extraction for 48 hours with methanol, followed by Dionex accelerated solvent extraction (ASE) for 15min/cell with ~170 mL of dichloromethane (CH₂Cl₂) and acetone at 1500 psi and 100°C. (The Dionex ASE unit provides automated sequential solvent extractions with temperature and pressure controls. ASE will be used in place of sequential Soxhlet extraction, which requires more solvent and more time.) The XAD-4 is then dried in a vacuum oven at -15 to -20 in Hg and 50 °C. Cleaned XAD-4 is transferred to clean 1L glass jars and stored in aluminum cans with activated charcoal. The TIGF filters will be cleaned by sonification in CH₂Cl₂ for 30 minutes, followed by another 30-minute sonification in methanol. Then they will be dried, placed in aluminum foil, and labeled. Each batch of precleaned XAD-4 resin and ~10% of precleaned TIGF filters are checked for blank levels. Batches with more than 10 µg of naphthalene are recleaned and rechecked. The XAD-4 resins will be assembled into glass cartridges (50 g of XAD between two screens), wrapped in aluminum foil and stored in a clean freezer prior shipment to the field.

At times, batches of Gelman ringed Teflon-membrane filters have yielded variable (by up to 100 µg per 47 mm filter over a few days) blank masses. As the time between manufacture and use increases, this variability decreases. Since Gelman has minimized its long-term inventory of these filters, and is manufacturing them on an as-ordered basis, this variability has been observed with greater frequency, though it is not widely reported. A one-month storage period in a controlled environment, followed by one week of equilibration in the weighing environment, appear to have reduced the variability to acceptable (within ± 15 µg per filter for re-weights of 47 mm and 37 mm diameter filters) levels. DRI has enough stock of these preconditioned filters to easily accommodate this study. The results of the laboratory filter treatments, chemical analyses, and visual inspections are recorded in a database with the lot numbers. A set of filter IDs is assigned to each lot so that a record of acceptance testing can be associated with each sample.

2.5.5 Integrated Sample Analyses Task (Section 5.4.5)

A summary of information on the PM instruments described below is provided in Table 2-19.

2.5.5.1 PM_{2.5} Mass Gravimetric Analysis (Section 5.4.5.1)

Unexposed and exposed Teflon-membrane filters are equilibrated at a temperature of 20 ± 5 °C and a relative humidity of 30 \pm 5% for a minimum of 24 hours prior to weighing. Weighing is performed on a Cahn 31 electro microbalance with ± 0.0001 mg sensitivity. The charge on each filter is neutralized by exposure to a polonium source for 30 seconds prior to the filter being placed on the balance pan. The balance is calibrated with a 20 mg Class M weight and the tare is set prior to weighing each batch of filters. After every 10 filters are weighed, the calibration and tare are re-checked. If the results of these performance tests deviate from specifications by more than ± 5 µg, the balance is re-calibrated. If the difference exceeds ± 15 µg, the balance is recalibrated and the previous 10 samples are re-weighed. Per DRI's Standard Operating Procedure, at least 30% of the weights are checked by a second technician and samples are re-weighed if these check-weights do not agree with the original weights within ± 0.015 mg. Pre- and post-weights, check weights, and re-weights (if required) are recorded on data sheets as well as being directly entered into a data base via an RS232 connection. All PM_{2.5} and PM₁₀ Teflon filters will be analyzed for mass. All weights are entered by filter number into the DRI aerosol data base.

2.5.5.2 Elements (Section 5.4.5.2)

Teflon-membrane filters will be analyzed with a Thermo Elemental X7 Inductively Coupled Plasma Mass Spectrometer with Collision Cell and Xi interface for the following elements: Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Br, Rb, Sr, Y, Zr, Mo, Pd, Ag, Cd, In, Sn, Sb, Ba, La, Au, Hg, Tl, Pb, and U.

Table 2-13 compares the elements that are quantified by XRF and ICP-MS and the associated minimum detection limits. Neither method will provide data for all specified elements. We recommend a combination of XRF using DRI protocol A and ICP-MS for selected elements (definitely Pb and Hg and possibly As, Zn, Ni, Mn and Cr). Note that Boron will not be analyzed, as it cannot be investigated using XRF or ICP-MS.

A quality control standard and a replicate from a previous batch are analyzed with each set of 14 samples. When a quality control value differs from specifications by more than $\pm 5\%$ or when a replicate concentration differs from the original value (when values exceed 10 times the detection limits) by more than $\pm 10\%$, the samples are re-analyzed. If further tests of standards show that the system calibration has changed by more than $\pm 2\%$, the instrument is re-calibrated as described above. All ICP-MS results are directly entered into the DRI data bases.

2.5.5.3 EC/OC (Section 5.4.5.3)

The thermal/optical reflectance (TOR) method measures organic (OC) and elemental (EC) carbon. The TOR method is based on the principle that different types of carbon-containing particles are converted to gases under different temperature and oxidation conditions. The different carbon fractions from TOR are useful for comparison with other methods which are specific to a single definition for organic and elemental carbon. These specific carbon fractions also help distinguish among seven carbon fractions reported by TOR:

- The carbon evolved in a helium atmosphere at temperatures between ambient and 120 °C (OC1)
- The carbon evolved in a helium atmosphere at temperatures between 120 °C and 250 °C (OC2)
- The carbon evolved in a helium atmosphere at temperatures between 250 °C and 450 °C (OC3)
- The carbon evolved in a helium atmosphere between 450 °C and 550 °C (OC4)
- The carbon evolved in an oxidizing atmosphere at 550 °C (EC1)

- The carbon evolved in an oxidizing atmosphere between 550 °C and 700 °C (EC2)
- The carbon evolved in an oxidizing atmosphere between 700 °C and 800 °C (EC3)

The thermal/optical reflectance carbon analyzer consists of a thermal system and an optical system. The thermal system consists of a quartz tube placed inside a coiled heater. Current through the heater is controlled to attain and maintain pre-set temperatures for given time periods. A portion of a quartz filter is placed in the heating zone and heated to different temperatures under non-oxidizing and oxidizing atmospheres. The optical system consists of a He-Ne laser, a fiber optic transmitter and receiver, and a photocell. The filter deposit faces a quartz light tube so that the intensity of the reflected laser beam can be monitored throughout the analysis.

As the temperature increases from ambient (~25 °C) to 550 °C, organic compounds are volatilized from the filter in a non-oxidizing (He) atmosphere while elemental carbon is not oxidized. When oxygen is added to the helium at temperatures greater than 550 °C, the elemental carbon burns and enters the sample stream. The evolved gases pass through an oxidizing bed of heated manganese dioxide where they are oxidized to carbon dioxide, then across a heated nickel catalyst which reduces the carbon dioxide to methane (CH₄). The methane is then quantified with a flame ionization detector (FID).

The reflected laser light is continuously monitored throughout the analysis cycle. The negative change in reflectance is proportional to the degree of pyrolytic conversion from organic to elemental carbon which takes place during organic carbon analysis. After oxygen is introduced, the reflectance increases rapidly as the light-absorbing carbon is burned off the filter. The carbon measured after the reflectance attains the value it had at the beginning of the analysis cycle is classified as elemental carbon. This adjustment for pyrolysis in the analysis is significant, as high as 25% of organic or elemental carbon, and it cannot be ignored.

The system is calibrated by analyzing samples of known amounts of methane, carbon dioxide, and potassium hydrogen phthalate (KHP). The FID response is ratioed to a reference level of methane injected at the end of each sample analysis. Performance tests of the instrument calibration are conducted at the beginning and end of each day's operation. Intervening samples are re-analyzed when calibration changes of more than $\pm 10\%$ are found.

Known amounts of American Chemical Society (ACS) certified reagent grade crystal sucrose and KHP are committed to TOR as a verification of the organic carbon fractions. Fifteen

different standards are used for each calibration. Widely accepted primary standards for elemental and/or organic carbon are still lacking. Results of the TOR analysis of each filter are entered into the DRI data base.

2.5.5.4 Ion Chromatographic Analysis for Chloride, Nitrate, and Sulfate (Section 5.4.5.4)

Water-soluble chloride, nitrate, sulfate, ammonium, sodium, and potassium are obtained by extracting the quartz-fiber particle filter in 15 ml of deionized-distilled water (DDW). The extraction vials are capped and sonicated for 60 minutes, shaken for 60 minutes, then aged overnight to assure complete extraction of the deposited material in the solvent. The ultrasonic bath water is monitored to prevent temperature increases from the dissipation of ultrasonic energy in the water. After extraction, these solutions are stored under refrigeration prior to analysis.

Water-soluble chloride (Cl^-), nitrate (NO_3^-), and sulfate (SO_4^{2-}) are measured with the Dionex 2020i (Sunnyvale, CA) ion chromatograph (IC). In IC, an ion-exchange column separates the sample ions in time for individual quantification by a conductivity detector. Prior to detection, the column effluent enters a suppressor column where the chemical composition of the component is altered, resulting in a matrix of low conductivity. The ions are identified by their elution/retention times and are quantified by the conductivity peak area. Approximately 2 ml of the filter extract are injected into the ion chromatograph. The resulting peaks are integrated and the peak integrals are converted to concentrations using calibration curves derived from solution standards. The Dionex system for the analysis of Cl^- , NO_3^- , and SO_4^{2-} contains a guard column (AG4a column, Cat. No. #37042) and an anion separator column (AS4a column, Cat. No. #37041) with a strong basic anion exchange resin, and an anion micro membrane suppressor column (250 × 6 mm ID) with a strong acid ion exchange resin. The anion eluent consists of sodium carbonate (Na_2CO_3) and sodium bicarbonate (NaHCO_3) prepared in DDW. The DDW is verified to have a conductivity of less than 1.8×10^{-5} ohm/cm prior to preparation of the eluent. For quantitative determinations, the ion chromatograph is operated at a flow rate of 2.0 ml/min.

The primary standard solution containing NaCl, NaNO_3 , and $(\text{Na})_2\text{SO}_4$ are prepared with reagent grade salts which were dried in an oven at 105 °C for one hour and then brought to room temperature in a desiccator. These anhydrous salts are weighed to the nearest 0.10 mg on a routinely calibrated analytical balance under controlled temperature (~20 °C) and relative humidity (±30%) conditions. These salts are diluted in precise volumes of DDW. Calibration standards are prepared at least once within each month by diluting the primary standard solution

to concentrations covering the range of concentrations expected in the filter extracts and stored in a refrigerator. The calibration concentrations prepared are at 0.1, 0.2, 0.5, 1.0, and 2.0 mg/ml for each of the analysis species.

Calibrations curves are performed weekly. Chemical compounds are identified by matching the retention time of each peak in the unknown sample with the retention times of peaks in the chromatograms of the standards.

A DDW blank is analyzed after every 20 samples and a calibration standard is analyzed after every 10 samples. These quality control checks verify the baseline and calibration, respectively. Environmental Research Associates (ERA, Arvada, CO) standards are used daily as an independent quality assurance (QA) check. These standards (ERA Wastewater Nutrient and ERA Mineral WW) are traceable to NIST simulated rainwater standards. If the values obtained for these standards do not coincide within a pre-specified uncertainty level (typically three standard deviations of the baseline level or $\pm 5\%$), the samples between that standard and the previous calibration standards are re-analyzed.

After analysis, the printout for each sample in the batch is reviewed for the following: 1) proper operational settings, 2) correct peak shapes and integration windows, 3) peak overlaps, 4) correct background subtraction, and 5) quality control sample comparisons. When values for replicates differ by more than $\pm 10\%$ or values for standards differ by more than $\pm 5\%$, samples before and after these quality control checks are designated for re-analysis in a subsequent batch. Individual samples with unusual peak shapes, background subtractions, or deviations from standard operating parameters are also designated for re-analysis.

2.5.5.5 Semi-Volatile Organic Compounds (Section 5.4.5.5)

Prior to extraction, the following deuterated internal standards are added to each filter-sorbent pair: naphthalene-d₈, acenaphthylene-d₈, phenanthrene-d₁₀, anthracene-d₁₀, chrysene-d₁₂, fluoranthene-d₁₀, pyrene-d₁₀, benz[a]anthracene-d₁₂, benzo[e]pyrene-d₁₂, benzo[a]pyrene-d₁₂, benzo[k]fluoranthene-d-12, coronene-d-12, and benzo[g,h,i]perylene-d₁₂, high molecular weight aliphatic hydrocarbons ranging from dodecane-d₂₆ to octacosane-d₅₈, cholestane-d₄; and polar organics ranging from benzoic-d₃ acid to cholesterol-d₆. The filter-XAD pairs will be extracted by Dionex ASE with dichloromethane followed by acetone to expand the polarity range of analytes; these extraction solvents have been reported to yield high recovery of PAH (Chuang et al., 1987) and other compounds of interest (Hawthorne et al., 1988, 1989).

The extracts are then combined and concentrated by rotary evaporation at 20 °C under gentle vacuum to ~1 mL and filtered through 0.45 mm Acrodiscs (Gelman Scientific), with the sample flask rinsed twice with 1 mL CH₂Cl₂ each time. Approximately 100 µL of acetonitrile is added to the sample and CH₂Cl₂ was evaporated under a gentle stream of nitrogen. The final sample volume is adjusted to 1 mL with acetonitrile. This procedure has been tested by Atkinson et al. (1988). The detailed procedure is described in DRI standard operating procedures.

The extracts are then split into two fractions. The first fraction is analyzed without further alteration for PAH, alkanes, hopanes, and steranes by a GC/MS using an electron impact select ion storage (SIS) method. The second fraction is derivatized using a mixture of bis(trimethylsilyl)trifluoroacetamide (BSTFA), trimethylsilylchlorosilane (TMCS), and silylation grade pyridine to convert the polar compounds into their trimethylsilyl derivatives for analysis of organic acids, cholesterol, sitosterol, and levoglucosan. Samples are then analyzed by GC/MS using isobutane chemical ionization SIS method.

For hopanes and steranes, the samples are precleaned prior to GC/MS analysis using a solid phase extraction (SPE) technique described by Wang et al. (1994a,b). Clean up is conducted on a 6ml Supelco SPE cartridge packed with 0.5g of SiOH. Samples are spiked on to a SPE cartridge along with ten microliters of n_tetacosane-d50 (internal standard) and the PAH internal standard described above. Elution and fractionation is conducted with 1ml of hexane followed by 1.25 ml of benzene/hexane (1:1). Hopanes and steranes are eluted along with n_tetacosane-d50 in the hexane fraction, while the PAH are eluted in the hexane/benzene with the PAH internal standards.

The samples are analyzed either by the EI (electron impact) or isobutane chemical ionization (polar compounds) GC/MS technique. A Varian Star 3800CX GC equipped with an 8200CX Automatic Sampler and interfaced to a Varian Saturn 2000 Ion Trap was used for these analyses. Injections (1 µL) were made in the splitless mode onto a 30 m 5% phenylmethylsilicone fused-silica capillary column (DB-5ms, J&W Scientific). Quantification of the individual compounds is obtained by selective ion storage (SIS) technique, monitoring the molecular ion (or the characteristic ion) of each compound of interest and the corresponding deuterated internal standard, added prior to extraction. Calibration curves for the GC/MS quantification are made for the most abundant and characteristic ion peaks of the hopanes, steranes, PAH and other organic compounds of interest using the deuterated species most closely matched in volatility and retention characteristics as internal standards. Authentic PAH standards (purchased from Aldrich, Inc.) plus National Institute of Standards and Technology

(NIST) Standard Reference Material (SRM) 1647 (certified PAH) with the addition of deuterated internal standards and of those compounds not present in the SRM (i.e., methoxylated phenols, hopanes, steranes, lactones, cholesterol) are used to make calibration solutions. For quantifying hopanes and steranes the following authentic standards are used: C27 20R-5a,14a,17a-cholestane (purchased from Aldrich), 17b(H),21b (H)-hopane, 17a(H),21b(H)-30-norhopane, and 17a(H),21b(H)-hopane (purchased from Chiron AS, Norway). The remaining hopane and steranes are identified based on their mass spectra and retention time comparison with data available in the literature (Wang and Fingas, 1995; Rogge et al., 1993). For quantification of the hopanes and steranes for which authentic standards are not available, the response factor of standards most closely matched in volatility and retention characteristics are used. A three-level calibration is performed for each compound of interest and the calibration check (using median calibration standards) is run every ten samples to check for accuracy of analyses. If the relative accuracy of measurement (defined as a percentage difference from the standard value) is less than 30%, the instrument is recalibrated.

Recently, the Organic Analytical Laboratory (OAL) has received Varian 1200 triple quadrupole gas chromatograph – mass spectrometer (GC/MS/MS) system. The tandem MS/MS system allows for structural elucidation of unknown compounds with precursor, product and neutral loss scan. The GC interface allows for sensitive analyses of complex mixtures in electron impact (EI) as well as positive and negative chemical ionization (CI) mode. Negative CI offers a superior sensitivity for the analysis of nitro-PAH (mutagens and/or suspected carcinogens) that could be emitted from combustion sources, including motor vehicle engines. The sensitivity of this instrument in full scan EI/MS mode is approximately 1 pg/ul with 20:1 signal-to-noise ratio (S/N). In EI/MS SIM mode it reaches 50 fg/ul with 10:1 S/N. For negative CI, 10 fg/ul of octafluoronaphthalene gives S/N of 20:1. This superior sensitivity offers the advantage of analyzing small samples collected during a short sampling time.

Table 2-14 presents the list of hydrocarbons and carbonyls to be analyzed for the study. Table 2-15 shows the list of PAH, including methylated PAH and oxy-PAH and nitro-PAH analyzed by the DRI OAL. Table 2-16 shows the list of hopanes, steranes, alkanes, and cycloalkenes that are usually analyzed by the OAL and Table 2-17 list organic acids and other polar organic compounds.

2.5.5.6 Gaseous Air Toxics (Section 5.4.5.6)

Gaseous air toxic include canister sampling for VOC (benzene, toluene, ethylbenzene, m-, p-,o-xylene, ie.BTEX, styrene, n-hexane, naphthalene,1,3-butadiene, MTBE), and DNPH-

coated Sep Pak cartridges sampling for carbonyl compounds (formaldehyde, acetaldehyde, acrolein). The DRI Organic Analytical Laboratory (OAL) routinely uses these methods and DRI standard operating procedures (SOPs) for sampling and analysis are available upon request.

Canister samples

The canister sampling procedure will essentially follow the pressurized sampling method described by EPA Methods TO-12 and TO-14 and the EPA document "Technical Assistance Document for Sampling and Analysis of Ozone Precursors" (October 1991, EPA/600-8-91/215). A stainless steel Viton pump draws in ambient air from the sampling manifold to fill and pressurize the sample canisters. A flow control device maintains a constant flow into the canisters over the desired sample period. This flow rate is preset to fill the canisters to about 1 atm above ambient pressure at the end of the sampling period (as described by EPA Method TO-14). For automatic operation, the timer starts and stops the pump at the appropriate time. The timer also opens the solenoid valve when the pump starts and closes it when the pump stops. The use of the solenoid manifold valves permits the automatic selection of preloaded canisters.

The canister sampling systems were custom-built at the DRI. They are multiple-event sampling systems, allowing unattended collection of three or six (plus one collocated) canister samples. The detailed Standard Operating Procedure (SOP) for canister samplers will be included in QA/QC plan.

For motor vehicle exhaust sampling, NO₂ is of concern, since it may react with 1,3-butadiene. NREL has indicated that they will consider funding a laboratory evaluation of a cobalt oxide denuder that removes both NO and NO₂. This evaluation will be done prior to Round 1 and will also include an evaluation of long-term stability of 1,3-butadiene in canisters. For the pilot study, we will use a denuder to remove NO and NO₂ and examine correlations of 1,3-butadiene with ethylene and propylene from the Gas/Diesel Split Study. Figure 2-9 shows that 1,3-butadiene is well correlated with ethene and propene, which are more stable combustion products. These samples were analyzed on-site with a GC-MS within a few minutes of sample collection. The loss of 1,3-butadiene in the Kansas City samples could be corrected using the correlations established in the Gas/Diesel PM Split Study. Whether these correlations are fuel specific is not known. However, we believe that these correlations may be more widely applicable since they involve compounds that are combustion products rather than from unburned fuel. As an option, we propose to deploy the same GC/MS that was used in the previous study for the first month of this study to establish both the stability of 1,3-butadiene and correlations with ethene and propene.

After sampling, an identification tag will be attached to each canister and the canister serial number, sample number, and sampling location, date, and time will be recorded on this tag. In addition a field sampling form and chain-of-custody form will be filled out giving all pertinent information on the collection of the sample.

Prior to sampling, the canisters are cleaned by repeated evacuation and pressurization with humidified zero air, as described in the EPA document "Technical Assistance Document for Sampling and Analysis of Ozone Precursors" (October 1991, EPA/600-8-91/215). Six repeatable cycles of evacuation to ~0.5 mm Hg absolute pressure, followed by pressurization with ultra-high-purity (UHP) humid zero air to ~20 psig are used. The differences between the DRI procedure and the EPA recommended method are that, in the DRI method, canisters are heated to 140°C during the vacuum cycle and more cycles of pressure and vacuum are used. According to our experience and that of others (Rasmussen, 1992), heating is essential to achieve the desired canister cleanliness. Also, the canisters are kept longer under vacuum cycles, about one hour in the DRI method, as opposed to half an hour in the EPA method. At the end of the cleaning procedure, one canister out of 12 in a lot is filled with humidified UHP zero air and analyzed by the gas chromatograph/flame ionization detection (GC/FID) method. The canisters are considered clean if the total non-methane organic compound (NMOC) concentration is less than 20 ppbC. The actual concentrations of blank-check canisters are typically below 10 ppbC.

Canister samples are analyzed for speciated VOC concentrations promptly upon receipt of samples from the field, using gas chromatography/mass spectrometry method according to guidance provided by the EPA Method TO-15. The GC/MS system includes: Entech 7100 preconcentrator, Varian 3800 gas chromatograph with FID and column switching valve, and Varian Saturn 2000 ion trap mass spectrometer. The Entech preconcentrator consisted of three traps: 50% glass beads/50% Tenax, held at –100°C during sample transfer, 100% Tenax held at –40°C and a final focusing trap (a piece of silico-steel capillary) held at –180°C. The sample is desorbed from the first trap at 10°C, from the second trap at 200°C and from the third one at approximately 70 °C to a transfer line heated to 110°C and connected to the head of the first column. The sample is injected at the head of a 60 m x 0.32 mm polymethylsiloxane column (CPSil-5, Varian, Inc.) held at 30°C. This column is connected to the switching valve leading into a 30 m x 0.53 mm GS-GasPro column (J&W Scientific). After approximately 7 min the valve was switched so that the effluent from the first column eluted onto a second 15 m x 0.32 mm polymethylsiloxane column connected to the mass spectrometer. The column switch was timed so that the C2 and C3 compounds eluted on the FID and all C4 and higher compounds eluted on the mass spectrometer. The GC program is as follows: 30°C held for 2 min, then

8°C/min up to 260°C. Calibration of the system is conducted with a mixture that contained the most commonly found hydrocarbons (75 compounds from ethane to n-undecane, purchased from Air Environmental), MTBE, and halocarbons (23 compounds from F12 to the dichlorobenzenes, purchased from Scott Specialty Gases). The standards are prepared in 6 L Silco-Steel canisters (Restek, Bellefonte, PA) by mixing three different standards through a multi-valve manifold using a Baratron absolute capacitance manometer (MKS Instruments, Andover, MA) to determine the pressure each standard added to the mixture. Prior to mixing, approximately 0.2 ml of ultrapure water is added to the canister to humidify the mixture (for mixture stability). The concentrations in the mixture are in the range of 0.2 to 10 ppbv. Three point external calibrations are run prior to analysis, and one calibration check is run every 24 hours. If the response of individual compounds are more than 10% off, the system is recalibrated.

For canisters the replicate analysis is conducted at least 24 hours after the initial analysis to allow re-equilibration of the compounds within the canister. The replicate analyses are flagged in our database and the programs we have for data processing extract these replicates and determine a replicate precision. Replicate analysis is important because it provides us with a continuous check on all aspects of each analysis, and indicates problems with the analysis before they become significant.

Carbonyl compounds

Formaldehyde, acetaldehyde and acroleine will be collected with Sep-Pak cartridges that have been impregnated with an acidified 2,4-dinitrophenylhydrazine (DNPH) reagent (Waters, Inc), according to the EPA Method TO-11A. When the exhaust is drawn through the cartridge, carbonyls in the sample are captured by reacting with DNPH to form hydrazones, which are separated and quantified using HPLC in the laboratory (Fung and Grosjean, 1981). After sampling, the cartridges will be eluted with acetonitrile. An aliquot of the eluent will be transferred into a 1-ml septum vial and injected with an autosampler into a high performance liquid chromatograph (Waters Alliance System) for separation and quantitation of the hydrazones (Fung and Grosjean 1981). Since acroleine undergoes isomerization when reacted with DNPH on the silica-gel cartridges forming two products, both peaks will be identified and quantified and the total concentration will be reported. Table 2-14 presents a list of hydrocarbons and carbonyls that will be analyzed.

2.5.6 Data Analysis Task

2.5.6.1 Data Validation

Data from the field, laboratory, and various quality control activities must be unified prior to reporting in a measurement database. Values must be accepted, corrected, flagged as suspect, or removed from this database after they are evaluated against validation criteria. Precision estimates associated with each value must be calculated from performance test data. Sample validation consists of procedures which identify deviations from measurement assumptions and procedures. Three levels of validation are applied which will result in the assignment to each measurement of one of the following ratings: 1) valid; 2) valid but suspect; or 3) invalid.

Level I sample validation takes place in the field or in the laboratory and consists of: 1) flagging samples when significant deviations from measurement assumptions have occurred; 2) verifying computer file entries against data sheets; 3) eliminating values for measurements which are known to be valid because of instrument malfunctions; and 4) adjustment of measurement values for quantifiable calibration or interference biases. The Level I validated data are appended to the master database. Each sample appears as a record within the database and is identified by a unique sample identification, site, date, and time and as a primary, collocated, blank, spiked, or replicate sample.

Level II validation applies a consistency test based on known physical relationships between variables to the assembled data. Examples include range checks (both single species and ratios of species) and examination of scatterplots and time-series plots for outliers. They also include comparisons of redundant measurements made by the same group by different methods or by different groups using the same method. Validation approaches will be described fully in the project QAPP. Examples include the following checks.

- Gravimetric Mass (DRI) versus 1) integration of the continuous QCM and nephelometer measurements, 2) total and carbon fractions, sum of species (ion, elements, carbon).
- EC from TOR versus OC minus integrated continuous PM measurements
- OC versus organic species by type (PAH, hopanes, steranes, alkanes, polars) and phase (VOC, SVOC and PM)
- Comparisons of BKI and DRI gravimetric mass

A data validation summary is maintained in the character field associated with each record to provide a traceability trail for all data adjustments, replacements, or deletions. The data validation flags and summaries accompany this final database. This database will be submitted in dBase format (or other format requested by ERG and EPA) on CD. The database will be accompanied by a quality assurance reports which document results of all quality assurance activities.

Level III sample validation is part of the subsequent data interpretation process. The examination of the variability of the exhaust composition profiles with emission rates and phase (e.g., cold start) will provide further validation and determination of consistency with prior studies. The first assumption upon finding a measurement which is inconsistent with physical expectations is that the unusual value is due to a measurement error.

2.5.6.2 Variability of Emission Rates of Volatile Air Toxics

Gasoline-powered vehicles emit a substantial portion of ozone-forming volatile organic compounds in the urban areas of the country and contribute to exposures to volatile air toxics such as BTEX, 1,2-butadiene and aldehydes. In this task, we will derive emission rates for individual toxic compounds and characterize the variability in the emission rates for each run with corresponding speciation data.

2.5.6.3 Development and Evaluation of Composition Profiles

Organic carbon and elemental carbon are the most abundant species in motor vehicle exhaust, accounting for over 95% of the total mass. The abundances of organic and total carbon can be quite variable in motor vehicle exhaust profiles. Elemental carbon is relatively more abundant in diesel exhaust than in gasoline exhaust, but is less from newer technology diesel engines. The relative abundance EC is less at lower engine load. We have found that gasoline vehicles emit relatively higher amounts of elemental carbon during cold starts and during high accelerations. Gasoline exhaust measured during the NRFAS (Watson et al, 1998) had an average split of 75% organic carbon and 25% elemental carbon with higher relative EC during cold starts (based on TOR/IMPROVE carbon measurements). Because of the variability of OC/EC splits, gasoline and diesel vehicles cannot be apportioned by carbon analysis alone, and EC is not a unique tracer for diesel exhaust.

Polycyclic aromatic hydrocarbons (PAH) are present in emissions from all combustion sources and the relative proportions of different PAH compounds in emissions from a given source may vary over several orders of magnitude. PAH exhibit a wide range of volatility with

naphthalene existing almost entirely in the gas phase, while BaP, other five-ring PAH, and higher ring PAH are predominantly adsorbed on particles. The intermediate three- and four-ring PAH (semi-volatile PAH) are distributed between the two phases.

Data from NFRAQS and the NREL Comparative Toxicity Study (Zielinska et al. 2001) show that gasoline vehicles emit certain PAHs in greater relative abundance to other PAHs than do diesel vehicles. Gasoline vehicle, whether low or high emitter, emit greater amounts of high molecular-weight particulate PAHs (e.g., benzo(k)fluoranthene, benzo(ghi)perylene, ideno(1,2,3-cd)pyrene, and coronene). These PAHs are found in used gasoline motor oil (but not in fresh oil and not in diesel engine oil). The oil acting as a scrubber to remove combustion-produced PAH may explain this. Diesel vehicles also emit particulate PAHs, but in lower relative proportions to other PAHs, especially the semi-volatile methylated PAHs. Diesel emissions contained higher proportions of dimethylnaphthalenes, methyl- and dimethylphenanthrenes, and methylfluorenes. These compounds are distributed between the gas and particle phase and thus require back-up traps to be quantitatively collected. Particulate methylated PAH are also more abundant in diesel than spark-ignition engine emissions. Emission rates of hopanes and steranes are the highest for both gasoline and diesel “high emitting” vehicles. Hopanes and steranes are present in lubricating oil with similar composition for both gasoline and diesel vehicles and are not present in gasoline or diesel fuels. While hopanes and steranes are useful markers for motor vehicle emission, they cannot be used to distinguish gasoline and diesel exhaust.

The source profiles will be weight fraction of gravimetric mass with one sigma analytical errors for individual measurements. The uncertainties in the composite profiles are the larger of either the one-sigma variations in fractional species abundance among members of the composite or the root mean square of the individual analytical uncertainties. Because dynamometer samples are typically collected at higher temperatures and shorter time periods than ambient samples, they tend to contain higher fractions of semi-volatile organic compounds. Most of the volatile compounds are contained in the OC1 fraction in the TOR measurements. To minimize the impact of the differences in phase distributions between source and ambient samples on the source apportionment calculations, we will also examine alternative parameters for normalization of species to weight fraction such as TC minus OC1.

2.5.7 Analysis of Continuous PM and EC Data Task

Analysis of continuous PM and EC data. The continuous particulate measurements from both the ambient and source measurements will be made available promptly for the relevant personnel attached to the project. The data will be provided in individual files pertaining to a

given day of measurement in the case of ambient sampling, or to a particular vehicle in the case of source sampling. The data will be calibrated to an agreed upon standard of pressure and temperature. In the case of source sampling, the data will be processed and interpolated as appropriate to provide a real time assessment of the elemental carbon and total carbon content. The data will also be time averaged and accumulated over the entire sampling period and will be compared with filter-based measurements.

1. Instrument comparison for particulate emissions. From dynamometer tests; PM mass versus elemental carbon (EC) / total carbon (TC) by photoacoustic versus EC/TC by Thermal Optical Reflectance (TOR) and Thermal Optical Transmittance (TOT). Compare ambient EC by photoacoustic with EC by TOR and TOT.
2. Analysis of PM mass, organic carbon (OC) / TC, and EC/TC by mode (phase, speed, and acceleration) and vehicle emitter type.

2.5.8 Maintenance of Emission Equipment Task (Section 5.4.8)

An important part of our QA and QC program is equipment maintenance. Maintenance improves reliability and precision of the equipment. Also, maintenance recommended by the manufacturer is usually a mandatory part of warranty coverage.

The ERG team has a history of providing high quality data. This could not be achieved without a robust equipment maintenance program that is designed in the context of a QMP. For this project we will continue our practice of integrating all required maintenance into the QAPP for each measurement equipment system. This will include at least; the remote sensing equipment, the PEMS/PAMS equipment, the portable dynamometer system and its analytical systems, and the data collection and laboratory equipment owned and operated by DRI.

ERG, BKI and DRI will provide for the maintenance, calibration, and operation of all project testing equipment, including the transportable dynamometer, regulated emissions analytical system, PM sampling equipment, PEMS/PAMS, RSDs, and other project equipment. Manufacturer's recommendations and good engineering practice will dictate types and frequency of routine maintenance performed. Additional maintenance and repairs will also be performed as the need may be indicated through calibrations and other equipment checks. Any equipment malfunctions will be corrected before vehicle testing is allowed to continue. Prior to use in the study, all necessary calibrations will be performed, including flow rates, temperatures, linearity, etc.

Any modifications to equipment will be approved in advance in writing from the Project Officer.

2.5.9 Health, Safety, and Environmental Practices Task (Section 5.4.9)

BKI understands the Government's concern that contractors, subcontractors, and other personnel who support EPA's research efforts have a history of concern for the welfare and safety of its employees and for the safety of government personnel in the work area. Our proposed program will ensure that our field operations are in full compliance with all applicable policies, rules, and regulations. To ensure our compliance with federal, state, and local regulations, policies, and procedures, the BKI Program Manager will assist by establishing, interpreting, and enforcing safety policies, rules, and regulations; conducting inspections, investigating accidents, and making recommendations; recommending and providing safety training; and reviewing safety protocols for hazardous operations.

The minimum personal protective equipment required in the field and laboratory where chemicals are handled are safety glasses, laboratory coats, and gloves. Depending upon the chemicals in use and the testing and procedures being performed, additional protective equipment may be required. These include goggles or a face shield when there is a chance for chemical splash, rotating machinery, or flying particles; hearing protection in high noise areas; safety shoes or for handling heavy equipment or gas cylinders; or respirators where hazard control equipment may not lower exposure levels to an acceptable limit or failure of this equipment during chemical handling would pose a threat that was immediately dangerous to life and health.

BKI provides all personal protective equipment and the necessary training for its use for employees. Employees have the responsibility to use the equipment as appropriate and to be sure it is in good working condition or is replaced.

ERG, BKI and DRI are committed to a safe working environment and will adhere to applicable health and safety practices and requirements.

Table 2-8. Summary of measurements and sample collection for the Kansas City LDGV Characterization Study

Train ID	Sample	Intended Analysis	Number of Samples/cycle	Time Resolution	Equipment Supplier ^a	Equipment Operator ^a
1	HC	Total volatile hydrocarbons	continuous	1 sec.	BKI	BKI
2	CO/CO ₂	CO, CO ₂	continuous	1 sec.	BKI	BKI
3	NO _x	NO, NO _x	continuous	1sec.	BKI	BKI
4	QCM	PM _{2.5} mass	continuous	1-5 sec.	EPA/SWRi	DRI
5	Nephelometer	PM _{2.5} mass	continuous	1-5 sec.	EPA	DRI
6	Photoacoustic	Black Carbon	continuous	1-5 sec.	DRI	DRI
7a	Teflon Membrane	gravimetric mass (each UDC phase), elements by ICP-MS (UDC composite)	3	310, 1116, 310 sec.	DRI	DRI
7a ^b	Quartz Filter backup behind Teflon filter	EC/OC by TOR (each UCD phase)	3	310, 1116, 310 sec.	DRI	DRI
8	Quartz Filter	EC/OC by TOR (each UCD phase), ions by IC (UDC composite)	3	310, 1116, 310 sec.	DRI	DRI
9	TIGF/XAD	PM and semi-volatile organic compounds by GC-MS (UDC composite)	1	1736 sec.	DRI	DRI
10	canisters with NO ₂ denuder	VOC speciation by GC-FID (UDC composite)	1	1736 sec.	DRI	DRI
11	DNPH cartridges	carbonyl compounds by HPLC-UV (UDC composite)	1	1736 sec.	DRI	DRI

a. Bevilacqua-Knight, Inc. (BKI), Desert Research Institute (DRI), Southwest Research Institute (SWRi)

b. Proposed (optional cost provided in latest budget)

Table 2-9. Base sampling configuration for the Kansas City LDGV Characterization Study

Source	Primary Inlet/connection	Size Cut	Primary inlet flow (lpm)	Channel ID	Secondary Inlet Flow (lpm)	Filter media/ instrument	UCD Phase	
BKI Dynamometer CVS Sampling System (450 lpm)	Side A	PM _{2.5} cyclone	113	7a	50	Teflon 1 (47mm) ^a	Phase 1	
						Teflon 2 (47mm) ^a	Phase 2	
						Teflon 3 (47mm) ^a	Phase 3	
						Teflon 4 (47mm) ^a	blank	
				8	50	Quartz 1 (47 mm)	Phase 1	
						Quartz 2 (47 mm)	Phase 2	
						Quartz 3 (47 mm)	Phase 3	
						Quartz 4 (47 mm)	blank	
					10	none		
		PM _{2.5} cyclone	113	9	113	TIGF/XAD	Phases 1,2,3	
						none		
		None	1.3	10	0.3	VOC canisters	Phases 1,2,3	
				11	1	DNPH	Phases 1,2,3	
	total					224.3		
	Side B	PM _{2.5} cyclone	113	4	5	QCM	cont.	
				5	1	Nephelometer	cont.	
				6	1	Photoacoustic	cont.	
				B4	3	TEOM ^b	cont.	
				B5	1	Dustrak ^b	cont.	
				B6				
				B7				
				B8				
					102	make-up air		
		None	113		113	make-up air		
total					226			
Grand total					450.3			

a. Proposed optional backup quartz filter behind Teflon.

b. Will be operated by DRI at no cost to EPA.

Table 2-10. Numbers of samples collected during the Kansas City LDGV Characterization Study

Run ID Channel #	Number of Tests	Teflon filter 7	quartz filter 8	TIGF/XAD 9	canister 10	DNPH cartridge 11
Pilot Study						
Tunnel Blank	3	3	3	3	3	3
Test Vehicles	3	9	9	3	3	3
Replicate Vehicle Tests	6	18	18	6	6	6
Field Transport Blanks	3	3	3	3		3
		33	33	15	12	15
Round 1						
Daily Tunnel Blanks	60	60	60	60	60	60
Test Vehicles	250	750	750	250	250	250
Replicate Vehicle Tests	15	45	45	15	15	15
Weekly Calibration Vehicle Tests	12	36	36	12	12	12
Field/Transport Blanks	12	12	12	12	0	12
		903	903	349	337	349
Round 2						
Daily Tunnel Blanks	60	60	60	60	60	60
Test Vehicles	230	690	690	230	230	230
Replicate Vehicle Tests	10	30	30	10	10	10
Repeat Vehicle from Round 1	25	75	75	25	25	25
Weekly Calibration Vehicle Tests	12	36	36	12	12	12
Field/Transport Blanks	12	12	12	12	0	12
		903	903	349	337	349
Total Round 1 and 2		1806	1806	698	674	698

Optional Task During Pilot for NREL

Run ID Channel #	Number of Tests	Teflon filter 7a	Quartz filter ^a 7b	quartz filter 8	TIGF/XAD 9	canister 10	DNPH cartridge 11
Tunnel Blank	2	2	5	2	2	2	2
Test Vehicles	2	6	15	6	2	2	2
Replicate Vehicle Tests	4	12	30	12	4	4	4
Field Transport Blanks	0	0	0	0	0		0
		20	50	20	8	8	8

a. Includes backup quartz filters for base tests at 47 C.

Notes: One dilution tunnel blanks will be collected daily during rounds 1 and 2 at the beginning of each day of testing. Twelve sets of sampling media will be returned to the laboratory as field/transport blanks per round.

Table 2-11. Numbers of samples analyzed during the Kansas City LDGV Characterization Study

	Tests	Composite	Teflon filter		quartz filter		TIGF/XAD POC and SVOC	TIGF POC	XAD SVOC	canister VOC	DNPH cartridge Carbonyls
			mass	elements	OC/EC	Ions					
Pilot Study											
Tunnel Blank	3		3		3		3			3	3
Test Vehicles	3		9		9		2	1	1	3	3
Replicate Vehicle Tests	6		18		18		4	2	2	6	6
Field Transport Blanks	3		3		3		3				3
			33		33		12	3	3	12	15
Round 1											
Daily Tunnel Blanks	60	10	60	6	60	6		6	6	6	6
Test Vehicles	250		750								
Truck - Pre 1980		1		4	12	4	4			4	4
Truck - 1980 to 1990		1		3	9	3	3			3	3
Truck - 1991 to 1995		3		2	18	2		2	2	2	2
Truck - 1996 and newer		5		2	30	2		2	2	2	2
Car - Pre 1980		1		6	18	6	6			6	6
Car - 1980 to 1990		1		4	12	4	4			4	4
Car - 1991 to 1995		3		3	27	3		3	3	3	3
Car - 1996 and newer		5		2	30	2		2	2	2	2
Replicate Vehicle Tests	15		45		45						
Weekly Calibration Vehicle Tests	12		36		36						
Field/Transport Blanks	12		12	6	12	6		3	3		6
			903	38	309	38	17	18	18	32	38
Round 2											
Daily Tunnel Blanks	60	10	60	6	60	6		6	6	6	6
Test Vehicles	230		690								
Repeat Vehicle from Round 1	25		75								
Truck - Pre 1980		1		4	12	4	4			4	4
Truck - 1980 to 1990		1		3	9	3	3			3	3
Truck - 1991 to 1995		3		2	18	2		2	2	2	2
Truck - 1996 and newer		5		2	30	2		2	2	2	2
Car - Pre 1980		1		6	18	6	6			6	6
Car - 1980 to 1990		1		4	12	4	4			4	4
Car - 1991 to 1995		3		3	27	3		3	3	3	3
Car - 1996 and newer		5		2	30	2		2	2	2	2
Replicate Vehicle Tests	10		30		30						
Weekly Calibration Vehicle Tests	12		36		36						
Field/Transport Blanks	12		12	6	12	6		3	3		6
			903	38	294	38	17	18	18	32	38
Total Round 1 and 2			1806	76	603	76	34	36	36	64	76

Optional Task During Pilot for NREL

	Tests	Teflon filter		quartz filter		quartz filter	TIGF/XAD POC and SVOC	TIGF POC	XAD SVOC	canister VOC	DNPH cartridge Carbonyls
		mass	elements	OC/EC	OC/EC	Ions					
Pilot Study (Optional)											
Tunnel Blank	2	2		5	2			2	2	2	2
Test Vehicles	2	6		15	6			2	2	2	2
Replicate Vehicle Tests	4	12		30	12			4	4	4	4
Field Transport Blanks											
		20		50	20			8	8	8	8

a. Includes backup quartz filters for base tests at 47 C.

Notes: This table does not include analyses for certification blanks from each lot of sampling media and replicate analyses for determination of analytical precision. The costs for these samples are included in per unit cost for each analysis.

Table 2-12. Analysis list of inorganic species for the Kansas City LDGV Emission Characterization Study

Species	Analysis Method ^a	MDL ^b (µg/filter)	Species	Analysis Method ^a	MDL ^b (µg/filter)
Chloride (Cl ⁻)	IC	1.5005	Cobalt (Co)	XRF	0.0115
Nitrite (NO ₂ ⁻)	IC	1.5005	Nickel (Ni)	XRF	0.0115
Nonvolatilized Nitrate (NO ₃ ⁻)	IC	1.5005	Copper (Cu)	XRF	0.0144
Phosphate (PO ₄ ³⁻)	IC	1.5005	Zinc (Zn)	XRF	0.0144
Sulfate (SO ₄ ⁼)	IC	1.5005	Gallium (Ga)	XRF	0.0259
Ammonium (NH ₄ ⁺)	AC	1.5005	Arsenic (As)	XRF	0.0230
Soluble Sodium (Na ⁺)	AAS	0.2362	Selenium (Se)	XRF	0.0173
Soluble Magnesium (Mg ⁺⁺)	AAS	0.0547	Bromine (Br)	XRF	0.0144
Soluble Potassium (K ⁺)	AAS	0.1498	Rubidium (Rb)	XRF	0.0144
Soluble Calcium (Ca ⁺⁺)	AAS	0.0979	Strontium (Sr)	XRF	0.0144
Organic Carbon (OC)	TOR	2.7590	Yttrium (Y)	XRF	0.0173
Elemental Carbon (EC)	TOR	2.7590	Zirconium (Zr)	XRF	0.0230
Sodium (Na)	XRF	0.9533	Molybdenum (Mo)	XRF	0.0374
Magnesium (Mg)	XRF	0.3456	Palladium (Pd)	XRF	0.1526
Aluminum (Al)	XRF	0.1382	Silver (Ag)	XRF	0.1670
Silicon (Si)	XRF	0.0864	Cadmium (Cd)	XRF	0.1670
Phosphorus (P)	XRF	0.0778	Indium (In)	XRF	0.1786
Sulfur (S)	XRF	0.0691	Tin (Sn)	XRF	0.2333
Chlorine (Cl)	XRF	0.1382	Antimony (Sb)	XRF	0.2477
Potassium (K)	XRF	0.0835	Barium (Ba)	XRF	0.7171
Calcium (Ca)	XRF	0.0634	Lanthanum (La)	XRF	0.8554
Titanium (Ti)	XRF	0.0403	Gold (Au)	XRF	0.0432
Vanadium (V)	XRF	0.0346	Mercury (Hg)	XRF	0.0346
Chromium (Cr)	XRF	0.0259	Thallium (Tl)	XRF	0.0346
Manganese (Mn)	XRF	0.0230	Lead (Pb)	XRF	0.0403
Iron (Fe)	XRF	0.0202	Uranium (U)	XRF	0.0317

^a IC=ion chromatography. AC=automated colorimetry. AAS=atomic absorption spectrophotometry.

TOR=thermal/optical reflectance. XRF=x-ray fluorescence.

^b Minimum detectable limit (MDL) is the concentration at which instrument response equals three times the standard deviation of the response to a known concentration of zero.

Additional Notes

1. Boron (specified in Section 3.3.2.2 of RFP) cannot be done by XRF.
2. XRF can be replaced with ICP-MS with greater sensitivity. However, cannot measure Sulfur and Chlorine and cost twice as much as XRF. Three Teflon filters can be extracted together with ICP-MS to reduce cost.

Table 2-13. Relative detection limits for XRF and ICP-MS elemental analysis.

Species	ICP/XRF sensitivity	XRF			ICP-MS
		Protocol A MDL ^b (µg/filter)	Protocol B MDL ^b (µg/filter)	Protocol C MDL ^b (µg/filter)	mdl ug/sample
Boron (B)		na	na	na	na
Sodium (Na)		na	na	na	0.1000
Aluminum (Al)	1.1920	0.1192	0.0858	0.0429	0.1000
Phosphorus (P)		0.0668	0.0477	0.0238	na
Sulfur (S)		0.0596	0.0417	0.0215	na
Chlorine (Cl)		0.1192	0.0882	0.0441	na
Silicon (Si)		0.0751	0.0524	0.0262	na
Calcium (Ca)	0.5364	0.0536	0.0381	0.0191	0.1000
Chromium (Cr)	2.2648	0.0226	0.0167	0.0080	0.0100
Manganese (Mn)	9.5360	0.0191	0.0131	0.0067	0.0020
Iron (Fe)	0.0894	0.0179	0.0131	0.0064	0.2000
Nickel (Ni)	0.5304	0.0106	0.0075	0.0037	0.0200
Copper (Cu)	3.2780	0.0131	0.0091	0.0045	0.0040
Zinc (Zn)	6.5560	0.0131	0.0091	0.0045	0.0020
Arsenic (As)	9.5360	0.0191	0.0131	0.0067	0.0020
Mercury (Hg)	30.9920	0.0310	0.0215	0.0108	0.0010
Lead (Pb)	89.4000	0.0358	0.0262	0.0131	0.0004
K		0.0727	0.0513	0.0262	
Ti		0.0346	0.0250	0.0119	
V		0.0298	0.0203	0.0104	
Co		0.0105	0.0074	0.0037	
Ga		0.0226	0.0167	0.0081	
Se		0.0143	0.0103	0.0051	
Br		0.0119	0.0086	0.0043	
Rb		0.0119	0.0081	0.0041	
Sr		0.0131	0.0093	0.0046	
Y		0.0155	0.0110	0.0055	
Zr		0.0203	0.0143	0.0070	
Mo		0.0322	0.0226	0.0113	
Pd		0.1311	0.0906	0.0453	
Ag		0.1430	0.1025	0.0513	
Cd		0.1430	0.1025	0.0513	
In		0.1550	0.1132	0.0572	
Sn		0.2026	0.1430	0.0739	
Sb		0.2146	0.1550	0.0763	
Ba		0.6198	0.4410	0.2146	
La		0.7390	0.5245	0.2622	
Au		0.0370	0.0262	0.0131	
Tl		0.0298	0.0215	0.0105	
U		0.0274	0.0203	0.0099	

^b Minimum detectable limit (MDL) is the concentration at which instrument response equals three times the standard deviation of the response to a known concentration of zero.

na - not available

Cost: XRF Protocol A (\$21/sample), XRFb (\$35/sample) XRFc (\$128/sample) for 15 elements and 23 additional at no cost.
Cost for ICP-MS (\$17/sample for digestion plus \$19 for first element plus \$2 for each additional element); \$58 per sample for 12 elements

**Table 2-14. Analysis list of hydrocarbons and carbonyl compounds for the
Kansas City LDGV Emission Characterization Study**

Hydrocarbons			Carbonyl Compounds
Ethane	MeCyPentane	m/p-xylene	Formaldehyde
Ethene	2,4-DiMePentane	2MeOctane	Acetaldehyde
Acetylene	223TriMeButane	3MeOctane	Acetone
propene	1MeCypentene	Styrene+heptanal	Acrolein
propane	Benzene	o-xylene	Propionaldehyde
isoButane	33DiMePentane	Nonene-1	Crotonaldehyde
1Butene+iButylene	CycloHexane	n-Nonane	Methyl Ethyl Ketone
1,3-Butadiene	4MeHexene	iPropBenzene	Methacrolein
n-Butane	2MeHexane	iPropCyHexane	Butyraldehyde
t-2-Butene	23DiMePentane	26DiMeOctane	Benzaldehyde
c-2-Butene	Cyclohexene	alpha-pinene	Glyoxal
3-Me-1-Butene	3MeHexane	36DiMeOctane	Valeraldehyde
isopentane	13DiMeCyPentane	nPropBenzene	m-Tolualdehyde
1-Pentene	3EtPentane	mEtToluene	Hexanaldehyde
2-Me-1-Butene	1-Heptene	pEtToluene	
n-Pentane	224TrMePentane	135TriMeBenzene	
Isoprene	t-3-Heptene	oEtToluene	
t-2-Pentene	n-Heptane	beta-pinene	
c-2-Pentene	244TMe-1-Pentene	1-Decene+bkgd	
2-Me-2-Butene	MeCyHexane	124TriMeBenzene	
22DiMeButane	25DiMeHexane	n-Decane	
CycloPentene	24DiMeHexane	iButBenzene	
4-Me-1-Pentene	234TrMePentane	sButBenzene	
3-Me-1-Pentene	Toluene	123TriMeBenzene	
CycloPentane	23DiMeHexane	Limonene	
23DiMeButane	2MeHeptane	Indan	
MTBE	4MeHeptane	Indene	
2-MePentane	3MeHeptane	13diethylbenzene	
22-DiMePentane	Hexanal	14diethylbenzene	
3-MePentane	225TMHexane	12diethylbenzene	
2-Me-1-Pentene	Octene-1	2-propylToluene	
1-Hexene	11DMeCyHexane	iPrToluene	
n-Hexane	n-Octane	n-Undecane	
t-3-Hexene	235TriMeHexane+Bgr.	1245tetraMeBenzene	
t-2-Hexene	24DiMeHeptane	1235tetraMeBenzene	
2-Me-2-Pentene	44DiMeHeptane	1234tetraMeBenzene	
c-3-Me-2-Pentene	26DiMeHeptane	1MeIndan	
c-3-Hexene	25DiMeHeptane	1-Dodecene	
c-2-Hexene	33DiMeHeptane	Naphthalene+Decanal	
t-3-Me-2-Pentene	EtBenzene	n-Dodecane	

a. Canister/GC-FID or MS with MLD = 0.1 ppbC.

b. DNPH cartridges/HPLC-UV with MDL = 0.1 ppbv.

Table 2-15. Analysis list of polycyclic aromatic hydrocarbons for the Kansas City LDGV Emission Characterization Study

Polycyclic Aromatic Hydrocarbons (PAH) ^a		Nitro-PAH ^b
Naphthalene	Anthrone	1-Nitronaphthalene
2-methylnaphthalene	9-methylanthracene	2-Nitronaphthalene
1-methylnaphthalene	Anthraquinone	2-Nitrobiphenyl
Biphenyl	3,6-dimethylphenanthrene	3-Nitrobiphenyl
2-Methylbiphenyl	A-dimethylphenanthrene	4-Nitrobiphenyl
1+2ethylnaphthalene	B-dimethylphenanthrene	1,3-Dinitronaphthalene
2,6+2,7-dimethylnaphthalene	C-dimethylphenanthrene	1,5-Dinitronaphthalene
1,3+1,6+1,7dimethylnaphth	D-dimethylphenanthrene	5-Nitroacenaphthene
1,4+1,5+2,3-dimethylnaphth	E-dimethylphenanthrene	2-Nitrofluorene
Acenaphthylene	1,7-dimethylphenanthrene	9-Nitroanthracene
1,2-dimethylnaphthalene	Fluoranthene	4-Nitrophenanthrene
3-Methylbiphenyl	1-MeFl+C-MeFl/Py	9-Nitrophenanthrene
Acenaphthene	Pyrene	3-Nitrophenanthrene
4-Methylbiphenyl	9-Anthraaldehyde	1,8-Dinitronaphthalene
Bibenzyl	Retene	2-Nitrofluoranthene
Dibenzofuran	B-MePy/MeFl	3-Nitrofluoranthene
A-trimethylnaphthalene	C-MePy/MeFl	1-Nitropyrene
B-trimethylnaphthalene	D-MePy/MeFl	2,7-Dinitrofluorene
C-trimethylnaphthalene	4-methylpyrene	7-Nitrobenz(a)anthracene
E-trimethylnaphthalene	1-methylpyrene	6-Nitrochrysene
F-trimethylnaphthalene	2,3-Benzofluorene	1,3-Dinitropyrene
2,3,5+I-trimethylnaphthalene	Benzonaphthothiophene	1,6-Dinitropyrene
J-trimethylnaphthalene	Benzo(c)phenanthrene	1,8-Dinitropyrene
2,4,5-trimethylnaphthalene	Benzo(a)anthracene	9,10-Dinitroanthracene
Fluorene	Chrysene	6-Nitrobenz(a)pyrene
1,4,5-trimethylnaphthalene	Benzanthrone	
A-methylfluorene	Benzo(a)anthracene-7,12-dione	
1-methylfluorene	5+6-methylchrysene	
B-methylfluorene	7-methylbenzo(a)anthracene	
9-fluorenone	1,4-chrysenequinone	
Phenanthrene	Benzo(b+j+k)fluoranthene	
Anthracene	BeP	
Xanthone	BaP	
Acenaphthenequinone	Perylene	
A-methylphenanthrene	7-methylbenzo(a)pyrene	
2-methylphenanthrene	9,10-dihydrobenzo(a)pyrene-7(8H)-one	
Perinaphthenone	Indeno[123-cd]pyrene	
B-methylphenanthrene	Dibenzo(ah+ac)anthracene	
C-methylphenanthrene	Benzo(ghi)perylene	
1-methylphenanthrene	Coronene	

a. TIGF/XAD and GC/MS with MDL = 0.02 ug/sample

b. TIGF/XAD and GC/MS with MDL = 0.01 ug/sample

**Table 2-16. Analysis list of hopanes, steranes and alkanes for the Kansas City
LDGV Emission Characterization Study**

Hopanes and Steranes ^a	Alkanes ^b
C27-20S5a(H), 14a(H)-cholestane	norfarnesane
C27-20R5a(H), 14β(H)-cholestane	heptylcyclohexane
C27-20S5a(H), 14β(H), 17β(H)-cholestane	farnesane
C27-20R5a(H), 14a(H), 17a(H)-cholestane & C29-20S13β(H), 17a(H)-diasterane	octylcyclohexane
C28-20S5a(H), 14a(H), 17a(H)-ergostane	nonylcyclohexane
C28-20R5a(H), 14β(H), 17β(H)-ergostane	norpristane
C28-20S5a(H), 14β(H), 17β(H)-ergostane	hexadecane
C28-20R5a(H), 14a(H), 17a(H)-ergostane	heptadecane
C29-20S5a(H), 14a(H), 17a(H)-stigmastane	decylcyclohexane
C29-20R5a(H), 14β(H), 17β(H)-stigmastane	pristane
C29-20S5a(H), 14β(H), 17β(H)-stigmastane	undecylcyclohexane
18a(H), 21β(H)-22,29,30-Trisnorhopane	octadecane
17a(H), 18a(H), 21β(H)-25,28,30-Trisnorhopane	nonadecane
C29-20R5a(H), 14a(H), 17a(H)-stigmastane	phytane
17a(H), 21β(H)-22,29,30-Trisnorhopane	dodecylcyclohexane
17a(H), 21β(H)-30-Norhopane	tridecylcyclohexane
17b(H), 21a(H)-30-Norhopane	tetradecylcyclohexane
17a(H), 21β(H)-Hopane	eicosane
17β(H), 21a(H)-hopane	heneicosane
22S-17a(H), 21β(H)-30-Homohopane	pentadecylcyclohexane
22R-17a(H), 21β(H)-30-Homohopane	hexadecylcyclohexane
17β(H), 21β(H)-Hopane	docosane
22S-17a(H), 21β(H)-30,31-Bishomohopane	triaicosane
22R-17a(H), 21β(H)-30,31-Bishomohopane	heptadecylcyclohexane
22S-17a(H), 21β(H)-30,31,32-Trisomohopane	octadecylcyclohexane
22R-17a(H), 21β(H)-30,31,32-Trishomohopane	tetracosane
	pentacosane
	hexacosane
	nonadecylcyclohexane
	eicosylcyclohexane
	heptacosane
	octacosane
	nonacosane
	triacontane
	hentriacontane
	dotriacontane
	tritriacontane
	tetratriacontane
	pentatriacontane
	hexatriacontane

a. TIGF/XAD and GC/MS with MDL = 0.02 ug/sample

a. TIGF/XAD and GC/MS with MDL = 0.1 ug/sample

Table 2-17. Analysis list of polar organics for the Kansas City LDGV Emission Characterization Study

Analytical Standards	Classification	Potential Organic Marker Type	MDL microgram/sample
hexanoic acid	alkanoic acid		0.05
heptanoic acid	alkanoic acid		0.05
methylmalonic	alkanedioic acid	secondary aerosol	0.05
guaiacol	methoxy phenol	wood smoke	0.05
benzoic acid	aromatic acid		0.05
octanoic acid	alkanoic acid		0.05
butenedioic (maleic) acid	alkenedioic acid	secondary aerosol	0.05
butanedioic (succinic) acid	alkanedioic acid	secondary aerosol	0.05
4-me-guaiacol	methoxy phenol	wood smoke	0.05
me-succinic acid	alkanedioic acid	secondary aerosol	0.05
nonanoic acid	alkanoic acid		0.05
4-ethyl-guaiacol	methoxy phenol	wood smoke	0.05
syringol	methoxy phenol	wood smoke	0.05
glutaric acid	alkanedioic acid	secondary aerosol	0.05
2-methylglutaric	alkanedioic acid	secondary aerosol	0.05
3-methylglutaric acid	alkanedioic acid	secondary aerosol	0.05
decanoic acid	alkanoic acid		0.05
4-allyl-guaiacol (eugenol)	methoxy phenol	wood smoke	0.05
4-methyl-syringol	methoxy phenol	wood smoke	0.05
hexanedioic (adipic) acid	alkanedioic acid	secondary aerosol	0.05
cis-pinonic acid	aromatic acid		0.05
3-methyladipic acid	alkanedioic acid	secondary aerosol	0.05
4-formyl-guaiacol (vanillin)	methoxy phenol	wood smoke	0.05
undecanoic acid	alkanoic acid		0.05
isoeugenol	methoxy phenol	wood smoke	0.05
heptanedioic (pimelic) acid	alkanedioic acid	secondary aerosol	0.05
acetovanillone	methoxy phenol	wood smoke	0.05
dodecanoic (lauric) acid	alkanoic acid		0.05
phthalic acid	aromatic diacid		0.05
suberic acid	alkanedioic acid	secondary aerosol	0.05
levoglucosan	carbohydrate	wood smoke	0.05
syringaldehyde	methoxy phenol	wood smoke	0.05
tridecanoic acid	alkanoic acid		0.05
isophthalic acid	aromatic diacid		0.05
vanillic acid	methoxy acid	wood smoke	0.05
homovanillic acid	methoxy acid	wood smoke	0.05
azelaic acid	alkanedioic acid	secondary aerosol	0.05
myristoleic acid	alkenoic acid	meat cooking	0.05
myristic acid	alkanoic acid		0.05
sebacic acid	alkanedioic acid	secondary aerosol	0.05
syringic acid	methoxy acid		0.05
pentadecanoic acid	alkanoic acid		0.05
undecanedioic acid	alkanedioic acid	secondary aerosol	0.05
palmitoleic acid	alkenoic acid	meat cooking	0.05
palmitic acid	alkanoic acid		0.05
isostearic acid	alkanoic acid		0.05
dodecanedioic acid	alkanedioic acid	secondary aerosol	0.05
heptadecanoic acid	alkanoic acid		0.05
traumatic acid	alkenoic acid		0.05
1,11-undecanedicarboxylic acid	alkanedioic acid	secondary aerosol	0.05
oleic acid	alkenoic acid		0.05
elaidic acid	alkenoic acid		0.05
stearic acid	alkanoic acid		0.05
1,12-dodecanedicarboxylic acid	alkanedioic acid	secondary aerosol	0.05
8,15-pimaradien-18-oic acid	resin acid	wood smoke	0.05
pimaric acid	resin acid	wood smoke	0.05
nonadecanoic acid	alkanoic acid		0.05
isopimaric acid	resin acid	wood smoke	0.05
dehydroabietic acid	resin acid	wood smoke	0.05
abietic acid	resin acid	wood smoke	0.05
eicosanoic acid	alkanoic acid		0.05
heneicosanoic acid	alkanoic acid		0.05
docosanoic acid	alkanoic acid		0.05
tricosanoic acid	alkanoic acid		0.05
tetracosanoic acid	alkanoic acid		0.05
cholesterol	sterol	meat cooking	0.05

Table 2-18. Potential instrument configuration for continuous and quasi-continuous measurement of PM

Instrument Manufacturer	Instrument Type (Measurement)	Sensor Technology	Time Resolution (sec.)	Sensor Operating Environment	
				Temperature Range (°C)	Sample Flow Rate (Lpm)
<u>QCM, RPM – 101</u> Booker Systems, UK	Inertial Micro- Balance (PM Mass)	Quartz Crystal/ Frequency Deficit	1	35 to 50	1 to 5
<u>DPM Monitor, 1105a</u> R & P, Albany, NY	Inertial Micro- Balance (PM Mass)	Tapered Element/Filter Frequency Deficit	15	35 to 50	1 to 3.5
<u>Dataram – 4</u> Thermo MIE, Bedford MA	Nephelometer (PM light Scattering)	Photo Diode/Two Wavelength	1	35 to 50	1 to 2
<u>Aethalometer, AE2</u> McGee Scientific, Berkeley, CA	Light Absorption (Black Carbon and PAH)	Photo Diode/Light Absorption at 800nm and 370nm	300	20 to 40	5

^a The instruments listed are an example only, based on the descriptions in Section 3.3. The contractor may propose alternative instruments.

Table 2-19. Potential instruments for integral measurement of PM

Instrument Manufacturer	Instrument Type (Measurement)	Sensor Technology	Suggested Sample Media	Sample Operating Environment	
				Temperature Range (°C)	Sample Flow Rate (Lpm)
Filter Holder 6186 R & P, Albany, NY	Gravimetric Micro-Balance (separate filters for LA92 Phase 1 and LA92 Phases 2-4.(PM Mass)	Gravimetric Micro-Balance	Teflo Filter	35 to 50	50 to 70
Thermo-Optical Carbon Aerosol Lab Analyzer Sunset Laboratory, Forest Grove, OR	Carbon Aerosol Analysis (PM Elemental and Organic Carbon Mass)	FID Detection of Thermaly Liberated CO2	Pre-Fired Quartz Filter	35 to 50	2 to15
Filter Holder 6186 R & P, Albany, NY	ICP-MS and/or XRF (PM Element Mass) ^b	Analysis Dependent	Teflo Filter	35 to 50	50 to 70
Filter Holder 6186 R & P, Albany, NY	IC and AC (PM Water Soluble Ions)	Analysis Dependent	Quartz Filter	35 to 50	50 to 70
Filter Holder 6186 R & P, Albany, NY	GC/MS (PM SVOC)	Analysis Dependent	XAD-4 Coated Filter	35 to 50	50 to 70
Summa Cannister Anderson Instruments, Atlanta, GA	GC/MS (VOCs)	Analysis Dependent	Summa Cannister	35 to 50	Sample Dependent
DNPH Cartridge Anderson Instruments, Atlanta, GA	GC/MS (Aldehydes and Ketones)	Analysis Dependent	DNPH Cartridges	35 to 50	Sample Dependent

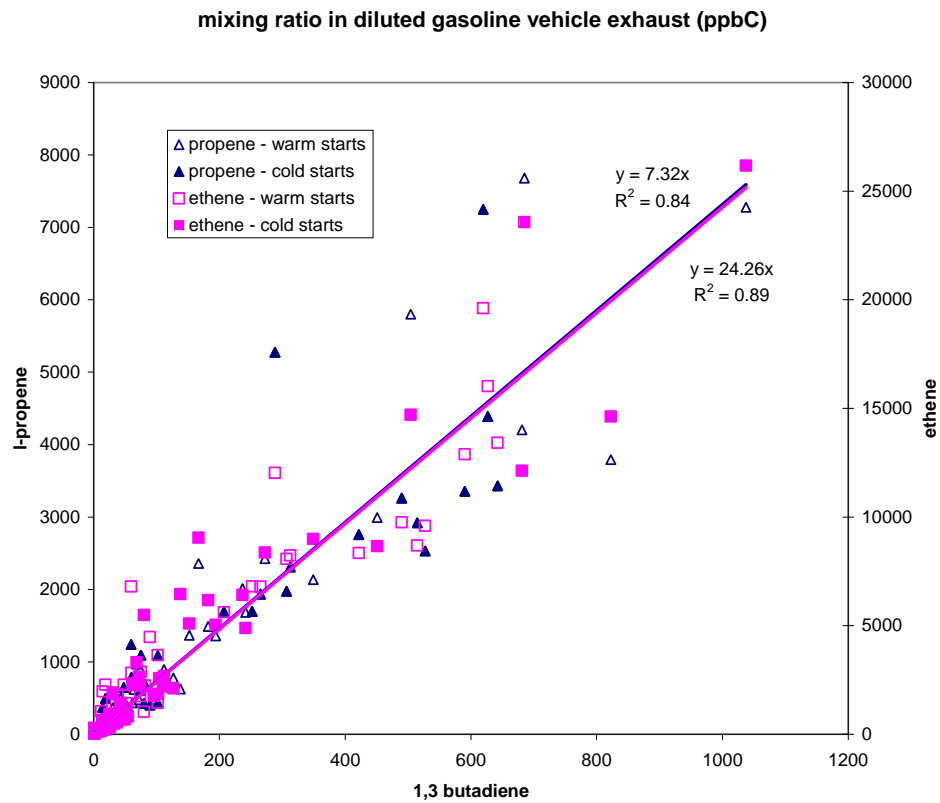


Figure 2-9. Correlation of 1,3-butadiene with ethene and propene for 57 LDGVs tested during the Gas/Diesel PM Split Study (Preliminary, unpublished data)

3.0 Organization

3.1 ERG Team Members

ERG's team brings to the PM characterization study a group of researchers and analysts with broad and complementary skills. Our key team members are recognized by their peers as leaders in their respective fields of study. Table 3-1 lists our key team members along with their anticipated role in the project, highlighting their relevant expertise and experience.

Table 3-1. Key ERG Team Members

Key Personnel / Role	Relevant Expertise and Experience
Sandeep Kishan (ERG) <i>Project Manager / Task Leader for Analysis and Reporting</i>	Project Manager for EPA's previous Driving Modes Study, a large scale effort involving vehicle recruitment, instrumentation, data collection and analysis, and extensive QA/QC. Managed recent effort to collect on-board activity data for off-road vehicles for TxDOT. Contributed to the development and testing of EPA's mobile source model MOBILE6, and an active participant in the FACA committee for the development of the MOVES model. Led the effort to develop an enhanced version of PART5 for Texas (PART5-TX) to incorporate I/M effects on PM emissions.
Andrew Burnette (ERG) <i>Task Leader for QAPP / Technical Lead for RSD and PEMS/PAMS Deployment</i>	Specialty areas include emissions evaluations using loaded mode tests, remote sensing devices and their applications, and PM emissions assessments. Recruited vehicles for emissions testing and/or PAMS instrumentation in Texas, Mexico, and Bangkok. Collected on-road emissions data for buses in Bangkok, combining second-by-second data for hydrocarbons, carbon monoxide, carbon dioxide, nitrogen oxides, oxygen, and smoke opacity with driving pattern information such as speed, acceleration, throttle position, and engine rpm to compare buses under similar driving conditions. Technical lead for data collection and analysis for PART5-TX model development, as well as RSD data collection and emissions characterization studies in Kansas City, Phoenix, Dallas, and California.
Dr. Tim DeFries (ERG) <i>Peer Review of Statistical Analysis and QAPP</i>	Expertise in mobile source emissions modeling, plume opacity, experimental design, and data analysis using statistical and neural network techniques. Daily familiarity with ordinary least squares regression, multiple linear regression, non-linear regression, analysis of variance, logistic regression, variance stabilizing transformations, and measurement-error modeling. Has used statistics to develop the QAPP/sampling plans for EPA's Driving Modes Study, representative driving cycles for on and off-road vehicles, exhaust and evaporative emissions of "off-FTP" driving, and to design a test program to collect data to improve evaporative emissions modeling.
Robert Slott (Consultant) <i>Peer Review for RSD</i>	Distinguished lecturer at Massachusetts Institute of Technology on issues dealing with mobile source pollution. Member of numerous national panels reviewing the effectiveness of remote sensing and related technologies and methods. Widely respected as an innovative thinker and student of human nature in the mobile source control industry.
William "Butch" Crews (BKI)	Supported EPA's Environmental Characterization Apportionment Branch (ECAB) emissions characterization projects for 31 years. Managed on site

Key Personnel / Role	Relevant Expertise and Experience
<i>Task Leader for Vehicle Testing</i>	operations, analytical, data processing, and machine shop support. Experience covers all aspects of the testing process from 2 and 4 stroke small light duty off-road and marine engines, through light-duty, alternative-fuel vehicles, to heavy-duty diesel engines. Has prepared Standard Operating Procedures and QC/QA plans and reports on all facets of emissions measurement. Led the design and evaluation of an injection system for formaldehyde, oxygenated compounds, and hydrocarbons into exhaust dilution tunnels to determine compound recoveries during modal operation.
Richard Snow (BKI) <i>On-Site Technical Lead for Vehicle Testing</i>	Helped plan, implement, and supervise projects to determine emissions from vehicles operated under a variety of conditions. Developed procedures to improve testing capabilities, and developed instrumentation and equipment for simulation of vehicle operating conditions. Leads a team providing on site operations support for the Environmental Characterization Apportionment Branch (ECAB). Played a key role in developing the operational and analytical capabilities of a transportable dynamometer system for performing independent, remote field studies to characterize emissions. Leads efforts to modify and fine tune mobile source operational and sampling equipment to meet specific project goals and objectives.
Dr. Eric Fujita (DRI) <i>Technical Lead for PM Sampling and Analysis</i>	Over 20 years of experience in managing and conducting air quality studies. Principal author of the field study plans for the 2000 Central California Ozone Study, 1997 Southern California Ozone Study (SCOS97-NARSTO), and the 1996/97 Northern Front Range Air Quality Study. Primary research interests is in the application of data from ambient monitoring programs, on-road tunnel measurements, in-use motor vehicle surveillance and inspection and maintenance programs, and from remote sensing to evaluate the effectiveness of vehicle emission control programs. Coordinated the laboratory comparisons of hydrocarbon measurements during the SCOS97-NARTSO, COAST and NARSTO-Northeast ozone studies.
Dr. Pat Arnott (DRI) <i>Technical Assistance for PM Sampling and Analysis</i>	Develops and deploys photoacoustic instruments for measurement of black carbon emission from vehicles in source sampling, and in ambient air quality studies. Measurements are often combined with other real time particulate emission measurements to establish detailed knowledge of the conditions giving rise to most of the black carbon and particulate emission to the atmosphere, and their environmental impacts. He teaches in the Atmospheric Sciences Program at the University of Nevada, Reno.
NuStats Team (Robert Santos, Mia Zmud, Stacey Bricka) <i>Task Leaders for Vehicle Recruitment</i>	Over the past 18 years, NuStats has become known for innovative survey planning, data collection, and methodological research. Since inception, NuStats has conducted more than 300 large-scale studies in more than 40 states and virtually every major metropolitan area of the United States. The firm provides a full array of research services: study management, study design, statistical sampling, data collection, database management, data analysis, geographic analysis and interpretation of results. NuStats draws upon the expertise of its research staff and utilizes such tools as computer-assisted telephone interviewing (CATI), behavioral diaries, face-to-face interviews, self-administered mail out questionnaires, computer-assisted personal interviewing (CAPI) using hand held computers, Web-based surveys, and personalized (very small) GPS units.
Dr. Imad Khalek (SwRI)	Has extensive experience in particulate emissions from internal combustion engines. An expert in dilution system design and particle measurements from

Key Personnel / Role	Relevant Expertise and Experience
<i>Peer Review and QC for Continuous PM Monitoring and Analysis</i>	combustion sources. Research efforts on ultra-fine particulate emissions have gained worldwide attention. Has investigated the influence of engine stabilization, exhaust catalysts and filters (traps), dilution systems, and dilution variables, on particle size distribution and number emission measurements. Also worked on modeling of binary homogenous nucleation of sulfuric acid and water droplet, and growth by hetero-molecular condensation and coagulation during exhaust dilution. Work has contributed to future particulate emission measurements and regulations.

As indicated in the table above, our key staff are fully qualified to conduct their respective technical and managerial tasks. Our overall management structure is organized functionally according to the requirements of the RFP. The following chart describes the organization of our team, showing specific responsibilities for the major project activities.

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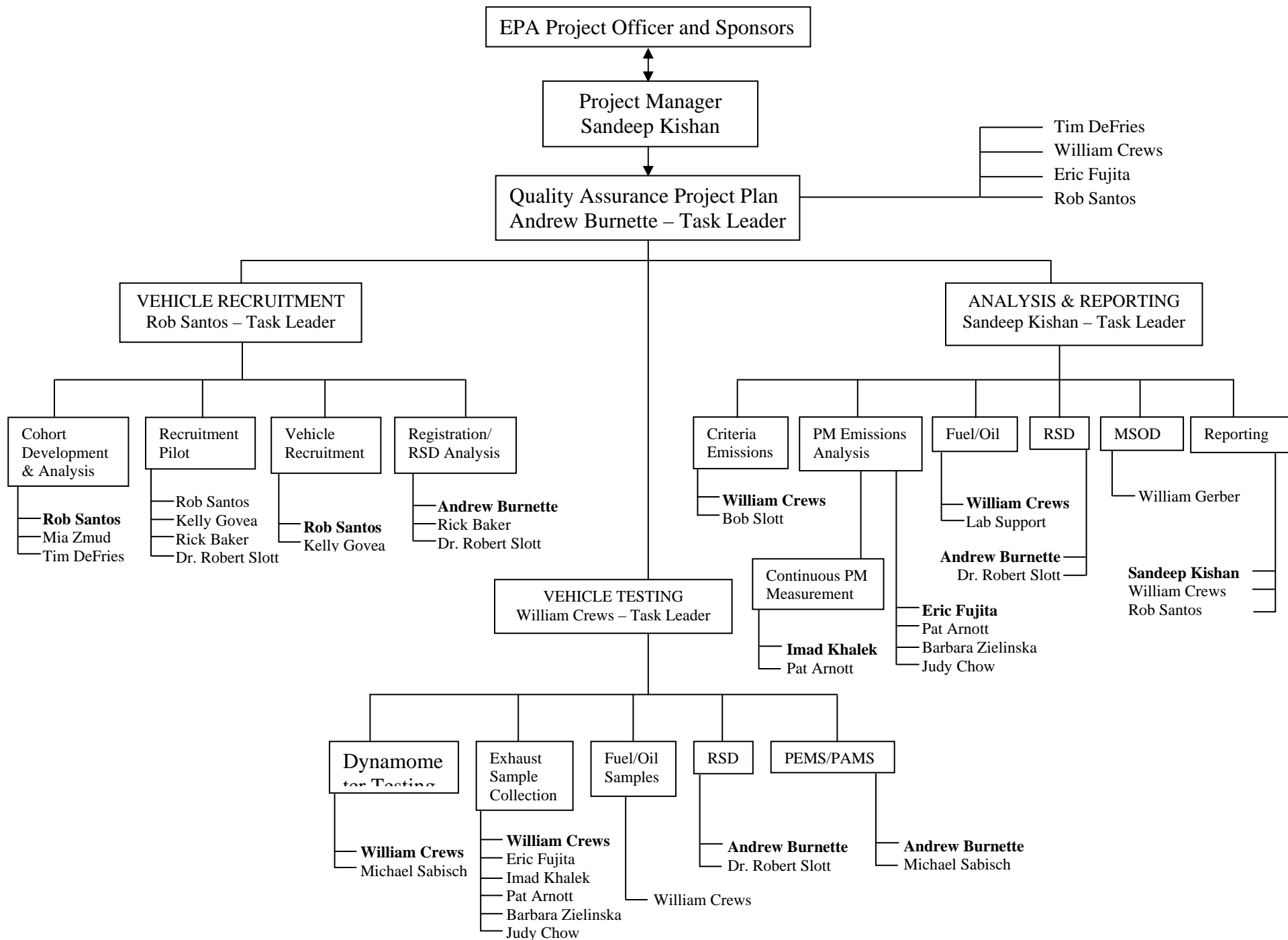


Figure 3-1. Project Management Organization

3.2 Communication with EPA Project Officer and Sponsors

The ERG Project Manager will coordinate all communications between the project team and EPA. Specifically, our Project Manager will communicate directly with the Project Officer regarding all technical matters. (Matters regarding contract issues will be directed to the EPA Contracting Officer, with the Project Officer included in all correspondence.) Questions or issues directed toward any of the Project Sponsors will be routed through the EPA Project Officer as well.

The ERG Project Manager will not authorize any substantive or significant change in operation procedures without first receiving written authorization of specific technical direction from the Project Officer. Similarly, comments and/or requested changes to deliverables will not be acted upon without written technical direction from the Project Officer.

All deliverables and required data files will be provided to the Project Officer in electronic form via a password protected Project Website. (Additional hard copies of deliverables will also be provided to the Project Officer as needed.) The Project Officer may also make this information available to the Project Sponsors at his discretion by providing them with password access as well. The Project Website is organized to provide easy access to the following:

- Project Status Reports
- Bi-Weekly Meeting Minutes
- Draft Reports
- Final Reports
- FTP-link for data transfer of large files (e.g., archived raw vehicle emissions data, vehicle registration data)

The website will also contain user instructions for downloading files, and a description of the process for providing comments or asking questions of the ERG Project Manager and/or Technical Staff. (The website will also serve as an effective communication tool for the ERG Team – see below.)

Bi-weekly calls will be held with the EPA Project Officer, arranged in advance. The ERG Project Officer will participate, as well as relevant Task Leaders and Technical Staff, as appropriate. Progress reports regarding schedule and budget will be generated by ERG in advance of these calls using MS Project, and the reports distributed to all participants for review.

Calls will cover schedule and budget status, technical progress as well as any deviations from the schedule, budget, or QAPP, and remedial actions taken/planned. Call minutes will be taken and distributed by email to all participants, and posted on the Project Website.

ERG will also provide the Project Officer with Monthly Progress Reports, as specified in the RFP. In addition to technical progress, ERG will include itemized reports of incentive expenditures once vehicle testing has begun. Any vehicle repair costs or other non-labor related expenditures (e.g., support vehicle rental costs) will also be itemized.

The ERG Project Manager will assist EPA and the Sponsors with all audit activities, and assure full cooperation of all team members with any such effort. The Project Manager will also review all questions and comments resulting from vehicle emission test data audits. Any errors or reporting discrepancies will be addressed jointly between the Project Manager and the EPA Project Officer.

4.0 Project Schedule

The recruitment task and the pilot testing task will be started as soon as our work plan is approved (anticipated on April 15, 2004). The pilot testing task is scheduled to be completed by May 30, 2004. A draft pilot study report will be delivered by June. The project schedule and a list of project deliverables is presented in the following tables.

Table 4-1. Proposed Project Schedule

Project Start	March 1, 2004
Kick-off Meeting	March 10-11, 2004
Project Workplan	April 12, 2004
Draft Quality Assurance Documents	April 19, 2004
Pilot Vehicle Testing	May 10, 2004
Final Quality Assurance Documents	June 20, 2004
Vehicle Recruitment Plan (including cohort evaluation)	June 15, 2004
Begin Vehicle Recruitment (Round 1)	June 25, 2004
Begin Vehicle Testing (Round 1)	July 7, 2004
End Vehicle Testing (Round 1)	September 20, 2004
Interim Report on Round 1	November 15, 2004
Begin Vehicle Recruitment (Round 2)	December 15, 2004
Begin Vehicle Testing (Round 2)	January 10, 2005
End Vehicle Testing (Round 2)	March 30, 2005
Draft Final Report	June 30, 2005
Final Report	August 30, 2005

Table 4-2. List of Deliverables

Task 1 – QAPP	
Project Work Plan	April 12, 2004
QAPP	April 20, 2004
QMP	April 20, 2004
Task 2 – Recruitment	
Cohort Frame Analysis	June 15, 2004
List of Non-respondent Criteria for EPA approval	May 30, 2004
Monthly Status Reports	Beginning May 15, 2004
Cohort Recruitment and Non-Respondent Analysis	June 10, 2004
Vehicle Registration Database (to Project Officer)	April 25, 2004 ¹
Cohort/Vehicle Summary Analysis Report	June 5, 2004
Pilot Study Report	June 20, 2004
Vehicle Recruitment Sample Plan	June 10, 2004
Recruitment Log, Round 1 (e.g., record of contact attempts, outcomes, demographics of informant, etc.)	October 15, 2004
Post-Round 1 Vehicle Analysis	November 15, 2004
Recruitment Log, Round 2	April 30, 2005
Task 3 – Vehicle Testing	
Monthly Project Report	Monthly
Pilot Study Report	June 20, 2004
Weekly Excel Spreadsheet Reports: Round 1	1 week after testing for Round 1
Weekly Excel Spreadsheet Reports: Round 2	1 week after testing for Round 2
Task 4 – Speciation Tasks	
<i>Round 1</i>	
Provide Validated Speciation Database	January 15, 2005
Provide Time-Matched Continuous PM/EC Data	November 15, 2004
<i>Round 2</i>	
Provide Validated Speciation Database	June 15, 2005
Provide Time-Matched Continuous PM/EC Data	April 30, 2005
Other Reports	
Final MSOD/Excel Database	July 10, 2005
Draft Final Report	June 30, 2005
Final Report	August 30, 2005
Meetings/Other	
Kickoff Meeting	March 10, 2004
Bi-weekly Conference Calls (notes via email)	Beginning second week in March 2004
Project Website Deployment	March 25, 2004

¹ Pending cooperation of respective state DMVs.