Kansas City PM Characterization Study

Final Report

United States
Environmental Protection
Agency

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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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This technical report does not necessarily represent final EPA decisions or positions. It is intended to present technical analysis of issues using data that are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments.

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KANSAS CITY PM CHARACTERIZATION STUDY

FINAL REPORT

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Acronyms

ALAPCO	Association of Local Air Pollution Control Officials
AMBHC	Ambient (background) Hydrocarbon
BC	BC
BKI	Bevilacqua Knight Incorporated
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CEM	Continuous Emissions Monitor
CFR	Code of Federal Regulations
CMB	Chemical Mass Balance
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COVs	Coefficients of Variation
CPU	Central Processing Unit
CRC	Coordinating Research Council, Inc.
CSV	Comma-separated Variables
CVS	Constant Volume Sampler
DAC	Data Acquisition and Control
DMV	Department of Motor Vehicles
DNPH	Dinitropehenylhydrazine
DOE	Department of Energy
DOT	Department of Transportation
DP	Dew Point
DR	DataRAM
DRI	Desert Research Institute
DT	DustTrak
DTC	Diagnostic Trouble Code
EC	Elemental Carbon
EPA	Environmental Protection Agency
ERG	Eastern Research Group
ESP	Environmental Systems Products
FHWA	Federal Highway Administration
FID	Flame Ionization Detector
GC/MS	Gas Chromatography / Mass Spectrometry
GC-FID	Gas Chromatography - Flame Ionization Detector
GDPMS	Gas/Diesel PM Split Study
GPS	Global Positioning System
HAP	Hazardous Air Pollutants
HC	Hydrocarbon
HH	Household
HPLC	High Performance Liquid Chromatography
HPLC-UV	High-Pressure Liquid Chromatography with UV Detector
IC	Ion Chromatography
ICP-MS	Inductively Coupled Plasma - Mass Spectrometry
I/M	Inspection and Maintenance
KCMSA	Kansas City Metropolitan Statistical Area

KCRHTS	Kansas City Regional Household Travel Survey
KS	State of Kansas
LDGV	Light Duty Gasoline Vehicles
LED	Light Emitting Diode
MARC	Mid-America Regional Council
MDL	Method Detection Limit
MO	State of Missouri
MSA	Metropolitan Statistical Area
MSAT	Mobile Source Air Toxic
MSOD	Mobile Source Observation Database
NIST	National Institute of Standards and Technology
NMHC	Non-Methane Hydrocarbon
NO	Nitric Oxide
NO2	Nitrogen Dioxide
NOX	Oxides of Nitrogen
NREL	National Renewable Energy Laboratory
OBDII	On-Board Diagnostics II (vehicle diagnostic system)
OC	Organic Carbon
ORD	Office of Research and Development (EPA)
PAH	Polycyclic Aromatic Hydrocarbons
PAMS	Portable Activity Measurement System
PDP	Positive Displacement Pump
PEMS	Portable Emissions Measurement System
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter (less than 2.5 microns in diameter)
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
QCM	Quartz Crystal Microbalance
RDD	Random Digit Dialing
RFP	Request for Proposals
RH	Relative Humidity
RSD	Remote Sensing Data
SBS	Second-by-Second
SCFM	Standard Cubic Feet per Minute
SI	Spark Iginition
SMT	SEMTECH
STAPPA	State and Territorial Air Pollution Program Administrators
STN	Speciation Trends Network
SVOC	Speciated Volatile Organic Compounds
TC	Total Carbon
TEOM	Tapered Element Oscillating Microbalance
THC	Total Hydrocarbon
TIGF	Teflon Impregnated Glass Fiber
TNMHC	Total Non-Methane Hydrocarbon
TOR	Thermal Optical Reflectance

USEPA	United States Environmental Protection Agency
UV-VIS	Ultraviolet-Visible Spectroscopy
VI	Vehicle Interface
VIN	Vehicle Identification Number
VOC	Volatile Organic Compounds
VSP	Vehicle Specific Power
XML	eXtensible Markup Language
XRF	X-Ray Fluorescence

Executive Summary

Overview of Study Objectives

This program evaluates exhaust emissions from light-duty gasoline vehicles (LDGVs) which includes measuring particulate matter (PM) and other components of exhaust emissions from approximately 480 randomly selected LDGVs in the Kansas City Metropolitan Area. Data obtained from this program will be used to evaluate and update existing and future mobile source emission models (MOBILE6 and MOVES).

In an effort to understand the emissions of a fleet comprised of both new and older vehicles, EPA has conducted numerous studies to measure emissions from a sample of vehicles and then projected them to the population as a whole. Gaseous emissions have been studied extensively through the last few decades, both through special studies and through analysis of vehicle inspection and maintenance (I/M) program data. However, particulate matter (PM) emissions from gasoline-powered motor vehicles are less understood. Through this study EPA has conducted a “watershed” research experiment to characterize PM emissions from a very carefully selected random sample of vehicles in a major metropolitan area.

It should be first noted that PM is a dynamic pollutant that is constantly being influenced by its environment therefore its formation is constantly changing both in the exhaust stream and in the ambient air. Our tests are a snapshot using specific measurements under specific laboratory and thermodynamic conditions. Real-world PM may differ significantly.

Many studies have tried to characterize the distribution of PM for a vehicle fleet. 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 PM emissions distributions of a carefully selected random sample of gasoline vehicles in Kansas City.
- Characterize gaseous and PM toxics exhaust emissions.
- Characterize the fraction of high emitters in the fleet.

In addition, there were a number of secondary goals for the study, including:

- Demonstrate the use of a cohort, and a sampling plan to select candidate vehicles;
- Test vehicles in an ambient environment close to their operating area, gather data in summer and winter conditions;
- Refine the use of Portable Emissions Measurement Systems (PEMS) configurations for large scale implementation;
- Compare results of laboratory grade measurement devices with PEMS;
- Develop useful continuous PM measurement techniques compared to traditional gravimetric measurement;
- Develop inventory of speciated HC constituents of vehicle exhaust in PM and gaseous modes;

- Gather emissions and activity data on vehicles driven by their owners in real world conditions; and
- Gather information to relate second by second vehicle driving and resulting PM emissions for developing input data for emissions models.

Another key feature of this study was intended to identify how real-world on-board portable emission measurement devices (PEMS) could be used to collect mass-based vehicle emissions data. These devices were put on all vehicles tested in this project. Additionally, a PEMS device was connected to every vehicle while it was simultaneously measured with laboratory grade instruments on a dynamometer. EPA intends to use the results of this program to evaluate whether PEMS devices can be a primary method to collect vehicle emissions data around the country for use in the development of fleet emissions inventories.

The KC study was conducted in three distinct Phases. In the Pilot phase the test facility in Kansas City was prepared and all equipment, staff, and logistics were mobilized. The team also tested three EPA-provided “correlation” vehicles to compare EPA Ann Arbor dynamometer laboratory measurements with those obtained using the EPA portable Clayton dynamometer at the KC test facility. The main study was started in June 2004 and was called Round 1 testing. During this round, approximately 250 vehicles were tested under summer conditions at the facility. In the final testing round, Round 2, approximately 250 additional vehicles were tested under winter conditions. Approximately 40 vehicles tested during Round 1 were re-tested in Round 2 to compare exhaust emissions changes due to seasonal changes.

Summary of Contractor’s Major Findings

This report represents the first steps in an ongoing review process that are being presented to EPA by its contractor, ERG, on its testing procedures, observations and data gathered under this contract. The contractor was also responsible for providing technical assessments following standard operating procedures, review of technical assessment and to identify any data quality issues as outlined in the statement of work and as described in the quality assurance project plan (QAPP).

The following paragraphs state some of the contractor’s major findings:

<u>Sampling Methodology Area</u>

One of the research goals was to carefully select a random sample of gasoline vehicles from the Kansas City Metropolitan Statistical Area (MSA). This was accomplished in Round 1 by using the Mid-American Regional Council (MARC) travel survey study that was completed in 2004 as our starting point for analysis. By comparing the MARC study to Census 2000 data on many demographic and geographic characteristics and found it represented the Kansas City MSA population. Within the MARC survey, 2,887 household had at least one vehicle that could be tested in Round 1 but only 1,236 were contacted. Of those households, 221 agreed to participate in the emission test program; 360 refused to participate; 497 could not be contact after multiple attempts and 106 no longer had valid phone numbers. The overall response rate was 21%.

Another research question dealt with whether nonrespondents were different from respondents. A total of 51 households were able to be converted after initially refusing to participate in the emission test program. The contractor found little difference between participants and refusers when looking at geographic and demographic characteristics. This effort to recruit vehicles that had initially refused participation was only conducted during Round 1 testing.

The Round 1 households were larger and owned more vehicles (again, given that vehicle ownership was a requirement for participation in the study, this finding was not surprising). The Round 1 households show a good geographic dispersion and tend to reflect more moderate income households. The Round 2 study design was similar to Round 1 and many of the household characteristics remained relatively constant and different from the MARC and Census data. Round 2 households were larger, owned more vehicles, reflected more moderate income levels and most tended to own single-family residences. In contrast to Round 1, Round 2 households' geographic dispersion was less urban.

EPA will be continuing it investigation into the characteristics of the KC vehicle fleet to hopefully get a better understanding of possible influences that might better understand factors that we help characterize fleet emissions.

Emission Results

A major goal of the vehicle test program was to gather gaseous and particulate matter emissions from a randomly selected stratified vehicle sample. The contractor has presented some of their analysis in this report. As expected, preliminary findings show that older vehicles have higher gaseous and particulate matter emission than newer vehicles. A major finding was the role that temperature plays in the formation of particulate matter. When comparing forty – three vehicles that were tested in both Rounds but at different temperatures their particulate matter emissions increased for all vehicle bins in Round 2. EPA will be further investigating both the gaseous and particulate matter to determine if other parameters might also be contributing to these emission increases and how these relate to the general vehicle fleet population.

Dyno vs PEMS Evaluation

Another secondary goal was to investigate the capabilities of portable emission measurement system (PEMS) to be able to measure gaseous emission accurately on wide variety of vehicles and compare it to laboratory dynamometers. The contractor reported in their overall summary that the PEMS device compared very favorable to the Clayton portable dynamometer and analyzers on all gaseous measurements. EPA will be conducting further analyze between each of the test cycle's three Phases (cold start, stabilizing and warm start) and also comparing all vehicle tests performed between each Round. A special note needs to be made that improvements to the PEMS software and instrumentation were made between Round 1 and Round 2 which needs to be factored into these analysis.

RSD Data Compared to Vehicle Sample Methodology

On-road data were collected using Remote Sensing Devices (RSD) during both Rounds of the study. The purpose of these deployments was to document the on-road fleet in the Kansas City area and to measure on-road emissions. The contractor presented preliminary results that compared RSD to PEMS second-by-second data connected to the dynamometer. The graphs presented in this report indicates that there might be no major differences or offsets in the gaseous measurements conducted between the general fleet and the fleet randomly selected for this study. EPA will be conducting its own investigation on the data gathered during this test program and will be releasing its conclusions in the near future.

Continuous PM Measurements Results

During this study, different types of analytical equipment were used to measure black carbon and total particle mass on a second-by-second basis. Particle mass was obtained using a DustTrak nephelometer, DataRAM4, and a quartz crystal microbalance (QCM). The contractor was able to provide some preliminary findings on these devices.

The contractor found that the black carbon rates generally decreased from older to newer vehicles. The black carbon rates and the DustTrak were generally higher for cars during the LA92's first Phase when compared to the other two Phases. The contractor noticed that the DataRAM4 PM emission rates were in great excess of those obtained with the DustTrak except for those cases where vehicles had low emission rates. The contractor concluded that the DataRAM4 might have a problem with high concentrations where the optics measurement probably gets dirty, and adds to a scattered signal that gets interpreted erroneously as PM.

The contractor also compared the QCM to PM emission rates and noted that with the exception of Pre-1981 Cars, the QCM reports a higher emission rate than the gravimetric filter. Also the emission rate for the Pre-1981 Trucks was also shown to be less than the Pre-1981 gravimetric filters. Improvements to the QCM equipment occurred between the two Rounds which was not been taken into consideration in this contractor's report. EPA will be conducting its own investigation on the data gathered during this test program and will be releasing its conclusions in the near future.

Particulate-Phase Emissions Speciation from Light-Duty Gasoline Vehicles

Full chemical speciation was determined for 26 individual/composite samples and 6 composite dilution tunnel blank samples in each test Round. The contractor's summary analysis can be found in this report which shows that emissions levels from individual/composite vehicle testing were well above the ranges of values for dilution tunnel blanks with the exception of hopanes and steranes emissions for the newer model-year strata. The contractor found that three PAHs could be potential markers for gasoline exhaust are indeno[123-cd]pyrene, benzo(ghi)perylene and coronene.

The contractor used the comparison of co-pollutants for assessing the overall accuracy and validity of the measurements. The contractor found that PM mass and total carbon (TC) are strongly correlated for the Phase 1 samples and poorly correlated for the lightly loaded Phase 3 samples. Similar results were obtained for elemental carbon (EC) measured by Thermal Optical Reflectance (TOR) versus average black carbon (BC) by the photoacoustic instrument. The contractor also noted when comparing to previous studies (e.g., Gasoline/Diesel PM Split Study) for highly loaded samples, PM mass is typically well correlated with TC and EC obtained by IMPROVE-TOR or STN-TOT agree with photoacoustic BC. That is not the case at lower sample loading where sampling artifacts associated with adsorbed organic compounds on the quartz filter may be relatively more important. The correlations of the sum of elements by X-Ray Fluorescence (XRF) analysis show the similar correlations to PM mass as TC, which again reflects the lower mass loadings for the Phase 3 samples. The contractor found that sulfur by XRF analysis is strongly correlated to sulfate by ion chromatography. It was shown that benzo(ghi)perylene, indeno[123-cd]pyrene and coronene all correlate well with TC emissions and that the sum of hopanes and steranes also correlated well with TC.

The contractor found abundances of various chemical species in the dilution blank and composite exhaust samples during each round of testing. Organic carbon (OC) and EC are the most abundant species in motor vehicle exhaust, accounting for over 95% of the total PM mass. For spark ignition (SI) vehicles, BC and PM emission rates can be several times larger during the cold start phase than during hot stabilized operation. Relatively clean SI vehicles produce BC emissions during the more aggressive portions of the driving cycle and during cold starts. Therefore, the emission profiles for clean SI vehicles from dynamometer tests may contain higher fractions of EC than would be produced in congested urban driving conditions. PM emissions from SI high-emitter contain predominantly OC. Variability of emissions from a vehicle may be as great as the difference between vehicles, particularly for the high emitters. The contractor found an abundances of individual organic species relative to total mass or carbon are generally consistent from profile to profile for organic and elemental carbon, PAH, hopanes & steranes, and nitroPAH. Alkanes and polars appear too variable to be useful for receptor modeling. Gasoline vehicles, whether low or high emitters, emit higher proportions of high molecular-weight particulate PAHs (e.g., benzo(b+j+k)fluoranthene, benzo(ghi)perylene, indeno(1,2,3-cd)pyrene, and coronene). Hopanes and steranes are markers for lubricating oil from internal combustion engines, and their emission rates were higher for high emitting vehicles. EPA will be conducting its own investigation on the data gathered during this test program and will be releasing its conclusions in the near future.

<u>Gaseous-Phase Emissions Speciation from Light-Duty Gasoline Vehicles</u>

Volatile organic compounds (VOC) chemical speciation was determined for the individual/composite samples and composite dilution tunnel blank samples. The contractor field-blank corrected all data and reported all their findings in this report. The contractor performed a validity check by comparing the total nonmethane hydrocarbon (NMHC) values from the DRI

VOC speciation samples to the corresponding data obtained by Bevilacqua Knight Incorporated (BKI). With the exception of two obvious outliers (S1-2 and S5-4), were shown to have good agreement for the uncomposited samples from Round 1. However, the contractor found that there was not agreement with Round 2. Further investigation, revealed a sampling train was disconnected from the main sampling line and capped off during some temperature experiments conducted between the Rounds.

The contractor developed a methodology for reconstructing the missing VOC speciation data by first calculating the ratios of reported concentration of each hydrocarbon compound to the total HC reported for each run. These ratios were then averaged for all valid canister samples and the resulting average and standard deviation of the ratios were used to estimate the hydrocarbon speciation for the invalid samples based on the total HC from BKI's bag samples. The contractor included this data in a separate table for its review.

The contractor found that that the distributions in emission rates for BTEX and formaldehyde show that newer model year vehicles are generally clean and that emissions of older vehicles are highly variable with some vehicles emitting BTEX and formaldehyde at rates exceeding that of normal emitters by more than two orders of magnitude. The contractor found an abundance of benzene, toluene, ethylbenzene and xylenes are similar among the samples and between Rounds 1 and 2. There also seems to be a strong correlation among related aromatic hydrocarbon species for all exhaust composites. EPA will be expanding its review of this data and will be conducting further analysis to make a better determination on all of these preliminary findings.

Next Steps in EPA’s Data Review and Analysis

This contractor’s report did not directly answer the main objectives of the study but the contractor provided EPA with enough quality assurances and checks for EPA to start address them. EPA will take this contractor’s report and will be reviewing its data and conducting its own comprehensive review and evaluation on the observations and data gathered during the study. EPA will release this report and data to the general public after receiving approval from our sponsors. EPA will also be comparing this data with other know emission test programs conducted by other testing organizations and by ourselves as part of its comprehensive review and will be releasing its findings in subsequent reports in its efforts better understand and address its use in the development of our models and regulations.

Overview of Test Program Results

Overview of Sample Selection and Recruiting

The recruitment process required deriving a targeted (stratified) sample of vehicles from a cohort of 2000 households generated through random sampling in the Kansas City Metropolitan Statistical Area (MSA). The Mid-American Regional Council (MARC) completed a comprehensive travel survey of Kansas City regional households in spring of 2004. [1] That study's resulting dataset was reviewed for use as the initial cohort of households.

The use of the MARC 2004 Household Travel Study (MARC Study) as the cohort from which to recruit vehicles allowed vehicle recruitment to begin earlier than planned in Round 1. It also provided, inherent in the data set, household data elements including year, make, model, body type, and fuel type for each household vehicle, home address and preferred method for contacting them. One of the challenges of Round 1 testing was that there were fewer than expected older vehicles available for recruitment. In fact, by the end of Round 1 testing, the available vehicle pool for recruiting the oldest vehicles (Pre-1981 and 1981-1990 trucks and cars) had been virtually exhausted. This posed a challenge for Round 2 testing. Fortunately, the Kansas and Missouri Vehicle Registration database provided a large pool of vehicles that can be sampled and recruited for testing. That database was used to draw representative stratified random samples for recruiting as many vehicles as necessary to achieve the desired sampling targets.

Meeting the study goals required deriving a targeted (stratified) sample of vehicles from a cohort of 2000 households generated through random sampling in the KCMSA. The methodology for generating the sample originally called for conducting a Random Digit Dialing (RDD) telephone survey of households (HH) in the KCMSA. This methodology relied on two key underlying assumptions:

- An RDD sample of HHs will generate a representative sample of the population in the Kansas City MSA, and
- The cohort of HHs participating in the RDD survey will provide a representative sample of vehicles for emissions testing.

Because ERG team member NuStats had recently completed the 2004 Kansas City Travel Behavior Survey for MARC, the use of the survey data (conducted in Spring 2004 using an RDD sample design) was recommended. NuStats conducted a comparison of the MARC data with Census 2000 data at the household and person levels using a number of demographic and geographic characteristics. As evidenced in Tables OS-1 and OS-2, using the MARC RDD sample to create a cohort of households satisfactorily represented the Kansas City MSA population on a number of demographic / geographic characteristics. [2]

[1] Kansas City Regional Household Travel Survey Final Report, http://www.marc.org/transportation/pdf/travelsurvey2003.pdf

[2] The MARC survey distributions are unweighted (or raw), allowing for more informed assessment of the product of RDD sampling. It should be noted that survey data are typically weighted to correct for discrepancies between known Census population distributions (for selected demographic variables) and the unweighted survey results. But a comparison of *weighted* survey data and the Census distributions would mask any real differences between survey and Census distributions for those

In the process of conducting the MARC household travel survey (which forms the foundation of the cohort for the EPA Emissions Testing Project), NuStats randomly sampled and contacted 5,500 regional households. Of these, 4,001 agreed to provide their information and 3,049 ultimately completed all aspects of the survey. Non-respondents are those 1,500 households that were contacted and firmly refused to participate.

A discussion of the characteristics of those 1,500 households that chose not to participate is very limited. Most refusals took place during the introduction to the study, prior to the interviewer obtaining any demographic information about the household. The only item that can be reviewed is the geographic distribution of refusers, since all sampled telephone numbers were initially flagged with the anticipated county of residence. This distribution is shown in Table OS-3, and the proportion of refusals matched the proportion of participants by county of residence.

Of those 4,001 households that agreed to participate in the MARC survey, 2,887 with at least one vehicle comprised the Round 1 sample. Of those, a total of 1,236 were contacted about participation in this Round 1 emissions testing effort. Of these households, 221 ultimately agreed to participate in the survey. The remainder either refused to participate (360), could not be contacted after multiple attempts (497), or their phone numbers were no longer valid (106). On average, each household was attempted 2.8 times. The overall response rate for the study was 21%.

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demographic variables that were used in generating the weighting adjustments. Thus, the survey data used in the comparison were not weighted.

Table OS-1. Demographic Comparison of MARC RDD Survey of Households and Census 2000 Distributions

Demographic Characteristic	RDD Survey (n=4,001)	Census 2000
Household size		
1	26.8%	27.4%
2	33.3%	33.0%
3	16.0%	16.2%
4+	23.9%	23.4%
total	*100.0%*	*100.0%*
HH Vehicles		
0	5.8%	7.4%
1	32.9%	33.9%
2	42.7%	41.7%
3+	18.6%	17.0%
total	*100.0%*	*100.0%*
HH Income		
< 15k	9.9%	12.2%
15k - < 25k	10.2%	11.3%
25k - < 50k	30.2%	30.1%
50k - < 100k	35.9%	33.6%
100k +	13.8%	12.8%
(refusal)	(5.9%)	--
total	*100.0%*	*100.0%*
Residency Type		
single family	76.8%	69.0%
all other	23.2%	31.0%
total	*100.0%*	*100.0%*
Race		
White	81.3%	81.6%
Black/African American	10.7%	14.1%
Other	8.0%	4.3%
total	*100.0%*	*100.0%*
Respondent Age		
< 20	29.6%	29.1%
20 - 24	4.3%	6.1%
25 - 54	43.3%	45.3%
55 - 64	9.9%	8.2%
65 +	12.8%	11.3%
refusal	(1.2%)	--
total	*100%*	*100.0%*

Table OS-2. Comparison of MARC RDD Survey and Census 2000 Geographic Distributions

County, State:	Census 2000	RDD Survey (N = 4,001)
Cass County, MO	4.6%	4.9%
Clay County, MO	11.1%	12.3%
Jackson County, MO	40.6%	39.9%
Platte County, MO	4.5%	4.6%
Johnson County, KS	26.6%	26.1%
Leavenworth County, KS	3.5%	3.3%
Wyandotte County, KS	9.1%	8.9%
total	100%	100%

Table OS-3. MARC Household Survey Non-Respondents and Respondents by County of Residence

County	Non-Responders	Respondents
Johnson County, KS	29.7%	26.4%
Leavenworth County, KS	3.6%	3.1%
Wyandotte County, KS	7.8%	8.6%
Clay County, MO	5.5%	4.8%
Cass County, MO	12.5%	12.3%
Jackson County, MO	37.5%	40.4%
Platte County, MO	3.5%	4.5%

Source: Non-Respondents based on Sample File for the Kansas City Regional Household Travel Survey (KCRHTS), unweighted. Includes all households that refused to participate in the study. Respondent proportion reflects the weighted distribution of households participating in the survey.

Of the 221 households that ultimately had their vehicles tested, 23 had initially refused to participate during the recruitment call but were converted after another focused attempt. An additional 29 households cancelled their initial scheduled testing, but agreed again to have the vehicle tested later during Round 1. Tables OS-4 and OS-5 compare the Round 1 participants vs. those that refused testing in terms of the county of residence, income, and vehicles owned. In terms of county of residence, the refusers were most likely to come from Jackson County, Johnson County, or Cass County. However, there was very little difference in the proportions of refusers and regular participants by county of residence. This effort to recruit vehicles that had initially refused participation was designed to be only a part of Round 1 testing.

Table OS-4. Round 1 Refusers and Respondents by County of Residence

County	Refusers	Regular Participants
Johnson County, KS	22.2%	25.6%
Leavenworth County, KS	2.2%	6.4%
Wyandotte County, KS	9.5%	10.4%
Clay County, MO	6.0%	4.8%
Cass County, MO	14.0%	9.6%
Jackson County, MO	43.2%	40.0%
Platte County, MO	2.9%	3.2%

Source: Non-Respondents based on unweighted KCRHTS data for refusers and regular participants in Round 1 of the study.

The refusers were more likely to report a lower income than that reported by regular participants (22% compared to 16%, respectively).

Table OS-5. Round 1 Refusers and Respondents by Income Level

Income	Refusers	Regular Participants
<15,000	8.8%	4.9%
15,000 - < 25,000	13.5%	10.6%
25,000 - <50,000	35.5%	37.4%
50,000 - < 75,000	18.9%	20.3%
75,000-<100,000	14.5%	17.9%
100,000+	8.8%	8.9%

Source: Non-Respondents based on unweighted KCRHTS data for refusers and regular participants in Round 1 of the study.

Section 3.2 of the main body of the report defines the study cohort as being derived from the MARC 2004 household travel study sample, and demonstrates that the MARC sample represented the KCMSA. In evaluating below the MARC sample with the Rounds 1 and 2 participant characteristics and the 2000 Census data for the study area, the first comparison is on key household characteristics, including household size, vehicles, household workers, household income, residence type, and home ownership as shown in Table OS-6. This table shows the raw and weighted MARC sample characteristics, the raw Rounds 1 and 2 participant characteristics, and the 2000 Census data for the study area.

Table OS-6. MARC Household Characteristics Compared to Census

Characteristic	MARC Raw Data	MARC Weighted Data	EPA Round 1 Data	EPA Round 2 MARC Data Only	Round 1 & Round 2	Census Data
Household Size						
1	28.40%	27.50%	16.80%	7.06%	10.84%	27.40%
2	34.00%	32.90%	32.80%	36.47%	34.94%	32.90%
3	15.80%	16.20%	14.40%	20.00%	18.07%	16.20%
4+	21.80%	23.50%	36.00%	36.47%	36.14%	23.50%
Household Vehicles						
0	5.30%	7.40%	0.00%	0.00%	0.00%	7.40%
1	32.00%	33.90%	12.80%	10.59%	12.05%	33.90%
2	44.20%	41.70%	44.80%	54.12%	49.40%	41.70%
3+	18.50%	17.00%	42.40%	35.29%	38.55%	17.00%
Household Vehicles		(Reweighted from above to include households with 1-3+ vehicles)				
1	33.79%	36.61%	12.80%	10.59%	12.05%	36.61%
2	46.67%	45.03%	44.80%	54.12%	49.40%	45.03%
3+	19.54%	18.36%	42.40%	35.29%	38.55%	18.36%
Geography						
Urban	18.50%	20.60%	23.20%	12.94%	16.87%	20.60%
Suburban 1st Ring	26.20%	26.00%	28.80%	25.88%	29.52%	26.00%
Remainder	55.20%	53.40%	48.00%	61.18%	53.61%	53.40%
Household Income						
< $15k	8.90%	9.60%	4.80%	3. 53%	4.22%	12.20%
$15k - < $25k	9.50%	9.70%	10.40%	7.06%	7.83%	11.30%
$25k- < $50k	29.70%	29.80%	36.80%	31.76%	34.34%	30.10%
$50k - < $100k	37.60%	36.10%	37.60%	40.00%	40.36%	33.60%
$100k +	14.40%	13.70%	8.80%	12.94%	10.84%	12.80%
Income refusals	5.50%	5.50%	1.60%	4.71%	2.41%	--
Residence Type						
Single family	78.40%	76.90%	87.20%	91.76%	87.95%	69.00%
All other types	21.60%	23.10%	12.80%	8.24%	12.05%	31.00%

Source: 2000 Census and Kansas City Regional Household Travel Survey (KCRHTS), weighted. As documented in the Kansas City Regional Household Travel Survey Final Report, the data were weighted by household size, household vehicles, and geography (home location). Round 1 & Round 2 participants are summarized using raw KCRHTS data as the EPA surveys didn't obtain demographic information.

- MARC Sample: For the most part, the weighted data compare favorably with the census data, indicating that the survey data set is representative of the regional population. The difference in the distribution of respondents based on residence type can be explained somewhat based on the proportion of sample types used in the study. Listed telephone numbers (those with complete address information for the household) are typically associated with households of longer tenure, which is correlated with living in a single-family dwelling and home ownership. Renters, who are considered to be more transient and living in housing types not characterized as single-family dwellings, may change telephone numbers more often and are typically more likely to have a number that is incomplete or not included in the listed telephone number database. The proportion of listed to not listed sample used in this study was 50/50, meaning that of the 40,000 pieces of sample used, 20,000 were associated with listed numbers and 20,000 were not. An effort more focused on renters would have required the use of more unlisted than listed numbers, which was not possible within the project's budget. Thus, the desire to achieve a good mix of residence type was balanced with the project budget and as a result, residence type came within 10% of the census parameters, but not within 5% like the other variables.
- Round 1 Participants. The Round 1 study design called for testing a specific combination of vehicles based on type (car vs. truck) and age. The testing goals were disproportionate to survey universe parameters, with a higher focus on older vehicles. In addition, only MARC households that owned vehicles could be considered for inclusion in the study. For comparison purposes, we have excluded households with 0 vehicles in one of the comparisons presented in Table OS-6. As a result of these various study parameters, the characteristics of the Round 1 households differs somewhat from those of the MARC and Census data. The Round 1 households were larger and owned more vehicles (again, given that vehicle ownership was a requirement for participation in the study, this finding was not surprising). The Round 1 households show a good geographic dispersion and tend to reflect more moderate income households. In terms of home ownership, there is a significantly higher proportion living in single-family residences. However, as with the main MARC survey, home ownership is a secondary variable of interest so this is not of great concern.
- Round 2 Participants. The Round 2 study design was similar to Round 1 and many of the household characteristics remained relatively constant and different from the MARC and Census data. Round 2 households were larger, owned more vehicles, reflected more moderate income levels and most tended to own single-family residences. In contrast to Round 1, Round 2 households' geographic dispersion was less urban.

Table OS-7 shows that the key person characteristics of MARC age and ethnicity also track the census fairly well. The higher proportion of "other" ethnicities reflects Hispanic respondents who identified themselves as such in answer to this question. With regard to the Rounds 1 and 2 data, the participants tend to be younger, on average. In terms of ethnicity, the Rounds 1 and 2 participants mirror the census extremely well.

Table OS-7. MARC Person Characteristics Compared To Census

Characteristic	MARC Raw Data	MARC Weighted Data	EPA Round 1 Data	EPA Round 2 MARC Data Only	Round 1 & Round 2	Census Data
Respondent Age						
<20	28.70%	30.30%	55.94%	53.94%	53.90%	29.10%
20 – 24	3.60%	3.60%	6.64%	5.45%	5.84%	6.10%
25 – 54	42.30%	41.70%	74.48%	70.91%	72.08%	45.30%
55 – 64	10.60%	9.80%	15.38%	20.61%	18.51%	8.20%
65+	14.80%	14.60%	10.14%	8.48%	9.42%	11.30%
Respondent Ethnicity						
White	84.80%	83.40%	79.20%	84.71%	82.53%	81.60%
Black/African American	9.10%	10.20%	12.80%	10.59%	11.45%	14.10%
Other	6.10%	6.40%	8.00%	4.71%	6.02%	4.30%

Source: 2000 Census and Kansas City Regional Household Travel Survey (KCRHTS), weighted. As documented in the Kansas City Regional Household Travel Survey Final Report, the data were weighted by household size, household vehicles, and geography (home location). Round 1 participants are summarized using raw KCRHTS data as the EPA surveys didn't obtain demographic information.

In addition to this MARC census comparison, ERG performed a comparison of the sample fleet with the KC fleet based on remote sensing measurements, in order to evaluate sample fleet and emissions relative to the KC fleet. The results of this analysis are provided later in this executive summary.

Testing Performed in Kansas City

The vehicle emissions tests were conducted in Kansas City using a LA-92 test cycle which consists of a cold start Phase 1 (first 310 seconds), a stabilized Phase 2 (311-1427 second), a 600-second engine off soak, and a warm start Phase 3 (repeat of Phase 1 of the LA92). Concentration and mass-based THC (total hydrocarbon), CO, CO_2, and NOx emissions measurements were gathered for study vehicles using EPA's Clayton Model CTE-50-0 portable CVS chassis dynamometer. In addition to the regulated gas pollutants measured via CVS, continuous measurements of PM mass were taken using an EPA-supplied Booker Systems Model RPM-101 Quartz Crystal Microbalance (QCM) and Thermo-MIE Inc. DataRAM 4000 Nephelometer. BC was measured continuously with a DRI photoacoustic instrument and integrated samples were collected and analyzed by DRI for PM gravimetric mass, elements, elemental and organic carbon, ions, particulate and semi-volatile organic compounds, and volatile organic air toxics. The samples were extracted from the dilution tunnel through a low particulate loss 2.5 μm cutpoint pre-classifier.

A major goal of the vehicle test program in Kansas City was to obtain up-to-date exhaust composition profiles of gasoline-powered vehicles for application in developing speciated emissions inventories and ambient source apportionment studies. An important issue in the general applicability of these vehicle exhaust composition provides as measured in Kansas City is determining whether gas-particle partitioning of certain organic compounds with the high-volume source sampling used in Kansas City differs substantially from the low-flow, ambient sampling techniques used in some source apportionment studies. To address this issue, organic samples were also collected during a portion of the second round of the study using ambient, low-flow samplers to compare with high-volume organic samples collected in the study.

Laboratory and on-road measurements of THC, CO, CO_2, and NOx emission concentrations and mass rates, along with OBD datastream information (when available) and vehicle activity data (via GPS) were gathered using eight portable emissions measurement systems (PEMS) provided by the USEPA. These systems, the SEMTECH-G manufactured by Sensors, Inc. were used to measure vehicle emissions concurrently with the dynamometer as the vehicle was receiving its LA-92 test.

The day prior to receiving the LA-92 dynamometer test, each study vehicle was driven on a pre-established "conditioning" route (similar in speed, acceleration, and distance to the LA-92 test). This conditioning drive allowed all vehicles to be similarly conditioned prior to dynamometer testing. PEMS instruments were used to measure THC, CO, CO_2, and NOx emissions information and activity data on all study vehicles as they were driven on their conditioning routes. Occasionally, study vehicles were unsuitable for dynamometer testing (generally vehicles that were too long or wide for the dynamometer of vehicles equipped with all-time all-wheel-drive). These "conditioning route" drives were also performed on these vehicles equipped with PEMS devices which allowed emissions information to be gathered on all study vehicles, regardless of dynamometer test eligibility.

In addition to PEMS measurements made during conditioning runs and dynamometer testing, over 60 program participants also participated in "driveaway" testing. This involved installing a PEMS unit on the participant's vehicle, driving the vehicle on the conditioning run, and then releasing the vehicle to the participant. The participant was encouraged to drive the vehicle as much as possible (i.e., by running their weekly errands), and to operate the vehicle as they normally would. This allowed activity, emissions, and fuel economy information to be gathered under "real-world" on-road driving conditions. The PEMS units continued to operate until the battery supply was depleted, typically 6 to 8 hours of operation.

In addition to the on-road activity data measured using PEMS instruments, activity dataloggers manufactured by Ease, Inc. were also used to gather activity data over a period of approximately one week on several study vehicles. However, these dataloggers weren't available until late during the second round of the study, limiting the amount of activity-only data gathered.

During both Rounds of the study, on-road data were collected using Environmental Systems Products (ESP)-supplied RSD equipment and personnel from the Saint Louis Clean Screen program. Two versions of RSD equipment were utilized for this study, the RSD 3000 (which is used in the St. Louis Clean Screen program), and the newer generation RSD 4000.

Fuel samples and oil samples were also gathered from all study vehicles, and sent to the USEPA NVFEL laboratory for analysis.

Summary of Results and Conclusions

It should be first noted that PM is a dynamic pollutant that is constantly being influenced by its environment therefore its formation is constantly changing both in the exhaust stream and in the ambient air. Our tests are a snapshot using specific measurements under specific laboratory and thermodynamic conditions. Real-world PM may differ significantly.

As mentioned above, all vehicles tested during the KC project were subjected to many on road and dynamometer tests. Measurements made during these tests are detailed in Section 4 of the main report. A summary is provided below. For brevity, only a summary of primarily the PM data is presented in this executive summary; all other pollutants are discussed in Section 4.

Round 1 vehicle testing targets and actual vehicles tested on the dynamometer are shown in Table OS-8. Although the total number of vehicles dynamometer tested exceeded project goals, several strata targets were not achieved (most notable in bins 1 and 5). The MARC vehicle database was solely used for vehicle recruitment (via random digit dialing, or RDD) for Round 1 recruiting. This database was supplemented with the Kansas City registration database after Round 1 to help recover these shortfalls during Round 2 recruiting.

Table OS-8. Number of Vehicles Dynamometer Tested During Round 1

Bin	Vehicle Type	Model Year Group	Round 1 Goal	Round 1 Tested	% of Goal
1	Truck	Pre-1981	16	2	13%
2	Truck	1981-1990	26	21	81%
3	Truck	1991-1995	26	18	69%
4	Truck	1996+	39	39	100%
5	Car	Pre-1981	16	6	38%
6	Car	1981-1990	51	49	96%
7	Car	1991-1995	34	39	115%
8	Car	1996+	42	87	207%
		Total	250	261	104%

Table OS-9 lists the various tests conducted during Round 1, in comparison with project goals. PEMS testing on conditioning runs was performed on all vehicles, regardless of dynamometer eligibility.

Table OS-9. Round 1 Tests Conducted

Test Type	Round 1 Goal	Round 1 Tested
PEMS Conditioning Test	All	284
Replicate PEMS Conditioning Test	1 per week	17
PEMS Driveaway Test	N/A	13
Dynamometer/PEMS Test	250	261
Dynamometer/PEMS Test Replicate	1 per week	15
Dynamometer/PEMS Control Vehicle Test	1 per week	12

In order to better achieve strata-specific test targets during Round 2 testing, the MARC database used for Round 1 recruiting was supplemented with the KC registration database for Round 2 recruiting of Bins, 1, 2, 5, and 6. As can be seen in Table OS-10, this significantly improved recruiting efforts.

Table OS-11 lists the various tests conducted during Round 2, in comparison with project goals. Regardless of dynamometer test eligibility, PEMS tests (on the conditioning run) were performed on all vehicles (excluding vehicles whose interiors would not accommodate a PEMS device).

Table OS-10. Number of Vehicles Dynamometer Tested During Round 2 (excluding Round 1 Retest Vehicles)

Bin	Vehicle Type	Model Year Group	Round 2 Goal	Round 2 Tested	% of Goal
1	Truck	Pre-1981	10	9	90
2	Truck	1981-1990	37	29	78
3	Truck	1991-1995	30	31	103
4	Truck	1996+	47	50	106
5	Car	Pre-1981	15	14	93
6	Car	1981-1990	34	36	106
7	Car	1991-1995	36	37	103
8	Car	1996+	27	29	107
		Total	236	235	100

Table OS-11. Round 2 Tests Conducted

Test Type	Round 2 Goal	Round 2 Tested
PEMS Conditioning Test (excluding replicates)	All	324
Replicate PEMS Conditioning Test	1 per week	19
PEMS Driveaway Test	50	51
Dynamometer/PEMS Test (excluding replicates)	236	235
Dynamometer/PEMS Test (Round 1Retests)	25	42
Dynamometer/PEMS Test Replicate	1 per week	11
Dynamometer/PEMS Control Vehicle Test	1 per week	12
PAMS Driveaway Test	N/A	8

Review of PM Emissions Trends

Figures OS-1 and OS-3 present composite $PM_{2.5}$ dynamometer measurements from Rounds 1and 2, respectively, classified by vehicle type and model year. Plots for all other criteria pollutants are presented in Section 4. As expected, newer vehicles have lower $PM_{2.5}$ emissions, and vehicle age appears to have a stronger influence on $PM_{2.5}$ emissions than vehicle type. The variability of emissions for vehicles in the same selection bin is also demonstrated by the plot.

Figures OS-2 and OS-4 present overlay plots of the percent projected-fleet distribution of composite $PM_{2.5}$ emissions from Rounds 1 and 2. Using both the Kansas City fleet distribution data complied for each vehicle testing stratum (vehicles taken from Kansas City vehicle registration list) and actual Rounds 1and 2 vehicle tested stratum distribution (actual vehicle recruited into the dynamometer testing program) we can project a simulated fleet distribution. A solid line represents cumulative percent projected-fleet distribution, while a dashed line represents percent projected-fleet distribution. The horizontal dashed line is a reference line that represents the maximum PM value (80 mg/mile) for Tier 1 vehicles tested under the Federal Test Procedure (approximately between model years 1996 – 2003). The $PM_{2.5}$ distribution shows that more than 95 percent of the fleet has $PM_{2.5}$ emission rates lower than 80 mg/mile. This simulation is applied here for QA/QC purposes only and not for modeling purposes. It provides some insight to the effectiveness of the recruitment process to acquire vehicles that emit high PM emissions.

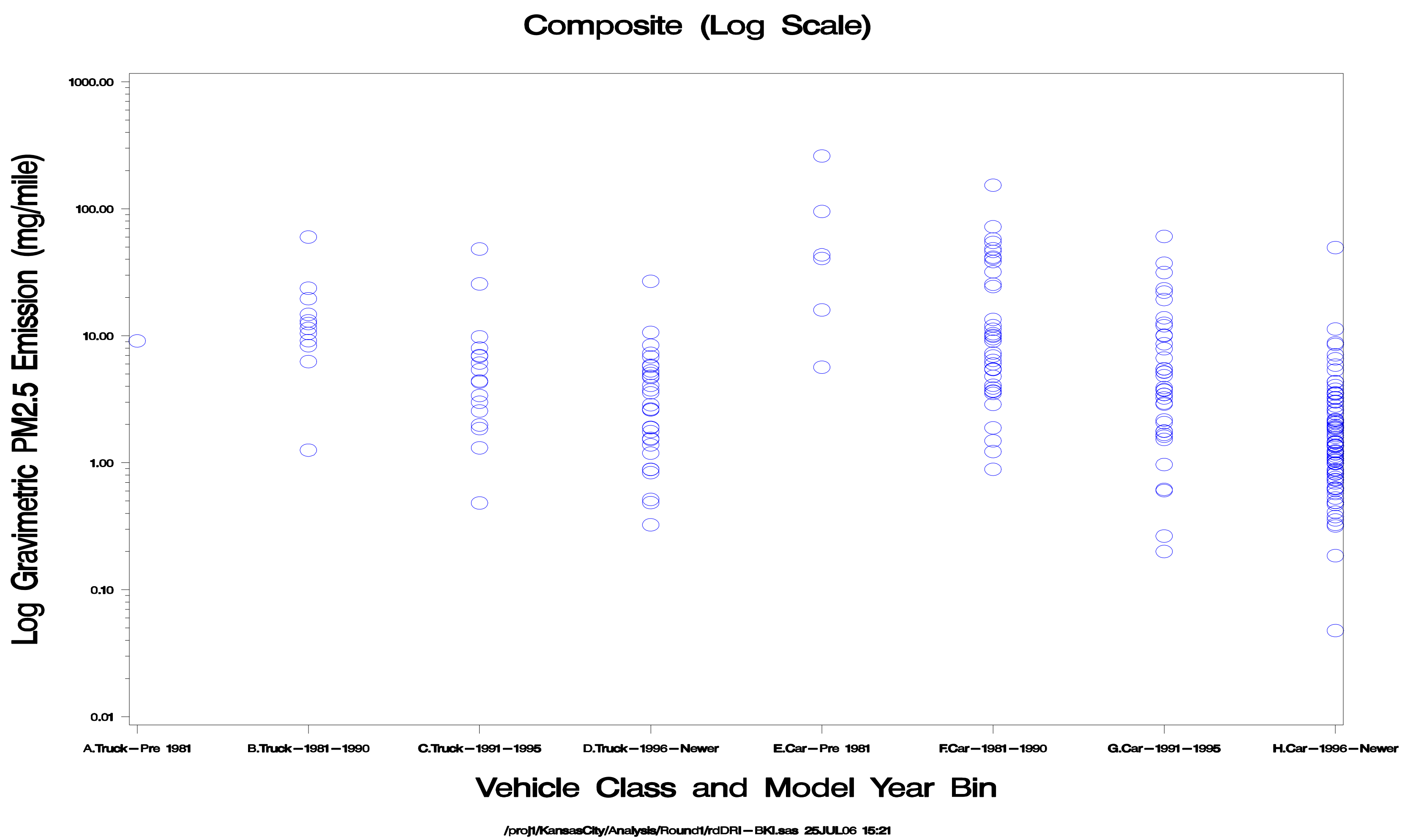


Figure OS-1. Round 1 - $PM_{2.5}$ Emissions by Class-Year Bin

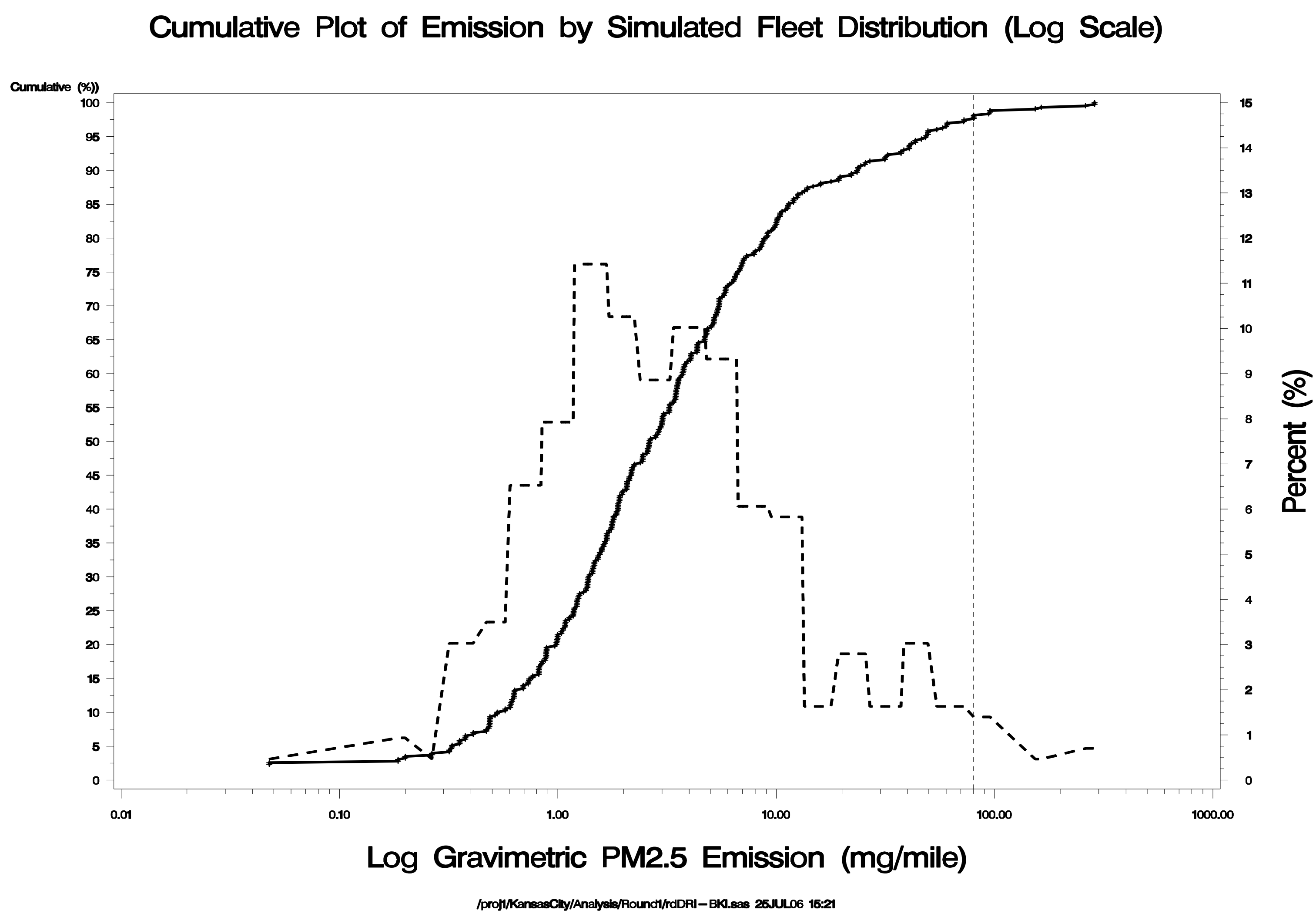


Figure OS-2. Round 1 – Percent Projected-Fleet Distribution of Composite $PM_{2.5}$

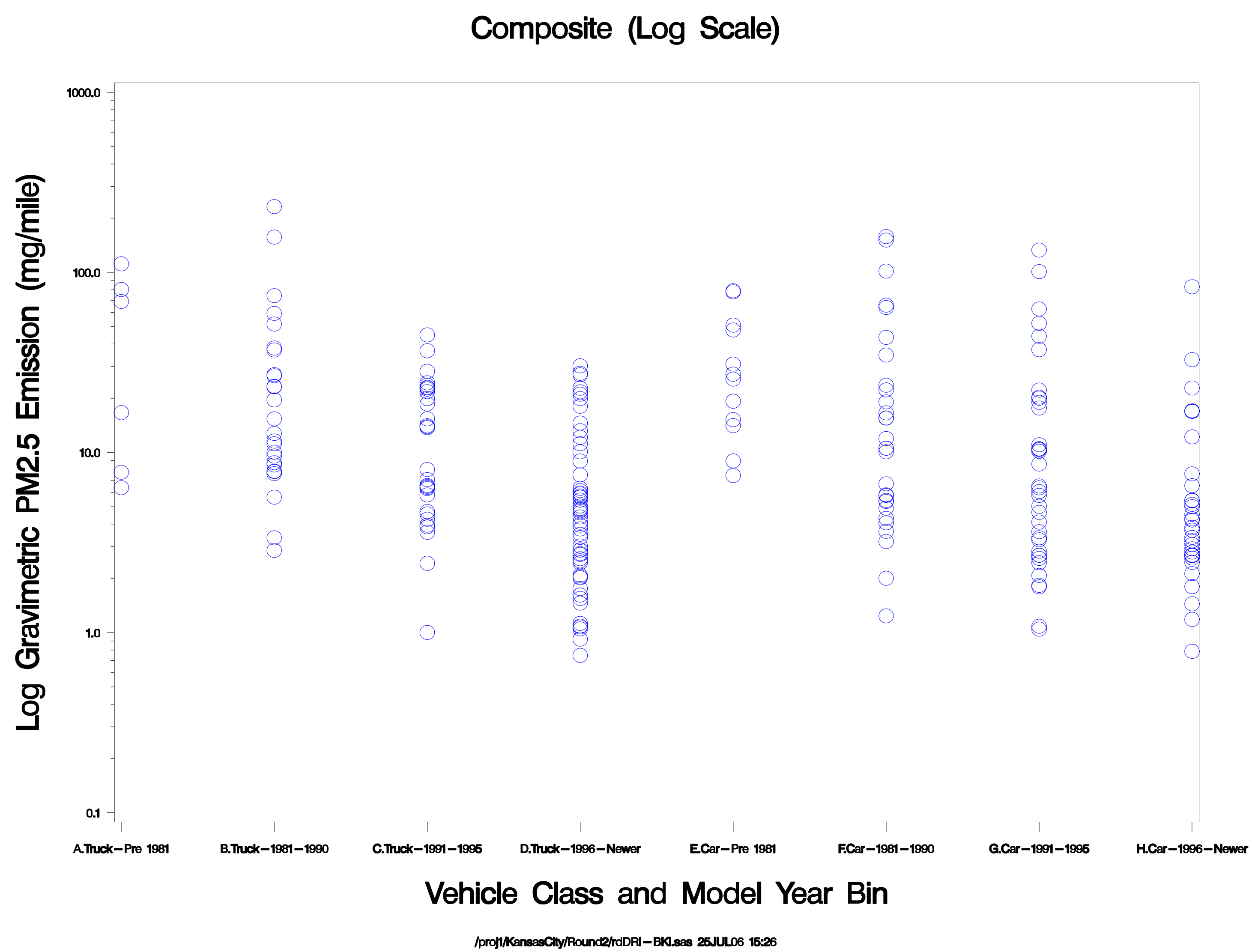


Figure OS-3. Round 2 - $PM_{2.5}$ Emissions by Class-Year Bin

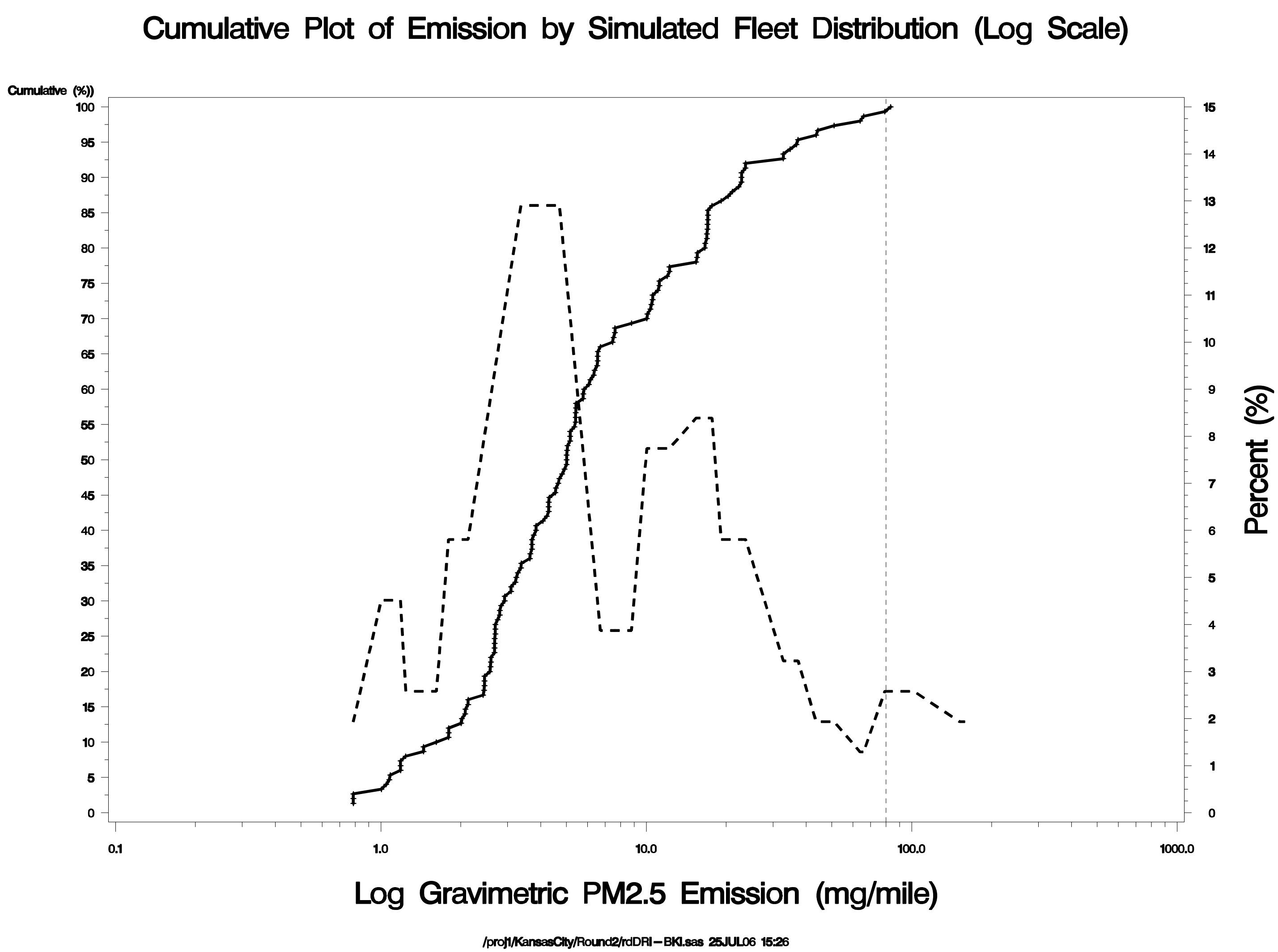


Figure OS-4. Round 2 - Percent Projected-Fleet Distribution of Composite $PM_{2.5}$

RSD Data Collection

On-road data were collected using Remote Sensing Devices (RSD) during both Rounds of the study. The purpose of these deployments was to document the on-road fleet in the Kansas City area and to measure on-road emissions. ERG subcontracted with Environmental Systems Products (ESP) to collect RSD data for this project. ESP used RSD equipment and personnel from the Saint Louis Clean Screen program. They also deployed a newer generation of RSD equipment (RSD 4000, as opposed to the older generation RSD 3000) in parallel to the equipment from their St. Louis program, so side-by-side data were collected using both generations of equipment. Note that for Round 2, only RSD 4000 equipment was used.

During Round 1 of the study, RSD sampling was conducted at eight sites. The ESP team collected data during 5-consecutive days in each of July, August, and September 2004. During Round 2, the ESP team collected RSD data at 5 sites during 5-consecutive days in each of January, February, and March of 2005.

Fleet model year distributions are presented in Section 4. The RSD measurements provided an opportunity to compare the vehicles which were tested in the KC project with the general Kansas City fleet. Even though different vehicles were contained in the two groups, the following analysis compares the individual vehicles of the same vintage in approximately similar driving conditions. ERG performed a comparison of RSD data collected in the Kansas City area with second-by-second (SBS) observations from the PEMS unit connected to the dynamometer.

Thousands of RSD observations yielded VINs, speed, acceleration, and concentrations of HC, CO, and NOx for a wide variety of vehicles in the Kansas City fleet. This data, along with measured RSD site grades and vehicle weights from the ERG VIN Decoder, were used to calculate vehicle specific power (VSP) for each instantaneous observation. The calculation was based on equations used by EPA in MOVES2004, using SAS code provided by Jim Warila.

The same calculations were performed on second-by-second observations obtained from a PEMS unit on the dynamometer. Having determined VSP for each instantaneous observation, the data was segregated by model year VSP bins for further analysis. Since the valid VSP range for RSD is 5 to 20 kW/tonne, only those measurements were retained. The VSP bins were created using ranges of 6 – 9, 9 – 12, and 12 – 18 kW/tonne. All dynamometer test cycle’s Phase data gathered during Round 1 was used except data gathered during Phase 1 of the LA92 test were dropped, since these would represent cold-start emissions, a scenario unlikely at the RSD sites selected for this study.

For each model year -VSP bin combination, the mean and variance of HC, CO, and NOx were calculated for both RSD and SBS data sets. For the SBS data, for a given bin, a test vehicle’s measurements were averaged first, then the average of the averages were calculated to produce the cell average.

Graphs of pollutant concentrations of RSD versus Dyno SBS for CO, and CO_2 for Rounds 1 and 2 are provided in Figures OS-5 through OS-8.

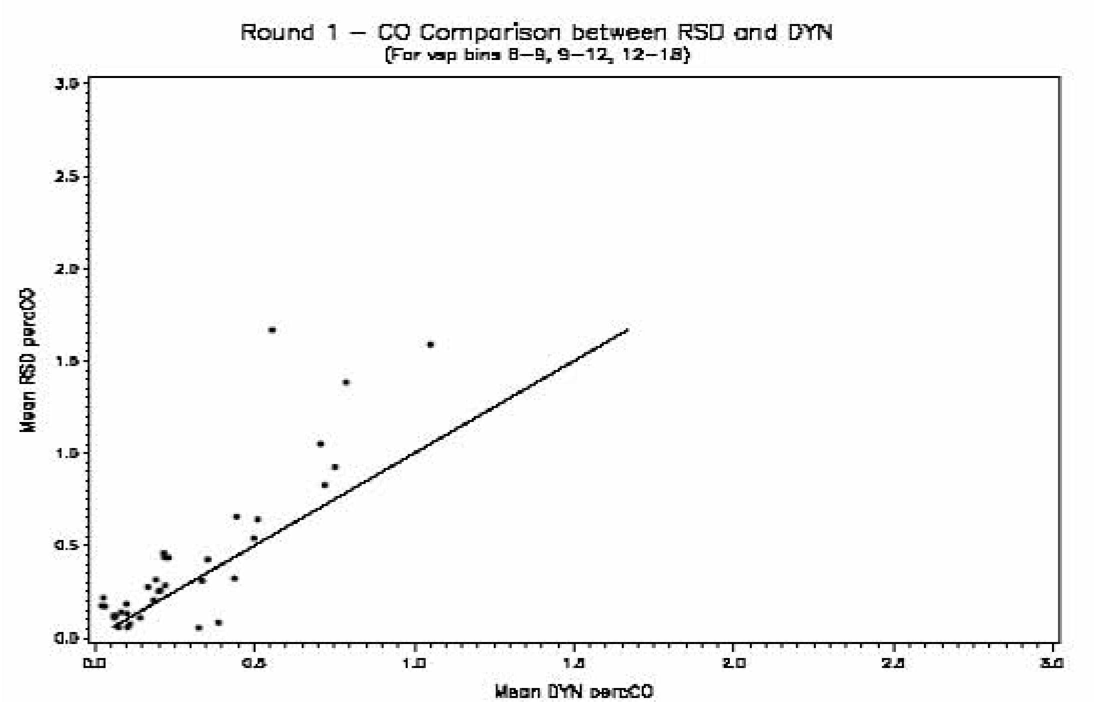


Figure OS-5. Round 1 RSD vs. Dynamometer CO Comparison

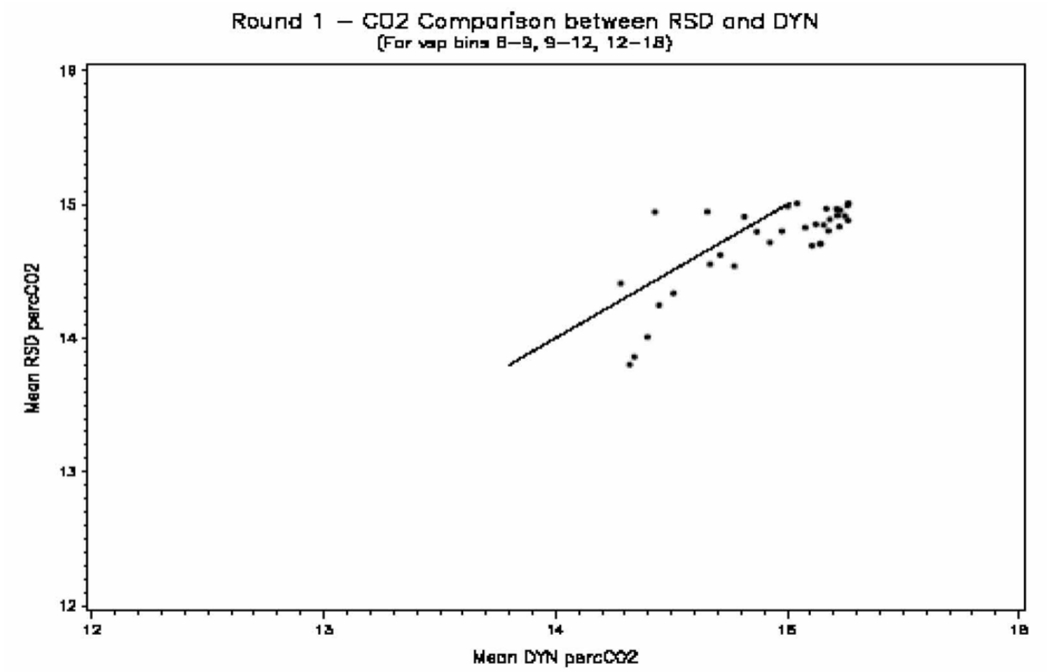


Figure OS-6. Round 1 RSD vs. Dynamometer CO_2 Comparison

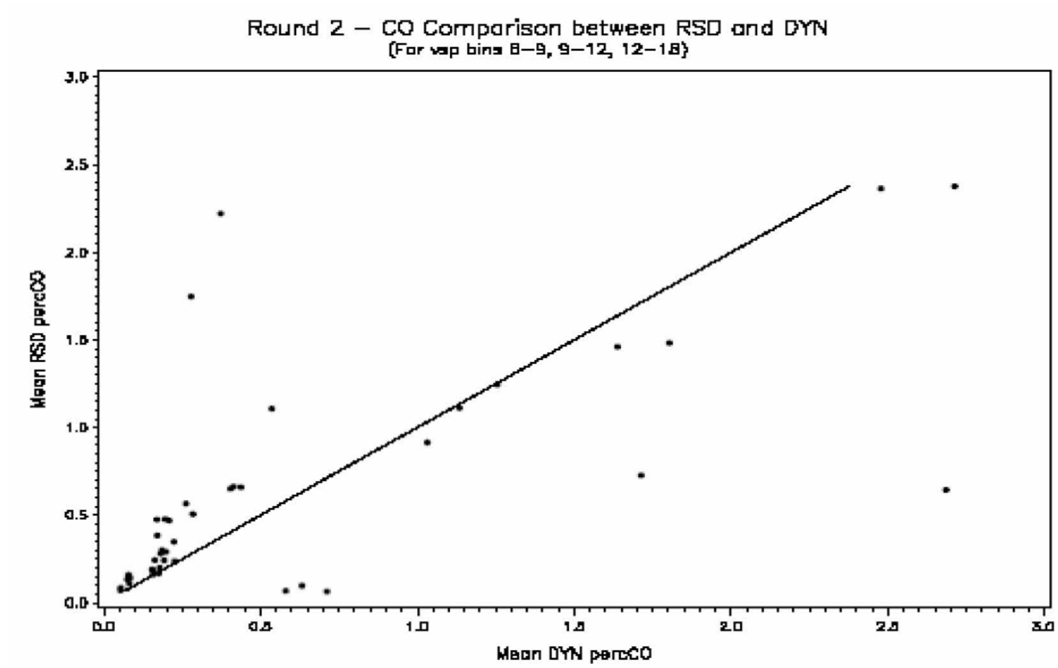


Figure OS-7. Round 2 RSD vs. Dynamometer CO Comparison

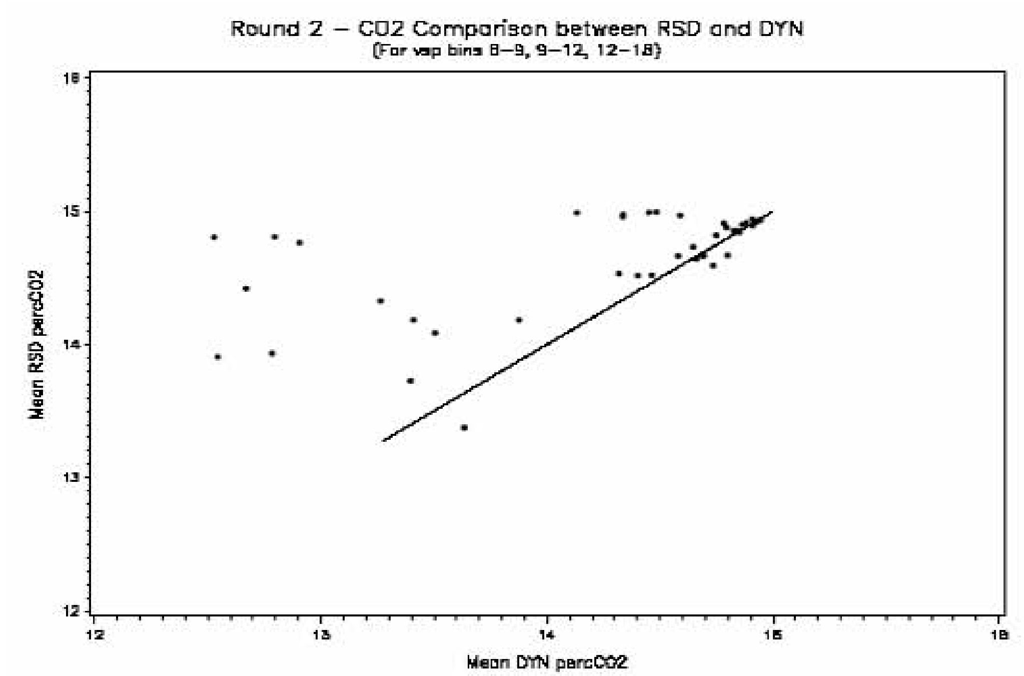


Figure OS-8. Round 2 RSD vs. Dynamometer CO_2 Comparison

Round 1 Summer Regulated Pollutants

Two hundred eighty-one vehicles were tested during Round 1. Their emissions results are summarized below in Table OS-12. This data has been aggregated together from the second-by-second files gathered from the BKI's laboratory analyzers for each individual vehicle's test phase and composite. Each vehicle's data was then average together within other vehicle data in each bin. This data has not been corrected for possible different ambient temperatures that the vehicle was conditioned and tested at.

Table OS-12. Round 1 Average Emission Data for Each Vehicle Bin including Individual Phase and Composite Test

Bin	Vehicle Type	Phase	THC g/mile	CO g/mile	CO2 g/mile	NOx g/mile	PM mg/mile
1	Truck	Phase 1	17.04	203.52	859.57	2.84	87.80
	Pre-1981	Phase 2	6.06	64.94	594.34	2.92	45.05
		Phase 3	8.54	68.45	647.32	2.9	9.14
		Composite	**1.89**	**19.81**	**136.89**	**0.6**	**44.80**
2	Truck	Phase 1	8.69	80.01	684.90	4.02	93.80
	1981-1990	Phase 2	2.58	41.25	408.36	2.29	37.85
		Phase 3	5.06	51.87	528.49	2.65	51.05
		Composite	**0.94**	**10.70**	**100.75**	**0.56**	**48.70**
3	Truck	Phase 1	4.30	34.66	770.23	4.19	14.48
	1991-1995	Phase 2	0.47	6.62	476.13	1.89	11.13
		Phase 3	1.33	11.96	636.71	2.54	14.41
		Composite	**0.31**	**2.88**	**118.96**	**0.52**	**12.37**
4	Truck	Phase 1	2.05	14.10	815.98	1.99	9.58
	1996+	Phase 2	0.11	2.12	480.59	0.51	4.01
		Phase 3	0.31	3.55	648.30	0.79	2.33
		Composite	**0.12**	**1.04**	**121.88**	**0.18**	**4.21**
5	Car	Phase 1	17.66	250.41	676.00	2.61	160.77
	Pre-1981	Phase 2	7.45	113.63	407.01	2.72	73.09
		Phase 3	11.85	137.86	515.28	2.87	63.73
		Composite	**2.20**	**30.18**	**100.38**	**0.56**	**77.09**
6	Car	Phase 1	5.70	43.34	647.44	4.20	35.02
	1981-1990	Phase 2	1.25	15.72	388.74	2.61	18.94
		Phase 3	2.62	21.62	527.28	3.33	8.79
		Composite	**0.53**	**4.76**	**98.69**	**0.64**	**19.24**
7	Car	Phase 1	3.37	25.78	634.01	2.92	11.43
	1991-1995	Phase 2	0.34	8.53	377.44	1.16	7.54
		Phase 3	0.94	10.01	510.75	1.61	5.08
		Composite	**0.24**	**2.58**	**95.67**	**0.34**	**8.22**
8	Car	Phase 1	2.00	12.76	634.13	1.87	7.40
	1996+	Phase 2	0.08	2.81	366.91	0.42	2.48
		Phase 3	0.20	2.78	492.57	0.60	1.80
		Composite	**0.11**	**1.00**	**93.51**	**0.16**	**2.86**

Round 2 Winter Regulated Pollutants

Two hundred ninety-seven vehicles were tested during Round 2. Their emissions results are summarized below in Table OS-13. This data has been aggregated together from the second-by-second files gathered from the BKI's laboratory analyzers for each individual vehicle's test phase and composite. Each vehicle's data was then average together within other vehicle data in each bin. This data has not been corrected for possible different ambient temperatures that the vehicle was conditioned and tested at.

Table OS-13. Round 2 Average Emission Data for Each Vehicle Bin including Individual Phase and Composite Test

Bin	Vehicle Type	Phase	THC g/mile	CO g/mile	CO2 g/mile	NOx g/mile	PM mg/mile
1	Truck	Phase 1	14.14	216.01	800.09	2.80	281.33
	Pre-1981	Phase 2	4.46	51.12	530.98	2.94	101.70
		Phase 3	7.17	57..96	618.29	2.93	28.12
		Composite	**1.47**	**17.82**	**123.74**	**0.59**	**106.13**
2	Truck	Phase 1	12.25	156.37	699.87	3.37	210.94
	1981-1990	Phase 2	1.78	23.64	456.72	2.4	31.43
		Phase 3	3.67	20.91	566.51	2.93	22.16
		Composite	**0.92**	**10.39**	**108.71**	**0.55**	**39.69**
3	Truck	Phase 1	5.92	79.06	776.50	3.56	40.05
	1991-1995	Phase 2	0.49	7.48	465.33	1.6	19.13
		Phase 3	1.18	10.54	587.15	2.03	5.22
		Composite	**0.37**	**4.78**	**114.33**	**0.43**	**20.65**
4	Truck	Phase 1	3.76	35.75	834.76	2.30	40.84
	1996+	Phase 2	0.14	2.89	468.84	0.64	6.02
		Phase 3	0.30	3.48	609.72	0.75	3.26
		Composite	**0.19**	**2.04**	**118.81**	**0.21**	**7.92**
5	Car	Phase 1	16.82	251.28	767.71	2.39	361.73
	Pre-1981	Phase 2	3.00	48.03	492.37	2.89	42.34
		Phase 3	4.73	57.55	609.40	3.12	14.31
		Composite	**1.30**	**16.90**	**117.49**	**0.57**	**57.47**
6	Car	Phase 1	8.83	113.86	652.62	3.49	114.81
	1981-1990	Phase 2	1.61	21.60	386.61	2.26	23.86
		Phase 3	2.81	26.61	493.37	2.79	13.68
		Composite	**0.71**	**8.68**	**95.86**	**0.54**	**28.17**
7	Car	Phase 1	6.37	89.09	701.82	2.77	55.06
	1991-1995	Phase 2	0.46	9.37	399.91	1.03	16.25
		Phase 3	1.00	10.32	525.36	1.41	6.70
		Composite	**0.38**	**5.41**	**101.08**	**0.31**	**18.51**
8	Car	Phase 1	4.11	39.35	700.27	1.79	46.88
	1996+	Phase 2	0.08	2.24	379.66	0.38	6.2
		Phase 3	0.12	2.00	494.48	0.45	4.21
		Composite	**0.19**	**2.06**	**97.47**	**0.14**	**8.23**

Summer vs. Winter Comparison of Regulated Pollutants

Forty-two vehicles were tested in both Rounds 1 and 2 of the study, for the purpose of comparing summer and winter vehicle emissions. Four of these vehicles were tested twice, for a total of forty-six retest pairs across Rounds 1 and 2. Figures OS-9 and OS-10 below present logarithmic plots comparing composite gravimetric $PM_{2.5}$ and NOx across the two Rounds of testing, with a 1:1 line provided for reference. Figure OS-11 shows the $PM_{2.5}$ measurements as a function of temperature for the two Rounds. The winter data show higher emissions and a larger variability in emissions.

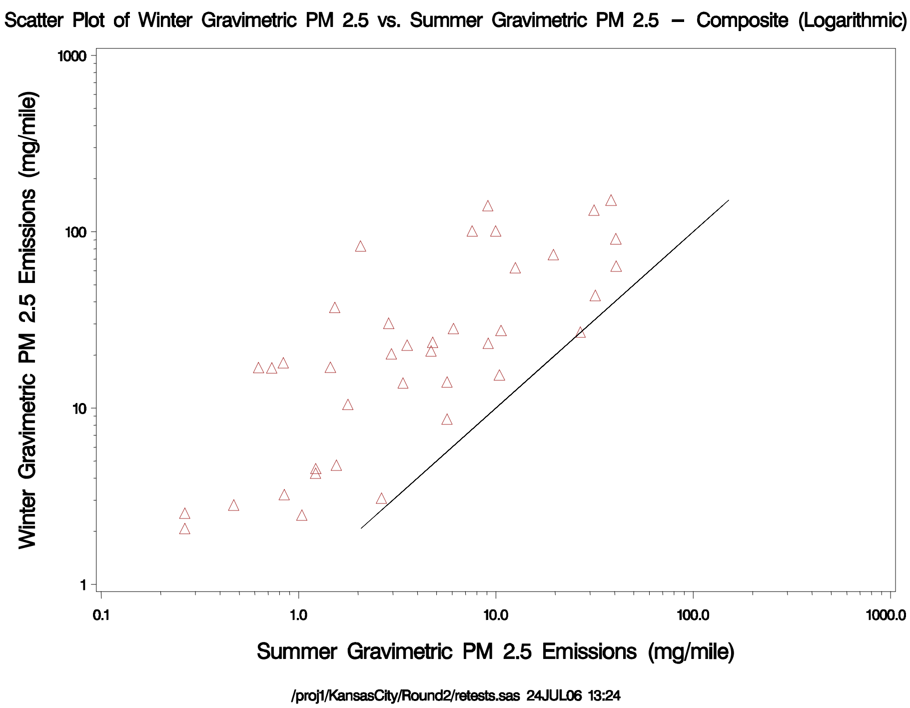


Figure OS-9. Winter vs. Summer Gravimetric PM 2.5

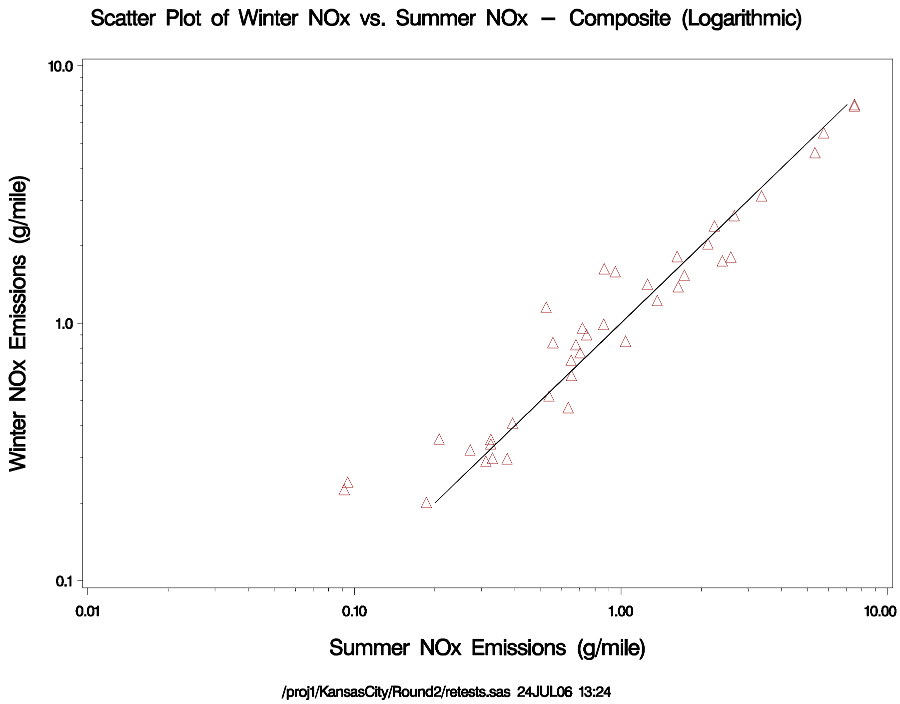


Figure OS-10. Winter vs. Summer NOx

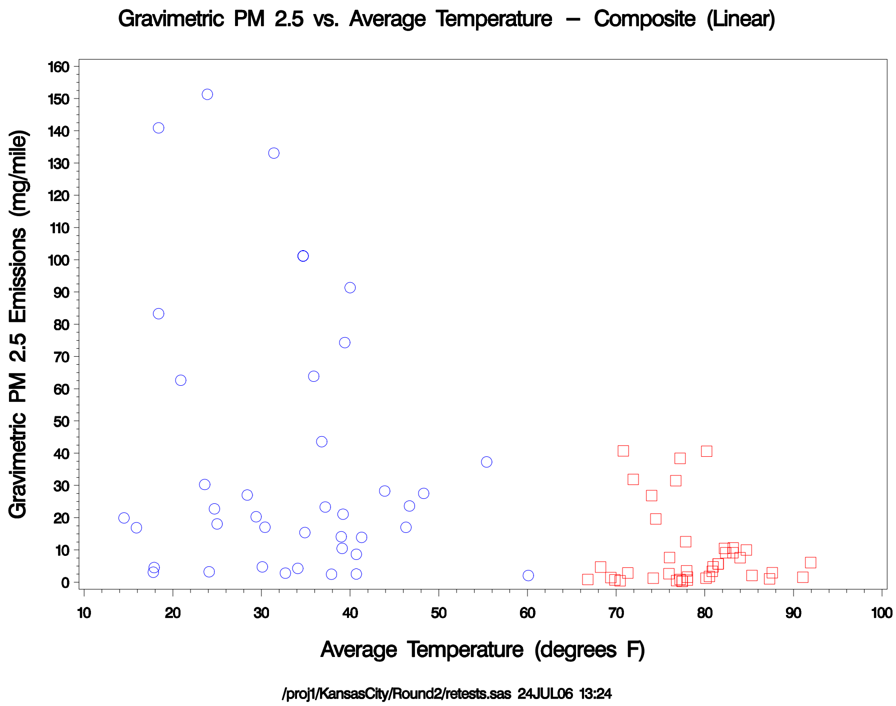


Figure OS-11. Gravimetric PM 2.5 vs. Average Temperature

Analysis of In-Round Duplicate Testing Results

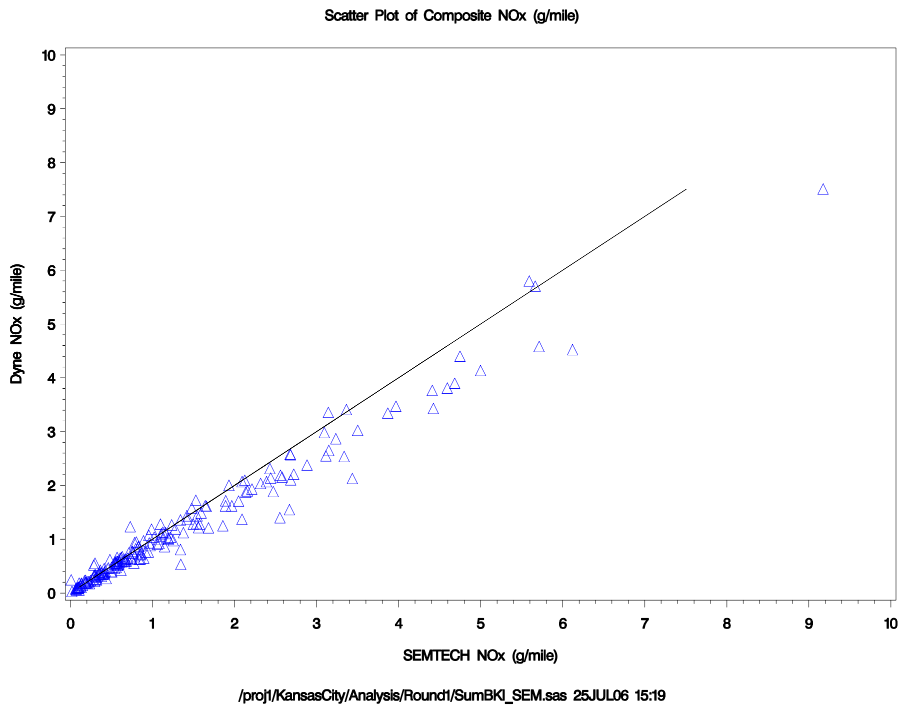
Sixteen vehicles were given duplicate tests during Round 1 of the study, while ten vehicles were given duplicate tests during Round 2. Table OS-14 shows a statistical analysis using a paired t-test on the duplicate measurements conducted during both Rounds of the study. A paired t-test is a sensitive test for evaluating repeat measurements. The table shows that random duplicate measurements were not significantly different. The relative humidity measurements were significantly different in Round 1 for the duplicates, but this does not appear to influence the NOx or other measurements in any meaningful way. We have also included the largest mean difference in the measurements in the far right column of the table. This column shows the threshold value for the mean difference beyond which the value would be called significant at the 95% confidence level for the number of paired measurements made. As shown, all mean values for all the emissions and temperatures are well below this threshold. Even the relative humidity in Round 2 was below this value and hence not significantly different.

Table OS-14. Paired t-test Results on In-Round Duplicate Tests

Round 1								
Variable	***Units***	***N***	***Mean***	***Std Error***	***t Value***	***Pr > |t|***	***t for 95% conf***	***Mean value needed for 95 % conf in diff***
PMdiff	mg/mi	15	0.03	0.66	0.05	0.96	2.15	1.41
HCdiff	g/mi	18	0.01	0.01	0.50	0.62	2.11	0.03
COdiff	g/mi	18	0.26	0.33	0.80	0.43	2.11	0.69
NXdiff	g/mi	17	0.02	0.03	0.70	0.49	2.12	0.06
tempdiff	deg. F	18	-0.76	0.85	-0.88	0.39	2.11	1.80
rhdiff	%	18	8.24	2.86	2.88	0.01	2.11	6.03
Round 2								
Variable	***Units***	***N***	***Mean***	***Std Error***	***t Value***	***Pr > |t|***	***t for 95% conf***	***Mean value needed for 95 % conf in diff***
PMdiff	mg/mi	9	-38.16	23.12	-1.65	0.14	2.31	53.32
HCdiff	g/mi	10	0.00	0.04	-0.04	0.97	2.26	0.09
COdiff	g/mi	10	1.66	2.01	0.82	0.43	2.26	4.55
NXdiff	g/mi	10	0.01	0.03	0.32	0.76	2.26	0.06
tempdiff	deg. F	10	-3.22	3.03	-1.06	0.31	2.26	6.84
rhdiff	%	10	5.40	6.05	0.89	0.40	2.26	13.68

Dynamometer vs. PEMS Emission Measurement Comparison

Figure OS-12 provides a comparison of tandem testing conducted during Round 1 (the summer portion of the study). All test results shown in Figure OS-12 are cold-start LA92 tests conducted on EPA's portable Clayton dynamometer. Results show dynamometer CO_2 and NO_x measurements made using both the dynamometer real-time (modal) bench in comparison with PEMS measurements. PEMS mass emission rates are derived from exhaust mass flow measurements made using an exhaust flowmeter assembly provided by EPA (as part of the PEMS package). Figure OS-13 shows the same information for Round 2 (the winter portion of the study). Comparison of phase-specific and total composite emission rates in the data shows a relatively good correlation between the PEMS and dynamometer methods of measurement.



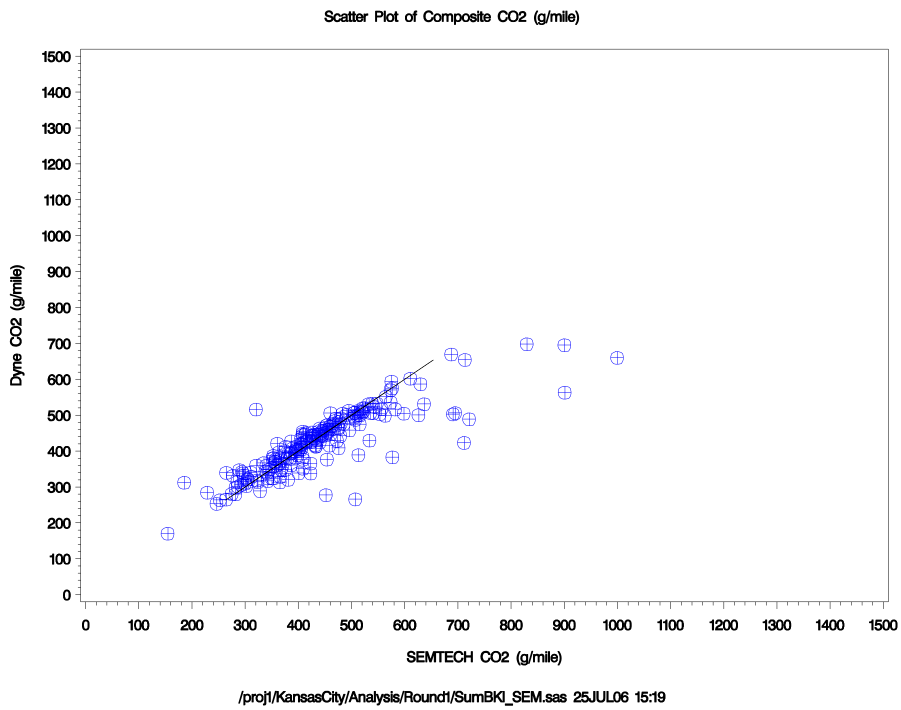
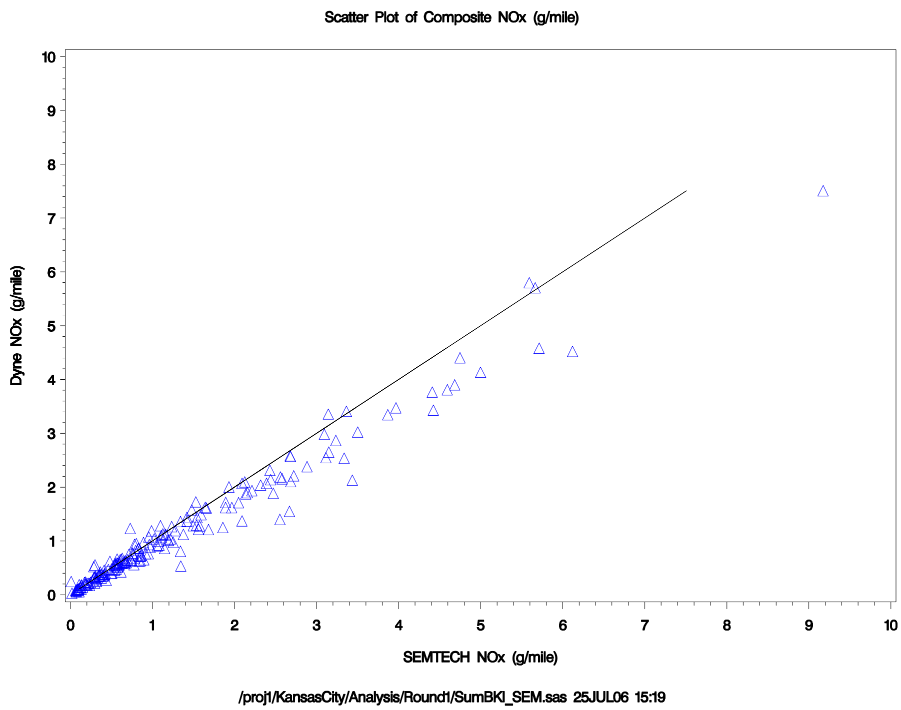


Figure OS-12. Results from Dynamometer vs. PEMS Emission Measurements Conducted During Round 1 (Summer Study)



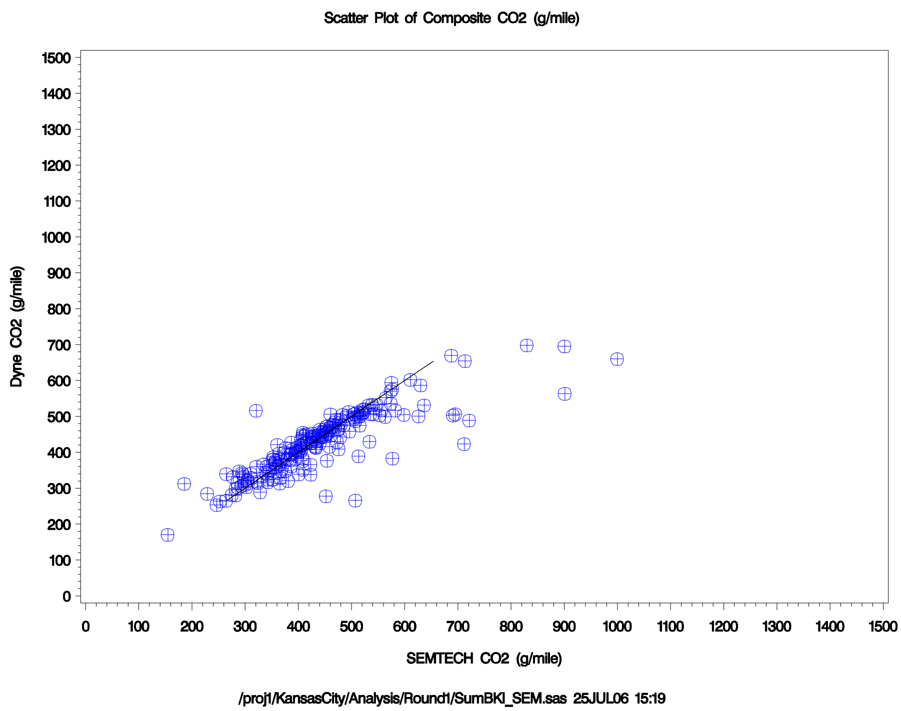


Figure OS-13. Results from Dynamometer vs. PEMS Emission Measurements Conducted During Round 2 (Winter Study)

Comparisons between fuel economy measured by the PEMS units during conditioning runs and PEMS unit measurements during the LA92 drive cycle are shown in Figures OS-14 (Round 1) and OS-15 (Round 2). These figures tend to reveal lower fuel economy determinations as measured by the PEMS in comparison with dynamometer measurements. This difference could be attributed to testing discrepancies such as how closely the laboratory LA92 drive cycle approximates the driving pattern and loads encountered with real-word driving. The difference could also be in part due to measurement discrepancies between the two systems, such as errors or bias in determining the true exhaust mass flow rate or errors or bias in the exhaust gas concentration measurements. Examination of results of tests comparing similar measurement systems but different driving patterns (such as shown in Figure OS-14 and OS-15) helps illustrate the influence of test conditions and testing variations (such as different vehicle speeds and loads), and comparison of results of tests using identical driving patterns but different measurement systems (such as shown in Figures OS-12 and OS-13) helps illustrate the measurement differences of two different systems (PEMS vs. dynamometer analytical bench).

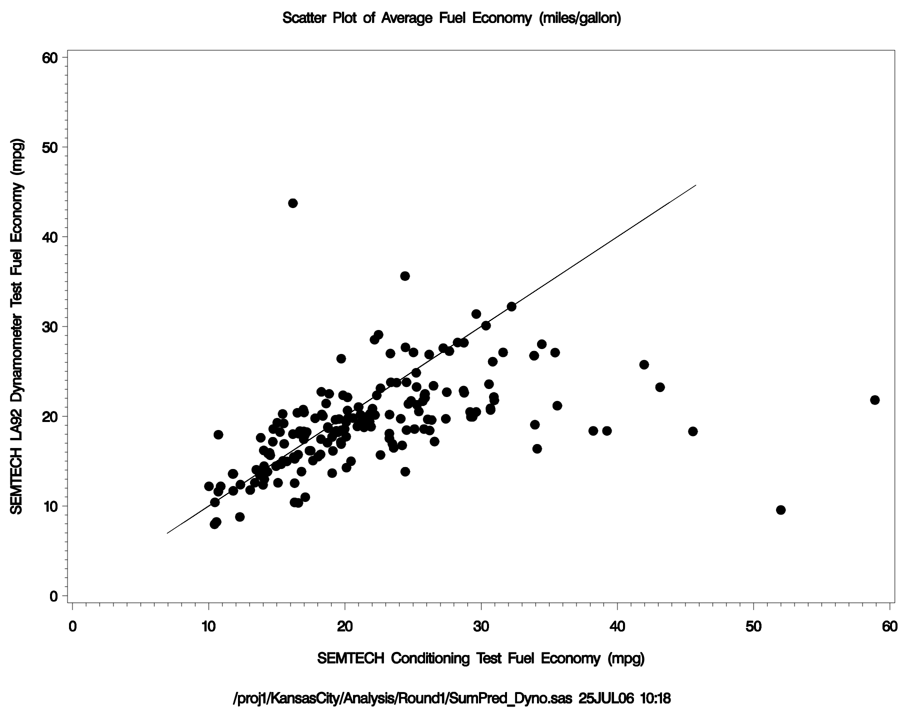


Figure OS-14. By-Vehicle Comparison of Conditioning Run vs. Dynamometer Testing Fuel Economy for Round 1

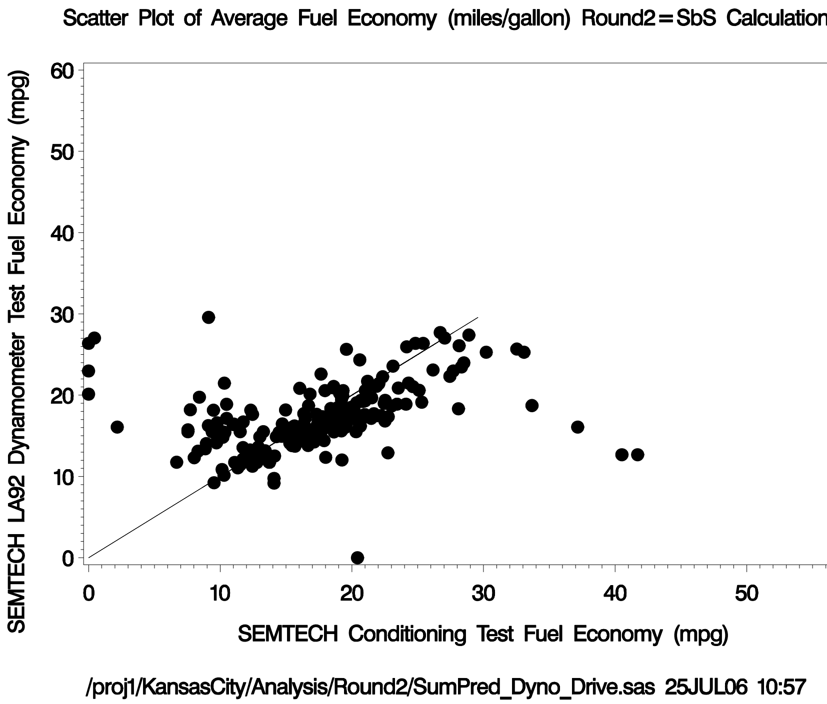


Figure OS-15. By-Vehicle Comparison of Conditioning Run vs. Dynamometer Testing Fuel Economy for Round 2

Continuous PM Emission Measurement Results

Emission rates for each phase of the unified cycle, for each stratum of vehicle model year ranges, measured continuously for BC and total particle mass (PM), are given in Tables OS-15 through OS-17. PM obtained from the DustTrak nephelometer are indicated by "DT" and those from the DataRAM4 are indicated as "DR". Note that BC emission rates generally decrease from older to newer vehicles, though because the class of older trucks (pre-1980) was only represented by 2 vehicles, the averages are highly uncertain. Note that BC and DT PM emission rates were highest (for cars) during Phase 1, though Phases 2 and 3 values were similar. Also note that emission rates computed from the DataRAM4 (DR) are usually in great excess of those obtained with the DustTrak, except for those cases of low emission rates. The DataRAM4 might have a problem with high concentrations where the optics measurement get dirty, and adds to a scattered signal that gets interpreted erroneously as PM.

Table OS-15. Emission rates in mg/mile for Phase 1 of the unified cycle for cars and trucks.

Phase 1		Car			Truck	
Model Year	BC	DustTrak	DataRam	BC	DustTrak	DataRam
Round 1						
1971-1980	63.9	249.2	396.7	72.5	171.5	194.2
1981-1990	18.1	112.7	781.8	19.7	324.8	4557.9
1991-2000	4.4	26.1	73.4	3.4	33.1	171.1
2001-2010	3.6	27.2	167.5	4.1	14.9	14.0
Round 2						
1971-1980	168.4	630.9	2285.7	57.3	422.0	2401.7
1981-1990	35.6	207.2	1026.5	68.1	364.3	1771.7
1991-2000	20.4	103.8	259.5	15.6	67.5	165.4
2001-2010	12.8	89.1	137.3	12.6	54.9	58.7

Table OS-16. Emission rates in mg/mile for Phase 2 of the unified cycle for cars and trucks.

Phase 2		Car			Truck	
Model Year	BC	DustTrak	DataRam	BC	DustTrak	DataRam
Round 1						
1971-1980	25.5	138.4	677.8	0.9	9.2	69.6
1981-1990	4.9	33.2	213.7	4.8	214.2	3800.6
1991-2000	0.7	11.8	70.6	0.5	10.9	78.4
2001-2010	0.3	3.8	32.0	0.5	3.2	2.8
Round 2						
1971-1980	20.0	50.8	82.4	3.2	41.8	129.8
1981-1990	3.1	31.3	186.0	10.4	39.4	91.3
1991-2000	1.2	20.8	111.3	0.6	15.2	32.8
2001-2010	0.4	2.5	2.9	0.3	1.5	2.0

Table OS-17. Emission rates in mg/mile for Phase 3 of the unified cycle for cars and trucks.

Phase 3		Car			Truck	
Model Year	BC	DustTrak	DataRam	BC	DustTrak	DataRam
Round 1						
1971-1980	37.5	92.1	105.6	1.9	4.8	4.7
1981-1990	3.8	22.2	142.7	7.3	192.0	2086.8
1991-2000	0.8	7.2	13.3	0.8	18.9	78.7
2001-2010	0.3	2.3	3.8	0.4	1.8	2.1
Round 2						
1971-1980	28.7	52.4	93.6	3.0	22.9	21.2
1981-1990	1.7	15.2	131.8	3.0	19.1	92.9
1991-2000	0.7	4.2	7.6	0.5	2.7	4.7
2001-2010	0.1	0.5	0.5	0.2	0.8	0.9

Comparison of QCM Versus Time-Inegrated Gravimetric Mass Measurements

Table OS-18 and OS-19 provide a summary of emission rates for each Phase of the Unified Test Cycle for both the QCM and the Gravimetric Filter results for Round 1 and Round 2, respectively. The table also lists the composite emission rate from the same calculation as that used for the FTP Cycle. It should be noted that, with the exception of Pre-1981 Cars, the QCM reports a higher emission rate than the gravimetric filter. Also the emission rate for the Pre-1981 Trucks are also shown to be less than the Pre-1981 Cars.

Table OS-18. Average Emission Rates in mg/mile Derived from QCM and Gravimetric Filter Measurements for all Test Phases.

Vehicle	QCM Emission Rates (mg/mi)			Grav Emission Rates (mg/mi)		
Year	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3
TRUCKS						
1970-1980	62.03	50.65	22.58	87.80	45.05	9.14
1981-1990	44.23	16.74	17.20	93.80	37.65	51.05
1991-1995	18.92	8.09	11.89	14.48	11.13	14.41
1996-2005	13.20	4.53	3.44	9.58	4.01	2.33
CARS						
1970-1980	202.96	15.16	33.18	160.77	73.09	63.73
1981-1990	32.95	23.87	18.18	35.02	18.94	8.79
1991-1995	16.28	6.94	7.02	11.43	7.54	5.08
1996-2005	14.98	3.29	2.96	7.40	2.48	1.80

Table OS-19. Average Emission Rates for Round 2 in mg/mile Derived from QCM and Gravimetric Filter Measurements for all Test Phases.

Vehicle	QCM Emission Rates (mg/mi)			Grav Emission Rates (mg/mi)		
Year	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3
TRUCKS						
1970-1980	139.04	39.79	22.27	281.33	101.70	28.12
1981-1990	104.91	20.83	21.37	210.94	31.43	22.16
1991-1995	38.25	16.28	10.95	40.05	19.13	5.22
1996-2005	33.33	8.38	7.51	40.84	6.02	3.26
CARS						
1970-1980	74.95	9.71	9.52	361.73	42.34	14.31
1981-1990	71.68	16.01	14.07	114.81	23.86	13.68
1991-1995	42.20	16.00	7.67	55.06	16.25	6.70
1996-2005	29.67	9.31	3.92	46.88	6.20	4.21

Figures OS-16 and OS-17 display the average continuous Round 1 CVS concentrations measured using the QCM for four categories (BINS) each of Cars tested for Phases 1 and 3 of the test cycle. Figures OS-18 and OS-19 present the same information for Round 2 vehicles. Comparisons of Phases 1 and 3 within each round of the study reveal continuous PM mass emission rate variations between cold start (Phase 1) and hot start (Phase 3) testing during an equivalent drive trace for the same vehicle. Comparison of equivalent Phases between both Rounds of the study may reveal seasonal continuous PM mass emission rate variation (Round 1 testing took place in the summer, while Round 2 testing occurred during the winter).

A nominal dynamometer speed trace is included in each figure for reference. Only vehicle tests for which no void or partial void was noted during reduction of the data were included in the averages. Consequently, these results should be considered as censured. It will be noted in these figures that the QCM consistently reports negative concentrations during parts of the various test cycle components. This should not be considered a flaw in the instrument but rather an indication that volatile components of particulate collected during accelerations and high-speed portions of the test cycle are desorbing from the collected particulate. This is a phenomena that is common to collected vehicle emissions particulate but not accounted for in integral filter measurements.

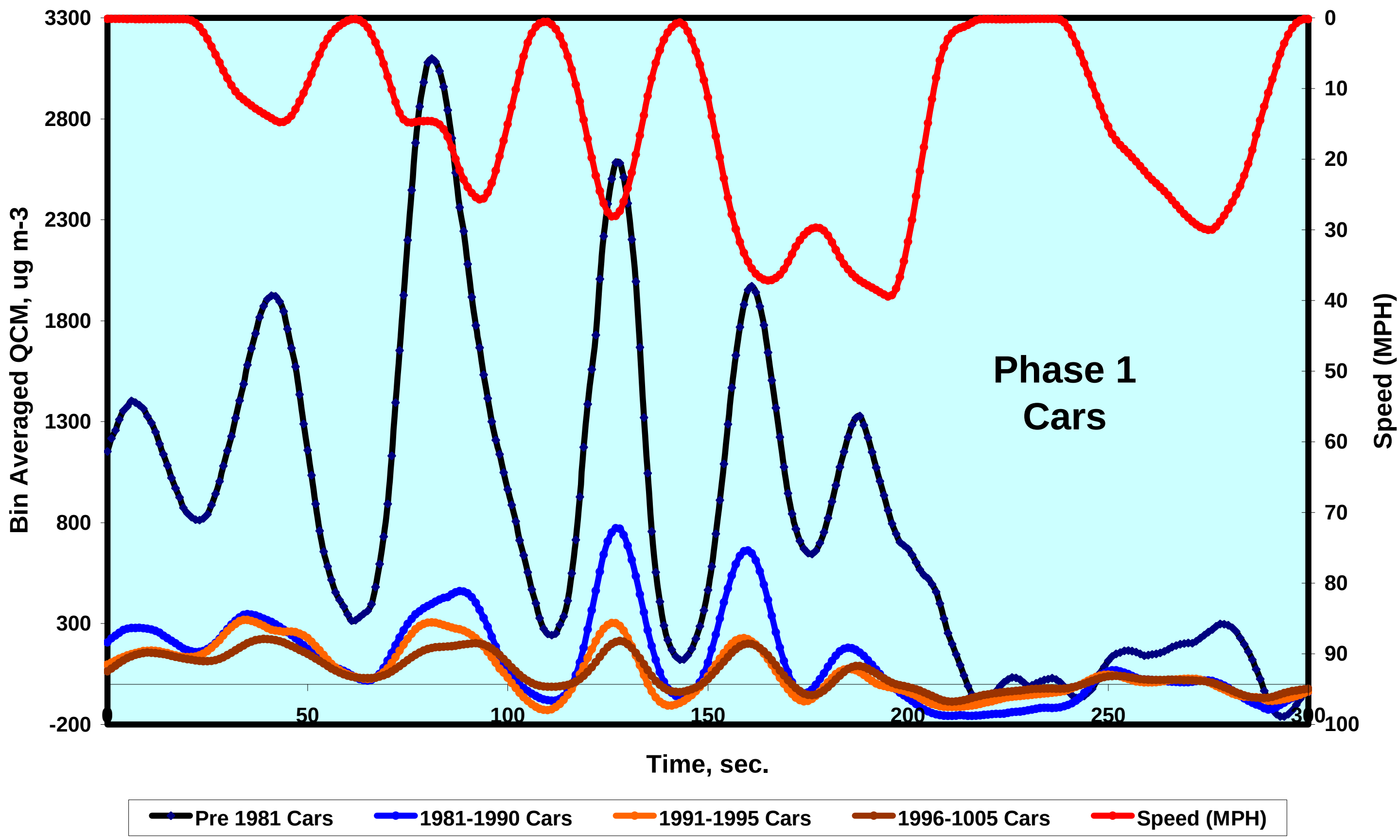


Figure OS-16 Round 1 Averaged CVS Particulate Mass Concentrations - QCM Phase 1 Cars.

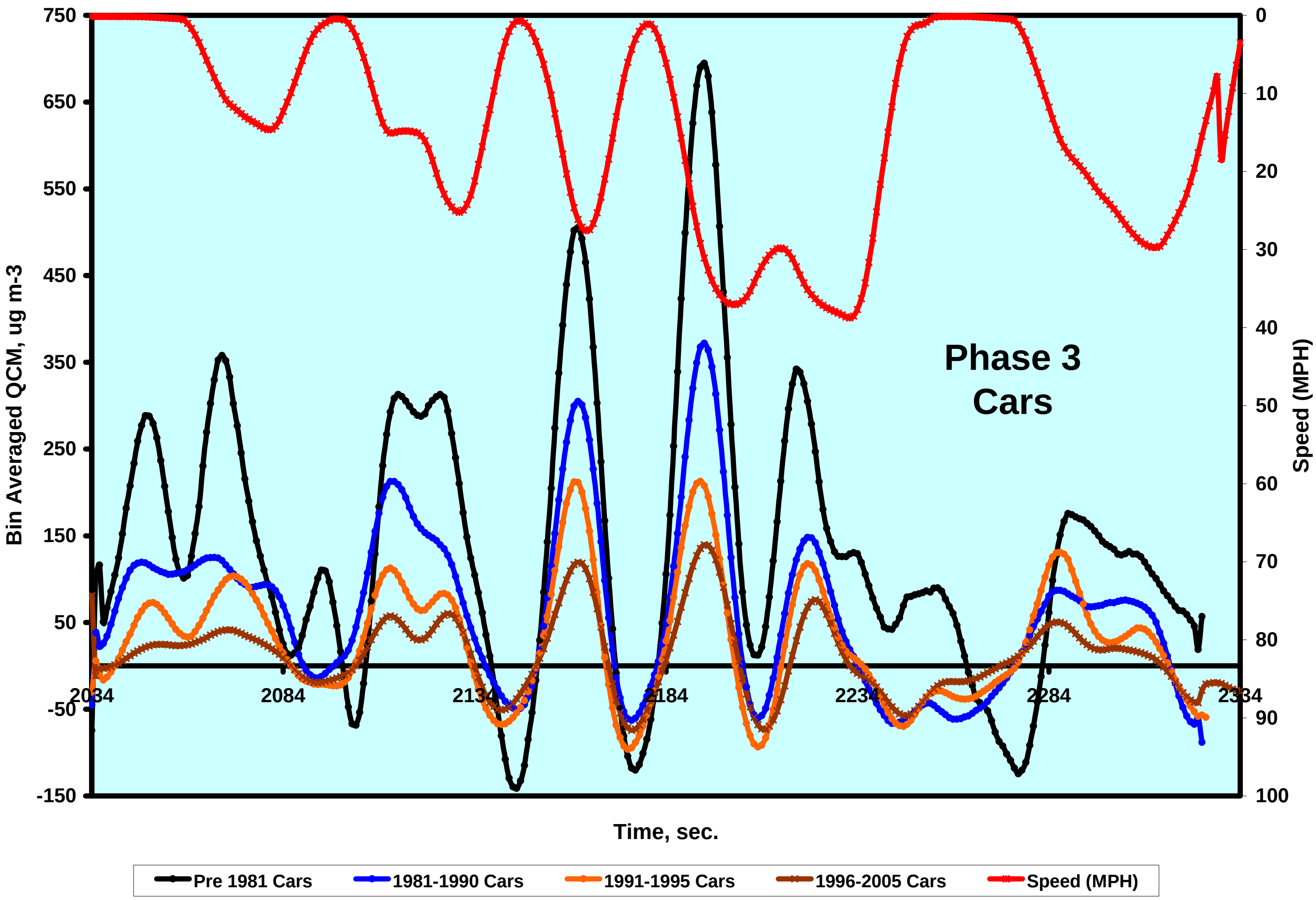


Figure OS-17 Round 1 Averaged CVS Particulate Mass Concentrations - QCM Phase 3 Cars.

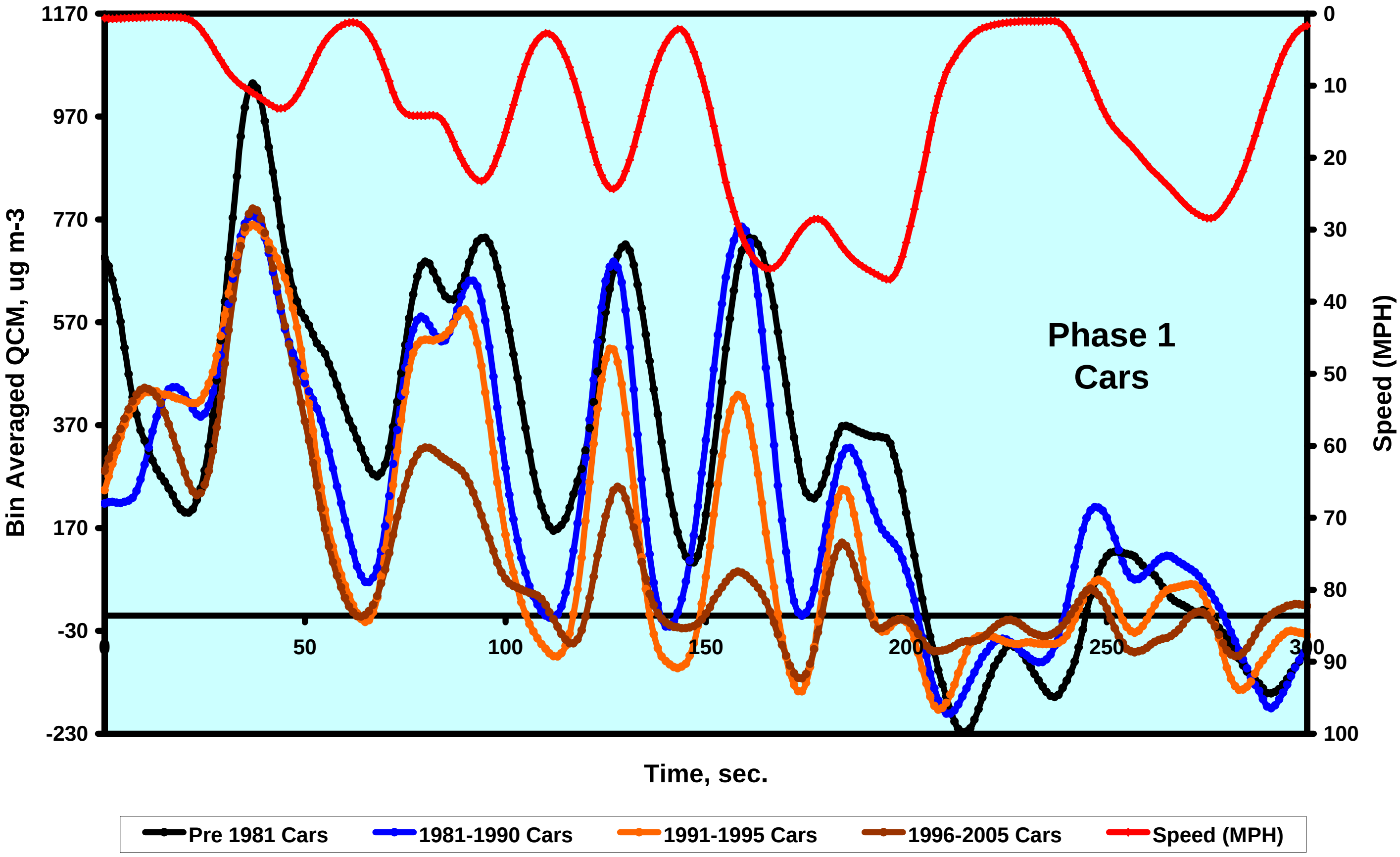


Figure OS-18 Round 2 Averaged CVS Particulate Mass Concentrations - QCM Phase 1 Cars.

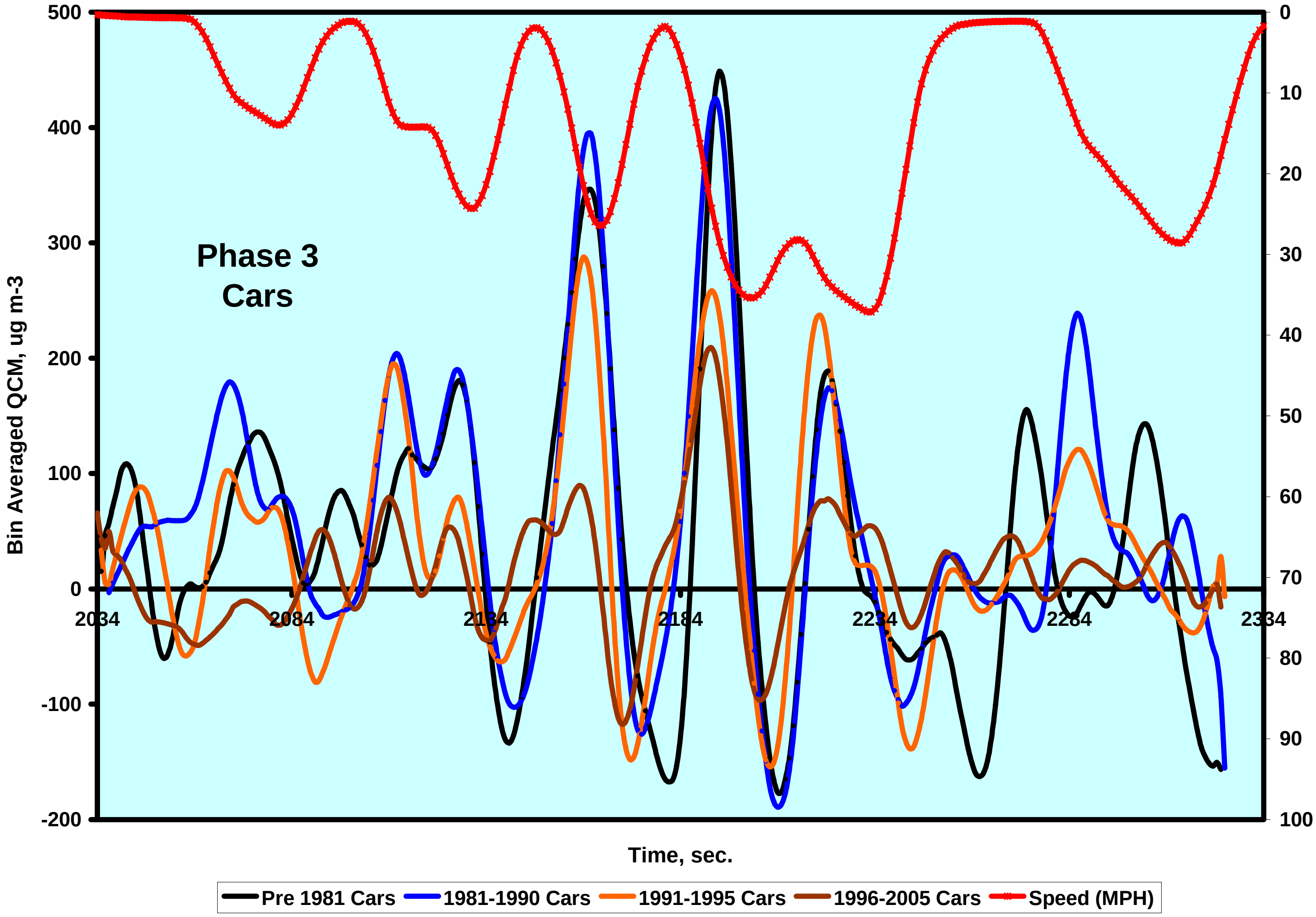


Figure OS-19 Round 2 Averaged CVS Particulate Mass Concentrations - QCM Phase 3 Cars.

Particulate-Phase Emissions Speciation from Light-Duty Gasoline Vehicles

Full chemical speciation was determined for 26 individual/composite samples and 6 composite dilution tunnel blank samples in each test round. The summaries of the PM data for composite exhaust and dilution blank samples in Tables OS-18 and OS-19 for Rounds 1 and 2, respectively, show that emissions levels are well above the ranges of values for dilution tunnel blanks with the exception of hopanes and steranes emissions for the newer model-year strata. Summary data include gravimetric mass, OC, and EC (in mg/mile) and PAH, hopanes, and steranes (in ug/mile). The three PAHs that are potential markers for gasoline exhaust are indeno[123-cd]pyrene, benzo(ghi)perylene and coronene.

Comparisons of co-pollutants can provide validation checks for assessing the overall accuracy and validity of the measurements. Species emitted from the same source type should correlate and exhibit average ratios of species that reflect the nature of the source. Figure OS-20 shows gravimetric mass versus total carbon by IMPROVE-TOR in ug/m^3 of diluted exhaust for Round 1 dynamometer test filters by test Phase. PM mass and TC are strongly correlated for the phase 1 samples and poorly correlated for the lightly loaded phase 3 samples. Similar results are shown in Figure OS-21 for the correlation of EC by TOR versus average BC by the photoacoustic instrument. As we have seen in prior studies (e.g., Gasoline/Diesel PM Split Study) for highly loaded samples, PM mass is typically well correlated with TC and EC obtained by IMPROVE-TOR or STN-TOT agree with photoacoustic BC. That is not the case at lower sample loading where sampling artifacts associated with adsorbed organic compounds on the quartz filter may be relatively more important. The correlations of the sum of elements by XRF analysis (Figure OS-22) show the similar correlations to PM mass as TC, which again reflects the lower mass loadings for the phase 3 samples. Figure OS-23 shows that sulfur by XRF analysis is strongly correlated to sulfate by ion chromatography. Figure OS-24 shows that benzo(ghi)perylene, indeno[123-cd]pyrene and coronene all correlate well with TC emissions and Figure OS-25 shows that the sum of hopanes and steranes also correlated well with TC.

The abundances of various chemical species in the dilution blank and composite exhaust samples during each round of testing are presented in Section 4. OC and EC are the most abundant species in motor vehicle exhaust, accounting for over 95% of the total PM mass. For spark ignition (SI) vehicles, BC and PM emission rates can be several times larger during the cold start phase than during hot stabilized operation. Relatively clean SI vehicles produce BC emissions during the more aggressive portions of the driving cycle and during cold starts. Therefore, the emission profiles for clean SI vehicles from dynamometer tests may contain higher fractions of EC than would be produced in congested urban driving conditions. PM emissions from SI high-emitter contain predominantly OC. Variability of emissions from a vehicle may be as great as the difference between vehicles, particularly for the high emitters. The abundances of individual organic species relative to total mass or carbon are generally consistent from profile to profile for organic and elemental carbon, PAH, hopanes & steranes, and nitroPAH. Alkanes and polars appear too variable to be useful for receptor modeling. Gasoline vehicles, whether low or high emitters, emit higher proportions of high molecular-weight particulate PAHs (e.g., benzo(b+j+k)fluoranthene, benzo(ghi)perylene, indeno(1,2,3-cd)pyrene, and coronene). Hopanes and steranes are markers for lubricating oil from internal combustion engines, and their emission rates were higher for high emitting vehicles.

Table OS-18. Summary of PM data for Round 1 composite exhaust samples[1].

Composites	PM Mass	OC	EC	EC/TC	PAH gas markers	Sum of Hopanes	Sum of Steranes
Dilution Tunnel Blanks							
S0-1	0.39	0.256	0.154	0.38	0.00	0.73	0.45
S0-2	0.53	0.129	0.020	0.13	0.16	0.73	0.48
S0-3	0.19	0.268	0.031	0.10	0.04	1.17	0.48
S0-4	0.24	0.293	0.030	0.09	0.00	0.73	0.35
S0-5	0.95	0.940	0.235	0.20	0.19	2.16	1.09
S0-6	0.70	0.588	0.142	0.19	0.18	2.42	1.90
Trucks							
S1-1	9.13	2.204	1.516	0.41	12.07	1.56	0.03
S1-2	81.73	26.070	17.884	0.41	373.42	31.36	5.79
S2-1	73.07	59.132	4.510	0.07	13.09	164.02	44.50
S2-2	20.11	11.332	6.588	0.37	113.03	8.32	3.52
S2-3	22.02	16.212	4.030	0.20	30.93	59.78	48.31
S2-4	76.16	28.193	25.780	0.48	254.90	36.02	14.42
S3-1	3.76	1.097	0.933	0.46	1.43	0.91	0.76
S3-2	22.36	8.186	5.641	0.41	39.02	22.74	6.07
S4-1	3.31	1.438	0.582	0.29	1.15	1.30	0.48
S4-2	2.12	1.801	1.178	0.40	2.28	2.82	1.73
Cars							
S5-1	18.14	9.029	9.929	0.52	128.83	120.60	0.00
S5-2	60.91	46.521	9.412	0.17	263.07	292.58	63.74
S5-3	9.46	7.177	2.549	0.26	4.62	29.35	5.18
S5-4	207.43	101.649	77.566	0.43	1031.44	405.41	63.62
S5-5	99.63	33.934	50.871	0.60	480.44	175.76	46.40
S6-1	41.62	35.609	0.639	0.02	4.01	52.49	12.35
S6-2	49.04	9.079	36.603	0.80	345.07	16.52	6.04
S6-3	10.10	3.738	4.739	0.56	19.03	5.24	0.67
S6-4	22.84	13.998	2.682	0.16	24.25	26.04	8.70
S7-1	7.66	3.856	2.316	0.38	8.04	10.84	7.25
S7-2	8.81	5.258	1.808	0.26	13.08	25.45	8.62
S7-3	4.12	1.666	0.994	0.37	11.97	11.46	0.45
S7-4	4.78	1.155	1.537	0.57	7.54	7.80	0.36
S8-1	1.81	0.983	0.544	0.36	0.34	1.01	0.57
S8-2	2.08	1.488	0.906	0.38	2.22	3.52	1.19
S8-3	3.48	2.346	1.339	0.36	2.27	3.45	1.29

[1] Gravimetric mass, OC, and EC are in mg/mile and PAH, hopanes, and steranes are in ug/mile. The three PAHs that are potential markers for gasoline exhaust are indeno[123-cd]pyrene, benzo(ghi)perylene and coronene.

Table OS-19. Summary of PM data for Round 2 composite exhaust samples[1].

Composites	PM2.5 Mass	Organic Carbon	Elemental Carbon	EC/TC ratio	PAH gas markers	Sum of Hopanes	Sum of Steranes
Dilution Tunnel Blanks							
W0-1	0.85	0.68	0.14	0.17	0.31	0.97	0.31
W0-2	0.27	0.66	0.03	0.05	0.00	0.29	0.20
W0-3	0.50	0.65	0.16	0.20	0.09	0.44	0.13
W0-4	0.39	0.71	0.08	0.10	0.13	0.49	0.18
W0-5	0.90	0.90	0.17	0.16	0.07	0.65	0.13
W0-6	0.45	0.70	0.10	0.13	0.09	0.48	0.25
Trucks							
W1-1	113.12	74.96	14.09	0.16	364.44	290.43	80.48
W1-2	43.21	31.26	10.01	0.24	87.72	93.86	5.61
W1-3	59.60	34.09	11.59	0.25	251.27	66.64	8.49
W2-1	52.30	25.69	22.84	0.47	319.34	173.27	15.77
W2-2	15.30	4.79	3.58	0.43	7.14	15.00	2.74
W3-1	5.98	2.50	2.66	0.52	128.18	23.96	1.63
W3-2	29.38	10.21	16.25	0.61	71.84	12.80	2.54
W3-3	23.57	7.94	9.00	0.53	21.35	12.01	1.29
W4-1	15.21	5.11	4.23	0.45	16.23	3.01	0.13
W2-3	6.89	2.09	3.35	0.62	9.79	1.98	0.71
W4-2	6.02	2.56	3.07	0.55	19.08	1.90	0.92
W4-3	11.65	5.30	5.24	0.50	26.19	7.96	0.87
Cars							
W5-1	16.82	8.54	7.39	0.46	14.78	6.85	0.57
W5-2	47.47	16.45	28.13	0.63	170.79	12.92	1.84
W5-3	45.26	15.57	15.66	0.50	252.19	18.94	11.78
W6-1	56.31	32.13	20.39	0.39	206.65	170.82	50.03
W6-2	17.14	7.33	9.59	0.57	24.79	5.72	3.35
W6-3	9.97	5.00	3.22	0.39	18.07	7.69	4.02
W6-4	73.13	49.20	4.27	0.08	51.57	216.55	98.98
W7-1	5.08	2.70	2.82	0.51	10.43	1.17	0.34
W7-2	12.44	6.68	3.84	0.36	34.37	6.43	2.23
W7-3	3.45	2.69	1.29	0.32	8.52	3.05	1.75
W7-4	4.65	2.58	1.49	0.37	11.31	0.75	0.46
W8-1	4.21	2.60	1.50	0.37	9.40	2.06	1.08
W8-2	8.46	2.95	4.53	0.61	14.39	2.13	1.47
W8-3	27.78	2.52	3.34	0.57	18.11	2.06	0.52

[1] Gravimetric mass, OC, and EC are in mg/mile and PAH, hopanes, and steranes are in ug/mile. The three PAHs that are potential markers for gasoline exhaust are indeno[123-cd]pyrene, benzo(ghi)perylene and coronene.

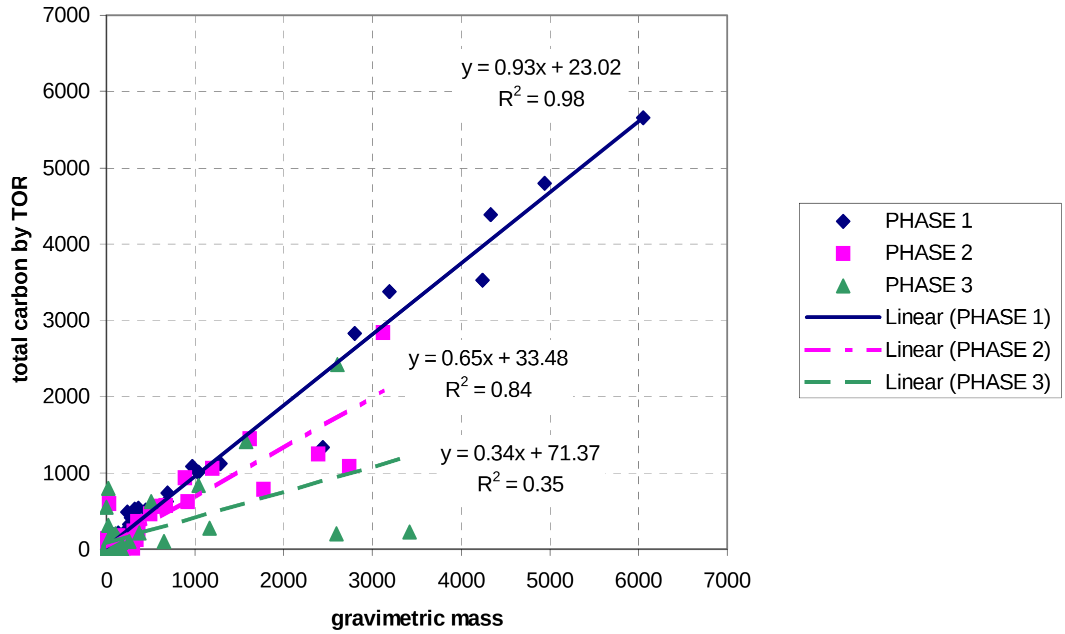


Figure OS-20. Gravimetric mass versus total carbon by TOR

For all dynamometer test filters, separated by test phase. Concentrations are in ug/m3 of diluted exhaust.

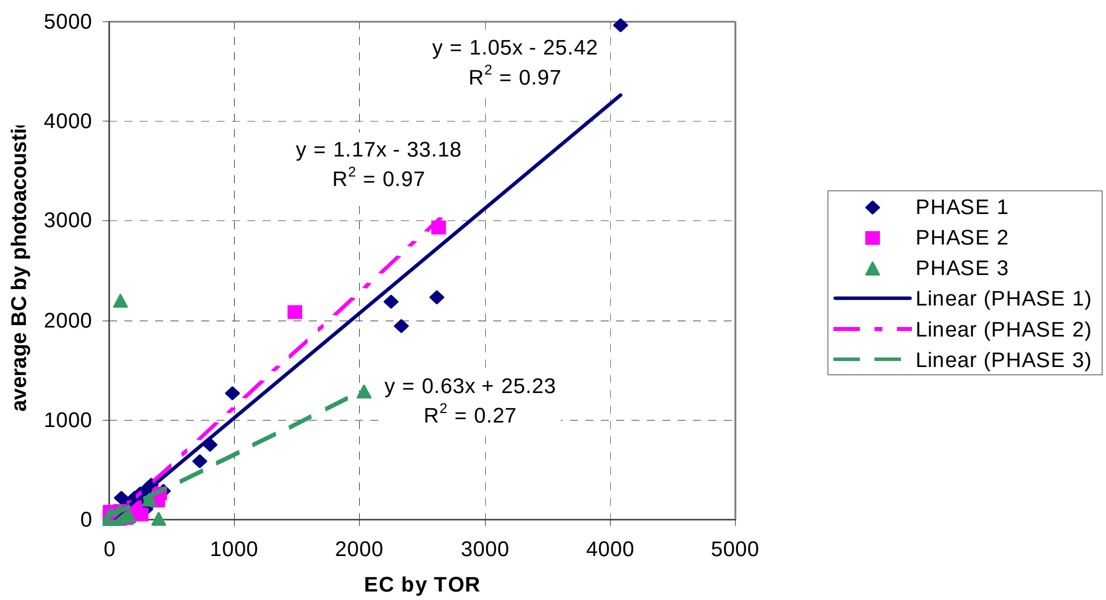


Figure OS-21. Elemental Carbon by TOR versus average BC by photoacoustic method

For all dynamometer tests, separated by test phase. Concentrations are in ug/m3 of diluted exhaust.

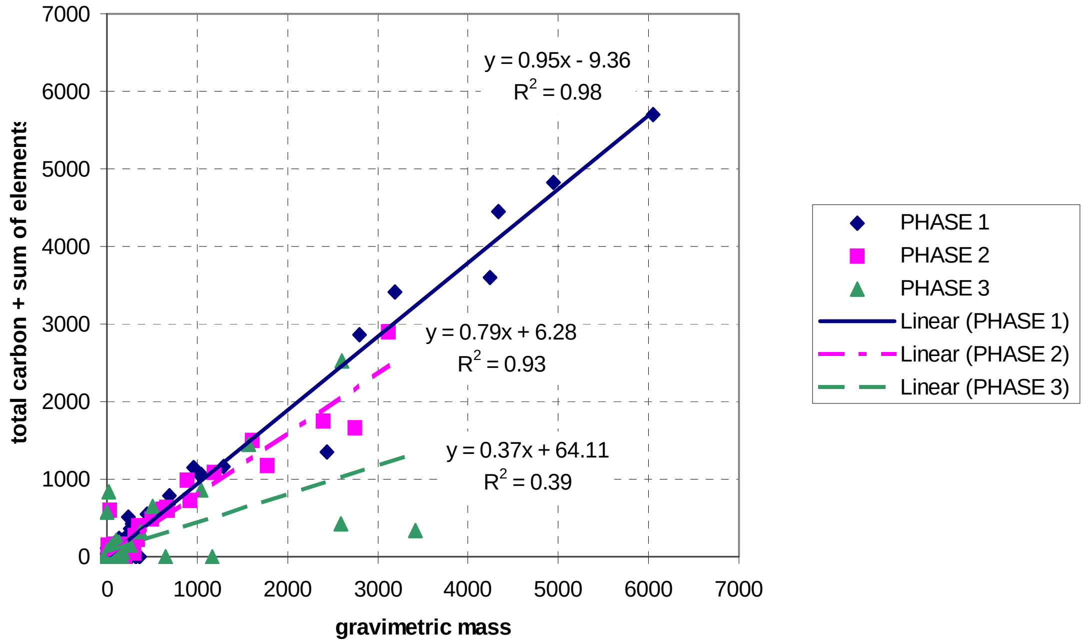


Figure OS-22. Gravimetric mass versus sum of XRF elements and total carbon by TOR

For all dynamometer tests, separated by test phase. Concentrations are in ug/m3 of diluted exhaust.

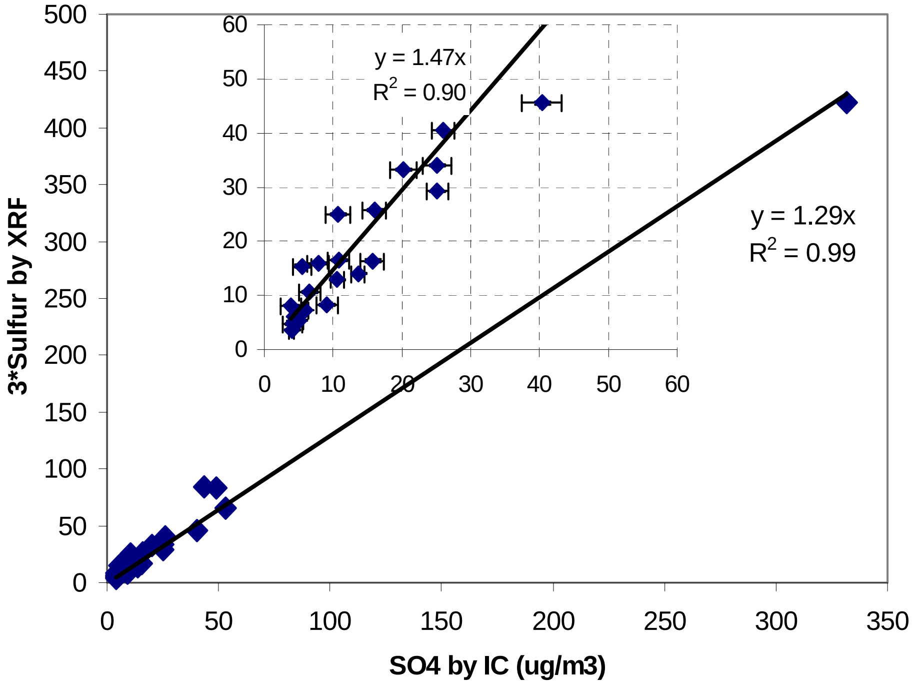


Figure OS-23. Sulfur by XRF *3 versus Sulfate by IC for all exhaust composites.

The inset shows the data without the significant outlier at SO_4=330 ug/m3. Concentrations are in ug/m3 of diluted exhaust.

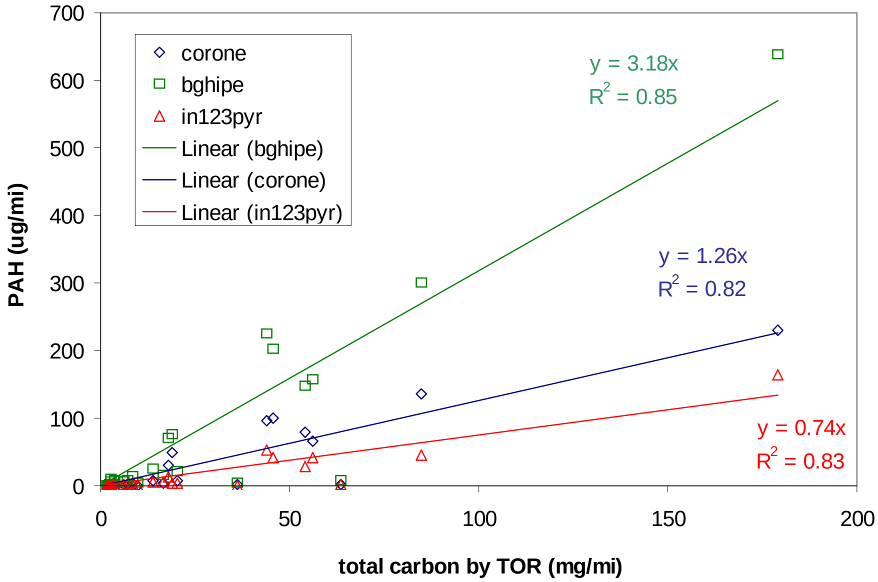


Figure OS-24. Total organic carbon by TOR versus indeno[123-cd]pyrene, benzo(ghi)pyrelene and coronene in mg/mile.

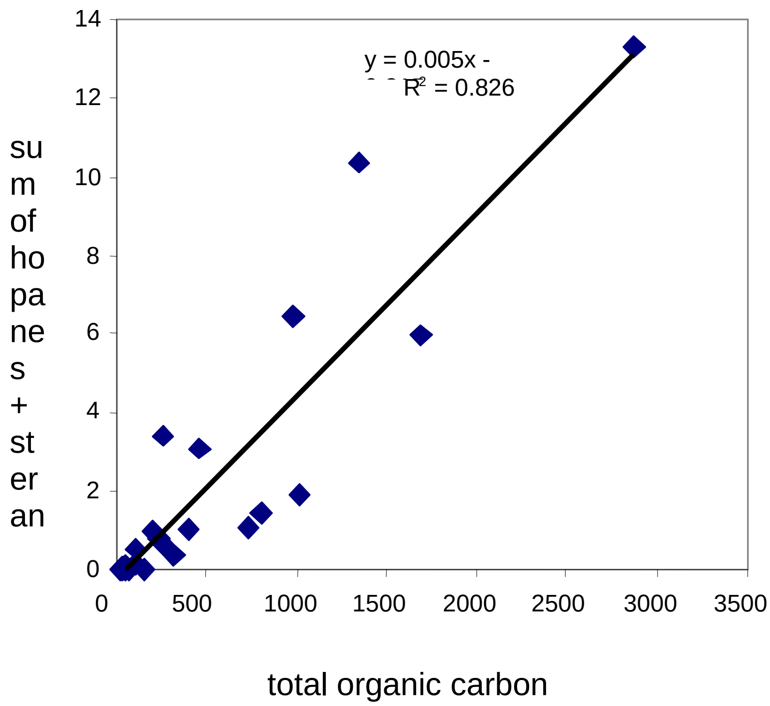


Figure OS-25. Total organic carbon by TOR versus sum of hopanes and steranes for exhaust composites.

Concentrations are in ug/m3 of diluted exhaust.

Gaseous-Phase Emissions Speciation from Light-Duty Gasoline Vehicles

VOC chemical speciation was determined for the individual/composite samples and composite dilution tunnel blank samples. All data are field-blank corrected. The chemical composition data for dilution tunnel blanks and exhaust samples are presented in Appendix B.

The total nonmethane hydrocarbon (NMHC) values from the DRI VOC speciation samples were compared to corresponding data obtained by BKI. With the exception of two obvious outliers (S1-2 and S5-4), Figure OS-26 shows good agreement for the uncomposited samples from Round 1. However, Figure OS-27 shows that there are two distinct groups of data in Round 2; one with better agreement between DRI and BKI and a second group with DRI values consistently near zero compared to widely varying values for BKI. A chronological plot of the ratios of DRI to BKI TNMHC values for Round 2 shows that DRI consistently obtained low values during the second half of Round 2. Sampling for VOC speciation was suspended for two weeks in mid-February during the NREL experiments on the effects of sampling temperature on measured PM emission rates. The appearance of consistently low DRI/BKI ratios for TNMHC coincides with the resumption of VOC sampling on February 22, 2005. The aldehyde data also show a similar chronological pattern with consistently lower values in the second half of Round 2, though not as sharply lower as the hydrocarbon data. The aldehyde sampler was connected to the same branch of the sampling train as the canister sampler. This branch of the sampling train was disconnected from the main sampling line and capped off during the temperature experiments. A leak somewhere in this part of the sampling train, which allowed room air to mix with vehicle exhaust, is the most probable explanation for the near-zero ratios after the mid point in Round 2. Accordingly, the data for VOC and carbonyl compounds for the second half of Round 2 must be considered invalid. Figure OS-28 presents a chronological figure of the ratio of TMNHC measured by DKI and BKI. Of the 57 canisters collected and analyzed for VOC speciation in Round 2, 32 were affected.

The distributions in emission rates in Figures OS-29 through OS-32 for BTEX and formaldehyde show that newer model year vehicles are generally clean and that emissions of older vehicles are highly variable with some vehicles emitting BTEX and formaldehyde at rates exceeding that of normal emitters by more than two orders of magnitude. The figures also illustrate the sampling problems that occurred during the second half of Round 2. Although unfortunate, the partial loss of VOC speciation data should be viewed in context of the two main project objectives, which are to establish the distribution of emissions for the in-use vehicles in Kansas City and chemical profiles for VOC and PM emissions. Even without the partial loss of data, the speciated emissions data alone would have not been sufficient to fully characterize the distribution of emissions of specific VOC or volatile MSAT. Rather it is the bulk hydrocarbons and PM emissions data for the larger set of test vehicles that provide the emissions distributions of the in-use vehicle fleet. The speciation profiles, averaged by appropriate factors such as season, region, or high versus normal emitters, provide the means for disaggregating total emissions to specific species.

The missing VOC speciation data were reconstructed by first calculating the ratios of reported concentration of each hydrocarbon compound to the total HC reported for each run. These ratios were then averaged for all valid canister samples and the resulting average and standard deviation of the ratios were used to estimate the hydrocarbon speciation for the invalid samples based on the total HC from BKI's bag samples. These reconstructed data are included with the data set for completeness in a separate table. The previous plots for BTEX emissions are shown in Figures OS-33 and OS-34 as fractions of individual species to the sum of BTEX. The abundances of benzene, toluene, ethylbenzene and xylenes are similar among the samples and between Rounds 1 and 2. Figure OS-35 shows the strong correlations among related aromatic hydrocarbon species for all exhaust composites.

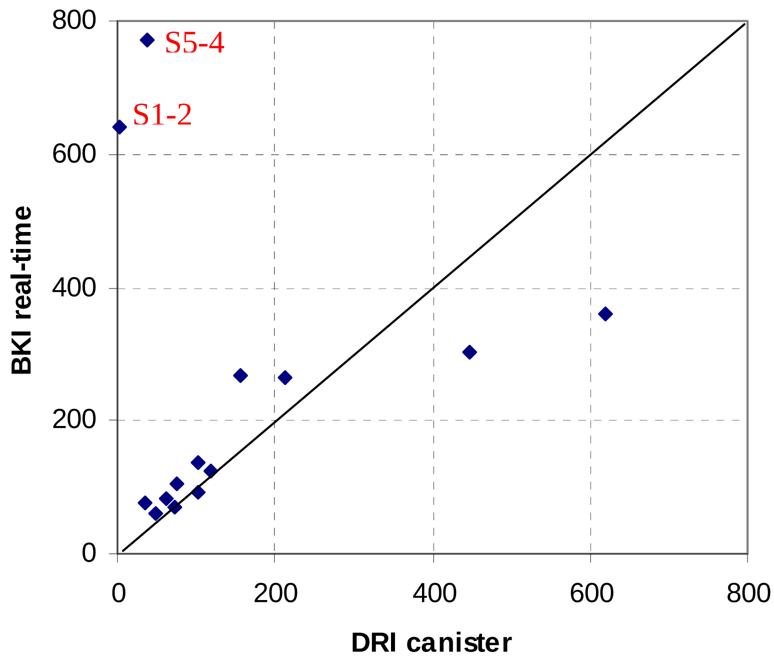


Figure OS-26. Correlation plot of BKI total TNMHC (ppmC) and DRI NMHC (ppmC) for Round 1.

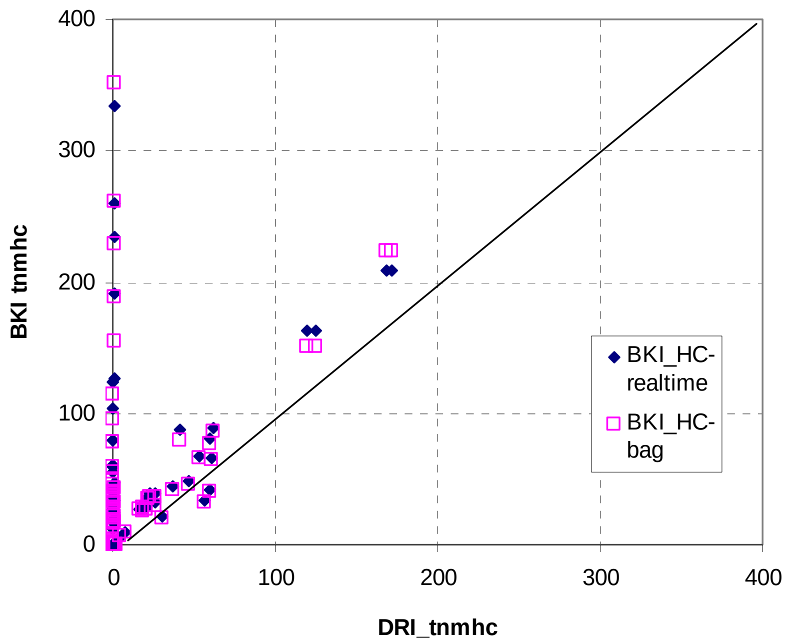


Figure OS-27. Correlation plots of BKI total TNMHC (ppmC) and DRI NMHC (ppmC) for Round 2.

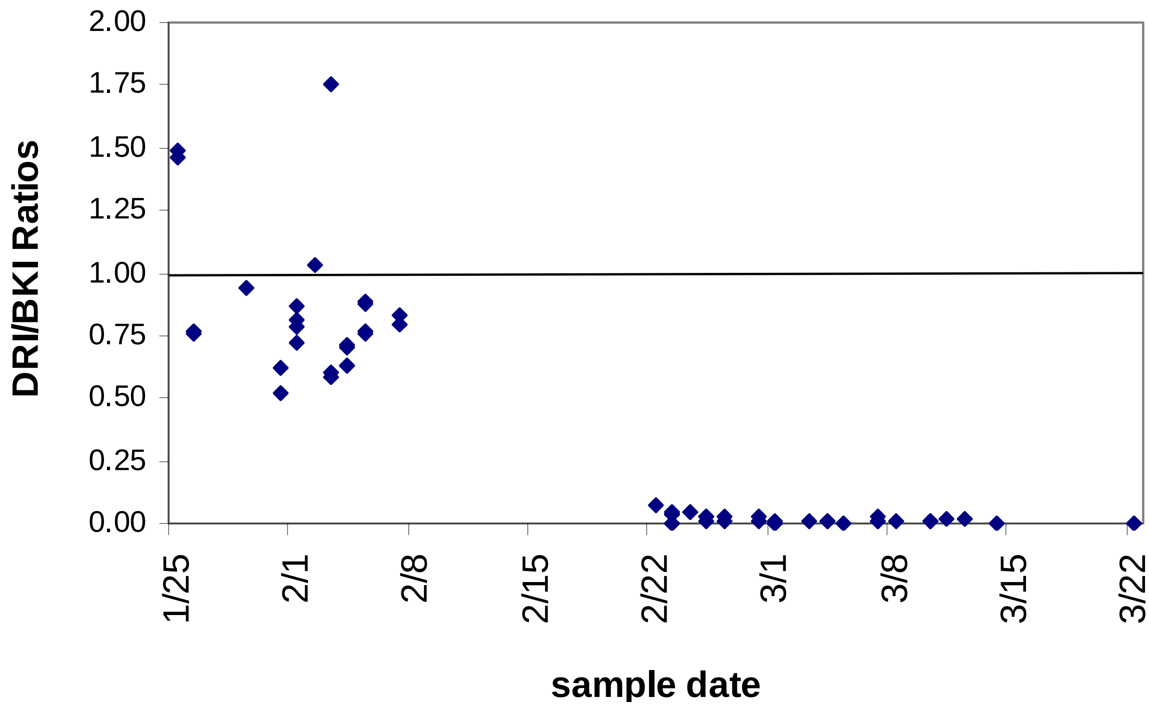


Figure OS-28. Ratios of the TNMHC measured by DRI to BKI during Round 2 shown chronologically.

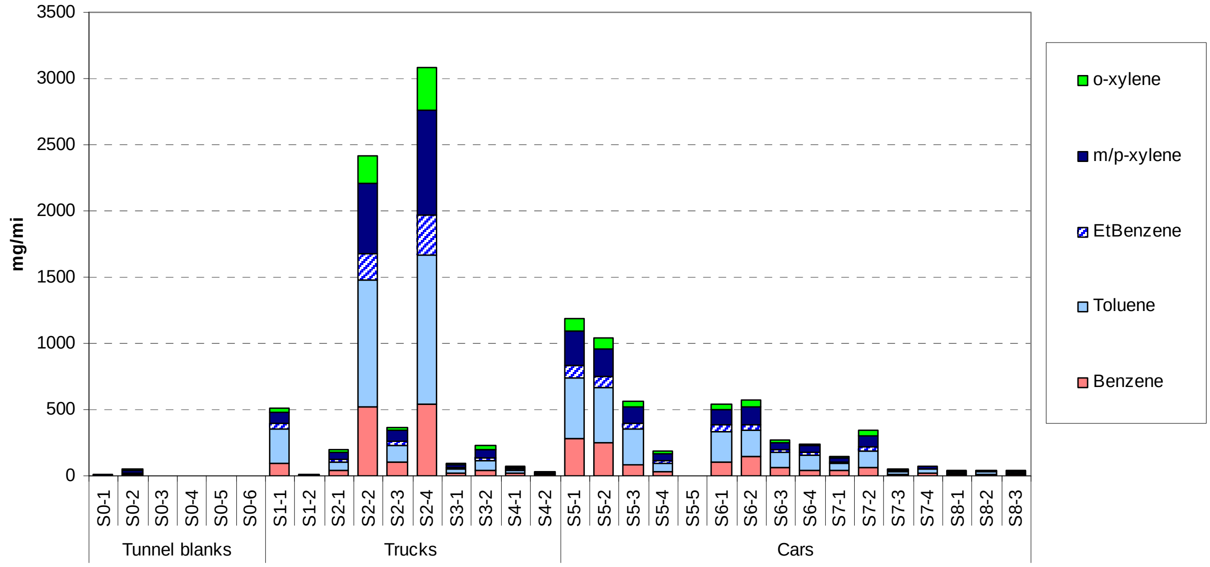


Figure OS-29. Emission rates (mg/mile) of BTEX for individual/composite samples from Round 1.

(Data for S1-2, S5-4 and S5-5 are suspect.)

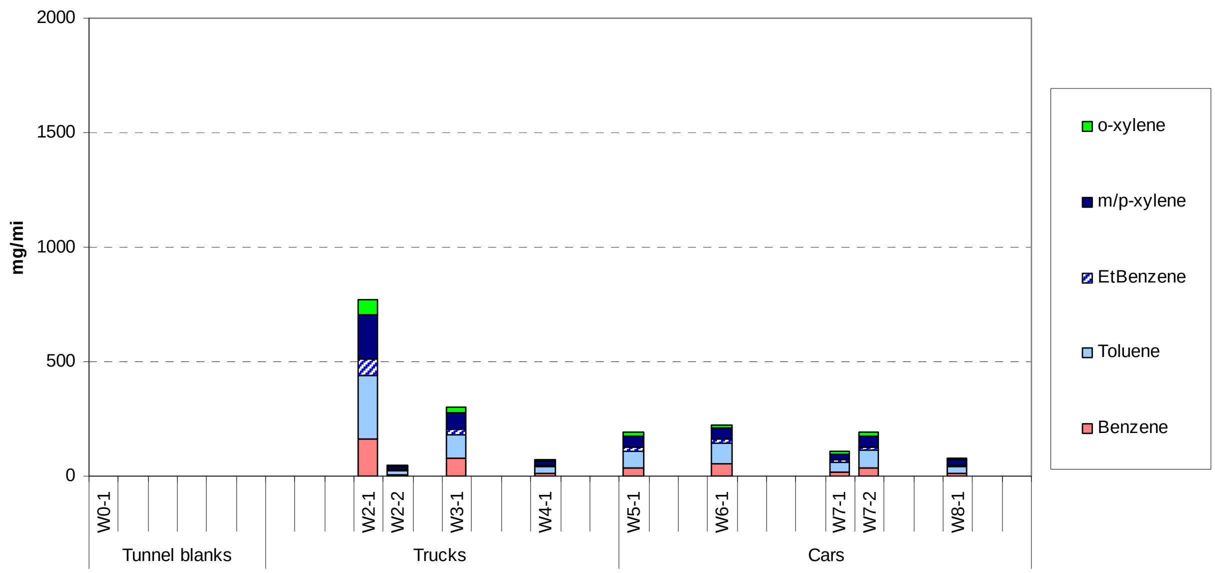


Figure OS-30. Emission rates (mg/mile) of BTEX for individual/composite samples from Round 2.

(Samples collected after mid-February 2005 are invalid and are not shown in the figures.)

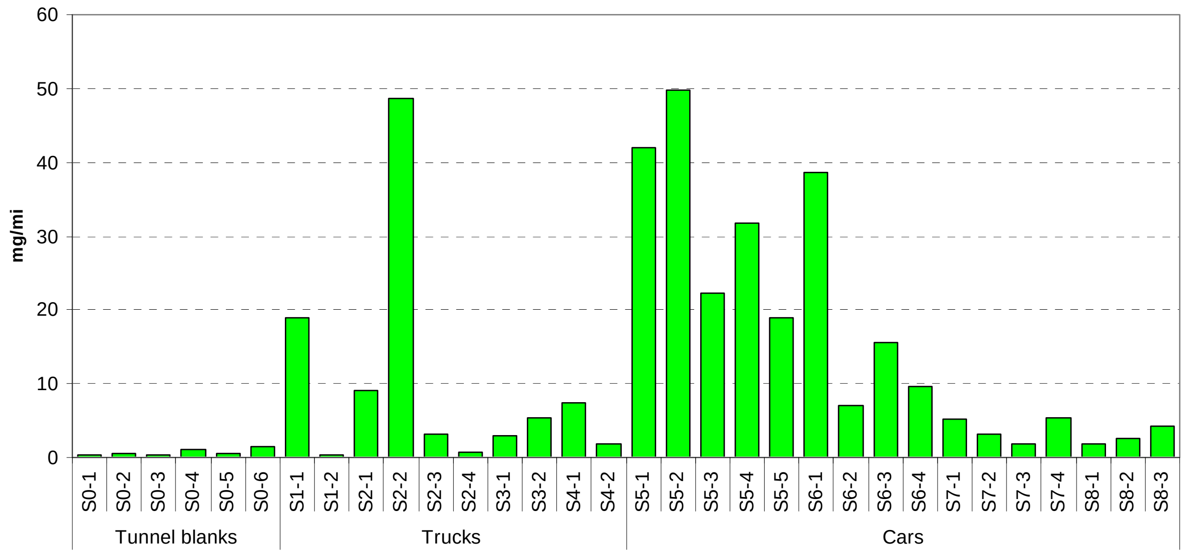


Figure OS-31. Emission rates (mg/mile) of formaldehyde for individual/composite samples from Round 1.

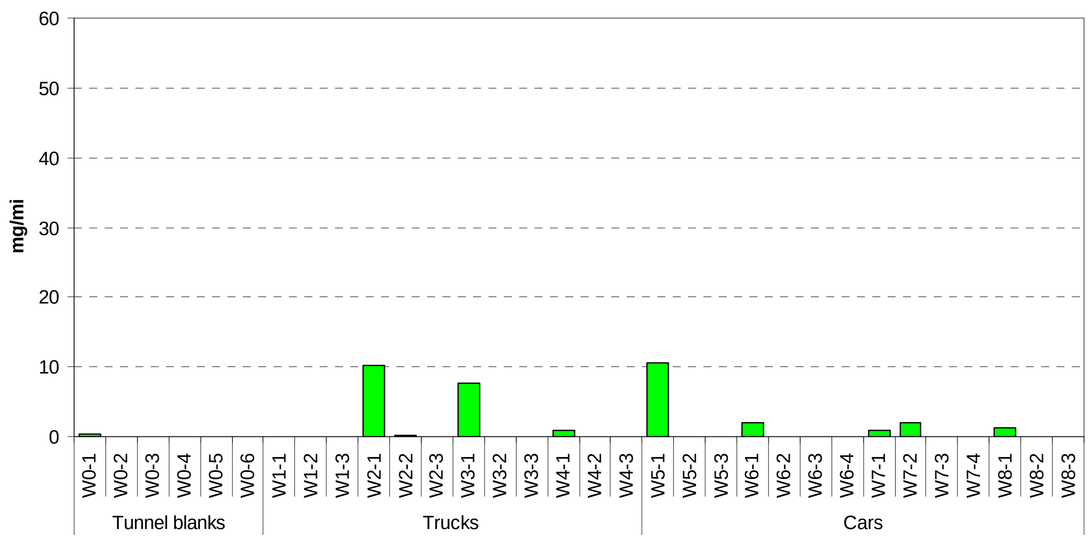


Figure OS-32. Emission rates (mg/mile) of formaldehyde for individual/composite samples from Round 2

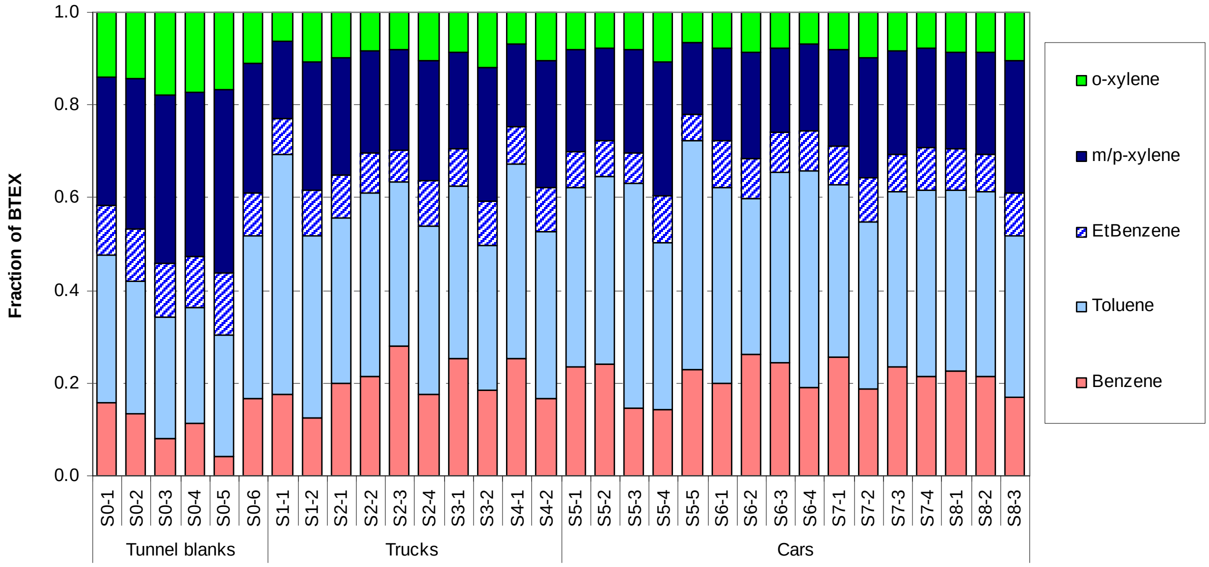


Figure OS-33. Fraction of BTEX for individual/composite samples from Round 1.

(Data for S1-2, S5-4 and S5-5 are suspect.)

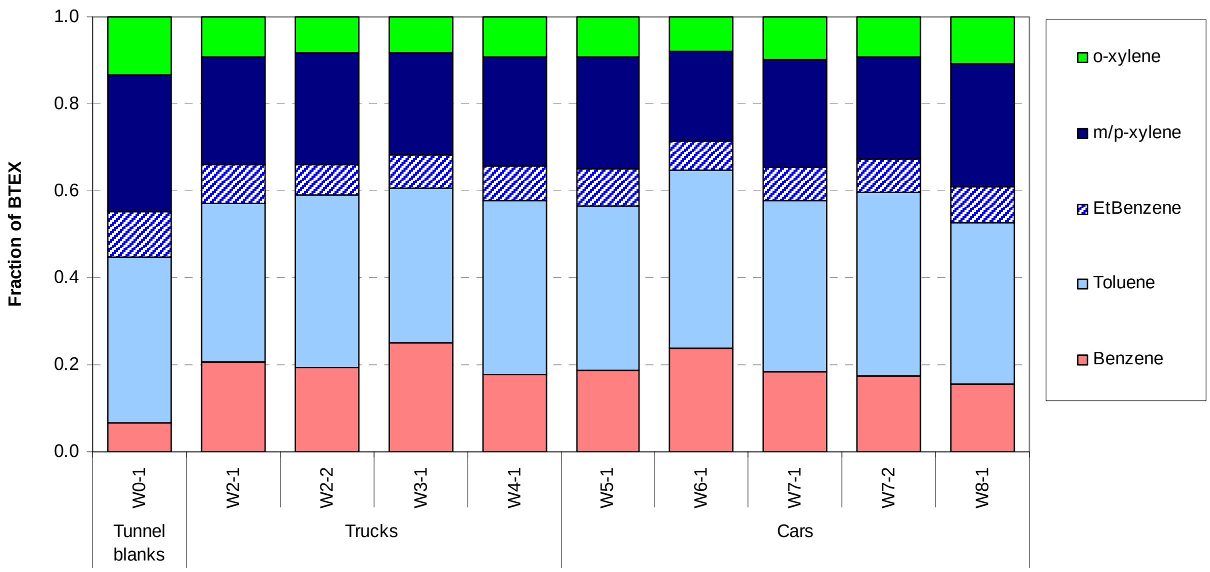


Figure OS-34. Fraction of BTEX for valid individual/composite samples from Round 2.

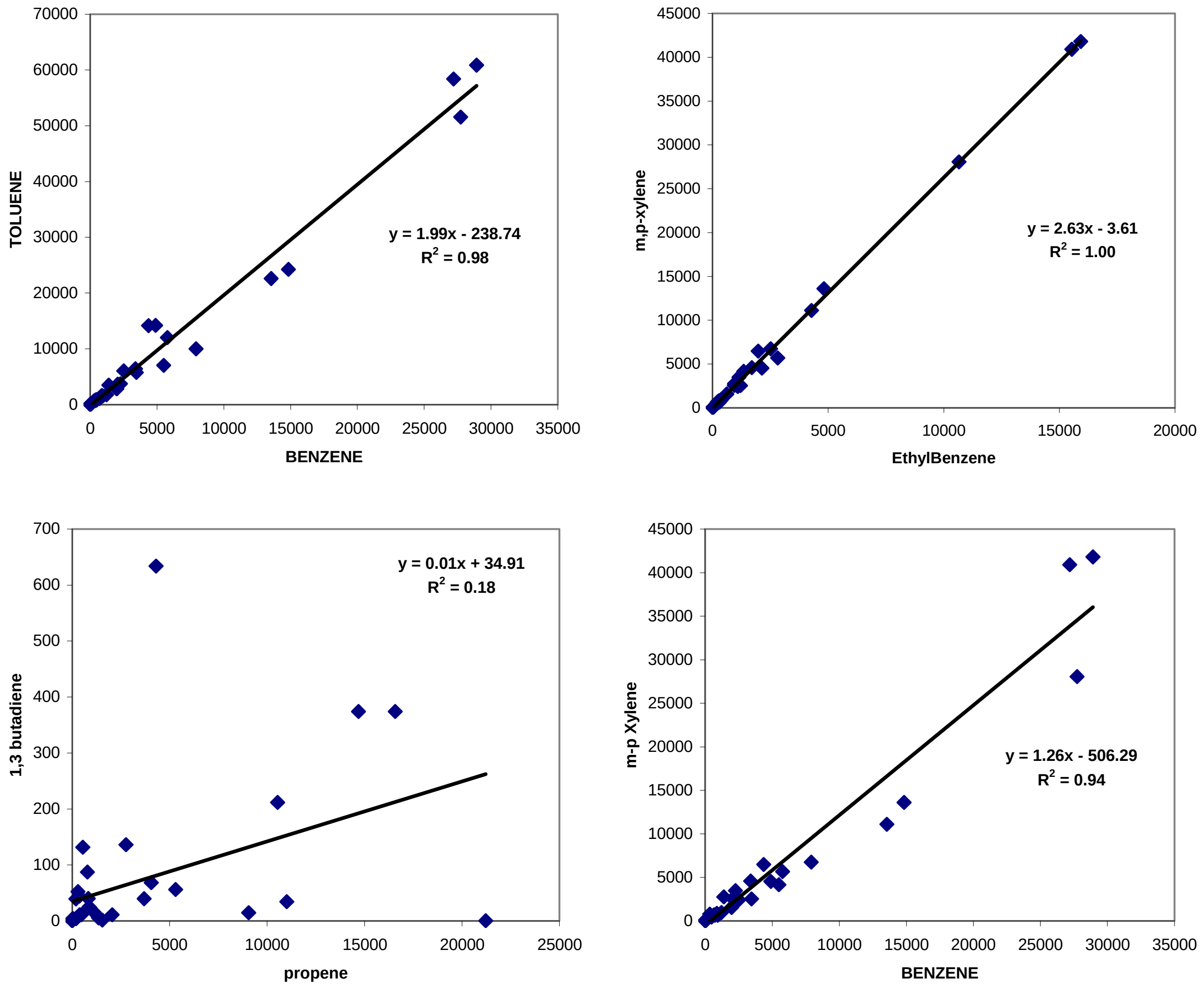


Figure OS-35. Correlation plots of related VOC species for all exhaust composites.

Concentrations shown are ppbC of diluted exhaust.

The lack of correlation and the low 1,3-butadiene/propene ratios shown in Figure OS-35 indicate that a substantial fraction of the 1,3-butadiene had been lost in most of the samples due to reaction with NOx. As previously mentioned, the true values are estimated by multiplying the propene values by the 1,3-butadiene/propene ratio from the DOE/NREL Gasoline/Diesel PM Split Study.

Acrolein is known to rearrange on DNPH cartridges to an unknown degradation product (acrolein-X) (Tejada, 1986). This rearrangement is sufficiently rapid that most of the acrolein may convert to acrolein-X, unless the sample is analyzed within a few hours. The problem is compounded by the fact that acrolein-X co-elutes in the HPLC analysis with butyraldehyde. A procedure was developed in a separate project conducted by the DRI for the Health Effects Institute (Fujita et al., 2006) and applied after the initial analyses to more accurately quantify acrolein and butyraldehyde.

In summary, the VOC profiles are very consistent across all categories for major air toxics (BTEX). Emission rates were highly variable, but higher for strata 1, 2, 5, and 6. Tunnel blanks showed very low concentrations relative to exhaust samples.

1.0 Introduction

The U.S. Environmental Protection Agency (EPA), the Coordinating Research Council (CRC), the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL), the U.S. Department of Transportation (DOT) Federal Highway Administration (FHWA), and the State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials (STAPPA/ALAPCO) sponsored a program to evaluate exhaust emissions from light-duty gasoline vehicles (LDGVs). The program measured particulate matter (PM) and other components of exhaust emissions from approximately 480 randomly selected, LDGVs in the Kansas City Metropolitan Area. Data obtained from this program will be used to evaluate and update existing and future mobile source emission models (MOBILE6 and MOVES).

In the Summer of 2004, EPA established a contract with Eastern Research Group, Inc. (ERG) to conduct a program in Kansas City to evaluate exhaust emissions from light-duty gasoline vehicles. The study was conducted in Kansas City in three parts:

Part 1: Pilot Study (June 2004)
Part 2: Round I Testing (July-September 2004)
Part 3: Round II Testing (January-April 2005)

1.1 Background

Mobile sources significantly contribute to ambient concentrations of air contaminants, including PM. Recent source apportionment studies for PM_{10} and $PM_{2.5}$ indicate that mobile sources can be responsible for over half of the ambient PM measured in an urban area (Motallebi, 1999; Magliano, 1998; Dzubay et al., 1988). Some of these source apportionment studies have attempted to differentiate between contributions from gasoline and diesel combustion. Studies conducted in Denver and Phoenix indicated that gasoline combustion from mobile sources contributed more to ambient PM than diesel combustion (Lawson and Smith, 1998; Ramadan, 2000). However, studies conducted in Los Angeles and the San Joaquin Valley in California indicate that diesel combustion contributed more than gasoline combustion to ambient PM (Schauer et al., 1996; Schauer and Cass, 2000). Existing emission inventories developed by the EPA also suggest diesel vehicles contribute more than gasoline vehicles to ambient PM concentrations.

Exhaust emissions of particulate matter from gasoline-powered motor vehicles have changed significantly over the past 30 years (Cadle et al., 1999). These changes have resulted from reformulation of fuels, the wide application of exhaust gas treatment, and changes in engine design and operation. Because of these evolving tailpipe emissions, along with the wide variability of emissions between vehicles of the same class (Hildemann et al., 1991; Cadle et al., 1997; Sagebiel et al., 1997; Yanowitz et al., 2000), well-defined average emissions profiles for the major classes of motor vehicles have not been established.

The majority of exhaust PM emitted by motor vehicles is in the $PM_{2.5}$ size range. Kleeman et al. (2000) have shown that gasoline and diesel fueled vehicles produce particles that are mostly less than 2.0 μm in diameter. Cadle et al. (1999) found that 91% of PM emitted by in-use gasoline vehicles in the Denver area was in the $PM_{2.5}$ size range, which increased to 97% for "smokers" (i.e., light-duty vehicles with visible smoke emitted from their tailpipes). Durbin et al. (1999) found that 92% of the PM was smaller than 2.5 μm for smokers. The mass median diameter of the PM emitted by the gasoline vehicles sampled by Cadle et al. (1999) was about 0.12 μm, which increased to 0.18 μm for smokers. Corresponding average emissions rates of $PM_{2.5}$ were 38 mg/mi for normal emitting gasoline vehicles and 222 mg/mi for gasoline smokers.

The research by Cadleet al. (1999) and Norbeck et al. (1998) 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%.

Emissions from smokers are comparable to those from diesel vehicles. Thus, older and poorly maintained gasoline vehicles could be significant sources of $PM_{2.5}$ (Sagebiel et al., 1997; Lawson and Smith, 1998). Durbin et al. (1999) point out that although smokers constitute only 1.1 to 1.7% of the light-duty fleet in the South Coast Air Quality Management District in California, they contribute roughly 20% of the total PM emissions from the light-duty fleet. Motor vehicles that are high emitters of hydrocarbons and carbon monoxide can be high emitters of PM (Sagebiel et al., 1997; Cadle et al., 1997). National distributions of smokers and high emitting vehicles for PM have not been evaluated.

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 example of a PM emission distribution is shown in Figure 1-1. We see that there 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.

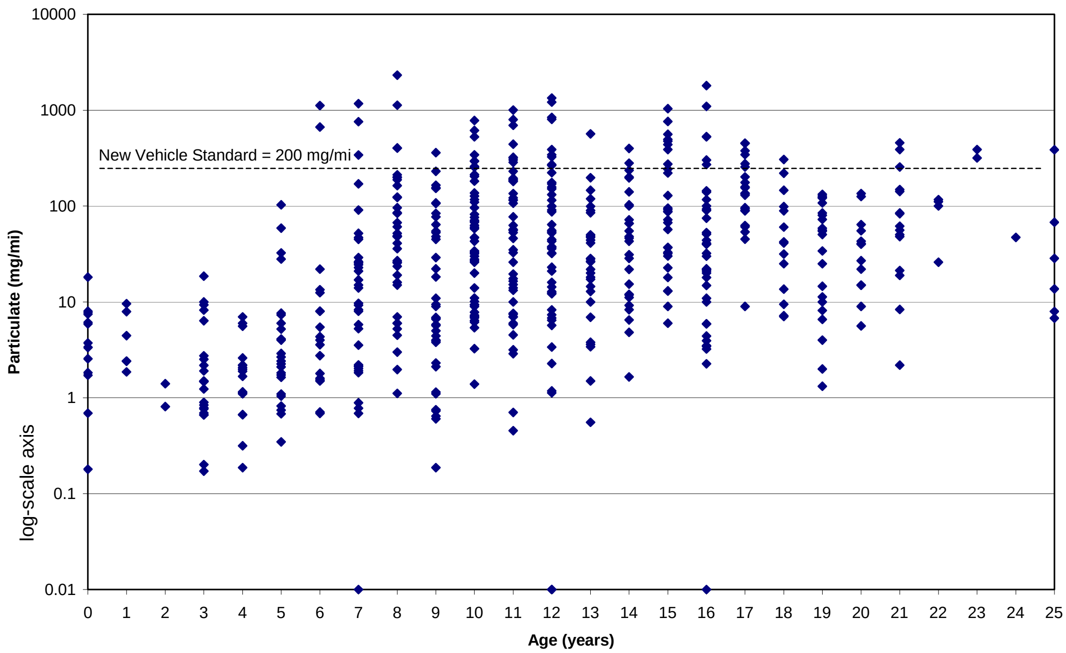


Figure 1-1. Example Plot of PM Data from Light-Duty Gasoline Cars and Trucks, Model Year 1994 and Older

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.

A major obstacle in previous emissions testing studies has been the recruitment of vehicles. Most studies have not incorporated random sampling in the study design due to the high non-participation rate and the high incentive costs associated with random sampling of vehicles. Therefore, few studies, and no studies evaluating light-duty PM emissions, can be used to represent the distribution of vehicle emissions in a large population.

1.2 Study outline

One of EPA's key missions has been to understand, evaluate, and reduce exhaust emissions from motor vehicles. Since the late 1960's, EPA has been focused on this mission and has implemented many regulations to achieve this goal. One primary mechanism to reduce emissions has been the promulgation of new emissions standards for pollutants from motor vehicles that require vehicle manufacturers to reduce emissions from new vehicles. However, even if a new vehicle has low emission levels, as that vehicle ages, its emissions will increase as its engine wears and its emissions control components deteriorate.

In an effort to understand the emissions of a fleet comprised of both new and older vehicles, EPA has conducted studies to measure emissions from a random sample of vehicles and then projected it to the population as a whole. Gaseous emissions have been studied extensively through the last few decades, both through special studies and through analysis of vehicle inspection and maintenance (I/M) program data. However, particulate matter (PM) emissions from gasoline-powered motor vehicles are less understood. Through this study EPA has conducted a "watershed" research experiment to characterize PM emissions from a very carefully selected random sample of vehicles in a major metropolitan area.

The metropolitan area chosen by EPA was Kansas City, MO/KS. The primary reason for this choice was that KC is the largest US metro area without an I/M program. In an I/M program area vehicles are regularly required to be tested and repaired to meet local emissions standards. Since I/M programs affect a vehicle's deterioration rate (by requiring repairs and maintenance that otherwise might not be performed), conducting a study on vehicles not subjected to an I/M program allows evaluation of vehicles under "natural" deterioration rates. The Kansas City fleet sample tested in this study was not influenced by any I/M program. In addition, PM emissions can be influenced by ambient temperature and this study was conducted throughout a wide range of summer and winter temperatures.

EPA envisioned this study to be a landmark study in which special attention was given to selecting a participating sample chosen from the general population in a scientific manner. In addition, all vehicle testing procedures were specified in a QA document approved by EPA. Calibration tests, replicate tests, laboratory correlation, non-response analysis, seasonal effects, and emissions test variability were all considered and included in the program design. EPA monitored the field testing closely, and ERG established a secure web site and an FTP site to report project status on a daily basis to EPA.

Another key feature of this study was intended to identify how real-world on board measurement devices (PEMS) could be used to collect mass-based vehicle emissions exhaust data. These devices were put on all vehicles tested in this project. Additionally, a PEMS device was connected to every vehicle while it was simultaneously measured with laboratory grade instruments on a dynamometer. This information may be used to assess the use of PEMS devices as a primary method for collecting on-road vehicle emissions data.

Data was closely managed on-site and then posted for further integrity and QA checks and analysis at other ERG offices. The data was delivered to EPA in raw and QA'd form. Quality-assured data was also put into the EPA MSOD format and delivered to EPA.

The ERG team used a prior transportation study conducted by Mid-America Regional Council as a starting point for recruiting vehicles for this project. The MARC 2004 Household study (Kansas City Regional Household Travel Survey Final Report, 2003) participants were used as a cohort for recruiting vehicles. ERG's subcontractor NuStats conducted this study for MARC.

The KC study was conducted in three distinct Phases. In the Pilot phase the KC facility was set up and all equipment, staff, and logistics were mobilized. The team also tested 3 EPA-provided "correlation" vehicles to compare EPA Ann Arbor dynamometer laboratory measurements with those obtained using the EPA portable Clayton dynamometer at the KC test facility. The Pilot Study is included in Appendix BB. The main study was started in June 2004 and was called Round 1 testing. During this round, approximately 250 vehicles were tested under summer conditions at the facility. In the final testing round, Round 2, approximately 250 additional vehicles were tested under winter conditions. Approximately 40 vehicles tested during Round 1 were re-tested in Round 2 to compare exhaust emissions changes due to seasonal changes.

During the course of testing, about 4 to 6 cars were usually tested each day. A typical scenario for testing of a vehicle was as follows. Mailouts describing the test program were initially sent to prospective vehicle owners. These vehicle owners were then recruited by ERG team personnel in call centers for participation in the study, and an incentive was established as a participation reward for each participant. An appointment for delivery of the vehicle to the testing site was established. A day before the scheduled appointment, the vehicle owner was contacted as a reminder. Once the vehicle arrived at the testing site, ERG's personnel evaluated the vehicle's condition and took several photographs to establish its general status. The test program and condition of the vehicle were discussed with the vehicle's owner, and several kinds of information were collected about the driver and the vehicle. Fuel and lubricating oil samples were extracted from each vehicle and stored for future analysis. Once the vehicle was accepted for testing, a portable emissions measurement system (PEMS) was installed on the vehicle and a conditioning test was conducted. This required that the vehicle be driven on a predetermined route for about 30 minutes to prepare it for dynamometer testing in a manner consistent with all other test vehicles. After the conditioning test, the PEMS was removed from the vehicle, and the vehicle was stored at the test site for testing the next day. On the following test day, the vehicle was pushed on to the dynamometer and the vehicle emissions testing components were attached to the vehicle. These included both the connection from the vehicle tailpipe to the dilution tunnel of the lab-grade testing equipment, and installation of PEMS device on the vehicle for simultaneous measurement. The vehicle was then driven through the three Phases of the LA-92 driving cycle, and its exhaust emissions were measured and recorded on a second by second basis. The following vehicle measurements were conducted during the testing:

Measurements via the dilution tunnel:

- THC via FID
- CO & CO2 via NDIR
- NOx via Chemiluminescence
- Gravimetric mass and elemental analysis through Teflon membrane collection
- EC/OC and Ion analysis though Quartz membrane collection
- PM and SVOC via TIGF/XAD
- Canister Sampling for 1-3 butadiene with NOx Denuder
- Carbonyls through DNPH Cartridges
- Continuous PM measurements via a Quartz Crystal Microbalance (QCM) and verified using DustTrak and DataRAM nephelometers

Measurements via PEMS devices:

- THC via FID
- CO via NDIR
- CO2 via NDIR
- O2 via Electrochemical Sensor
- NO via NDUV

- Vehicle parameters via OBDII connector (if available)
- Temperature and relative humidity via portable weather probe
- Location, velocity, altitude via GPS

In addition, all ambient and dilution tunnel conditions including temperature, humidity, and ambient THC levels were independently measured and recorded on a continuous basis. At the end of the dynamometer testing, equipment was removed from each vehicle, the vehicle was taken off the dynamometer and checked for any damage, and was then stored for customer pickup. Participants were given their incentives during vehicle pickup. Some vehicles were selected for additional instrumentation with PEMS devices before their release, and the participants were requested to drive the vehicle in their usual way. No route or duration was specified (although the drivers were encouraged to perform as much of their regular driving as possible with the PEMS device installed). Drivers then returned to the testing facility the next day for the removal of the PEMS equipment.

Another component of the testing program included the RSD testing of the general KC fleet during Round 1 and Round 2. Over the 3-4 months of in-field testing, RSD vans were conducting tests for about one week each month. This information was used to compare the KC fleet with the sample tested at the KC testing facility.

After the testing was completed, emissions data from each aspect of the testing program was put through several iterations of QA/QC. The ERG team then converted all the data into EPA's MSOD format and delivered all the information to EPA. All raw files and final MSOD data set have undergone a thorough EPA review.

Summary of Goals

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. The study itself was conducted in three parts: a Pilot Study, Round 1, and Round 2.

Initially, the Pilot Study was used to set up the testing facility in Kansas City, finalize all testing and data handling procedures, and test 3 vehicles at the EPA Ann Arbor facility and the Kansas City facility to establish the baseline relationship between the two facilities. Testing was conducted in two Rounds in the Summer of 2004 (Round 1), and the Winter of 2004/2005 (Round 2). Vehicles were recruited and then tested with Portable Emissions Measurement Systems (PEMS) and on conventional dynamometers with laboratory grade emissions measurement systems. The following sections provide an overview of the numbers of vehicles tested in both Rounds.

The KC testing program was designed by EPA to collect vehicle exhaust measurements from a randomly selected set of vehicles so that the following primary goals could be met:

- Characterize PM emissions distribution in the Kansas City fleet;
- Identify the high emitter percentage in that fleet;

- Collect exhaust emissions (both gaseous and PM toxics) for vehicles in the fleet.

In addition, there were a number of secondary goals for the study, including:

- Demonstrate the use of a cohort, and a sampling plan to select candidate vehicles;
- Test vehicles in an ambient environment close to their operating area, and gather data in summer and winter conditions;
- Refine the use of PEMS configurations for large scale implementation;
- Compare results of laboratory grade measurement devices with PEMS;
- Develop useful continuous PM measurement techniques compared to traditional gravimetric measurement;
- Develop inventory of speciated HC constituents of vehicle exhaust in PM and gaseous modes;
- Gather emissions and activity data on vehicles driven by their owners in real world conditions; and
- Gather information to relate second by second vehicle driving and resulting PM emissions for developing input data for emissions models;

Pilot Testing

The first field testing phase was Pilot Testing. Details of the Pilot Testing are available in a separate report (provided in Appendix BB). The primary goals of this phase were:

- Set up a testing facility in Kansas City that will be used for the entire study;
- Finalize all testing methodologies, testing procedures, and data handling procedures; and
- Test three vehicles in Ann Arbor and Kansas City to establish the relationship between the emission results from the two facilities.

Setting up the testing facility was an intense task. A warehouse was selected in KC to serve as the testing facility. EPA's portable dynamometer was transported to this facility and was set up for emissions testing. All testing equipment for gaseous and PM emissions measurement were arranged and detailed handling procedures for handling vehicles, equipment, and data were established. In addition, three EPA provided vehicles were tested in Ann Arbor and at this facility to compare results between the two laboratories.

1.2.2 Round 1 Testing

The main study in Kansas City started in July of 2004. This period was designated as Round 1. Vehicles were tested in typical Midwest summer conditions. Although the total number of vehicles dynamometer tested exceeded project goals, several strata targets were not achieved (most notably in bins 1 and 5). The MARC vehicle database was solely used for vehicle recruitment (via random digit dialing, or RDD) for Round 1 recruiting.

Table 1-1 lists the various tests conducted during Round 1, in comparison with project goals. PEMS testing on conditioning runs was performed on all vehicles, regardless of dynamometer eligibility.

Table 1-1. Round 1 Tests Conducted

Test Type	Round 1 Goal	Round 1 Tested
PEMS Conditioning Test	All	284
Replicate PEMS Conditioning Test	1 per week	17
PEMS Driveaway Test	N/A	13
Dynamometer/PEMS Test	250	261
Dynamometer/PEMS Test Replicate	1 per week	15
Dynamometer/PEMS Control Vehicle Test	1 per week	12

1.2.3 Round 2 Testing

The goals of the Round 2 testing were similar to those of Round 1 testing. One important additional goal of Round 2 testing was to test the vehicles in colder weather where PM formation mechanisms may be different than those in warmer weather. In order to better achieve strata-specific test targets during Round 2 testing, the MARC database used for Round 1 recruiting was supplemented with the KC registration database for Round 2 recruiting of Bins, 1, 2, 5, and 6. This significantly improved recruiting efforts. This additional database for recruiting older vehicles provided an additional pool of the older, less populated vehicle group. Due to the sampling methodology developed, more older vehicles were recruited as a fraction of their population due to the higher likelihood of high emitters as well as high emissions variability within this group.

Table 1-2 lists the various tests conducted during Round 2, in comparison with project goals. Regardless of dynamometer test eligibility, PEMS tests (during the conditioning run) were performed on all vehicles (excluding vehicles whose interior would not accommodate a PEMS device).

Table 1-2. Round 2 Tests Conducted

Test Type	Round 2 Goal	Round 2 Tested
PEMS Conditioning Test (excluding replicates)	All	324
Replicate PEMS Conditioning Test	1 per week	19
PEMS Driveaway Test	50	51
Dynamometer/PEMS Test (excluding replicates)	261	279
Dynamometer/PEMS Test Replicate	1 per week	12
Dynamometer/PEMS Control Vehicle Test	1 per week	12
PAMS Driveaway Test	N/A	8

1.2.4 Round 1 to Round 2 Retest Vehicles

Selected vehicles were originally tested during Round 1 and were then retested at the start of Round 2 in order to provide summer/winter correlation data. Forty-two of these Round 1 retest vehicles were tested (exceeding the retest target of 25 vehicles) in order to ensure all strata were filled.

1.3 Report Presentation

This report summarizes the results of the testing conducted in Kansas City, KS in July 2004 through April 2005. Section 2 presents information on facility site selection and project setup, including calibration of the instrumentation used during testing. Section 3 discusses vehicle recruitment and sampling methodologies. Section 4 presents a discussion of the testing process, as well as data summaries and test conclusions.

The report appendices contain extensive supplementary data, plots, and charts referenced in this document. A detailed index of the contents in the appendices is provided at the end of this document. The ERG team performed many levels of QA/QC on data obtained during the course of the study, and the final datasets were provided to EPA in a format suitable for loading into the Mobile Source Observation Database. As EPA uses these data for input into MOVES, further data editing may be necessary before the data are released to the public.

2.0 Site Selection and Project Setup

In March 2004, ERG conducted a pilot study to establish a testing facility in Kansas City, finalize all testing methodologies, testing procedures, and data handling procedures, and test three vehicles in Ann Arbor and Kansas City to establish the relationship between the emission results from the two facilities. At the conclusion of the study in June 2004, ERG prepared and submitted a report on its outcome.

The site chosen to conduct testing was located at 6636 Berger Avenue, Kansas City, KS. This property had about 7,000 sq ft total floor space, with about 1,000 sq ft office and 2 restrooms. With four 14' x 14' bay doors plus two wall vent fans, this site provided adequate ventilation and easy access. The facility lacked an overhead water sprinkler system, which meant it could be used at sub-freezing temperatures. About 5,000 sq ft of main floor space was available for the test area and vehicle soaking, with another 900 sq ft of area for working on and inspecting vehicles. The site also included three offices plus a common area. The front entrance and parking was ideal to greet vehicle owners. The site had ample outdoors parking and storage, and the building was ready to occupy after minor clean up.

2.1 QAPP

A final Quality Assurance Project Plan (QAPP) was prepared and submitted in August 2004, in accordance with Section 4.0 of the original EPA task order for this project. The plan, developed in consultation with the EPA's project officer and sponsors, specifies the details required to collect and analyze the source samples in a manner consistent with the objectives of the study.

The QAPP covered aspects of the test program as outlined in the EPA task order, including the following areas:

- Contractual support in maintaining, calibrating, and operating mobile source emissions measurement equipment used in the field. The necessary support includes analyzing the collected samples, data processing, and report writing.
- Pilot programs (including a report on all sample data analyzed)
- Vehicle recruitment
- Vehicle testing
- Speciation
- Quality assurance/quality control
- Data management and integration
- Data analysis
- Oral and written reports
- A methodology for regularly transferring and reviewing all data streams within this project

2.2 Dynamometer Setup

Vehicle driving simulation was conducted using EPA-ORD's transportable dynamometer, a Clayton Model CTE-50-0 chassis dynamometer mounted within a towable

Fruehauf trailer. The dynamometer is a vintage 1975 model and has been in service routinely over the last 15 years on similar field studies. The dynamometer is capable of simulating a continuous spectrum of loads from 3 to 50 Hp @ 50 mph and inertias from 1750 to 3000 pounds in 250 pound increments and 3000 to 5500 pounds in 500 pound increments. Cooling fluid for the dynamometer's water brake power absorption unit consists of a 50/50 mixture of water and glycol. The fluid is recirculated and cooled by a self-contained pumping and cooling system.

For this study, the dynamometer was set up in one quadrant of a large building. Large (14' x 14') bay doors on either end of the building were opened and provided natural ventilation to ambient conditions. Power for the dynamometer and associated utilities was obtained from the building's power grid. The dynamometer, as mounted on the Fruehauf trailer, is elevated approximately 3 feet above ground level. Ramps and an electric winching system were installed to bring the test vehicles onto the dynamometer for cold start emissions testing.

The dynamometer and associated equipment was originally set up on site for the pilot study, and remained in place for the duration of both Rounds 1 and 2. One modification was made to the dynamometer before beginning Round 1, as suggested after reviewing results from the pilot study. The change involved switching the speed signal from the front, coupled roll, to the rear, uncoupled roll. To accomplish this, a speed encoder was installed on the rear roll, wired to the driver's aid, and calibrated.

A Positive Displacement Pump-Constant Volume Sampler (PDP-CVS) system was used to quantitatively dilute exhaust gas from the vehicle operating on the dynamometer. The PDP-CVS system employed an 8-inch diameter stainless steel dilution tunnel with particulate filtered inlet air and a SutorBilt PDP operating at ~540 SCFM. The outside of the dilution tunnel was insulated with Insulwrap and the temperature of the diluted exhaust and dilution tunnel was maintained at a constant temperature of 46^{o}C using a 27.3 kW, electric dilution air heater (Unique Products model number 507-574) whose feedback control thermocouple had been moved to a location near the PDP inlet. The dilution air was also treated to reduce humidity levels by placing a re-generative desiccant-type dryer (TempAir model TD400) at the dilution tunnel inlet. The dryer was used only during Round 1, treating the humid air typical of Kansas City in the summer time. Both the heater and the dryer were powered with a portable, diesel-fueled 50kW generator located outside and adjacent to the facility. Diluted exhaust exiting the CVS-PDP system was routed through 8-inch diameter ducting to an existing, wall-mounted exhaust fan to remove diluted exhaust from the building.

The transportable dynamometer system has used modal emissions analysis for the determination of regulated emissions in previous field studies. A bag sampling system was constructed and installed for this study to give dual modal/bag analysis capabilities. Total Hydrocarbons (THC) were analyzed with a Horiba Model FIA-236 Flame Ionization Detector. Oxides of nitrogen (NOx) were analyzed with a Horiba Model CLA-220 Chemiluminescence instrument. Carbon monoxide (CO) and carbon dioxide (CO2) were analyzed with Horiba Model AIA-210 infrared instruments. A Horiba Model AIA-23 infrared instrument was used to analyze low level CO concentrations. All instruments were rack mounted and plumbed for introduction of zero, span, and sample gases through the use of solenoid valves and pushbutton controls. Regulated emission analytical instrumentation remained powered on 24 hours per day. Sample delay times (8-12 seconds) were measured during the Pilot Study in order to time align modal gaseous data with the vehicle speed trace. The sample line lengths were not the same lengths. The THC analyzer had a dedicated heated sample line, and the CO, CO2, and NOx instruments used a second common sample line and water trap (chiller) to remove moisture from the sample stream. Time alignment was performed for each analyzer during post processing of the data.

2.3 Maintenance and Calibration of CVS, Dynamometer and Regulated Emissions Instrumentation

Constant Volume Sampler (CVS)

As specified in Section 4.2.1 of the QAPP, and in accordance with 86.119-78 paragraph (c) of 40 CFR July 1, 1983, monthly propane injections were conducted on the CVS-PDP system to verify CVS flow. Results of the propane injections, conducted on July 25, August 30, and September 30 of 2004, and January 10, February 24, and March 29 of 2005 are given in Appendix E. Injections were conducted in triplicate on each date, with the dilution tunnel heated to its normal operating temperature of 46°C ± 3°C, and results were calculated for both bag and modal (real time) HC analysis. Propane mass injected was determined gravimetrically by recording before and after weights of the propane cylinder on a digital balance. Propane mass recovered was calculated using analyzed HC concentrations and a previously determined PDP V0 of 0.306 cubic feet/revolution. Agreement between propane injected and propane recovered was within the CFR guidelines of ± 2%, except for the bag calculated values in August 2004 and modal calculated values in January 2005. No explanation could be found (or at least verified) for the rather large percent differences (>4%) found in these two cases. No corrective actions were performed in either the August 2004 or the January 2005 cases and in each case, the next scheduled injection was within the 2% CFR guidelines.

Regulated Emissions Instrumentation

Per Section 4.2.1 of the QAPP, all analyzers used in the measurement of HC, CO, NOx, and CO_2 were calibrated in accordance with requirements 86.121-82, 86.122-78, 86.123-78, and 86.124-78, respectively, all of which can be found in 40 CFR July 1, 1983. Instrumentation used to measure regulated emissions (THC, NOx, CO, CO_2) associated with chassis dynamometer operation were checked for linearity prior to study startup and on a monthly basis during the study itself. Linearity checks were performed 5 times during the study, twice during Round 1 and three times during Round 2. Linearity checks were performed via multipoint calibrations. Appendix E presents results of the multipoint calibration checks. Known, down-scale standard concentrations ($Conc_{std}$) were generated with a capillary type 10-point gas divider using zero gas and a known concentration of the gas of interest. Instrument response to the down-scale standard concentrations was measured and recorded as $Conc_{meas}$. Linear regression was performed on the pairs of standard and measured concentrations to determine the slope, intercept, and correlation coefficient (R^2) of the best-fit first order curve. Slope and intercepts of the regression curve were applied to the measured concentrations to produce regression concentrations $Conc_{reg}$. The difference between $Conc_{std}$ and $Conc_{reg}$ are given as a percent in the last column, and in general, are less than ± 2 %, as required for certification testing. Based on the results of the monthly multipoint calibrations, the instruments were found to remain within linearity specifications and no adjustments were required.

Working span gases for the NOx, HC, CO, and CO_2 instrumentation were obtained from Scott Specialty Gases as Continuous Emissions Monitor (CEM)-1 daily standards with a vendor provided analytical accuracy of ± 1 %. Zero airs and FID fuels were obtained both from a local vendor (Kirk Gases) and from Scott Specialty Gases. Nominal NO span gas concentrations were 90 ppm. Both a high range and low range multigas was used for the CO, CO2, and HC instruments. Nominal high range gas concentrations were 900 ppm CO, 2.5% CO2, and 900 ppmC HC, while nominal low range concentrations were 90 ppm CO, 0.9% CO2, and 90 ppmC HC.

Dynamometer

Dead weight calibrations were performed on the dynamometer's torque cell throughout the course of Rounds 1 and 2, as indicated in Table 2-1. Results remained consistent throughout the study. In addition, a daily, single point dead weight check was performed starting mid-way through Round 1 to ensure the integrity and proper adjustment of the real time torque measurement system. The daily check was initiated in response to an intermittent short occurring in the torque recording system early in Round 1, which was subsequently traced to a rusted rivet connection and corrected.

Table 2-1. Dynamometer Torque Cell- Dead Weight Calibrations

Wt Applied	Equivalent	Measured	Measured	Measured	Measured	Measured	Measured
lbs	***Hp@50mph***	***Hp@50mph***	***Hp@50mph***	***Hp@50mph***	***Hp@50mph***	***Hp@50mph***	***Hp@50mph***
		07/25/2004	10/04/2004	1/11/05	1/25/05	2/26/05	4/7/05
50	18.5	18.6	18.6	18.5	18.6	18.5	18.6
40	14.8	14.9	14.9	14.8	14.9	14.7	14.9
15	5.55	5.6	5.5	5.5	5.5	5.3	5.5
5	1.85	2	1.8	1.8	1.8	1.6	1.8
0	0	0.1	0	0	0	0	0

Other daily performance checks included PDP speed, dynamometer speed, and dynamometer coastdowns. Coastdowns were conducted as set out in Section 4.2.1 of the QAPP, and as outlined in 40 CFR part 86. Results of the daily performance checks are presented in Appendix E. Measured PDP speeds ranged from 1772 rpm to 1765 rpm (excepting one day with a measured speed of 1748 rpm), or about 0.5%, over the course of Round 1, and from 1768 to 1780 over the course of Round 2, indicating excellent control over tunnel flows. Measured dynamometer roll speeds were within 1% of actual measured roll speeds during both Rounds excepting two days when there was a difference of ~ 1.4 %. A slight adjustment was made to the dynamometer speed measuring system midway through Round 2 which can be seen in the control chart given in Figure 2-1. This adjustment was made after replacing the dynamometer's reflective tape strip, which was used to make the daily QA speed measurement. Replacement of the reflective tape resulted in greater accuracy and less variability in the QA roll speed measurements and a speed adjustment of <0.5% was necessary.

All daily dynamometer coastdowns were performed with an inertia of 3500 pounds and a load setting of 6.0 Hp @ 50 mph (indicated). Daily dynamometer coastdown times and speeds are presented in Figures 2-2 and 2-3, respectively. During Round 1, daily measured coastdown times ranged from 22.38 to 24.62 seconds, but remained between 23 and 24 seconds for the majority of test days, with no trends toward increasing or decreasing times. This is a good indicator that no problems were developing in the dynamometer that would affect frictional losses or vehicle loading; i.e., the dynamometer was functioning consistently throughout Round 1. During Round 2, coastdown times were shorter than in Round 1 and ranged from 20.5 to 23.09 seconds. As Round 2 progressed, coastdown times generally increased and by the end of Round 2, coastdown times were approximately the same as found in Round 1. The faster coastdown times found in the beginning of Round 2 appear to coincide with the colder test days, in which dynamometer frictional (bearing) losses were presumably greater. A dynamometer roller bearing began to deteriorate on January 23, 2005 and was replaced the next day, January 24, 2005. Coastdown times measured prior to and after the bearing replacement indicate that there was no measurable change in frictional losses.

2.3.1 Setup and Calibration of Instruments and Samplers

DRI installed and operated a suite of instruments to provide continuous PM analysis and to collect batch samples of particle and gaseous exhaust components for later analysis in accordance with the methods and procedures specified in the project QAPP. These instruments collected sample air from the dynamometer dilution system via two isokinetic probes, provided by Bevilacqua-Knight Inc (BKI) and EPA, were inserted within 5 cm of the center line of the CVS dilution tunnel prior to a 90-degree bend in the dilution tunnel. Figure 2-4 illustrates the sample train as it was installed during Rounds 1 and 2, and Figures 2-5 and 2-6 present photographs of some of the instrumentation used. Heated conductive lines (47°C) carried air from the probes to the continuous instruments. Approximately 2.3 meters of heated (47°C), insulated 3/8" ID copper tubing was used to carry sample air to the time-integrated samplers[3]. As shown in the Figure 2-4 schematic, a small 2 liter stainless steel chamber containing a $PM_{2.5}$ size cut cyclone (Bendix 240) was included in the sampling lines just before they entered the filter samplers. Both the cyclone chambers and sampler plenum or diffuser were heated to 47C and insulated.

[3] Transport times were calculated to be 12 msec in the heated lines, and less than 1 second for the cyclone chambers.

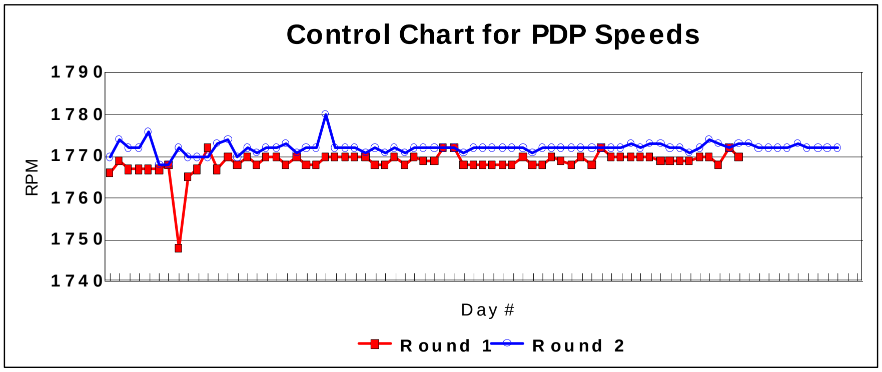


Figure 2-1. Control Chart for Daily PDP Speeds

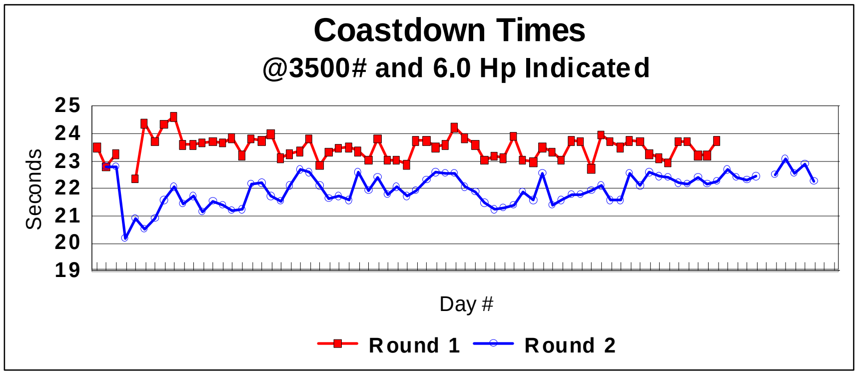


Figure 2-2. Control Chart for Daily Dynamometer Coastdown Times

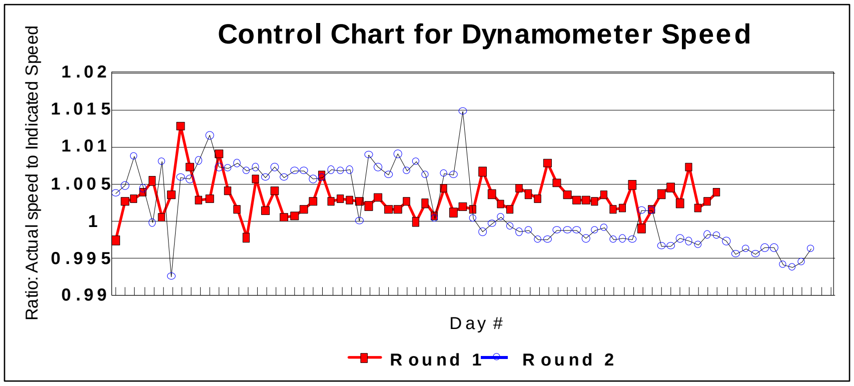


Figure 2-3. Control Chart for Daily Dynamometer Speeds

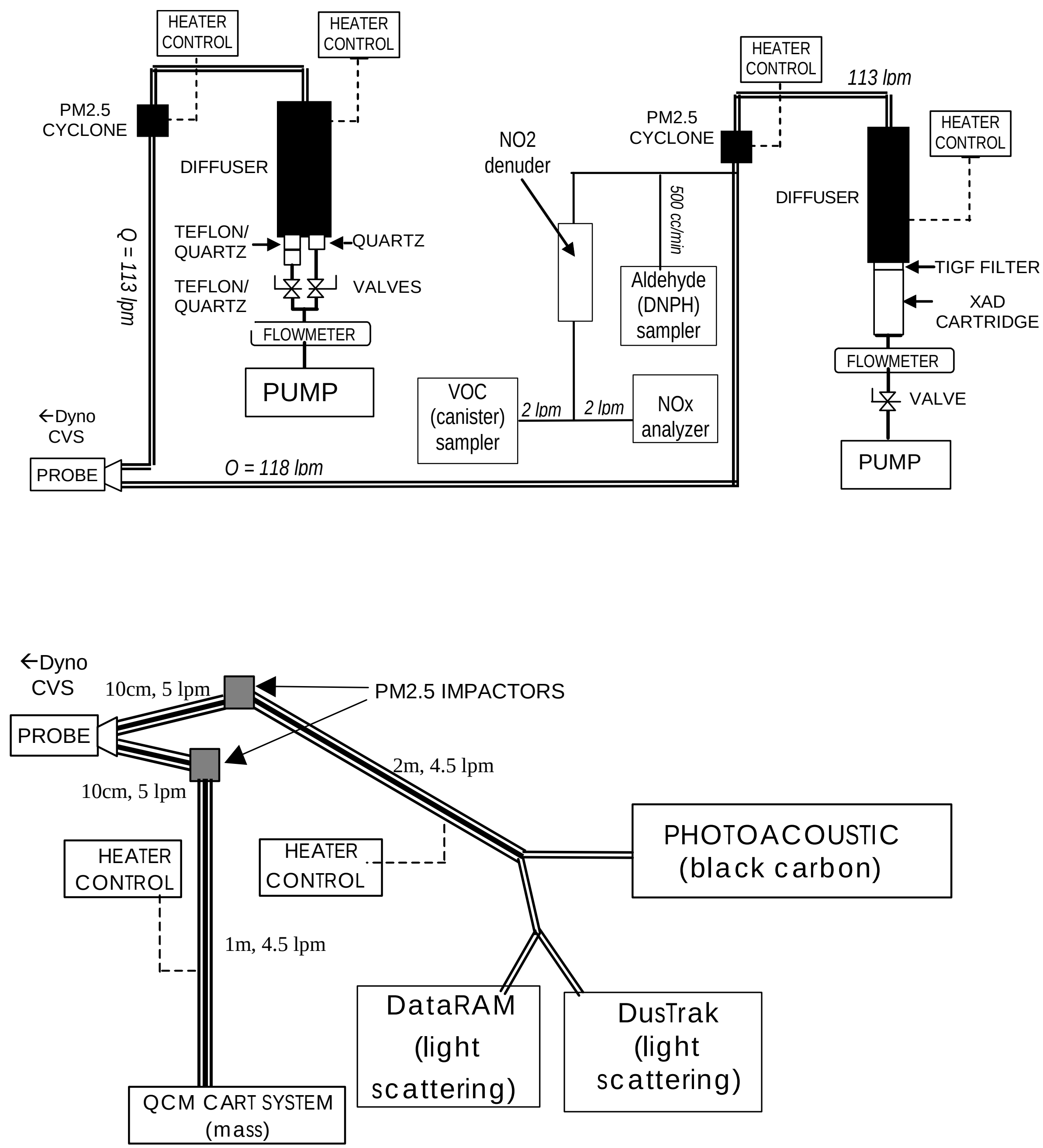


Figure 2-4. Schematic of Sampling Train with Flow Rates.
(Heated Tubing is Shown as Double Lines, all heated components are maintained at 47± 2 °C)

The following instruments were operated continuously during all tests:

A Photoacoustic instrument was designed and built at DRI. It continuously measures the concentration of light-absorbing material (primarily BC) in the airstream by the photoacoustic principle, in which the absorption of modulated light by particles results in thermal-acoustic pulses that can be detected by a highly-sensitive transducer and phase-locked amplifier. The measurement does not depend on flow rate, but flow was maintained at about 1 lpm with heated (47°C) sample lines.

The Quartz Crystal Microbalance (QCM) Cart System. This system was developed by Booker Systems specifically for the Kansas City (KC) project and is now being manufactured by SENSORS, Inc. The system, an integration of five separate components, is illustrated in Figure 2-5 and pictured in Figure 2-6. Sample air from the CVS dilution tunnel is passed through a 2.5 micron particulate pre-classifier to a micro proportional sampler (MPS) where it is either diluted or bypassed and directed to a valve unit in the flow controller system (FCS). The MPS is a clean-air dilution system used to reduce the dynamic range of the source aerosol concentration (Brockmann, 1984). The FCS, under control of a computer, will pass diluted, undiluted, or filtered ambient air to the QCM at a rate of 1 lpm depending on the expected concentration of the particulate emissions. There the QCM monitors the accumulated mass of particles on a quartz surface in real-time (Dickens and Booker, 1998). The MPS, FCS, and QCM operate at a controlled temperature of 47 ± 2 °C. The cart in which they are mounted is also temperature controlled at 47 ± 2 °C. After passing through the QCM, the sample air dew point (DP) is measured continuously using a dew point (DP) monitor (Vaisala, model M170). The computer acts as both a system control and data acquisition system for the MPS, FCS, QCM and DP monitor.

The QCM cart system was used during Part 1 of the Kansas City study as described above. The only change made for Part 2 of the KC study was the incorporation of the DP measurement into the QCM. The DP monitor was used during Part 2 as a quality assurance backup measurement. Quality Assurance for the QCM Cart System consisted of activities in three periods associated with the tests; immediately before the tests, during the tests, and during the reduction of data collected during the tests. These activities are summarized below:

- *Immediately before the tests* – All parameters on the QCM Cart are calibrated and adjusted by the manufacturer. Critical flow quantities are calibrated using both a Gilibrator (Gillian, Inc.) and a TSI model 4043 flow monitor (TSI Inc.). Both of these are transfer standards traceable to NIST standards. Pressure sensors are adjusted accordingly. Temperatures are calibrated using a platinum resistance thermometer. The sample transport flow heated lines are adjusted using K type thermocouples. These are then used to control the heated lines in use. Crystal frequency differences are checked using known mass loadings determined using an analytical gravimetric balance. Sample transport flow is determined using SKC flow controlled pumps (Model 2000). The calibration of these is tested using the TSI model 4043 and Biometrics model 2000 flow standards. The Biometrics flow monitor qualifies as a secondary standard traceable to NIST. In addition to these measures, the QCM's response to changes in sample air humidity is determined using the Vaisala, model M170 dew-point monitor.

- *Procedures Followed During the Tests* – Quality assurance during the tests consists of providing operational logs of instrument operation. This is done in two parts: first, the instrument operator keeps a personal log noting all conditions that might affect the quality of the QCM data. This includes general test conditions such as dynamometer operation and test weather conditions. Since the control computer displays all QCM parameters in real time, crystal frequency and resulting mass collection, sample flow, temperatures, and operational pressures, the operator can also assess failures in QCM operation. An example of this is failure of the quartz crystal frequency during periods when it overloads. Secondly, in addition to the operators log, the control computer creates a primary operation log for the QCM by logging all internal parameters for the instrument. This, in addition to the operator's log, represents the primary QA record for the QCM. Parameters logged by the QCM are listed in Table 4-30 of Section 4. During the test, sample transport flow is checked weekly using the TSI 4043 flow monitor. Dilution flow is also checked and the TSI flow monitor is then used to provide a continuous monitor of QCM sample flow. Periodic checks of this monitor's output are recorded in the operator's log.

- *Post Test Reduction of Data* – Reduction of the QCM mass data provides an opportunity to bring to bear all of the QA records created before and during the tests. As the data are reduced, the operator's log and the primary QA record are used to assess the validity of the results and generate QA indicators for voided data and data that should be treated as questionable pending further investigation. These indicators are listed in Table 4-32.

The Nephelometer – DataRAM is another commercially available portable monitor for particulate matter, which operates on the same principle as the DustTrak but uses two wavelengths for more uniform response to varying particle sizes. The measurement does not depend on flow rate, but flow was maintained at 2 lpm with heated (47°C) sample lines.

The DustTrak is a commercially available portable monitor for particulate matter. The TSI DustTrak estimates the concentration of particulate mass by measuring the intensity of light scattered perpendicular to a laser beam directed through the airflow stream. The measurement does not depend on flow rate, but flow was maintained at about 1.5 lpm with heated (47°C) sample lines.

Time-integrated samples for laboratory analysis were collected during each unified cycle test and a 60-minute tunnel blank each day as follows using specially adapted samplers designed and constructed at DRI:

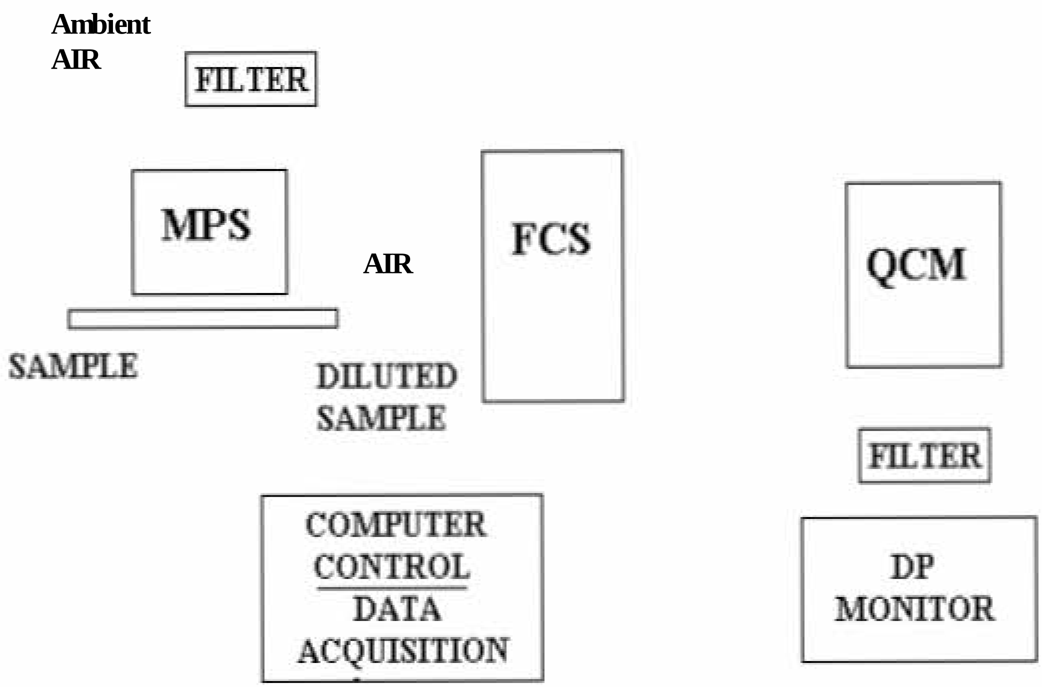


Figure 2-5. Components of the QCM Cart System

Teflon & Quartz filter sampler

Heated lines attached to probes into CVS tunnel

QCM (blue case on left) and photoacoustic instrument (right side)

Figure 2-6. Onsite Sampling Train

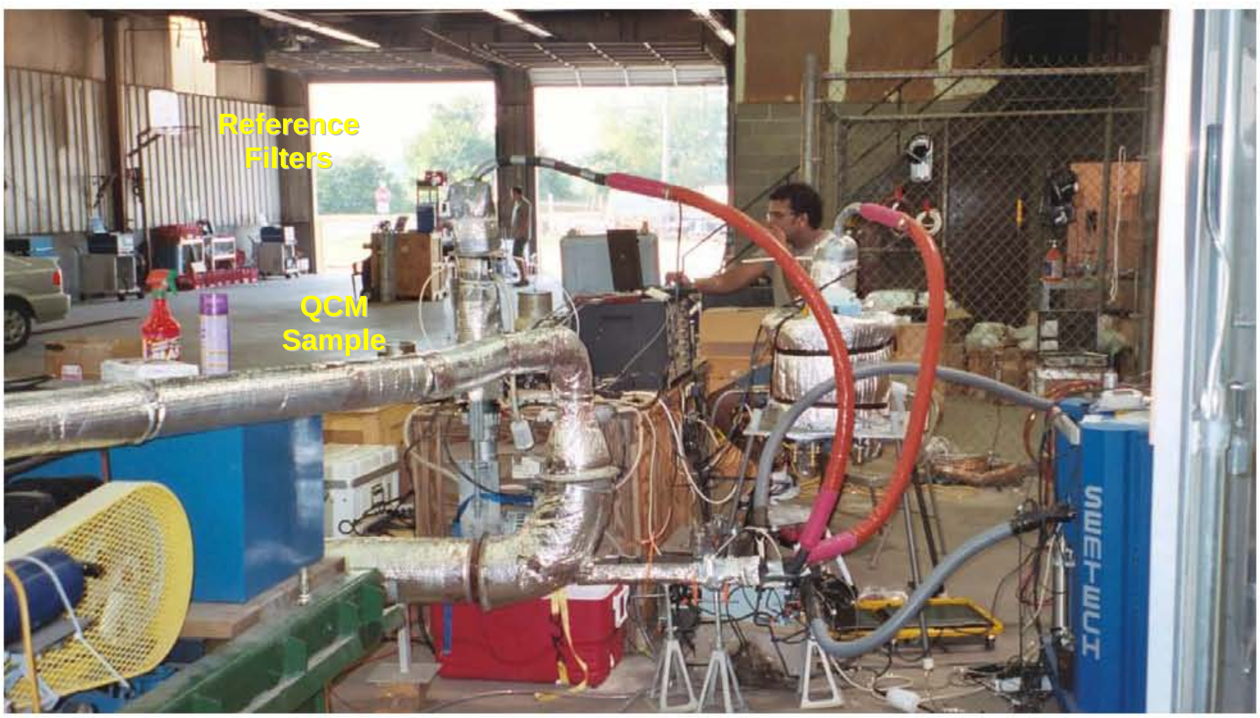


Figure 2-7. KC Facility Instrumentation

Filter samples were collected during each phase of the unified cycle tests using procedures and sampler design based on the widely used DRI Sequential Filter Sampler. A similar sampler was used in the Gasoline Diesel PM Split Study (Lawson et al, 2006) and was shown to collect equivalent PM mass to direct sampling from the CVS dilution tunnel. These tests were conducted to verify that no significant particle losses or adsorption artifacts occurred in the sampling train even with a much longer residence time and without temperature control. See Figure S-1 in Appendix MM (2006 Gasoline Diesel PM Split Study) for more information.

Pre-weighed Gelman polymethylpentane ringed, 2.0 mm pore size, 47 mm diameter PTFE Teflon-membrane Teflo filters (No. RPJ047) collected particles for measurement of gravimetric mass and elements. Pallflex 47 mm diameter pre-fired quartz-fiber filters (#2500 QAT-UP) were used for water-soluble chloride, nitrate and sulfate and for organic and elemental carbon measurements. Sample air was drawn from the CVS via ½" heated copper tubing to a small heated stainless steel chamber. The sample air exited via a $PM_{2.5}$ cyclone contained in the chamber to a heated diffusing chamber approximately 50 cm tall and 35 cm in diameter, manufactured from anodized aluminum, containing a temperature and relative humidity (RH) probe. From this chamber, which was necessary to allow the sample airstream to track from the inlet line to the filter ports located radially around the base without any particle loss due to impaction[4], the sample air exited through two filter cartridges. Up to eight cartridges could be installed in the base of the diffusing chamber, allowing four successive pairs of filters to sample without changing cartridges. Airflow through the cartridges was switched by means of microprocessor controlled relays and solenoid valves, that responded to TTL line digital signals from the dynamometer control. A 30 second delay was included to account for transport time thru the dynamometer and sampling system, based on empirical data collected with the continuous instruments. Flow rates for each filter were set to 56 lpm by adjustable valves to give a combined flow of approximately 113 lpm as required by the inlet cyclone, and monitored by TSI flowmeters with serial data outputs. A single oil-less pump was used to draw air through the sampler.

Samples were collected by a separate sampler for determination of particulate and semi-volatile organic compounds on Pallflex TX40HI20-WW 102 mm diameter Teflon-impregnated glass fiber (TIGF) filters followed by glass cartridges containing Aldrich Chemical Company, Inc. 20-60 mesh Amberlite XAD-4 (polystyrene-divinylbenzene) adsorbent resins at a flow rate of 112 lpm. The material collected on these media is removed by solvent extraction and analyzed at DRI by gas chromatography and mass spectrometry. A single filter and adsorbent pair were collected for each unified cycle, combining Phases 1, 2 and 3. Sampling was suspended during the 10-minute soak period by turning off the pump. Sample air was drawn from the dynamometer CVS via ½" heated copper tubing to a small heated stainless steel chamber. The sample air exited via a $PM_{2.5}$ cyclone contained in the chamber to a heated diffusing chamber, containing a thermistor temperature probe, 42 cm long and 9.5 cm in diameter. In this chamber the sample air decelerates and expands sufficiently to deposit uniformly on the 100 cm diameter filter face as it exits through the filter followed by the XAD cartridge. Flow rates were

[4] Inspection of the interior of the sampler plenum/diffusing chamber after the completion of both Rounds of testing showed no detectable particle deposits. The residence time in the chamber is difficult to estimate, since the sample air is expected to track directly to the filters, but was observed to be <30 seconds in smoke tests conducted with a DustTrak instrument connected to one of the sampler ports.

approximately 113 lpm as required by the inlet cyclone, and were monitored by an in-line TSI 4000 mass-flow meter. A single oil-less pump, switched on and off by a relay linked to TTL line signals from the dynamometer control, was used to draw air through the sampler.

Aldehydes were collected on 2,4-dinitrophenylhydrazine (DNPH) cartridges using a 6-channel sampler with integrated pump and mass flow controller. Sample air was drawn from the heated cyclone chamber via a ¼" diameter Teflon hose at 500 cc/min. A single cartridge was exposed for the duration of the 3 Phases of the unified cycle. Sampling was suspended during the 10-minute soak by switching to an unused channel by a relay linked to TTL line signals from the dynamometer control. As stated in Section 4.3 of the QAPP, for commercial 2,4-DNPH cartridges (Waters Sep-Pak XpoSure Aldehyde Sampler), DRI analyzed 5% of the purchased cartridges to ascertain the blank variability. Another 5% were analyzed if the initial data showed that the blank variability was marginally acceptable (at or slightly higher than 1/3 of the desired lower quantifiable limits (LQL)). This is necessary because unless cartridges are prepared in-house there is no other indication of the quality of the product, such as reagent and blank cartridge purity. In carbonyl measurements, the blank variability is the single most important factor in determining the lower quantifiable limit of the measurement; other factors such as flow rate, and analytical variability are secondary in importance.

VOC**:** Sample air was drawn from the heated cyclone chamber via a ¼" diameter Teflon hose and passed through a Teflon filter and a cobalt oxide denuder coated to remove NO_x before being pumped into a Summa polished steel canister. A chemiluminescence real-time NOx analyzer was installed downstream from the denuder to monitor its efficiency. Air flow for the canister sampler was controlled by a needle valve to obtain the necessary flow rate to fill the canisters to approximately 15"Hg positive pressure over the duration of the complete unified cycle. Sampling was interrupted during the 10-minute soak by switching to a bypass channel. The sampler draws a total flow of 2 lpm, but only about 300 cc/min of that was pumped into the canisters. Sampling was suspended during the 10-minute soak by switching to an unused channel by a relay linked to TTL (digital electronic) line signals from the dynamometer control.

Prior to the start of each round, all samplers were checked for leaks and the in-line flow meters were cross-calibrated using reference flow measurement devices. Leak testing was performed by capping the inlet lines leading to each sampler and turning on the pumps. If the flow meter readings decreased to less than 10% of the nominal sampling flow rate in a reasonably short time, the system was passed. If not, the source of the leak was identified and fixed, then the test repeated. With the exception of the Teflon/Quartz filter sampler, all units achieved near-zero flow rates during the leak test. Due to the friable nature of the pre-fired quartz filters, it is not possible to obtain a perfect seal in the filter holders without damaging the media, but the <10% criteria were still met for each filter individually and for the system as a whole. In addition to the vacuum test, the sum of flows through each of the two filter cartridges was compared to the total flow entering the inlet and found to agree within 5%.

All flowmeters were calibrated using either a Gillibrator electronic bubble meter (Gilian Inc.) or a rotameter (Dwyer Instruments) that had been cross-calibrated with a Roots meter at DRI. Calibration flows were measured at the inlet point of each sampler (or outlet for the canister sampler) with appropriate sampling media installed. The resulting multi-point calibrations were used to calculate the desired nominal flow rates, and these were marked on a label on each flowmeter so that the operator could observe any deviations during testing. Variations in nominal flow rate due to sampler problems were recorded in a logbook. The sampler flow calibrations are shown in Tables 2-2 and 2-3. Flows were audited periodically using the same reference devices. If the deviation from the original calibration was 10% or more the flowmeter would be re-calibrated, however, this did not prove necessary at any time. Since the DNPH sampler used an electronic mass/flow controller, only a 1-point flow audit was performed on that unit between Rounds.

Table 2-2. Round 1 Sampler Calibration and Audit Results

	rotameter	**Qactual**	**flowmeter**	**ERR**		**regression stats**				**target**	**audit**	**ERR**
	scfh	**slpm**	**slpm**			**r2**	**m**	**b**		**flow**	**reading**	
XAD	273	128	121	-6%		0.99	1.03	2.87		113	**107**	5%
	250	117	112	-4%								
	227	106	100	-6%								
Teflon	125	58	54.7	-6%		1.00	1.06	0.40		56.5	**53**	6%
	110	51	47.6	-7%								
	140	65	61	-6%								
Quartz	124	57	54.7	-5%		1.00	1.01	2.14		56.5	**54**	5%
	97	45	41.8	-7%								
	152	71	67.4	-5%								
DNPH		0.534	0.498	-7%		1.00	1.02	0.02		0.500	**0.465**	8%
		0.555	0.519	-7%								
		0.508	0.473	-7%								
		0.531	0.499	-6%								

Qactual = flow rate determined by reference method
slpm = standard liters per minute (20C, 1 atm)
scfh = standard cubic feet per hour (20C, 1 atm)
ERR = (indicated or target flow - actual flow)/actual flow
Regression stats on the slope of the line: $y = mx + b$

Table 2-3. Round 2 Sampler Calibration and Audit Results

	rotameter	Qactual	flowmeter	ERR	regression stats			target	audit	ERR
	scfh	slpm	slpm		r2	m	b	flow	reading	
XAD	255	123	122.5	0%	1.00	0.99	0.75	113	**113**	0%
	230	111	110	-1%						
	187	90	90	0%						
Teflon	133	64	65	2%	1.00	1.13	-7.04	56.5	**57**	0%
	114	55	55	0%						
	98	47	46	-2%						
Quartz	140	67	65	-4%	1.00	1.01	-3.2	56.5	**54**	4%
	119	57	55	-4%						
	99	48	45	-6%						
DNPH								495	**485**	2%

For each integrated sample, the run number, start and stop time, elapsed time, initial and final flow rate, and any exceptional occurrences were recorded on log sheets that were kept with the media at all times. Bar coded stickers with unique media IDs were attached to all media and their corresponding log sheets for tracking. Immediately after the conclusion of each test cycle, the media were repacked with the log sheets and stored in a refrigerator, except for the canisters, which were packed and shipped via 2-day express to DRI each day. All media were packed into coolers with ice packs and shipped overnight back to DRI where they were logged in and placed in cold storage until analysis. Media were shipped on a near weekly basis during Round 1. Continuous data were backed up via the wireless network and processed at the end of each sampling day to determine phase-averaged values. Run number, date, time, and vehicle license plate number were attached to all files to identify the data.

2.3.2 Additional Support Equipment

Table 2-4 lists equipment that was either rented or purchased to support the sampling efforts.

Table 2-4. Sampling Support Equipment Rented or Purchased by ERG, On-Site

Name	Purpose	Notes
Oil-less Air Compressors	To supply clean, dry dilution air to the micro-dilution system used with the QCM.	Purchased. Provides up to 5 SCFM at 100 psig. Has a 25 gal. tank. Water trap and filtration provided by EPA.
AC Electricity Generator	To supply power for the CVS dilution air heater.	Rented from United Rentals. Wacker model G-50. 50-kilowatt capacity. Diesel fueled. Power umbilical provided by BKI.
CVS Dilution Air Dryer	To reduce CVS dilution air humidity.	Rented from United Rentals. TempAir (Rupp Industries) model TD 400. Dries up to 400 CFM. Requires 230 V, 1 phase, 30 A, electric supply. Portable desiccant-type dehumidifier. Alumina silicate wheel continuously absorbs gas-phase water. Heated slip-stream of dried air re-directed back to used section of wheel to desorb water and regenerate the wheel. These were used primarily during Round 1.
Refrigerator	To store particulate filter media.	Purchased. 14 cubic feet, upright.
Freezers	To store fuel samples.	Purchased. 10 cubic feet and 24 cubic feet, chests.

2.4 PEMS Setup

The eight portable emissions monitoring systems (PEMS) and associated equipment EPA provided for Round 1 of the study were also used for Round 2 testing. These systems, the SEMTECH-G manufactured by Sensors, Inc. were used vehicle THC, CO, CO_2, and NO_x emissions during each vehicle's preconditioning run, emissions during dynamometer testing (in tandem with the dynamometer bench), and in some instances emissions from participants vehicles after the vehicles were picked up from testing. Details on PEMS testing are provided in Section 4.7. Differences between Round 1 and Round 2 PEMS testing are described in the following section.

2.4.1 Changes from Round 1

Round 2 test procedures, equipment, and testing conditions differed somewhat from those during Round 1. The most notable differences are discussed in an Appendix to the updated QAPP, and are presented below:

Onsite PEMS repair support

Onsite PEMS repair support was available throughout the Round 2, and greatly reduced equipment downtime and shortages. Most PEMS problems were minor issues such as stuck solenoids, loose or dirty contacts and fittings, water in the system, or blown relays, and were able to be repaired quickly. Most large repairs, such as system module and CPU board replacements, could also be accomplished onsite (after receipt of necessary repair materials).

Temperatures and ambient conditions

Round 2 testing was conducted during the winter, as opposed to the Round 1 summer study. Since this portion of the study was to be conducted at ambient temperatures, an enclosed and heated structure was erected in which to conduct PEMS installation activities. This prevented operation of the units sub-freezing temperatures (beyond their specified operating temperature range). Operation of the PEMS units below freezing temperatures was occasionally necessary, and resulted in various operational problems, such water freezing in the FID exhaust drain lines and internal filters, and freezing in the flowmeter pressure-differential measurement tubes and exhaust sample lines. The signal transducer boxes used with the new pressure-differential flowmeters occasionally would not warm up to operating temperature (as indicated by the "warm-up" indicator LED), and some emissions measurement drift was seen during some conditioning runs (as evidenced by pre-test and post-test audits). This drift may be due to auditing the PEMS in the heated installation bay and then performing the conditioning test in a vehicle's trunk or bed at ambient temperatures.

Flowmeter changes

Hot-wire anemometer-style flowmeters were used throughout the Round 1 summer portion of the study. These were replaced with pressure-differential style flowmeters for Round 2 of the study. These new flowmeters transmitted pressure signals through flexible tubes to a signal transducer box which converted the pressure-differential signal and exhaust temperature measurement into an exhaust mass flow rate determination.

Flowmeter mounting changes

License plate brackets and suction cup clamp assemblies were primarily used to install the flowmeters used during Round 1 of the study. This posed concerns associated with participants or pedestrians burning themselves (particularly on driveaway testing) or the assemblies falling off. Occasionally, flowmeters were hung underneath the rear of the vehicle, which was generally laborious and exposed the flowmeter to water and possible dragging damage. The new pressure-differential flowmeters were significantly larger and heavier, so common bicycle racks were used for flowmeter installations during Round 2. Wire meshes were secured to these racks to allow mounting of license plates and to protect against burns.

Software changes

Several PEMS software changes were implemented prior to or during Round 2. This new software allowed use of the new pressure-differential flowmeters, and it also allowed activation of auto-zero and automatic FID heater shut-down after a period of time (auto-zeros were performed only on drive-away testing). Another software update involved adding a "session manager" which "bundled" all the audits and second by second test information into one file. The following software changes were implemented throughout the study (including both Rounds 1 and 2):

- Rollout beginning July 12, 2004: Software Version 9.03
- Rollout beginning August 17, 2004: Software Version 9.03 SP1

- Rollout beginning November 23, 2004: Software Version 9.04
- Rollout beginning December 6, 2004: Software Version 9.05 SP1
- Rollout beginning December 16, 2004: Software Version 9.05 SP2

Testing was continued with Software Version 9.05 SP2 through the end of Round 2.

QCM changes

The QCM cart system used during Part 1 of the Kansas City study is described in Section 2.3.1. DP measurement was incorporated into the QCM for Part 2 of the KC study, in order to provide a QA backup measurement. In addition, relative humidity (RH) and the relative humidity temperature were added to the list of parameters recorded by the QCM System Computer Control/Data Acquisition System, as described in Section 4.5.2.2.

2.4.2 Procedural changes between Rounds 1 and 2

The equipment downtime experienced during Round 1 was greatly reduced during Round 2 through the addition of an on-site PEMS repair and support person. Most repairs were minor, such as stuck solenoids, loose or dirty contacts and fittings, water in the system, or blown relays, and were able to be repaired quickly. Most large repairs, such as system module and CPU board replacements, were also accomplished onsite (after necessary repair items were received onsite). This increase in equipment up-time allowed significantly more driveaways to be conducted in Round 2 than were possible during Round 1 of the study.

As mentioned in Section 2.4.1, the hot-wire anemometer-style flowmeters used throughout the Round 1 summer portion of the study were replaced with pressure-differential style flowmeters for Round 2 of the study. Measurements from the original hot-wire anemometer flowmeters were adversely affected by heat radiation effects at low vehicle speeds and idle. Since convective cooling minimized these effects when vehicles were in motion, low-speed and idle flow measurements were biased low. This bias was eliminated with the use of pressure-differential style flowmeters provided for Round 2 of the study. These flowmeters relied on a bank of differential pressure sensors (as opposed to a hot-wire anemometer) in order to determine corrected mass exhaust flowrates. However, the orifices in the differential pressure sensors used in these new flowmeters were susceptible to particulate matter clogging and moisture freezing. This condition was minimized as much as possible by thoroughly purging all orifices with high-pressure dry compressed nitrogen prior to each use, and by maintaining the flowmeters and tubing assemblies in above-freezing conditions.

Earlier in the study, problems were encountered with preventing moisture and exhaust fumes from entering vehicles during testing. The new flowmeters required additional tubing to be routed out of the trunk (generally requiring the trunk to be propped open wider). Standard household pipe insulation purchased at a hardware store was found to fairly effectively seal trunks. Carbon monoxide detectors were used to ensure vehicle exhaust was not entering the passenger compartment.

As mentioned in Section 2.4.1, Round 2 testing was conducted during the winter, as opposed to the Round 1 summer study. Operation of the PEMS units below freezing temperatures was occasionally necessary, and proved to be problematic because of water freezing in system components and measurement drift. Battery life seemed greatly reduced during Round 2 testing, perhaps due to battery cycle fatigue (these were the original batteries used since the start of the study) and also possibly due to operation in the cold temperatures.

In order to prevent trunks from inadvertently popping open, as would occasionally happen with the original vice-grip-devised trunk latches, heavy-duty zip-ties were used (with metal rings installed in the trunk latch assembly) to secure trunks. These zip ties, which are typically used for securing building ventilation and may be found at a typical hardware store, also prevented motorists from tampering with the PEMS units installed in trunks during driveaway tests.

Experience gained during Round 1 of the study helped streamline Round 2 testing. For example, installation procedures and sequences were modified in order to minimize lost time in the event of equipment malfunctions. Certain “tricks” and procedures for equipment software helped expedite installations and minimize system resets. The incorporation of a session manager into the host software also allowed consolidation of audit and test information into one test file, thereby expediting equipment setup and reducing time needed for test processing and analysis.

3.0 Vehicle Recruitment

3.1 Recruitment Process

The recruitment process required deriving a targeted (stratified) sample of vehicles from a cohort of 2000 households generated through random sampling in the Kansas City Metropolitan Statistical Area (MSA). The Mid-American Regional Council (MARC) completed a comprehensive travel survey of Kansas City regional households in spring of 2004.[5] That study's resulting dataset was reviewed for use as the initial cohort of households. As demonstrated in more detail in the next section (3.2), the MARC data, when compared with Census 2000 data at the household and person levels using a number of demographic and geographic characteristics, created a cohort that represents the Kansas City MSA population. As a result, there was no need to conduct a survey of households to develop the initial sample cohort for this study. This dataset was the primary dataset for recruitment during Rounds 1 and 2 of the study. Vehicles were recruited from the Kansas City Metropolitan Area (KCMA) (see Figure 3-1). The Kansas City MSA counties included:

- Johnson County, KS
- Leavenworth County, KS
- Wyandotte County, KS
- Clay County, MO
- Cass County, MO
- Jackson County, MO
- Platte County, MO

[5] Kansas City Regional Household Travel Survey Final Report, http://www.marc.org/transportation/pdf/travelsurvey2003.pdf

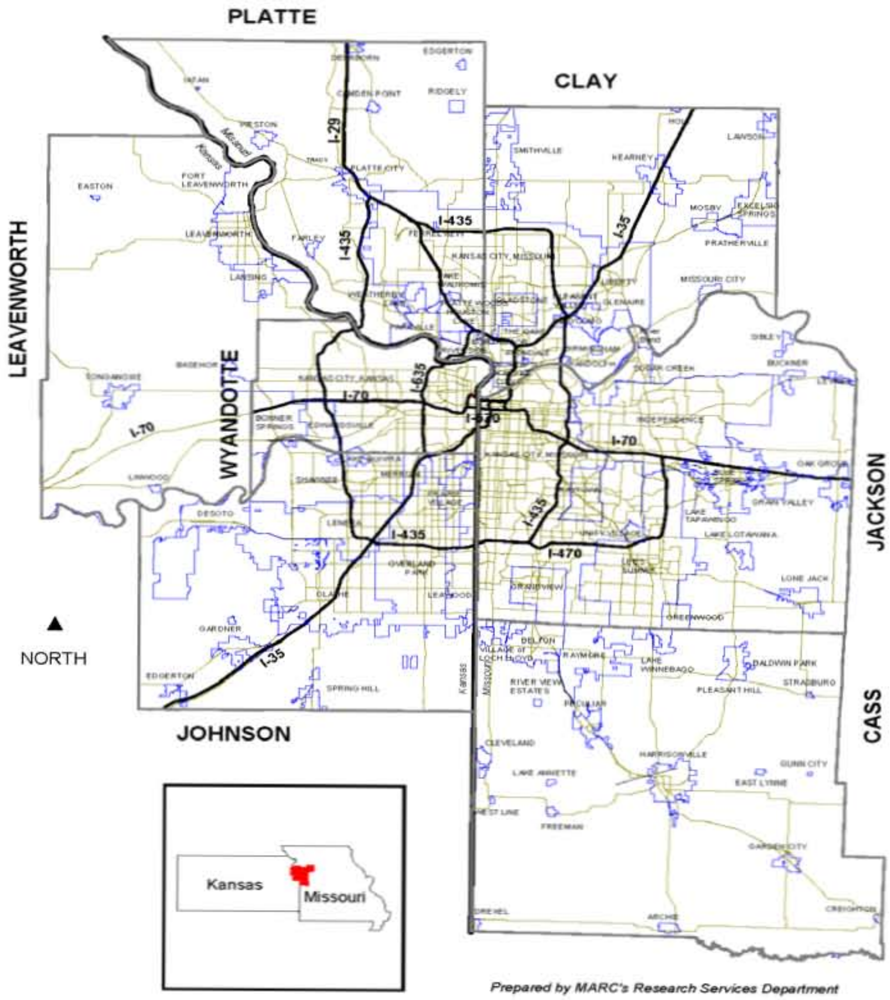


Figure 3-1. Kansas City Metropolitan Area

The use of the MARC 2004 Household Travel Study (MARC Study) as the cohort from which to recruit vehicles allowed vehicle recruitment to begin earlier than planned in Round 1. It also provided, inherent in the data set, household data elements including year, make, model, body type, and fuel type for each household vehicle, home address and preferred method for contacting owner. All participants in the MARC study were aged 21 or older.

One of the challenges of Round 1 testing was that there were fewer than expected older vehicles available for recruitment. In fact, by the end of Round 1 testing, the available vehicle pool for recruiting the oldest vehicles, i.e., Strata 1, 2, 5, 6 (Pre-1981 and 1981-1990 trucks and cars) had been virtually exhausted. This posed a challenge for Round 2 testing.

Fortunately, the Kansas and Missouri Vehicle Registration database provided a large pool of vehicles that can be sampled and recruited for testing. That database was used to draw representative stratified random samples for recruiting as many vehicles as necessary to achieve the desired sampling targets. Moreover, to ensure adequate participation, Round 2 recruitment activities commenced with the older vehicle samples, and then turned to the more prevalent newer vehicles.

As a final note on sampling, the use of the vehicle registration files did not conflict with the use of the MARC RDD sampling frame for Round 1 (and Round 2 of the more prevalent vehicle strata). The use of DMV lists triggered the adoption of an efficient dual frame sample design ("dual" because there are two sources of sample – and RDD household sample, and the DMV list of vehicles). The adoption of a dual frame design in this case is good science because (1) the DMV frame (like the RDD frame) is complete, with virtually 100% coverage of the vehicle fleet population; and (2) the efficiency of identifying rare or low prevalence vehicles (e.g., older trucks) from the DMV list is considerable relative to the alternative of large scale screening of households.

Incentives Test

Prior to the start of testing in Round 1, an incentive survey was conducted to identify the appropriate levels of incentives necessary to ensure sufficient regional vehicles would be available for the emissions testing program. The survey was successful in identifying specific levels of incentives and particular groups of respondents to help in identifying the appropriate incentive packages to initially offer potential participants. It also provided some initial insight into participation rates, especially on those who refused to participate in the study and the level of incentives that would convert them to a prospective participant. The MARC study database served as the sample for the survey.

Overall, the program description and discussion of incentives were sufficient to generate interest in the program. Two-thirds of all incentives test respondents agreed to schedule their vehicles for testing when the program would begin.

In terms of the incentives, the survey provided excellent guidance in terms of structure and application. Most respondents indicated that a full-size rental car would be sufficient for the 24- to 48-hour period during which their vehicles would be at the testing facility. Variances in acceptable cash levels led to the recommendation of offering $75 and staging incentives in $25 increments up to $200 for those who refused to participate.

Incentives were utilized in both Round 1 and Round 2 of the study. The following table provides a summary of the total number of incentives offered and amount paid for each Round and for the study as a whole. The average incentive amount needed for those that actually had their vehicle tested was about $113.00.

A summary of the incentives offered during the study is shown in Table 3-1.

Table 3-1. Summary of Incentives for the KC Study

Incentive Level	Round 1 Counts	Round 2 Counts	Total
$0-$50	10	13	23
$50-$100	81	85	166
$100-$150	166	182	348
$150-$200	45	27	72
$200-$250	9	44	53
$250-$300	3	7	10
$300-$350	1	2	3
$350-$400	1	6	7
>$400	2	0	2
Totals	318	366	684

Sampling

A questionnaire guided interviewers in screening households for vehicles that met the project needs (see Appendices C and D for all recruitment-related materials). Some vehicle types were excluded from the study, and the vehicle characteristics (e.g. body configuration) were incorporated into the questionnaire. Those vehicles that qualified were flagged for possible recruitment. Body configuration was used because certain size vehicles could not be accommodated on the dynamometer.

The sampling process was very flexible which allowed for quick changes in scheduling vehicles for testing. A vehicle file used for sampling was posted daily to the project website, along with flags to indicate eligible vehicles, those sampled, and status of scheduling (waiting to be scheduled, scheduled, tested, etc.).

Scheduling Calls

As vehicles were sampled, the households were re-contacted for scheduling (if not done at the time of sampling). The following parameters guided the scheduling process:

1) Vehicles were scheduled for drop off and pick up daily except for Sundays. A master scheduling list that showed valid scheduling dates was prepared.
2) In general, vehicles dropped off Monday through Friday were picked up Tuesday through Saturday. Vehicles dropped off on Saturday were picked up on Monday. Occasionally, vehicles were kept for more than 24-hour periods (depending on drop-off times).
3) Participants were asked to drop off vehicles between 7 and 9 am, and to pick them up between 4 and 6 pm the following day. Special times and pick-up options were offered, depending on the importance of the vehicle to the testing process.

A daily scheduling file that contains information on vehicles scheduled from the current day onward was posted on an on-line Project site. Contained in this file was the vehicle make, model, and year, along with owner name, home phone, and alternative number, as well as the incentive package promised/expected.

Packets

Scheduled participants received via U.S. mail a thank you letter, a map to the testing site (personalized from Yahoo.com), a general information brochure about the project, and contact information. The packet also included a copy of a vehicle owner survey and a checklist reminding participants to bring their driver's license and insurance card. The cover letter referenced the agreed-upon incentive.

Reminder Call

The afternoon / evening prior to the scheduled test date, participants received a reminder call regarding their appointment time for bringing the specific vehicle to the testing site.

Toll-free Hotline

A toll-free hotline was maintained for participants to use for questions and canceling or rescheduling their testing appointment.

3.2 Cohort / Vehicle Frame Analysis

Meeting the study goals required deriving a targeted (stratified) sample of vehicles from a cohort of 2000 households generated through random sampling in the KCMSA. The methodology for generating the sample originally called for conducting a Random Digit Dialing (RDD) telephone survey of households (HH) in the KCMSA. This methodology relied on two key underlying assumptions:

- An RDD sample of HHs will generate a representative sample of the population in the Kansas City MSA, and
- The cohort of HHs participating in the RDD survey will provide a representative sample of vehicles for emissions testing.

Because NuStats had recently completed the 2004 Kansas City Travel Behavior Survey for MARC, the use of the survey data (the survey was conducted in Spring 2004 using an RDD sample design) was recommended. NuStats conducted a comparison of the MARC data with Census 2000 data at the household and person levels using a number of demographic and geographic characteristics. As evidenced in Tables 3-2 and 3-3, using the MARC RDD sample to create a cohort of households satisfactorily represented the Kansas City MSA population on a number of demographic / geographic characteristics.[6] The only substantial difference appears in

[6] The MARC survey distributions are unweighted (raw), allowing for more informed assessment of the product of RDD sampling. It should be noted that survey data are typically weighted to correct for discrepancies between known Census population distributions (for selected demographic variables) and the unweighted survey results. But a comparison of *weighted* survey data and the Census distributions would mask any real differences between survey and Census distributions for those

the non-white race comparisons, and this is easily explainable and not of concern for research purposes. First, it is well known that the race/ethnicity questions were problematic in Census 2000, and the MARC RDD and Census white population percentages match up well. Secondly, and perhaps more importantly, the income distributions of the RDD sample and Census align well, suggesting that the RDD survey captured a representative sample of the population according to income (which is associated with race).

Table 3-2. Demographic Comparison of MARC RDD Survey of Households and Census 2000 Distributions

Demographic Characteristic	RDD Survey (n=4,001)	Census 2000
Household size		
1	26.8%	27.4%
2	33.3%	33.0%
3	16.0%	16.2%
4+	23.9%	23.4%
total	100.0%	100.0%
HH Vehicles		
0	5.8%	7.4%
1	32.9%	33.9%
2	42.7%	41.7%
3+	18.6%	17.0%
total	100.0%	100.0%
HH Income		
< 15k	9.9%	12.2%
15k - < 25k	10.2%	11.3%
25k - < 50k	30.2%	30.1%
50k - < 100k	35.9%	33.6%
100k +	13.8%	12.8%
(refusal)	(5.9%)	--
total	100.0%	100.0%
Residency Type		
single family	76.8%	69.0%
all other	23.2%	31.0%
total	100.0%	100.0%
Race		
White	81.3%	81.6%
Black/African American	10.7%	14.1%
Other	8.0%	4.3%
total	100.0%	100.0%
Respondent Age		
< 20	29.6%	29.1%
20 - 24	4.3%	6.1%
25 - 54	43.3%	45.3%
55 - 64	9.9%	8.2%

demographic variables that were used in generating the weighting adjustments. Thus, the survey data used in the comparison were not weighted.

65 +	12.8%	11.3%
refusal	(1.2%)	--
total	100%	100.0%

Table 3-3. Comparison of MARC RDD Survey and Census 2000 Geographic Distributions

County, State:	Census 2000	RDD Survey (N = 4,001)
Cass County, MO	4.6%	4.9%
Clay County, MO	11.1%	12.3%
Jackson County, MO	40.6%	39.9%
Platte County, MO	4.5%	4.6%
Johnson County, KS	26.6%	26.1%
Leavenworth County, KS	3.5%	3.3%
Wyandotte County, KS	9.1%	8.9%
total	100%	100%

Table 3-2 presents a number of (unweighted) comparisons of the household and person level characteristics from the RDD MARC survey to that of the Census 2000.

Table 3-3 presents the distributions of the (unweighted) RDD MARC sample and the Census 2000 on the County level.

3.3 Cohort Respondent / Nonrespondent Analysis

In the process of conducting the MARC household travel survey (which forms the foundation of the cohort for the EPA Emissions Testing Project), NuStats randomly sampled and contacted 5,500 regional households. Of these, 4,001 agreed to provide their information and 3,049 ultimately completed all aspects of the survey. Non-respondents are those 1,500 households that were contacted and firmly refused to participate.

A discussion of the characteristics for those 1,500 households that chose not to participate is very limited. Most refusals took place during the introduction to the study, prior to the interviewer obtaining any demographic information about the household. The only item that can be reviewed is the geographic distribution of refusers, since all sampled telephone numbers were initially flagged with the anticipated county of residence. This distribution is shown in Table 3-4 and the proportion of refusals matched the proportion of participants by county of residence.

Of those 4,001 households that agreed to participate in the MARC survey, 2,887 with at least one vehicle comprised the Round 1 sample. Of those, a total of 1,236 were contacted about participation in this Round 1 emissions testing effort. Of these households, 221 ultimately agreed to participate in the survey. The remainder either refused to participate (360), could not be contacted after multiple attempts (497), or their phone numbers were no longer valid (106). On average, each household was attempted 2.8 times. The overall response rate for the study was 21%.

Of the 221 households that ultimately had their vehicles tested, 23 had initially refused to participate during the recruitment call but were converted after another focused attempt. An additional 29 households cancelled their initial scheduled testing, but agreed again to have the vehicle tested later during Round 1. Tables 3-5, 3-6, 3-7, and 3-8 compare the Round 1 participants vs. those that refused testing in terms of the county of residence, income, and vehicles owned. The bin breakdown of these vehicles is presented in Section 3.6.

In terms of county of residence, the refusers were most likely to come from Jackson County, Johnson County, or Cass County. However, there was very little difference in the proportions of refusers and regular participants by county of residence.

Table 3-4. MARC Household Survey Non-Respondents and Respondents by County of Residence

County	Non-Responders	Respondents
Johnson County, KS	29.7%	26.4%
Leavenworth County, KS	3.6%	3.1%
Wyandotte County, KS	7.8%	8.6%
Clay County, MO	5.5%	4.8%
Cass County, MO	12.5%	12.3%
Jackson County, MO	37.5%	40.4%
Platte County, MO	3.5%	4.5%

Source: Non-Respondents based on Sample File for the Kansas City Regional Household Travel Survey (KCRHTS), unweighted. Includes all households that refused to participate in the study. Respondent proportion reflects the weighted distribution of households participating in the survey.

Table 3-5. Round 1 Refusers and Respondents by County of Residence

County	Refusers	Regular Participants
Johnson County, KS	22.2%	25.6%
Leavenworth County, KS	2.2%	6.4%
Wyandotte County, KS	9.5%	10.4%
Clay County, MO	6.0%	4.8%
Cass County, MO	14.0%	9.6%
Jackson County, MO	43.2%	40.0%
Platte County, MO	2.9%	3.2%

Source: Non-Respondents based on unweighted KCRHTS data for refusers and regular participants in Round 1 of the study.

The refusers were more likely to report a lower income than that reported by regular participants (22% compared to 16%, respectively).

Table 3-6. Round 1 Refusers and Respondents by Income Level

Income	Refusers	Regular Participants
<15,000	8.8%	4.9%
15,000 - < 25,000	13.5%	10.6%
25,000 - <50,000	35.5%	37.4%
50,000 - < 75,000	18.9%	20.3%
75,000-<100,000	14.5%	17.9%

100,000+	8.8%	8.9%

Source: Non-Respondents based on unweighted KCRHTS data for refusers and regular participants in Round 1 of the study.

The refusers were more likely to own a truck. As a result, trucks were added as part of the rental fleet in Round 2 (note that the mitigation of such refusals by adding trucks ultimately was inconclusive.)

Table 3-7. Round 1 Refusers and Respondents by Vehicle Type

Vehicle Type	Refusers	Regular Participants
Car	79.7%	84.2%
Truck	20.3%	15.8%

Source: Non-Respondents based on unweighted KCRHTS data for refusers and regular participants in Round 1 of the study.

As was anticipated, the refusers were somewhat more likely to own an older vehicle.

Table 3-8. Round 1 Refusers and Respondents by Vehicle Year

Vehicle Year	Refusers	Regular Participants
Pre -1981	9.3%	5.9%
1981 to 1990	35.2%	39.2%
1991 to 1995	16.4%	18.1%
1996+	39.1%	36.9%

Source: Non-Respondents based on unweighted KCRHTS data for refusers and regular participants in Round 1 of the study.

3.4 Cohort Recruitment Analysis

Section 3.2 defined the study cohort as being derived from the MARC 2004 household travel study sample and demonstrated that the MARC sample represented the KCMSA. This section compares the MARC sample with the Rounds 1 and 2 participant characteristics and the 2000 Census data for the study area.

The first comparison is on key household characteristics, including household size, vehicles, household workers, household income, residence type, and home ownership as shown in Table 3-9. This table shows the raw and weighted MARC sample characteristics, the raw Rounds 1 and 2 participant characteristics, and the 2000 Census data for the study area.

Table 3-9. MARC Household Characteristics Compared to Census

Characteristic	MARC Raw Data	MARC Weighted Data	EPA Round 1 Data	EPA Round 2 MARC Data Only	Round 1 & Round 2	Census Data
Household Size						
1	28.40%	27.50%	16.80%	7.06%	10.84%	27.40%
2	34.00%	32.90%	32.80%	36.47%	34.94%	32.90%
3	15.80%	16.20%	14.40%	20.00%	18.07%	16.20%
4+	21.80%	23.50%	36.00%	36.47%	36.14%	23.50%
Household Vehicles						
0	5.30%	7.40%	0.00%	0.00%	0.00%	7.40%
1	32.00%	33.90%	12.80%	10.59%	12.05%	33.90%
2	44.20%	41.70%	44.80%	54.12%	49.40%	41.70%
3+	18.50%	17.00%	42.40%	35.29%	38.55%	17.00%
Household Vehicles		(Reweighted from above to include households with 1-3+ vehicles)				
1	33.79%	36.61%	12.80%	10.59%	12.05%	36.61%
2	46.67%	45.03%	44.80%	54.12%	49.40%	45.03%
3+	19.54%	18.36%	42.40%	35.29%	38.55%	18.36%
Geography						
Urban	18.50%	20.60%	23.20%	12.94%	16.87%	20.60%
Suburban 1st Ring	26.20%	26.00%	28.80%	25.88%	29.52%	26.00%
Remainder	55.20%	53.40%	48.00%	61.18%	53.61%	53.40%
Household Income						
< $15k	8.90%	9.60%	4.80%	3.53%	4.22%	12.20%
$15k - < $25k	9.50%	9.70%	10.40%	7.06%	7.83%	11.30%
$25k- < $50k	29.70%	29.80%	36.80%	31.76%	34.34%	30.10%
$50k - < $100k	37.60%	36.10%	37.60%	40.00%	40.36%	33.60%
$100k +	14.40%	13.70%	8.80%	12.94%	10.84%	12.80%
Income refusals	5.50%	5.50%	1.60%	4.71%	2.41%	--
Residence Type						
Single family	78.40%	76.90%	87.20%	91.76%	87.95%	69.00%
All other types	21.60%	23.10%	12.80%	8.24%	12.05%	31.00%

Source: 2000 Census and Kansas City Regional Household Travel Survey (KCRHTS), weighted. As documented in the Kansas City Regional Household Travel Survey Final Report, the data were weighted by household size, household vehicles, and geography (home location). Round 1 & Round 2 participants are summarized using raw KCRHTS data as the EPA surveys didn't obtain demographic information.

MARC Sample: For the most part, the weighted data compare favorably with the census data, indicating that the survey data set is representative of the regional population. The difference in the distribution of respondents based on residence type can be explained somewhat based on the proportion of sample types used in the study. Listed telephone numbers (those with complete address information for the household) are typically associated with households of longer tenure, which is correlated with living in a single-family dwelling and home ownership. Renters, who are considered to be more transient and living in housing types not characterized as single-family dwellings, may change telephone numbers more often and are typically more likely to have a number that is incomplete or not including in the listed telephone number database. The proportion of listed to not listed samples used in this study was 50/50, meaning that of the 40,000 pieces of sample used, 20,000 were associated with listed numbers and 20,000 were not. An effort more focused on renters would have required the use of more unlisted than listed numbers, which was not possible within the project's budget. Thus, the desire to achieve a good mix of residence type was balanced with the project budget and as a result, residence type came within 10% of the census parameters, but not within 5% like the other variables.

Round 1 Participants. The Round 1 study design called for testing a specific combination of vehicles based on type (car vs. truck) and age. The testing goals were disproportionate to survey universe parameters, with a higher focus on older vehicles. In addition, only MARC households that owned vehicles could be considered for inclusion in the study. For comparison purposes, we have excluded households with 0 vehicles in one of the comparisons presented in Table 3-9. As a result of these various study parameters, the characteristics of the Round 1 households differs somewhat from those of the MARC and Census data. The Round 1 households were larger and owned more vehicles (again, given that vehicle ownership was a requirement for participation in the study, this finding was not surprising). The Round 1 households show a good geographic dispersion and tend to reflect more moderate income households. In terms of home ownership, there is a significantly higher proportion living in single-family residences. However, as with the main MARC survey, home ownership is a secondary variable of interest so this is not of great concern.

Round 2 Participants. The Round 2 study design was similar to Round 1 and many of the household characteristics remained relatively constant and different from the MARC and Census data. Round 2 households were larger, owned more vehicles, reflected more moderate income levels and most tended to own single-family residences. In contrast to Round 1, Round 2 households' geographic dispersion was less urban.

Round 2 Retests. Table 3-10 shows distribution of the Round 1 vehicles that were retested in Round 2, along with household characteristics. The study goals required 25 such tests to be conducted, 43 vehicles were actually retested.

Table 3-10. MARC Household Characteristics for Round 1 Retests in Round 2

Characteristics	Round 1 Retest Data (%)
Household Size	
1	9.52%
2	35.71%
3	14.29%
4+	40.48%
Total	100.00%
Household Vehicles	
1	19.05%
2	54.76%
3+	26.19%
Total	100.00%
Household Income	
0-14,999	4.76%
15,000-24,999	4.76%
25,000-34,999	9.52%
35,000-49,999	9.52%
50,000-74,999	21.43%
75,000+	28.57%
DK	11.90%
RF	9.52%
Total	100.00%
County	
Johnson	30.95%
Clay	9.52%
Platte	21.43%
Wyandotte	14.29%
Jackson	16.67%
Leavenworth	4.76%
Cass	2.38%
Total	100.00%

Table 3-11 shows that the key person characteristics of MARC age and ethnicity also track the census fairly well. The higher proportion of "other" ethnicities reflects Hispanic respondents who identified themselves as such in answer to this question. With regard to the Rounds 1 and 2 data, the participants tend to be younger, on average. In terms of ethnicity, the Rounds 1 and 2 participants mirror the census extremely well.

Table 3-11. MARC Person Characteristics Compared To Census

Characteristic	MARC Raw Data	MARC Weighted Data	EPA Round 1 Data	EPA Round 2 MARC Data Only	Round 1 & Round 2	Census Data
Respondent Age						
<20	28.70%	30.30%	55.94%	53.94%	53.90%	29.10%
20 – 24	3.60%	3.60%	6.64%	5.45%	5.84%	6.10%
25 – 54	42.30%	41.70%	74.48%	70.91%	72.08%	45.30%
55 – 64	10.60%	9.80%	15.38%	20.61%	18.51%	8.20%
65+	14.80%	14.60%	10.14%	8.48%	9.42%	11.30%
Respondent Ethnicity						
White	84.80%	83.40%	79.20%	84.71%	82.53%	81.60%
Black/African American	9.10%	10.20%	12.80%	10.59%	11.45%	14.10%
Other	6.10%	6.40%	8.00%	4.71%	6.02%	4.30%

Source: 2000 Census and Kansas City Regional Household Travel Survey (KCRHTS), weighted. As documented in the Kansas City Regional Household Travel Survey Final Report, the data were weighted by household size, household vehicles, and geography (home location). Round 1 participants are summarized using raw KCRHTS data as the EPA surveys didn't obtain demographic information.

The 2000 Census Transportation Planning Package Profile for the seven-county metropolitan region was used to review the worker flow characteristics. As shown in Figure 3-2, the commute trip characteristics of the participating MARC household members on the assigned travel day tracks those reflected in the census fairly well. In terms of gender, the MARC survey contains a slightly higher proportion of female workers compared to male workers, but still within 5% of the census. The Round 1 participants tend to have more men then women while in Round 2, participants were more likely to be women.

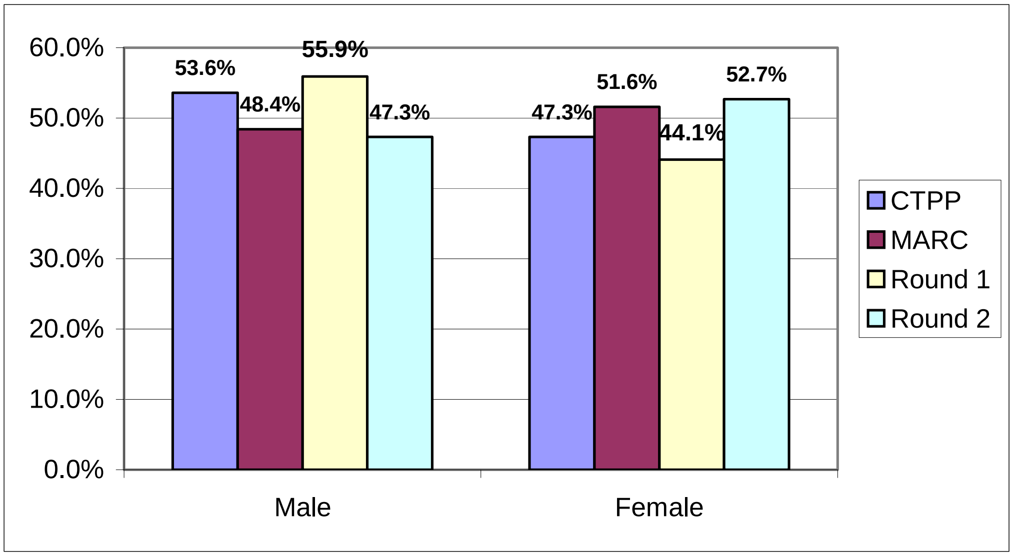


Figure 3-2. Worker Comparison

As in the journey to work data, the majority of employed respondents in the MARC survey reported driving or riding as an auto passenger to work (91%) on the assigned travel day. The proportion of MARC workers telecommuting was higher than what was reported in the census (6% compared to 3%), while the proportion of workers who commuted by walk or bike was relatively the same. "Other" responses included taxi and paratransit modes (e.g., alternative mode of flexible passenger transportation that does not follow fixed routes or schedules such as minibuses and vans).

Round 1 and Round 2 participants virtually all drove to work. The difference was expected, given the requirements of vehicle ownership and the need to drive a vehicle to the testing facility in the morning hours. Table 3-12 shows the mode to work comparison for the four datasets.

Table 3-12. Mode to Work Comparison

Mode	CTPP	MARC	ROUND 1	ROUND 2
Auto	93.7%	91.1%	99.6%	99.2%
Transit	1.3%	1.3%	0.0%	0.0%
Bike/Walk	1.3%	1.4%	0.4%	0.0%
Other	0.6%	0.3%	0.0%	0.8%
Work at Home	3.2%	5.9%	0.0%	0.0%

Source: 2000 Census and Kansas City Regional Household Travel Survey (KCRHTS), weighted. As documented in the Kansas City Regional Household Travel Survey Final Report, the data were weighted by household size, household vehicles, and geography (home location). Round 1 participants are summarized using raw KCRHTS data as the EPA study recruitment surveys did not obtain demographic information.

The MARC survey respondents reported the same work commute time as what was captured in the census journey to work data (24 minutes for the survey and 23 minutes for the census). Figure 3-3 shows the travel time comparison for the four datasets. The largest noticeable difference between the two data sources is in the 20 to 29 minute commutes, where the census shows 26% of all trips taking this long, while in the survey data, only 20% were of that length. This difference is somewhat attributable to the way the census question was worded (how many minutes did it usually take this person to get to work last week) compared to how the work trip travel time was computed (time it took to leave home and arrive at work on a specific travel day, with the trip start and end times being reported by the respondent).

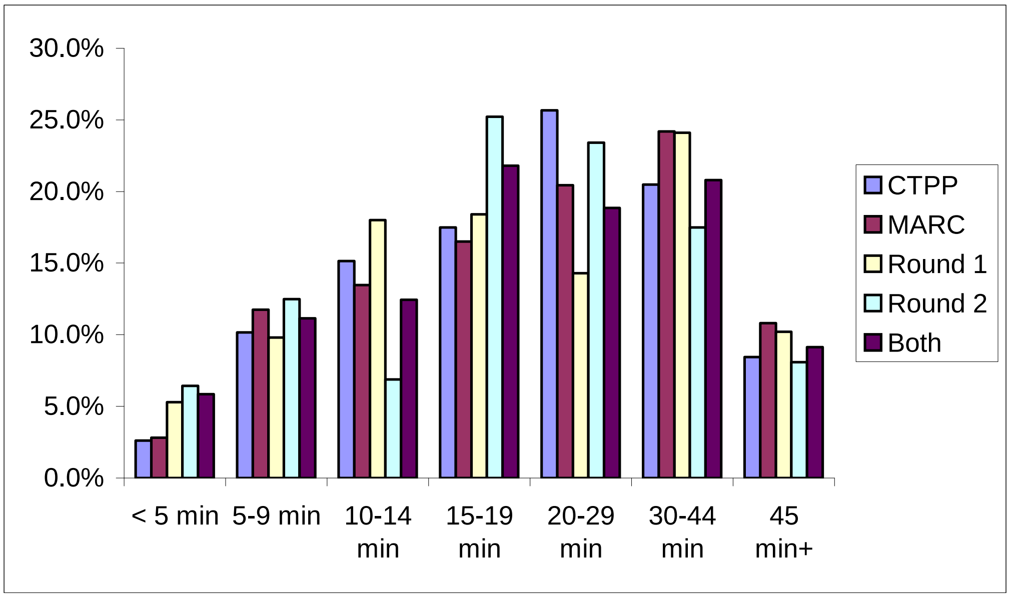


Figure 3-3. Travel Time Comparison

The Round 1 participants had shorter commutes, on average (22.5 minutes compared to 23.7 minutes overall). They reported considerably fewer commute trips of 20 to 29 minutes in particular. Round 2 participants also had shorter commutes with considerably more reported, however, in the 15 to 19 minute range than any of the other three datasets.

In general, with regard to both demographic and the journey to work information reported by the participating households, the Kansas City Regional Household Travel Survey is representative of the study area population. The Round 1 and Round 2 participants represent the vehicle-owning households in the region, and also reflect the testing goals. They are slightly larger in size, tend towards middle income, and are slightly younger. Round 1 participants are likely to be male, while Round 2 are more likely to be female.

Figure 3-4 illustrates the sample flow in deriving the 2,887 households for the emissions study from the MARC Kansas City Household Travel Study Sample. Figure 3-5 illustrates the sample flow in deriving the 4,081 households from the Vehicle Registration Database.

Figure 3-4. Kansas City Regional Household Travel Survey Sample Flow Summary

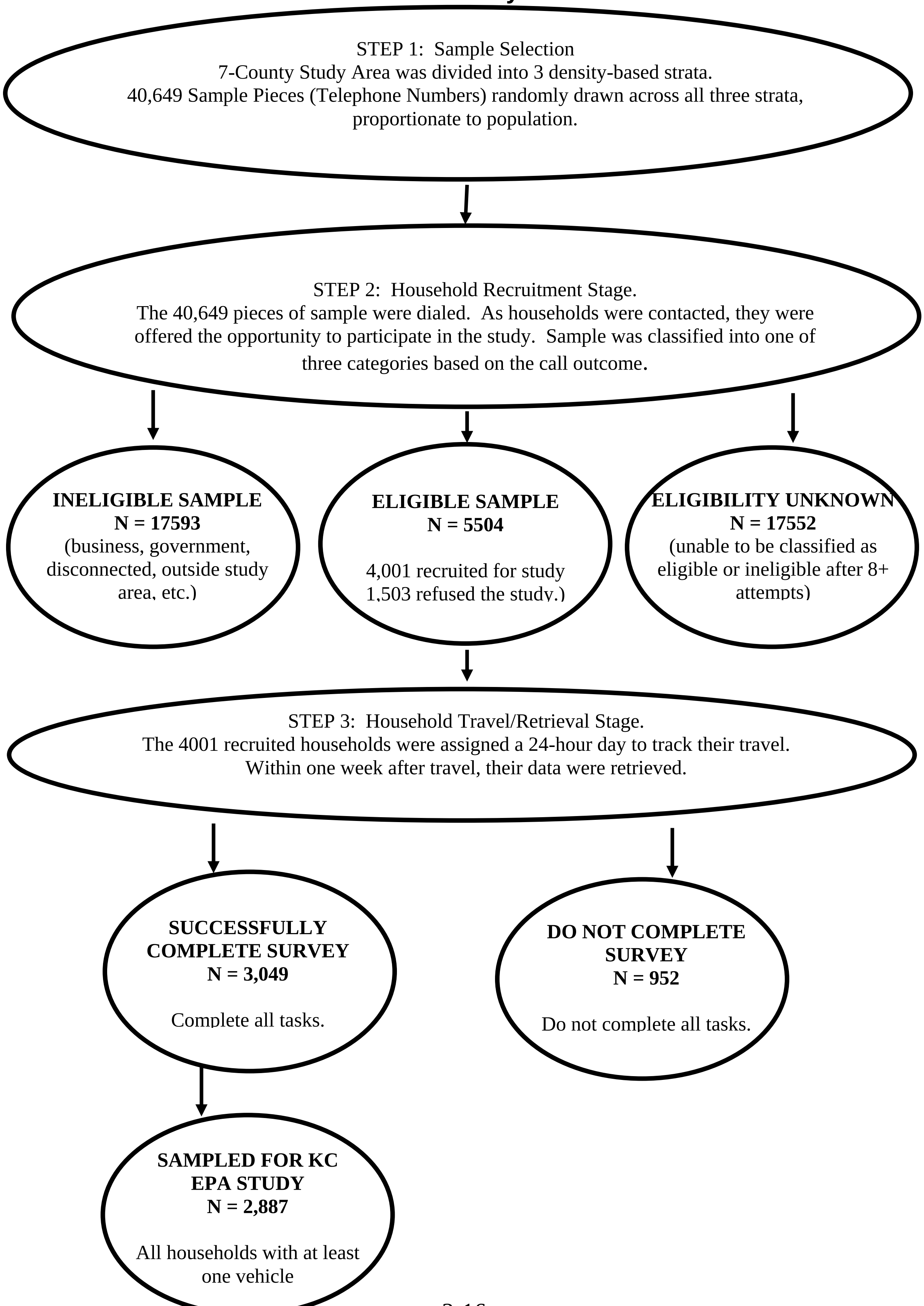
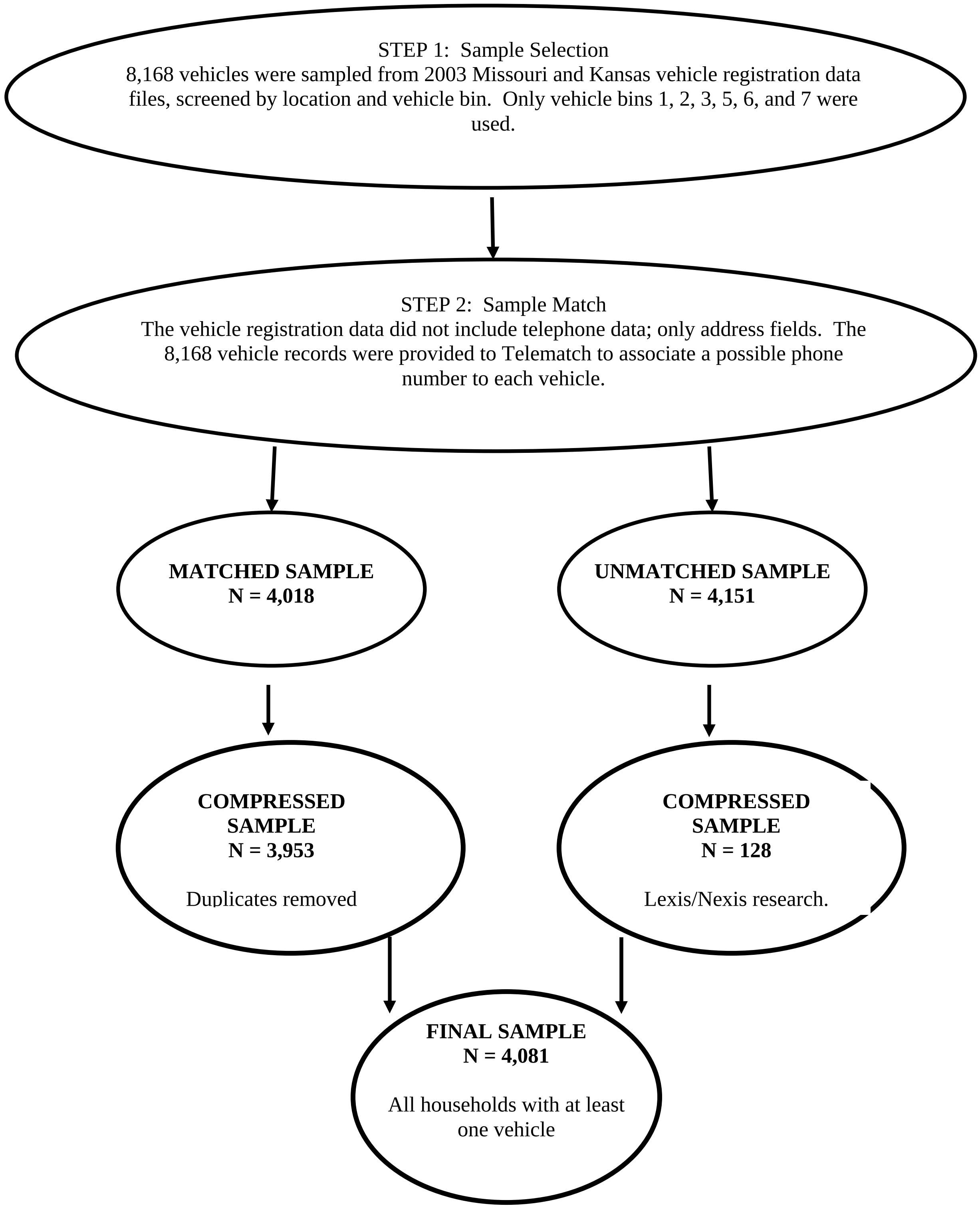


Figure 3-5. KS and MO Vehicle Registration Database Sample Flow Summary



3.5 Vehicle Recruitment Sample Plan

This section documents the sample plan and stratification scheme derived for the study. It is presented in two sections. First, the original sample plan derived for Round 1 is introduced. Second, a final sample plan designed for Round 2 using Round 1 data is presented.

Original Round 1 Sample Plan

The RFP initially proposed a stratification scheme and a sample allocation based on optimal allocation for obtaining the desired total of 480 tested vehicles across Rounds 1 and 2. After reviewing the back-up materials, the project team agreed that the data used to design the sample were subject to substantial uncertainty and that the project would benefit from re-visiting the sample design using a larger data set. Accordingly, EPA and ERG provided PM emissions data and DMV registration data for the development of an enhanced sample design. A summary of the source of the PM data provided by EPA is shown in Table 3-13.

Table 3-13. Summary of Data Used for Development of Sample Sizes for the KC Study

		Number of IM240 Tests		Total Tests
Study Number	**Study Description**	**CAR**	**TRUCK**	
CRC E-54	Central Carolina Vehicle Particulate Emission Study	158	77	235
CRC E-24-1	Cadle, S.H. et al (September 1999) "Light-Duty Motor Vehicle Partioculate Matter Measurement in the Denver, Colorado Area, *J. Air Waste Manage. Assoc*. 49 PM-164-174	56	17	73
CRC E-24-2	Measurement of Primary Particulate Matter Emissions from Light-duty Motor Vehicles (Norbeck, et al.)	212	110	322
Grand Total		426	204	630

The project team endorsed the recommendation to employ the MARC RDD data set as a source of vehicles. This was significant because the substantial pool of vehicles that is immediately available from the MARC sample involves virtually no screening effort. Therefore, the stratified sample design strategy called Neymann allocation (which ignores screening costs across vehicle class/age strata) was an appropriate starting point for designing an optimal allocation sample design.

The sample design addressed two issues:

- Determination of attractive vehicle age cutpoints to form strata; and
- Development of optimal allocation of sample sizes to individual strata.

Developing Vehicle Age Cutpoints

Eight strata for sampling vehicles are to be formed by crossing vehicle type (truck vs. car) by Vehicle Year Made (4 age groupings). There is flexibility in designating the cutpoints of the three oldest vehicle ages. The task was to use available PM data to determine appropriate cutpoints. Our approach employs a sequential strategy – first determine the best cutpoint for the oldest vehicle year make category, then address the newer age groupings.

Tables 3-14 and 3-15 present four scenarios for specifying the oldest age groupings. See the “Pre X” and “(X+1) to 1989” rows. We varied the cutpoint for the “Pre X” stratum using 1980, 1981, 1982 and 1983 (see column headings). In an ideal world we want a cutpoint to maximize “between” stratum variance yet minimize “within” stratum variance. This means we want to see divergent Mean Values across strata coupled with less divergent standard deviations across strata. Tables 3-14 and 3-15 show that the ideal world clearly does not exist, but that strata means diverge most (for cars) when X=1981 (i.e., using “Pre-1981” as the oldest make category). This was our recommendation.

Table 3-14. Mean PMs for Eight Strata Under Four Alternative Cutpoints for the Oldest Vehicles

Sampling Vehicles			X=1980	X=1981	X=1982	X=1983
Type	**Model Year**	**Strata**	**Mean PM 1**	**Mean PM 2**	**Mean PM 3**	**Mean PM 4**
Truck	Pre X	1	40.46	40.46	37.07	36.51
Truck	(X+1) to 1989	2	18.30	18.30	18.88	18.67
Truck	1990 to 1995	3	6.55	6.55	6.55	6.55
Truck	1996 & newer	4	5.28	5.28	5.28	5.28
Car	Pre X	5	39.68	39.12	36.86	34.27
Car	(X+1) to 1989	6	17.01	14.85	14.31	13.62
Car	1990 to 1995	7	5.90	5.90	5.90	5.89
Car	1996 & newer	8	3.12	3.12	3.12	3.12

Table 3-15. Standard Deviations of PMs for Eight Strata Under Four Alternative Cutpoints for the Oldest Vehicles

Sampling Vehicles			X=1980	X=1981	X=1982	X=1983
Type	**Model Year**	**Strata**	**Stdev PM 1**	**Stdev PM 2**	**Stdev PM 3**	**Stdev PM 4**
Truck	Pre X	1	39.34	39.35	38.47	37.53
Truck	(X+1) to 1989	2	20.50	20.50	20.93	21.21
Truck	1990 to 1995	3	6.89	6.89	6.89	6.89
Truck	1996 & newer	4	5.09	5.09	5.09	5.09
Car	Pre X	5	28.63	31.54	31.56	29.97
Car	(X+1) to 1989	6	23.67	20.64	19.94	20.16
Car	1990 to 1995	7	7.47	7.47	7.47	7.47
Car	1996 & newer	8	3.49	3.49	3.49	3.49

Using the recommendation above, we then examined four alternative cutpoints for the middle vehicle age strata. Tables 3-16 and 3-17 present the results of this analysis. We see in

Table 3-15 that a significant reduction in PM variation for stratum 3 occurs when using 1990 as the cutpoint to divide the range 1981-1995 into two strata. Thus, we recommended that age categories 1981-1990 and 1991-1995 be adopted.

Table 3-16. Mean PMs for Eight Strata Under Four Alternative Cutpoints for the Middle-Aged Vehicles

Means by strata			Z=1989	Z=1990	Z=1991	Z=1992
Type	**Model Year**	**Strata**	**Mean PM 1**	**Mean PM 2**	**Mean PM 3**	**Mean PM 4**
Truck	Pre -1981	1	40.46	40.46	40.46	40.46
Truck	1981 to Z	2	18.30	17.53	16.09	15.56
Truck	(Z+1) to 1995	3	6.55	4.57	4.86	5.08
Truck	1996 & newer	4	5.28	5.28	5.28	5.28
Car	Pre -1981	5	39.12	39.12	39.12	39.12
Car	1981 to Z	6	14.85	14.40	13.73	12.70
Car	(Z+1) to 1995	7	5.90	5.43	5.09	5.12
Car	1996 & newer	8	3.12	3.12	3.12	3.12

Table 3-17. PM Standard Deviations for Eight Strata Under Four Alternative Cutpoints for the Middle-Aged Vehicles

Sampling Vehicles			Z=1989	Z=1990	Z=1991	Z=1992
Type	**Model Year**	**Strata**	**Stdev PM 1**	**Stdev PM 2**	**Stdev PM 3**	**Stdev PM 4**
Truck	Pre-1981	1	39.34	39.35	39.35	39.35
Truck	1981 to Z	2	20.50	19.07	18.60	18.42
Truck	(Z+1) to 1995	3	6.89	3.95	4.20	4.31
Truck	1996 & newer	4	4.36*	4.36*	4.36*	4.36*
Car	Pre-1981	5	31.54	31.54	31.54	31.54
Car	1981 to Z	6	20.64	19.96	19.32	18.48
Car	(Z+1) to 1995	7	7.47	7.15	6.52	6.65
Car	1996 & newer	8	4.36*	4.36*	4.36*	4.36*

The data supported our recommendation to employ the following year of make categories for stratification purposes: Pre-1981; 1981-1990; 1991-1995 and 1996+. We used this in the development of an optimal design, as described in the following section.

Optimal Allocation using PM Emission Rate

We used the PM emission rate data to assess the optimal allocation of test vehicles across the eight sampling strata recommended above. Table 3-18 presents the results of this design exercise. Column A exhibits the standard deviation of PM emission rate for each stratum. The relative values across strata are used to establish differential sampling rates, shown as "Neymann relative f" in Column B. Column C is not used in the optimal allocation design, but shows how vehicles in the Kansas City area distribute naturally (proportionately) across strata. (Here we used the MARC RDD percentage distribution of vehicles across strata because we verified that this was consistent with the distributions of vehicles obtained from DMV records in the counties comprising the Kansas City MSA.)

Table 3-18. Neymann (Optimal) Allocation Using PM per Vehicle-Mile

Type	Model Year	Strata	A PM Emission Rate Std Dev	B Neymann Relative Sampling Rates	C Vehicle % using MARC RDD	D Optimal Alloc %	E Optimal Sample N	F Available via MARC	G Ratio: Available to N
Truck	Pre-1981	1	39.35	9.02	1.1%	6.1%	29	71	2.4
Truck	1981-1990	2	19.07	4.37	3.7%	9.9%	47	295	6.2
Truck	1991-1995	3	3.95	0.91	7.2%	4.0%	19	514	26.9
Truck	1996+	4	4.36	1.00	28.6%	17.5%	84	2048	24.4
Car	Pre-1981	5	31.54	7.23	1.3%	5.7%	28	84	3.0
Car	1981-1990	6	19.96	4.57	7.4%	20.7%	99	571	5.8
Car	1991-1995	7	7.15	1.64	13.4%	13.4%	64	982	15.3
Car	1996+	8	4.36	1.00	37.3%	22.8%	109	2636	24.1
Totals					100%	100%	480	7201	

The optimal differential sampling rates in Column B give rise to the distribution of the optimal sample across strata as seen in Column D. By comparing the corresponding percentages in Columns C and D we see which strata are "oversampled" and which are "undersampled" under an optimal allocation design. Column E shows the optimal allocation of vehicles to strata under a design where N=480 total vehicles are tested.

Column F shows the number of vehicles available from the pool (cohort) of MARC RDD households. Column G presents the ratio of available to needed vehicles for testing under the optimal allocation design. We see that the MARC RDD sample offered an ample supply of vehicles across all strata for recruitment.

Table 3-18 is useful for optimizing the overall estimate of mean PM emission rate during operation. However, our principal objective is to develop an estimate of total PM annual emissions, and for this we need additional information regarding the average use of vehicles (i.e., annual mileage). Data for annual mileage by vehicle class and year-of-make were provided by ERG and incorporated into Table 3-18.

The following documents the analyses used to recommend year-of-make cutpoints and develop an optimal sample design using Neymann allocation. It details several optimal allocation designs as well as a proportionate design based on annual PM emissions rather than vehicles, and an alternative design that balanced an optimal allocation (for estimating mean PM rate), the inclusion of high emitters in the older vehicle fleet, and the desire to protect ourselves against unanticipated surprises in any one stratum.

Optimal Allocation using Annual PM Emissions

Table 3-19 develops an optimal allocation design based on annual volume of PM emissions. Column A exhibits the average mileage driven by vehicles per stratum, and Column AA presents the stratum specific standard deviations formed by taking the product of PM emission standard deviation and the average annual vehicle mileage. The resulting relative sampling rates under Neymann allocation appear in Column B, and the resulting percentage allocations of sample to strata appear in Column D. The optimal allocation distribution can be contrasted with a proportionate allocation design by comparing the row entries of Columns C (for a proportionate design) to the corresponding cell in Column D (under the optimal allocation design). The optimal allocation of tests to strata under a design totaling N=480 is presented in Column E. We see that the optimal design using Annual PM emissions does not differ much from a proportionate design. This is primarily a function of the low prevalence of older, higher emitting vehicles in the active fleet.

As a parting note to this section, the optimal allocation derivation relies on a statistical estimation methodology that incorporates external auxiliary information – i.e., annual vehicle mileage. As such, the optimal allocation derivation is conditional on the average mileage data (in a formal mathematical statistical sense). The conditional approach is invoked in Column AA by using:

Std dev(annual emissions) = Ave mileage x Std dev(PM rate).

That is, we assume that the estimate of annual PM emissions will be developed using average mileage data obtained from a source outside this study (rather than taking a measurement for each vehicle being tested). If actual vehicle mileage of each tested vehicle is to be used in the annual PM estimation process, then an additional source of variation (i.e., sampling error from annual mileage) will have to be taken into account. (Also, the estimation process will need to be explicitly specified.) However, this was not recommended because the resulting estimates are subject to very large sampling errors.

Table 3-19. Neymann (Optimal) Allocation Using Annual PM Emissions

Type	Model Year	Strata	A	A'	AA	B	C	D	E	F	G
			PM Emission Rate Std Dev	Ave annual Vehicle Mileage	Annual PM Emission Std Dev	Neymann Relative Sampling Rates	Vehicle % using MARC RDD	Optimal Alloc %	Optimal Sample N	Available Vehicles using MARC	Ratio: Available to N
Truck	Pre-1981	1	39.35	2,260	88,925	2.49	1.1%	1.5%	7	71	9.8
Truck	1981-1990	2	19.07	4,771	90,991	2.55	3.7%	5.2%	25	295	11.8
Truck	1991-1995	3	3.95	9,034	35,685	1.00	7.2%	4.0%	19	514	26.9
Truck	1996+	4	4.36	15624	68,182	1.91	28.6%	30.2%	145	2048	14.1
Car	Pre-1981	5	31.54	3,915	123,490	3.46	1.3%	2.5%	12	84	7.0
Car	1981-1990	6	19.96	5,750	114,766	3.22	7.4%	13.2%	63	571	9.0
Car	1991-1995	7	7.15	8,363	59,798	1.68	13.4%	12.4%	60	982	16.5
Car	1996+	8	4.36	12282	53599	1.50	37.3%	31.0%	149	2636	17.7
AA = A x A'						Totals	100%	100%	480	7201	

Proportionate Allocation using Annual PM Emissions.

An alternative design is one that allocates sample to strata proportionately to the percentage contribution of PM emissions from the collection of vehicles in each stratum. Table 3-20 presents this design.

Table 3-20. Sample Allocation for Proportionate Design Based on Annual Percentage PM Emissions Across Strata

			A	B	C*	D	E	F	G	H
Type	**Model Year**	**Strata**	**Avg Annual Mileage**	**Avg PM Emiss**	**Mean Annual PM Volume Per Vehicle**	**Vehicle % Using MARC RDD**	**% Contrib. Total PM Emiss.**	**Annual Volume PM Propor N**	**Avail Vehicles Using MARC**	**Ratio: Avail. to Sample N**
Truck	Pre-1981	1	2,260	40.46	91434	1.1%	1.7%	8	71	8.7
Truck	1981-1990	2	4,771	17.53	83643	3.7%	5.2%	25	295	11.7
Truck	1991-1995	3	9,034	4.57	41286	7.2%	5.0%	24	514	21.3
Truck	1996+	4	15624	5.28	82494	28.6%	39.9%	192	2048	10.7
Car	Pre-1981	5	3,915	39.12	153168	1.3%	3.4%	16	84	5.2
Car	1981-1990	6	5,750	14.4	82797	7.4%	10.4%	50	571	11.5
Car	1991-1995	7	8,363	5.43	45413	13.4%	10.3%	49	982	19.9
Car	1996+	8	12282	3.12	38321	37.3%	24.2%	116	2636	22.7
					*C = A x B	100%	100%	480	7201	

Column A of Table 3-20 presents the average annual mileage of vehicles in a given stratum (defined by the rows). Column B shows the average PM emission rate for vehicles in each stratum. The mean annual PM emissions per vehicle in each stratum is furnished in Column C by taking the product of corresponding cell values in Columns A and B.

Column E reflects the stratum percentage contribution to total PM emissions. It is calculated using the product of the mean annual PM volume per vehicle (Col. C) and the percentage of vehicles associated with each stratum (Col. D). For instance pre-1981 cars (stratum 5) represent 1.3% of vehicles in Kansas City, but account for 3.4% of annual vehicle emissions.

A proportionate allocation of sample to strata based on total annual vehicle emissions is presented in Column F.

Optimal Allocation Using Annual PM Emissions

Table 3-21 provides the analogue to Table 3-20 but using the percentage distribution of annual emissions (Column E) rather than the percentage distribution of vehicles (as shown in Table 3-19, Column C).

Table 3-21. Optimal Allocation Design Based on Annual Percentage PM Emissions Across Strata

Type	Model Year	Strata	A	B	C	D	E	F	G	H	I
			PM Std Dev	Ave annual mileage	Annual PM Emission Std Dev	Neymann Relative Sampling Rates	% Contributed to total PM Emission	Optimal Allocation %	Optimal Sample N	Available via MARC	Ratio: Available to N
Truck	Pre-1981	1	39.35	2,260	88,925	2.49	1.7%	2.1%	10	71	6.9
Truck	1981-1990	2	19.07	4,771	90,991	2.55	5.2%	6.8%	32	295	9.1
Truck	1991-1995	3	3.95	9,034	35,685	1.00	5.0%	2.5%	12	514	42.0
Truck	1996+	4	4.36	15624	68,182	1.91	39.9%	38.6%	185	2,048	11.0
Car	Pre-1981	5	31.54	3,915	123,490	3.46	3.4%	5.9%	28	84	3.0
Car	1981-1990	6	19.96	5,750	114,766	3.22	10.4%	16.9%	81	571	7.0
Car	1991-1995	7	7.15	8,363	59,798	1.68	10.3%	8.7%	42	982	23.4
Car	1996+	8	4.36	12,282	53,599	1.50	24.2%	18.4%	88	2,636	29.9
						Totals	100%	100%	480	7,201	

Allocation Using an Ad Hoc Weighting Strategy.

The optimal allocations above were designed to maximize the statistical precision of a specific estimate (e.g., annual PM emissions). However, a competing research objective is to account for the rare but higher emitting vehicles making up the older fleet. As an ad hoc way of addressing this issue, we adjusted the optimization parameters that appear in Table 3-21 by including average PM emission rate. Table 3-22 presents the results of this approach. This design shows substantial increased allocations to the pre-1981 strata, so much so that there may not be sufficient vehicles available from the MARC sample to achieve the targets.

Comparison of Designs.

Table 3-23 presents a comparison of designs presented above. The designs were derived from optimizing PM emission rates, optimizing annual PM emissions using vehicle distributions, and optimizing annual PM emissions using PM emission distributions, and appear as Columns A, B and D, respectively. Column C shows the allocation under the proportionate design -- proportionate to annual PM emissions.

Table 3-22. An Ad Hoc Weighting Strategy

Type	Model Year	Strata	A	A’	A”	AA	B	C	D	E	F	G
			PM Std Dev	Ave Annual Mileage	Avg PM Emiss	Ad Hoc Weighting Factor	Relative Sampling Rate	MARC RDD %	Alt. Alloc %	Ad Hoc Sample N	Available via MARC	Ratio: Available to N
Truck	Pre-1981	1	39.35	2,260	40.46	3,597,921	22.06	1.1%	7.8%	38	71	1.9
Truck	1981-1990	2	19.07	4,771	17.53	1,595,077	9.78	3.7%	11.7%	56	295	5.3
Truck	1991-1995	3	3.95	9,034	4.57	163,081	1.00	7.2%	2.3%	11	514	46.0
Truck	1996+	4	4.36	15624	5.28	359,999	2.21	28.6%	20.4%	98	2,048	20.9
Car	Pre-1981	5	31.54	3,915	39.12	4,830,914	29.62	1.3%	12.5%	60	84	1.4
Car	1981-1990	6	19.96	5,750	14.4	1,652,624	10.13	7.4%	24.3%	116	571	4.9
Car	1991-1995	7	7.15	8,363	5.43	324,702	1.99	13.4%	8.6%	41	982	23.7
Car	1996+	8	4.36	12282	3.12	167,229	1.03	37.3%	12.4%	59	2,636	44.4
						AA=AxA'xA"	Totals	100%	100%	480	7201	

Table 3-23. Optimal Designs, a Proportionate Design, and Two Alternatives

Type	Model Year	Strata	A TABLE 3-18. Opt Alloc PM Emission Rate	B TABLE 3-19 Opt Alloc PM Annual Volume & Vehicle Percent	C TABLE 3-20 Annual Volume PM Propor N	D TABLE 3-21. Opt Alloc PM Annual Volume & Percent Distn	E TABLE 3-22 Ad Hoc Design	F (New) Alternative Design	G Available Vehicles
Truck	Pre-1981	1	29	7	8	10	38	30	71
Truck	1981-1990	2	47	25	25	32	56	50	295
Truck	1991-1995	3	19	19	24	12	11	50	514
Truck	1996+	4	84	145	192	185	98	75	2,048
Car	Pre-1981	5	28	12	16	28	60	30	84
Car	1981-1990	6	99	63	50	81	116	100	571
Car	1991-1995	7	64	60	49	42	41	65	982
Car	1996+	8	109	149	116	88	59	80	2,636
				480	480	480		480	7,201

480

The optimization of the average PM emission rate (Column A) presents the largest oversampling of early-make vehicles (see rows 1-2, and 5-6). Optimizing annual emissions (Columns B and D) tends to only slightly oversample vehicles relative to a design (Column C) that proportionately allocates sample based on annual PM emissions for all vehicles in a stratum. It is not the case that a proportionate design based on annual PM emissions calls for large samples from early-make vehicle strata. In fact, the proportionate design calls for samples of only 8 Pre-1981 trucks and 16 Pre-1981 cars.

Column E presents the Ad Hoc design that weights the allocation of sample to strata by all three factors – PM rate, PM emissions and mileage. Finally, for the purposes of discussion, we have added Column F, a new "alternative design." Column F was formed by establishing a minimum target representation of N=30 tests. The minimum would be invoked for three strata: (stratum 1) Pre-1981 trucks; (stratum 3) 1991-1995 trucks; and (stratum 5) Pre-1981 cars. To compensate for the increase in sample size in these strata, the sample sizes of the two largest strata (1996+ trucks and cars) were drawn down roughly proportionately.

Final Sample and Stratification

After considering the various designs, we recommended our Alternative Design (Column F, Table 3-23) for Round 1 of the study. We believed this to be a robust design because it offered protection against surprises in the data (e.g., higher than expected variability in the older fleet, and higher than expected variability in 1991-1995 trucks), yet aligns fairly closely with the original optimal allocation strategy to estimate mean PM rates.

In preparing the Round 2 sample design, the ultimate performance of the sample plan was analyzed. These considerations are discussed in full in the next section.

Final Round 2 Sample Plan

With Round 1 completed, the PM data from those tests were used to revisit the sample design for Round 2. The objective of this effort was to develop a more optimal sample for Round 2 given actual PM data from KS vehicles. Such an approach optimizes the estimate of overall (annualized) OM emissions by the KC vehicle fleet. However, the design must also take into account a competing research goal – that of measuring PM emissions in warm (summer) and cold (winter) temperature environments. This section documents the process used to develop the Round 2 sample design.

PM Distributions from Round 1 Testing

Using results from Round 1 tested vehicles, PM distribution of the overall sample was examined. It appears as Chart 1. The distribution of PMs was highly skewed: median PM is 3.10 mg/mile, the mean is 11.85, and the PM range is 0.09 to 287.15 mg/mile – large by any standard. Moreover, the 90th percentile value is about 25.7 mg/mile. In fact, the mean value lies near the 85th percentile.

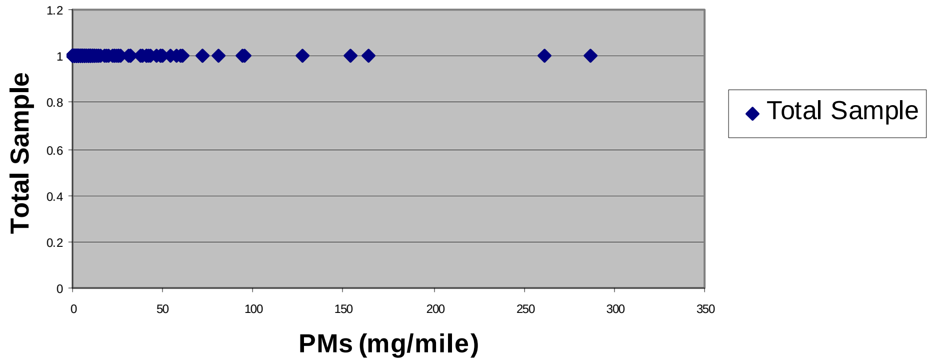


Chart 1. Distribution of Total PMs for Round 1 tested Vehicles for the Total Sample

Chart 2 presents the spread of PMs by Stratum (Bin). One can see the monotonic increase in dispersion of PMs as you go from newer vehicles to older vehicles. (1 to 4 for trucks and 5 to 9 for cars) It is also clear that the distributions of PM vary substantially across strata. It is important to note that when the goal is to develop a good statistical estimate of the PM emissions for the KC fleet, the level of emissions within each stratum is not as important as the standard deviation of PM distributions within strata.

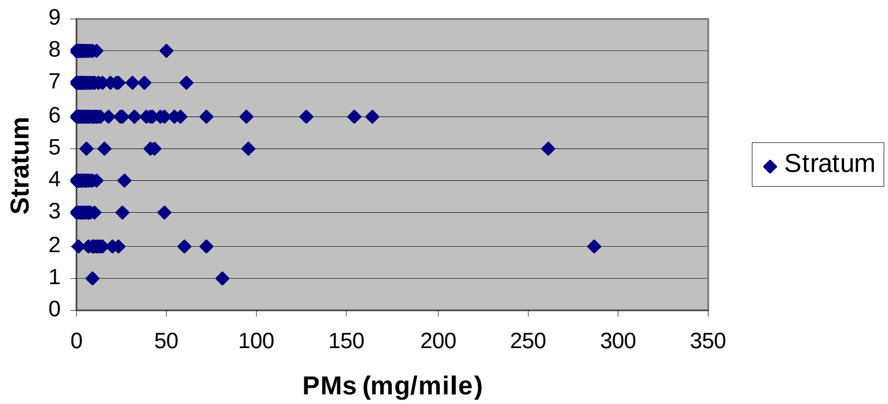


Chart 2. Comparative Distributions of Round 1 Tested Vehicle PMs by Strata/Bin

Another aspect of PM production is observed in older vehicles. Older vehicles tend to be driven less than newer ones, and this serves to dampen the older vehicle contribution to total annual vehicle PM emissions in the KC vehicle fleet. The lower use of older vehicles is illustrated in Chart 3. On average, older vehicles are driven far fewer miles annually than newer vehicles. For this initial evaluation model year average miles driven data from the MOBILE6 was used.

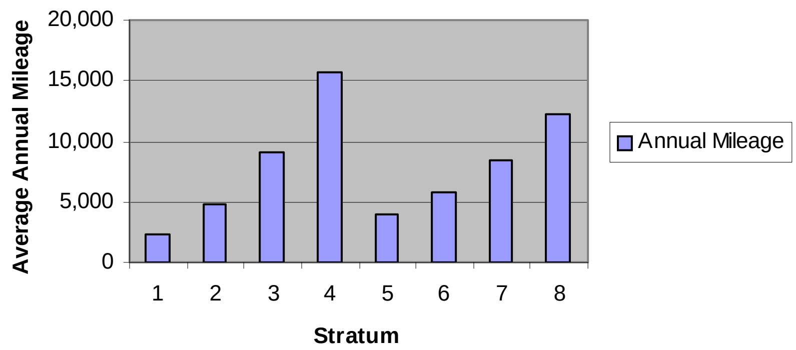


Chart 3. Average Annual Mileage Per Vehicle by Stratum

Chart 4 compares the percentage distributions across strata for three measures:

- annual PM volume,
- vehicles in the KC fleet, and
- total miles driven by KC fleet vehicles.

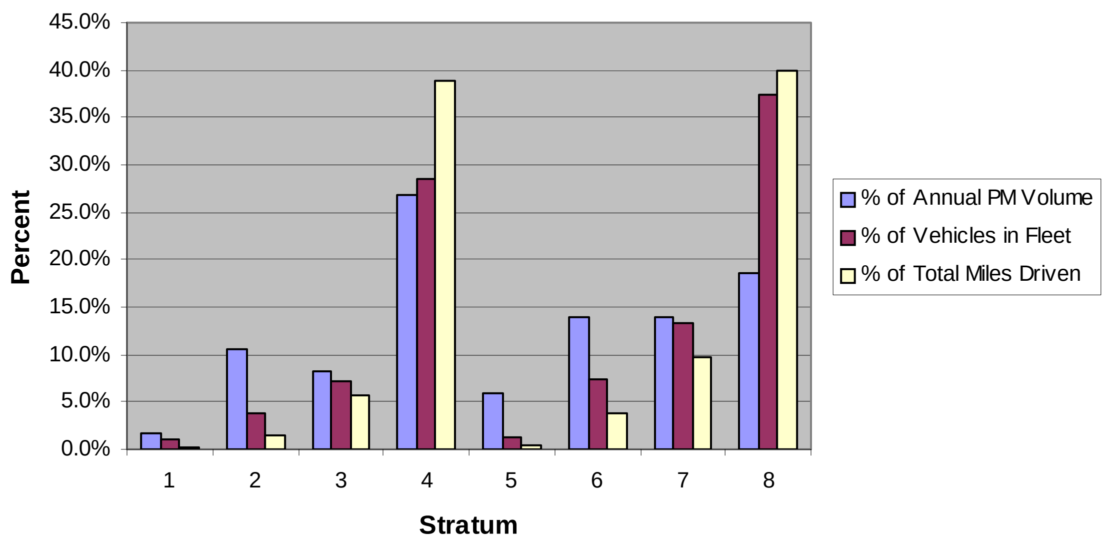


Chart 4. Percentages of Annual PM Volume, Vehicles in Fleet and Total Miles Driven Relative to Total by Stratum

The oldest vehicles not only comprise the smallest portion of the fleet, but they also account for a small fraction of all vehicle miles driven. For instance, roughly 80% of annual vehicle miles are driven by 1996+ cars and trucks, while under 1% of total vehicle miles are driven by Pre-1981 cars and trucks combined. Similarly, Pre-1981 cars and trucks account for about 7% of total annual PM volume, while 1996+ vehicles account for roughly 45% of PM volume. Even if the emissions rates of older vehicles are very high, their low usage in terms of vehicle-miles relative to the rest of the fleet results in a relatively small percentage contribution total PMs.

Revised Optimal Allocation Using the Round 1 PM Emissions Rate

The PM emission rate data from Round 1 vehicle testing to assess the optimal allocation of test vehicles across the eight sampling strata that cross-classify vehicle type (truck vs. car) and year of make (Pre-1981, 1981-1990, 1991-1995; 1996+). Table 3-24 presents the results of this design exercise and compares this to the original optimal sample design and the hybrid design currently being used. Column A exhibits the standard deviation of PM emission rate for each stratum based on actual Round 1 vehicle testing. (The standard deviation measures the variability of PM emission rates within a stratum.) Column B presents the standard deviation of annualized PM emissions using the revised PM emissions data from Round 1 testing and EPA data on annual usage (available previously).

Table 3-24. Using Round 1 Annualized PM Volume to Compare Original & Revised Optimal Allocations with the Current Sample Design

			A	B	C	D	E	F
Type	**Model Year**	**Strata**	**REVISED PM Std Dev**	**REVISED Annual Volume PM Std Dev**	**ORIGINAL Optimal Sample N**	**REVISED Optimal Sample N**	**CURRENT Design**	**(D - E) Rev. Opt -Current Difference**
Truck	Pre-1981	1	44.76	101148	7	8	30	-22
Truck	1981-1990	2	39.35	187734	25	50	50	0
Truck	1991-1995	3	8.20	74097	19	38	50	-12
Truck	1996+	4	4.23	66123	145	135	75	60
Car	Pre-1981	5	89.23	349380	12	32	30	2
Car	1981-1990	6	21.47	123453	63	65	100	-35
Car	1991-1995	7	8.17	68291	60	65	65	0
Car	1996+	8	2.64	32442	149	86	80	6
				Totals	480	480	480	

The original optimal allocation using EPA data appears in Column C. The revised optimal allocation using Round 1 vehicle testing data appears in Column D. Column E presents the allocation of tests under our current sampling plan. Note, for instance, that sample allocations for the original (Col. C) and revised (Col. D) optimal allocations are similar for Pre-1981 and 1996+ trucks as well as 1981-1995 cars, but very different for all other Strata.

A striking difference between the original optimal design and the revised optimal design is the suggested decrease in the sample size of newer cars (1996+): from 149 to 86. This is principally due to the revised estimated PM standard deviation for stratum 8 – the estimate dropped by roughly 40% from 4.36 to 2.64. This had a corresponding reduction in the optimal sample size for that stratum.

More striking is the similarity of the revised optimal allocation design (Col. D) and our Current Design (Col. E). This is illustrated in Column F, showing the difference between the revised optimal design and our current design (F = D-E) for each stratum. Half of the strata (i.e., Strata 2, 5, 7, 8) are within a few tests of the actual "optimal". The largest discrepancies are with Pre-1981 trucks (which was explicitly planned to be an oversample), 1996+ trucks, and 1981-1990 cars.

The suggested reduction of sample size from Pre-1981 cars is consistent with the original optimal allocation. The low prevalence of these vehicles in the population does not warrant the oversampling of this stratum for the purpose of estimating overall PM emissions from the KC fleet. Relative to the smaller optimal sample size of 1996+ cars (n=86), the larger optimal sample size of 1996+ trucks (n=145) is easy to understand. There is 60% higher variation in PM standard deviation of 1996+ trucks (relative to 1996+ cars, i.e., 4.23/2.64 = 1.60) because they include large gas-guzzlers (e.g., heavy duty pick-ups) as well as smaller more fuel efficient trucks (e.g., compact pick-ups and car-based SUVs). This represents a wide variation in vehicle emitting capacity (much wider than what exists for newer cars). All such trucks enjoy popularity and this wide variation needs to be picked up in the sample, meaning a larger sample of tests from 1996+ trucks. Having said this, we recognize and need to adapt our final design to reflect the fact that some newer, larger trucks cannot be tested with present equipment. This should be taken into account when setting the final sample sizes.

Other issues that need to be taken into account and would draw the design away from a strict optimal allocation design are the need to test cars and trucks more heavily in the middle strata that feature vehicles built between 1981-1995. Finally, there is the goal of measuring cold temperature vehicle emissions. The final design must balance these competing needs and objectives.

Final Sample Design

Table 3-25 presents final design, along with its impact on Round 2 recruiting given Round 1 performance. Column A shows the current design, Column B presents the revised optimal design (based on Round 1 PM tests), and Column F exhibits the final design (which was the result of extensive dialogue with EPA and stakeholders reviewing the material in this memo and other research data).

Table 3-25. Sample Allocation for Three Designs and Impact of Final Design on Round 2 Testing

Type	Model Year	Strata	A Current Design	B REVISED Optimal Sample N	C FINAL DESIGN REVISION	D Round 1 Vehicles Tested	E Recommended Round 2 Goals	F FINAL ROUND 2 Goals
Truck	Pre-1981	1	30	8	12	2	10	10
Truck	1981-1990	2	50	50	56	21	35	37
Truck	1991-1995	3	50	38	48	18	30	30
Truck	1996+	4	75	135	84	39	45	47
Car	Pre-1981	5	30	32	21	6	15	15
Car	1981-1990	6	100	65	84	49	35	34
Car	1991-1995	7	65	65	74	39	35	36
Car	1996+	8	80	86	112	87	25	27
			480	480	491	261	230	236

The goal was to recalibrate the design to increase the precision of estimating PM emissions for the KC vehicle fleet. The major revisions feature:

- a reduction of the Pre-1981 Truck tests from 30 to 12,
- a reduction of tests for 1981-1990 cars from 100 to 84,
- an increase of tests for 1996+ cars from 80 to 112.

Although the final design reduces variance by only 1.4% relative to the current design, the goals of winter testing and representation of middle category vehicles (i.e., those built between 1981-1995) are better addressed under the final design.

Implications by Round

Column D of Table 3-25 presents the number of Round 1 vehicle tests by Stratum. A smaller number of vehicle tests are required for the older truck and car strata relative to the current design. This is because the Round 1 PM data reinforced the appropriateness of smaller sample sizes from these strata because they contribute relatively little to overall PM emissions.

3.6 Round 1 Recruitment – Goals and Recruitment Statistics

This section reviews the Round 1 vehicle recruitment goals and documents efforts in meeting these goals. Table 3-26, details the overall study recruitment goals and Round 1 goals by Vehicle year, type (truck or car) and demonstrates the progress made in reaching those goals.

Table 3-26. Vehicle Recruitment Goals for Round 1

CLASS	Year	Strata	Goal	Scheduled	Round 1 Tested	Tested % of Goal	Round 1 Goals	Tested % of Round 1 Goals
Truck	Pre-1981	1	30	4	2	7%	16	13%
Truck	1981 to 1990	2	50	26	21	38%	26	73%
Truck	1991 to 1995	3	50	24	18	36%	26	69%
Truck	1996 & newer	4	75	59	39	49%	39	95%
Car	Pre-1981	5	30	7	6	20%	16	38%
Car	1981 to 1990	6	100	63	49	50%	51	98%
Car	1991 to 1995	7	65	52	39	58%	34	112%
Car	1996 & newer	8	80	106	87	106%	42	202%
			480	341	261	53%	250	102%

The sample flow can be viewed in two perspectives: household sample flow and vehicle recruitment sample flow. The household sample flow during the recruitment process is illustrated in Figure 3-6. A total of 341 vehicles were recruited and scheduled for testing during Round 1. Seventy-six percent (76%) of those were tested (261). Some vehicles were not tested (20 vehicles did not qualify for dynamometer testing; 16 of those participated in PEMS testing only). Because not all cars scheduled were tested, progress in meeting the Round 1 goals can best be measured in viewing the “Tested % of Round 1” column. Two classes of vehicles, Class 7 and Class 8, met 100% of their Round 1 goals. Class 4 and class 6 were slightly below their Round 1 goal. The remaining classes were under tested due to eligibility and sampling constraints.

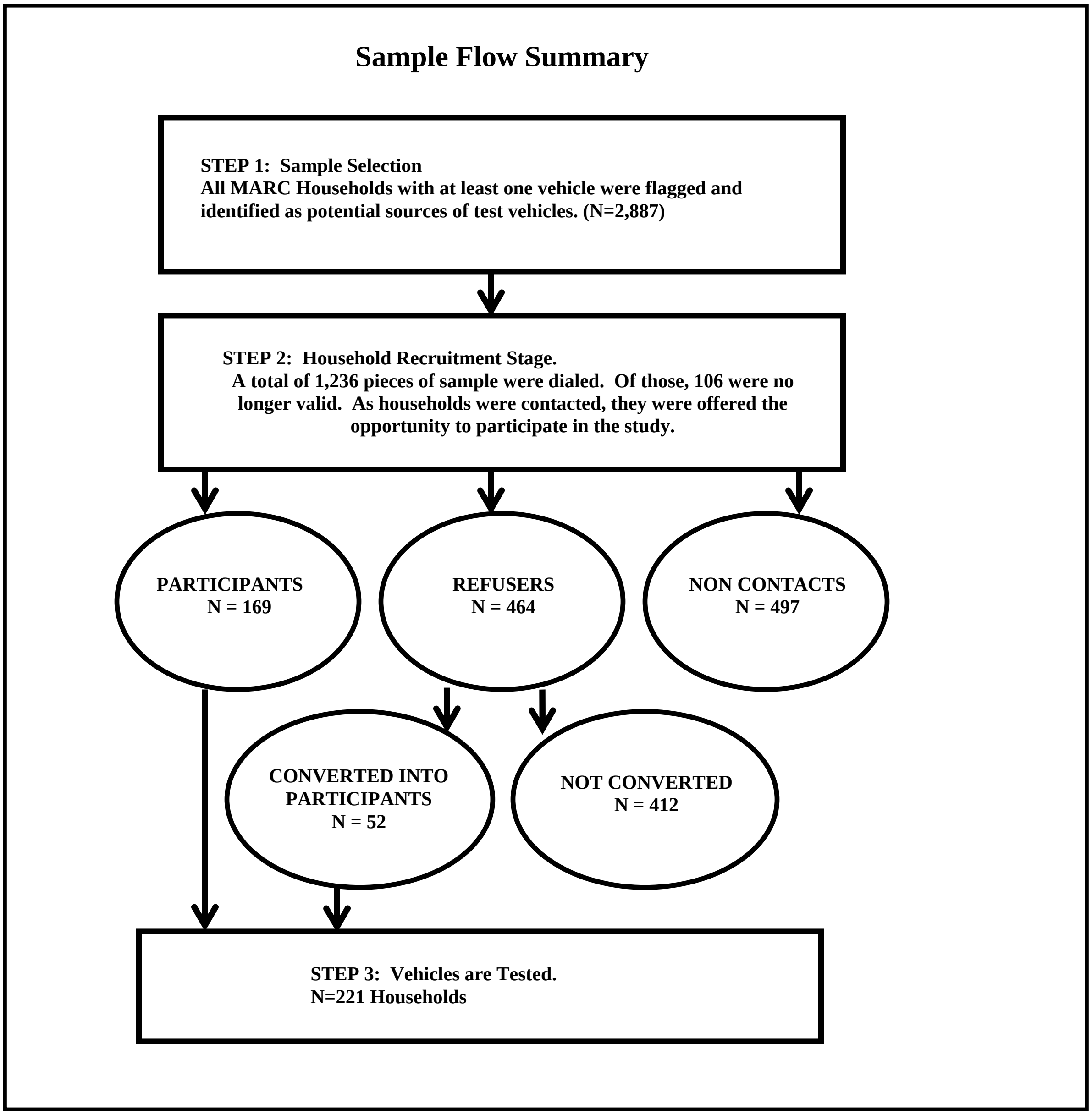


Figure 3-6. Household Sample Flow Summary

One of the challenges of Round 1 testing was that there were fewer than expected older vehicles available for recruitment. In fact, by the end of Round 1 testing, our available vehicle pool for recruiting the oldest vehicles, i.e., Strata 1, 2, 5, 6 (Pre-1981 and 1981-1990 trucks and cars) had been virtually exhausted. The impact of this is observed in the total percentages that were tested for Classes 1, 2, 5, and 6 (13%, 73%, 38% and 98%, respectively) in Table 3-26. The sample flow for vehicle recruitment is summarized in Table 3-27.

Table 3-27. Vehicle Recruitment Sample Flow by Class, Round 1

Strata	Year	Body Type	Project Goal	Round 1 Scheduled	Round 1 Vehicles Tested	Round 1 Goals	Vehicles Contacted by Phone	Canceled Scheduled Refusers	Scheduled Vehicle Refusers Recruited	Final Vehicles Refused Participation	Final Vehicles not Contacted
1	Pre-1981	Truck	30	4	2	16	73	0	0	23	24
2	1981 to 1990	Truck	50	26	21	26	268	7	7	94	90
3	1991 to 1995	Truck	50	24	18	26	178	8	6	43	59
4	1996 & newer	Truck	75	59	39	39	487	13	10	151	123
5	Pre-1981	Car	30	7	6	16	90	1	1	38	26
6	1981 to 1990	Car	100	63	49	51	561	12	10	175	192
7	1991 to 1995	Car	65	52	39	34	311	22	9	82	91
8	1996 & newer	Car	80	106	87	42	669	27	15	177	208
Total			480	341	261	250	2637	90	58	783	813

3.7 Round 2 Recruitment – Goals and Recruitment Statistics

This section reviews the Round 2 vehicle recruitment goals and documents efforts in meeting these goals. Table 3-28 details the overall study recruitment goals and Round 2 goals by Vehicle year, type (truck or car) and demonstrates the progress made in reaching those goals.

Table 3-28. Vehicle Recruitment Goals For Round 2

Strata	Year	Btype	Project Goal	Round 2 Scheduled	Round 2 Tested	Tested % of Goal	Round 2 Goals	Tested % of Round 2 Goals
1	Pre-1981	Truck	30	13	9	30%	10	90%
2	1981 to 1990	Truck	50	61	29	58%	37	78%
3	1991 to 1995	Truck	50	53	31	62%	30	103%
4	1996 & newer	Truck	75	82	50	67%	47	106%
5	Pre-1981	Car	30	19	14	47%	15	93%
6	1981 to 1990	Car	100	52	36	36%	34	106%
7	1991 to 1995	Car	65	49	37	57%	36	103%
8	1996 & newer	Car	80	41	29	36%	27	107%
			480	370	235	49%	236	100%

The sample flow can be viewed in two perspectives: household sample flow and vehicle recruitment sample flow. The household sample flow during the recruitment process is illustrated in Figure 3-7. A total of 370 vehicles were recruited and scheduled for testing during Round 1. Sixty-four percent (64%) of those were tested (235). Some vehicles were not tested (48 vehicles did not qualify for dynamometer testing; 37 of those participated in PEMS testing only). Three classes of vehicles, Class 1, Class 2, and Class 6, were below their Round 2 goal. All other classes were 100% or higher. The sample flow for Round 2 vehicle recruitment is summarized in Table 3-29.

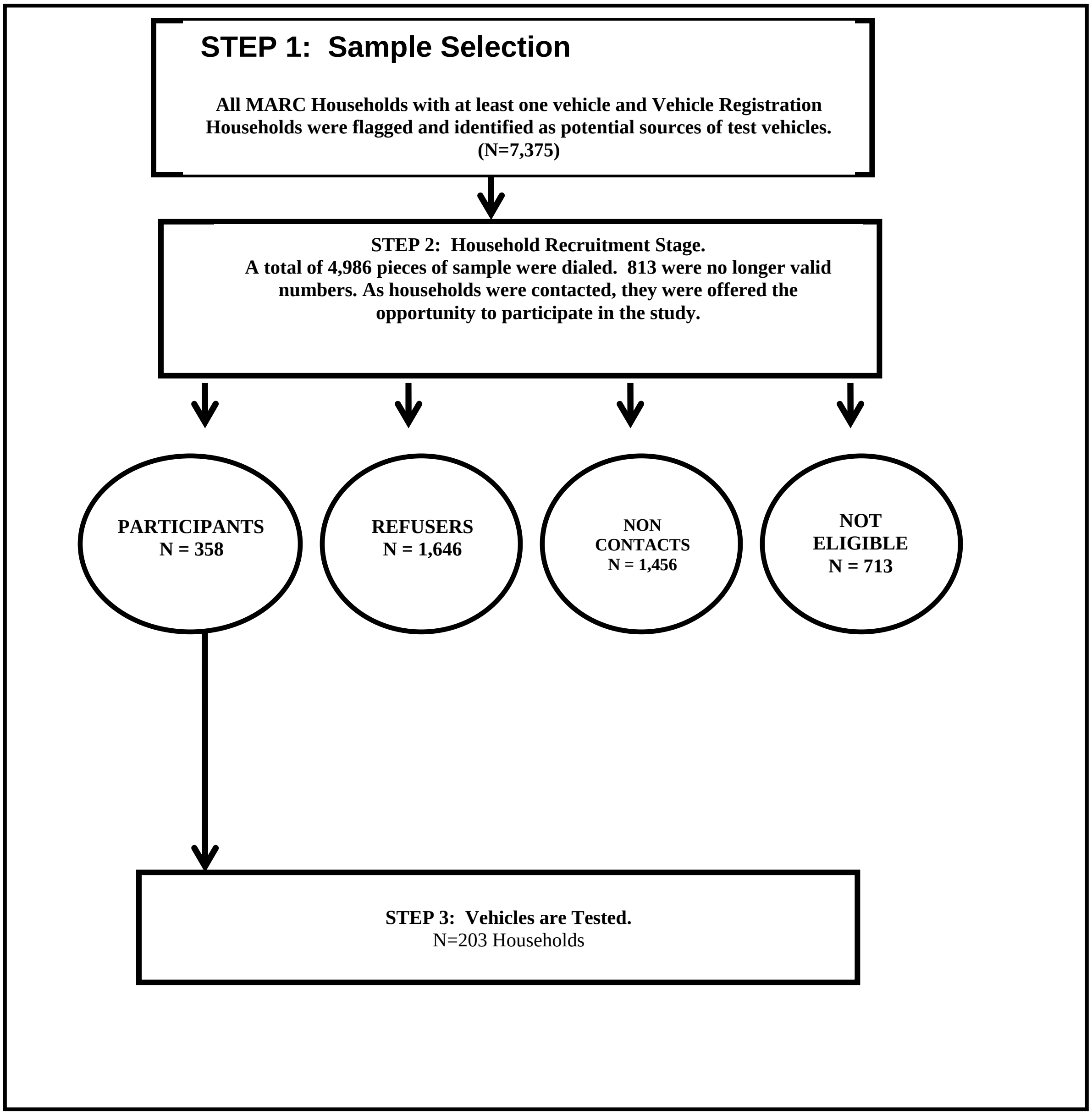


Figure 3-7. Sample Flow Summary for Round 2

Table 3-29. Round 2 Vehicle Recruitment Sample Flow by Class

Class	Year	Body Type	Project Goal	Round 2 Scheduled	Round 2 Tested	Round 2 Goals	Number Vehicles Contacted by Phone	Final Vehicles Refused Participation	Final Vehicles Not Contacted
1	Pre-1981	Truck	30	13	9	10	479	153	65
2	1981 to 1990	Truck	50	61	29	37	986	424	149
3	1991 to 1995	Truck	50	53	31	30	796	200	395
4	1996 & newer	Truck	75	82	50	47	1232	358	558
5	Pre-1981	Car	30	19	14	15	767	307	75
6	1981 to 1990	Car	100	52	36	34	910	274	269
7	1991 to 1995	Car	65	49	37	36	543	131	219
8	1996 & newer	Car	80	41	29	27	1121	312	504
Total			480	370	235	236	6834	2159	2234

3.8 Tested Vehicles

3.8.1 Round 1

Round 1 Vehicle testing targets and actual vehicles dynamometer tested are shown in Table 3-30. Although the total number of vehicles dynamometer tested conducted exceeded project goals, several strata targets were not achieved (most notable in bins 1 and 5). The MARC vehicle database was solely used for vehicle recruitment (via random digit dialing, or RDD) for Round 1 recruiting. This database was supplemented with the Kansas City registration database after Round 1 to help recover these shortfalls during Round 2 recruiting.

Table 3-30. Number of Vehicles Dynamometer Tested During Round 1

Bin	Vehicle Type	Model Year Group	Round 1 Goal	Round 1 Tested	% of Goal
1	Truck	Pre-1981	16	2	13%
2	Truck	1981-1990	26	21	81%
3	Truck	1991-1995	26	18	69%
4	Truck	1996+	39	39	100%
5	Car	Pre-1981	16	6	38%
6	Car	1981-1990	51	49	96%
7	Car	1991-1995	34	39	115%
8	Car	1996+	42	87	207%
		Total	250	261	104%

Table 3-31 lists the various tests conducted during Round 1, in comparison with project goals. PEMS testing on conditioning runs was performed on all vehicles, regardless of dynamometer eligibility.

Table 3-31. Round 1 Tests Conducted

Test Type	Round 1 Goal	Round 1 Tested
PEMS Conditioning Test	All	284
Replicate PEMS Conditioning Test	1 per week	17
PEMS Driveaway Test	N/A	13
Dynamometer/PEMS Test	250	261
Dynamometer/PEMS Test Replicate	1 per week	15
Dynamometer/PEMS Control Vehicle Test	1 per week	12

3.8.2 Round 2

In order to better achieve strata-specific test targets during Round 2 testing, the MARC database used for Round 1 recruiting was supplemented with the KC registration database for Round 2 recruiting of Bins, 1, 2, 5, and 6. As can be seen in Table 3-32, this significantly improved recruiting efforts.

Table 3-32. Number of Vehicles Dynamometer Tested During Round 2 (excluding Round 1 Retest Vehicles)

Bin	Vehicle Type	Model Year Group	Round 2 Goal	Round 2 Tested	% of Goal
1	Truck	Pre-1981	10	9	90
2	Truck	1981-1990	37	29	78
3	Truck	1991-1995	30	31	103
4	Truck	1996+	47	50	106
5	Car	Pre-1981	15	14	93
6	Car	1981-1990	34	36	106
7	Car	1991-1995	36	37	103
8	Car	1996+	27	29	107
		Total	236	235	100

Despite addition of the KC registration database, recruitment and testing of "older" vehicles (Bins 1, 2, 4, and 5) was challenging for several reasons:

- Overall, fewer older vehicles were available in the MARC and registration databases (relative to newer vehicles).
- A large percentage of the registration database households listed with a 1981 or older truck no longer had access to that vehicle.
- Unwillingness or inability of a vehicle owner to participate and a high number of incorrect owner contact information were other factors which hampered efforts for older bin recruiting.

All possible efforts, such as increasing incentives for vehicles in these bins and offering special vehicle pick-up and drop-off services, were made to encourage program participation, especially in these hard to fill bins. In addition, the records with VINs that were matched to households with incorrect contact information were researched to obtain current owner contact information.

In addition to recruitment challenges, testing older vehicles was problematic because these vehicles were often in such a state of disrepair that they would be unsafe to test on the dynamometer. Repairs were performed on all possible vehicles in order to maximize test percentages (i.e., replacement of brakes, tires, motor mounts, fuel pumps, etc.). Vehicles were only rejected from dynamometer testing if repairs were too extensive (such as a vehicle that would require a new clutch or transmission to test) or if the vehicle would be unsafe to test (and repairs to render the vehicle safe were again too extensive).

Other issues that hindered dynamometer testing included the recruitment of vehicles that could not be tested due to dimensions (too long or wide for the dyne), vehicles with all-time all-wheel drive, or vehicles with traction control that could not be disengaged. Air-cooled vehicles also were rejected from dynamometer testing in order to avoid engine damage from overheating.

In order to minimize the number of untestable vehicles recruited, feedback is provided to recruitment staff on all vehicles that cannot be tested because of the above reasons. In addition, recruiting targets were adjusted (increased) during Round 2 in order to better achieve goals for bins 1, 2, 5, and 6. As can be seen from Table 3-32, based on all the efforts exerted to meet the goals for testing vehicles in each bin, we were quite successful in meeting most of the targets.

Table 3-33 lists the various tests conducted during Round 2, in comparison with project goals. Regardless of dynamometer test eligibility, PEMS tests (on the conditioning run) were performed on all vehicles (excluding vehicles whose interior would not accommodate a PEMS device).

Table 3-33. Round 2 Tests Conducted

Test Type	Round 2 Goal	Round 2 Tested
PEMS Conditioning Test (excluding replicates)	All	324
Replicate PEMS Conditioning Test	1 per week	19
PEMS Driveaway Test	50	51
Dynamometer/PEMS Test (excluding replicates)	236	235
Dynamometer/PEMS Test (Round 1Retests)	25	43
Dynamometer/PEMS Test Replicate	1 per week	11
Dynamometer/PEMS Control Vehicle Test	1 per week	12
PAMS Driveaway Test	N/A	8

3.8.3 Round 1 to Round 2 Retest Vehicles

Table 3-34 shows recruiting and testing statistics for vehicles which were originally tested during Round 1 and were then retested at the start of Round 2 in order to provide summer/winter correlation data. Forty-two of these Round 1 retest vehicles were tested (exceeding the retest target of 25 vehicles) in order to ensure all strata were filled. Results of the Round 1 to Round 2 retest vehicle testing are presented in Section 4.

Table 3-34. Round 2 Dynamometer Tests of Vehicles Originally Tested During Round 1

BIN	Vehicle Type	Model Year Group	Retest Goal	Actual Retested	% of Goal
1	Truck	Pre-1981	1	1	100%
2	Truck	1981-1990	4	4	100%
3	Truck	1991-1995	2	2	100%
4	Truck	1996+	5	9	200%
5	Car	Pre-1981	2	3	150%
6	Car	1981-1990	4	4	100%
7	Car	1991-1995	4	7	175%
8	Car	1996+	3	12	400%
		Total	25	42	172%

4.0 Vehicle Emission Testing

4.1 Typical Testing Day

Vehicles arrived at the test facility at an appointed time determined via the NuStats scheduling process. Upon arrival, each vehicle first received a unique identification code for documentation tracking purposes, and was then inspected for test worthiness. Specific vehicle information, in the form of digital photographs, interview questionnaires, checklists, and hard copy data forms, was recorded for later input into the MSOD data table EQUIP_IN.dbf.

During the inspection process, each test vehicle was evaluated for recently performed repairs, as well as potential repairs which might be necessary. This served primarily to ensure that the vehicle could safely be operated on the road and dynamometer. If repairs were required, the vehicle owner was notified and his/her permission was obtained before repairs were performed. If the repairs could not be performed on-site, the vehicle was taken to a local repair shop. Records of the repair, along with a brief narrative, were maintained. Following repair, the vehicle was outfitted in the normal fashion, conditioned, and cued for testing.

A SEMTECH PEMS unit was then installed on the vehicle to monitor emissions. The PEMS unit used for the conditioning drive underwent a complete warm-up, zero and audit sequence to verify CO, CO_2, NO_x, and THC measurement accuracy. Calibrations were performed as necessary to bring the PEMS into proper calibration. At this point, each test vehicle was prepped using a predetermined route that included high speed accelerations, driving at freeway speeds, and driving at stop and go traffic patterns. This route is described in detail in Appendix K. This vehicle preparation was conducted for about 45 minutes, at which point the PEMS was uninstalled and the vehicle was soaked overnight at ambient temperatures for testing the next day.

The following day, the vehicle was mounted on the dynamometer, and a PEMS unit was installed on the vehicle to monitor undiluted emissions, in tandem with the emissions measurements to be performed by the dynamometer bench. A Positive Displacement Pump-Constant Volume Sampling (PDP-CVS) system was used to dilute and transport the vehicle tailpipe exhaust to analyzers during the dynamometer test (shown in Figure 4-1).

In addition to the regulated gas pollutants measured via CVS, continuous measurements of PM mass were taken using an EPA-supplied Booker Systems Model RPM-101 Quartz Crystal Microbalance (QCM) manufactured by Sensor's, Inc. and a Thermo-MIE Inc. DataRAM 4000 Nephelometer. BC was measured continuously with a DRI photoacoustic instrument and integrated samples were collected and analyzed by DRI for PM gravimetric mass, elements, elemental and OC, ions, particulate and semi-volatile organic compounds, and volatile organic air toxics. The samples were extracted from the dilution tunnel through a low particulate loss 2.5 μm cutpoint pre-classifier. Figure 4-2 presents a schematic of the sampling instrumentation.

It should be first noted that PM is a dynamic pollutant that is constantly being influenced by its environment therefore its formation is constantly changing both in the exhaust stream and in the ambient air. Our tests are a snapshot using specific measurements under specific laboratory and thermodynamic conditions. Real-world PM may differ significantly.

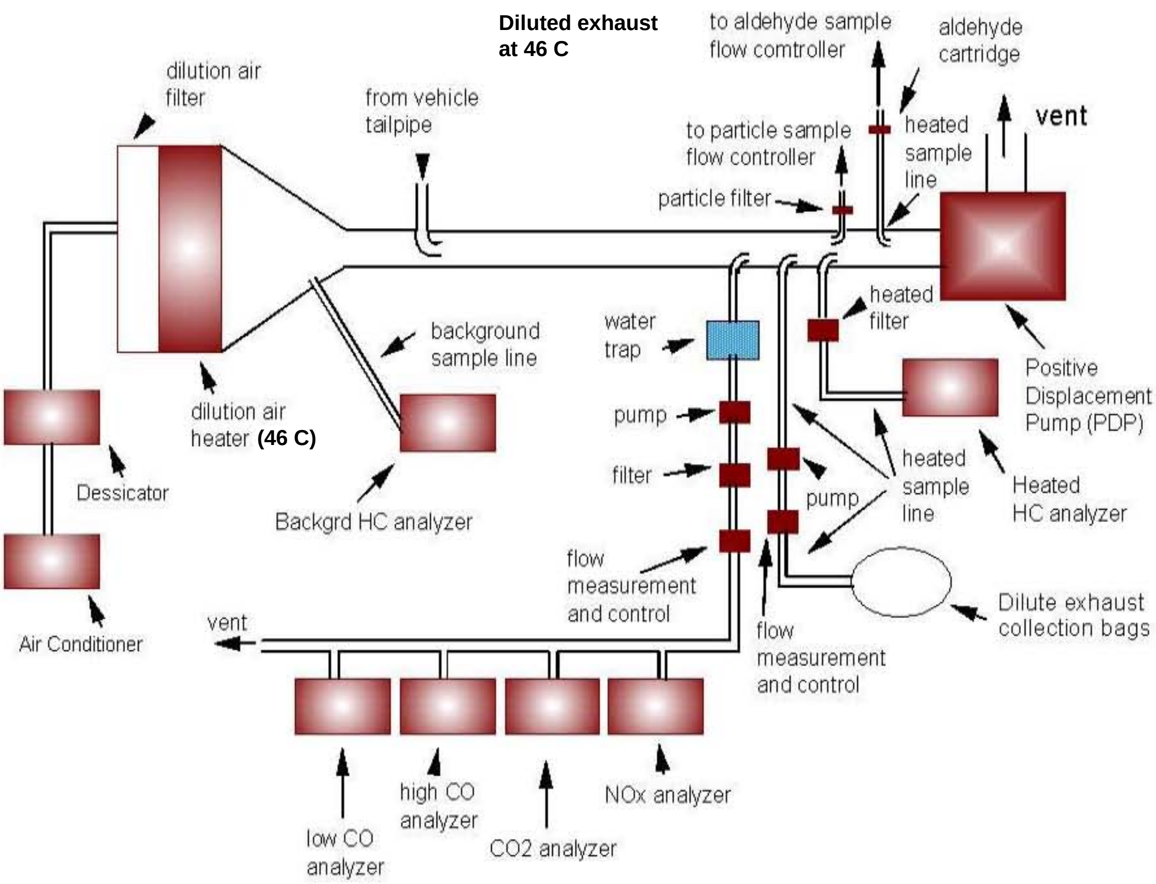


Figure 4-1. CVS Sampling System Schematic

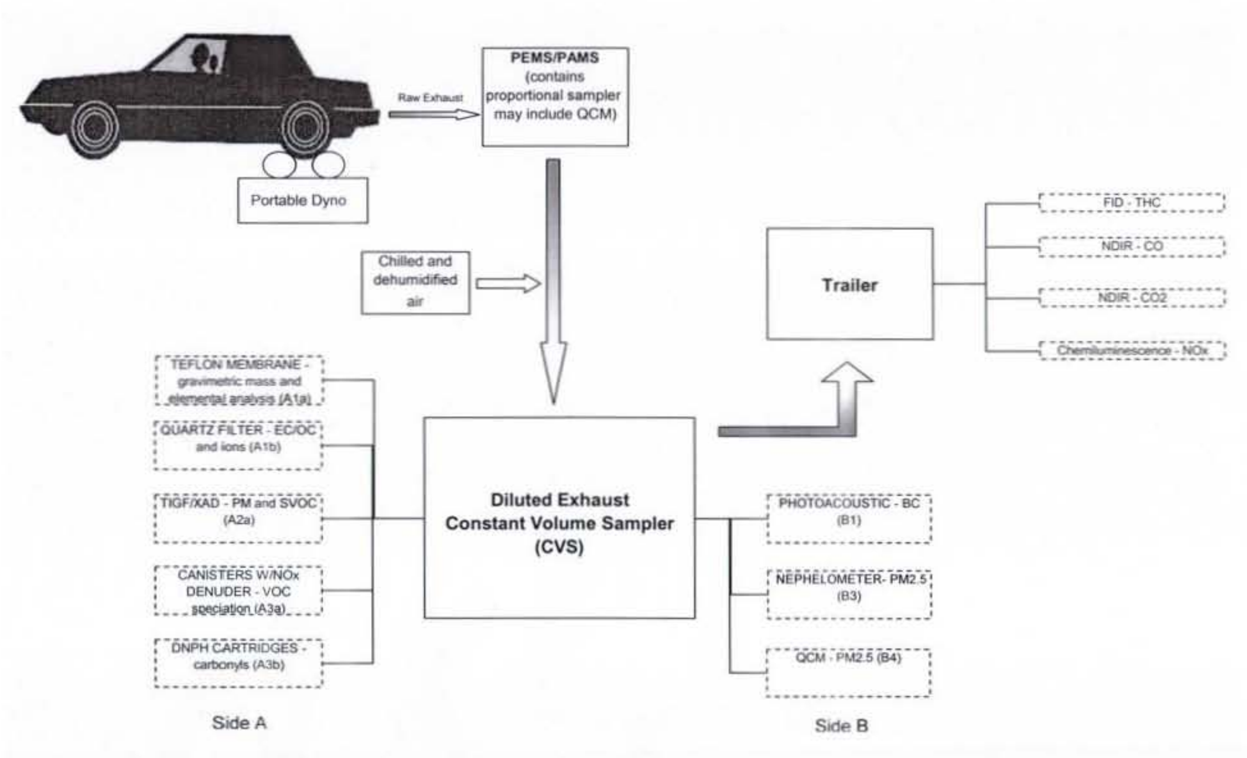
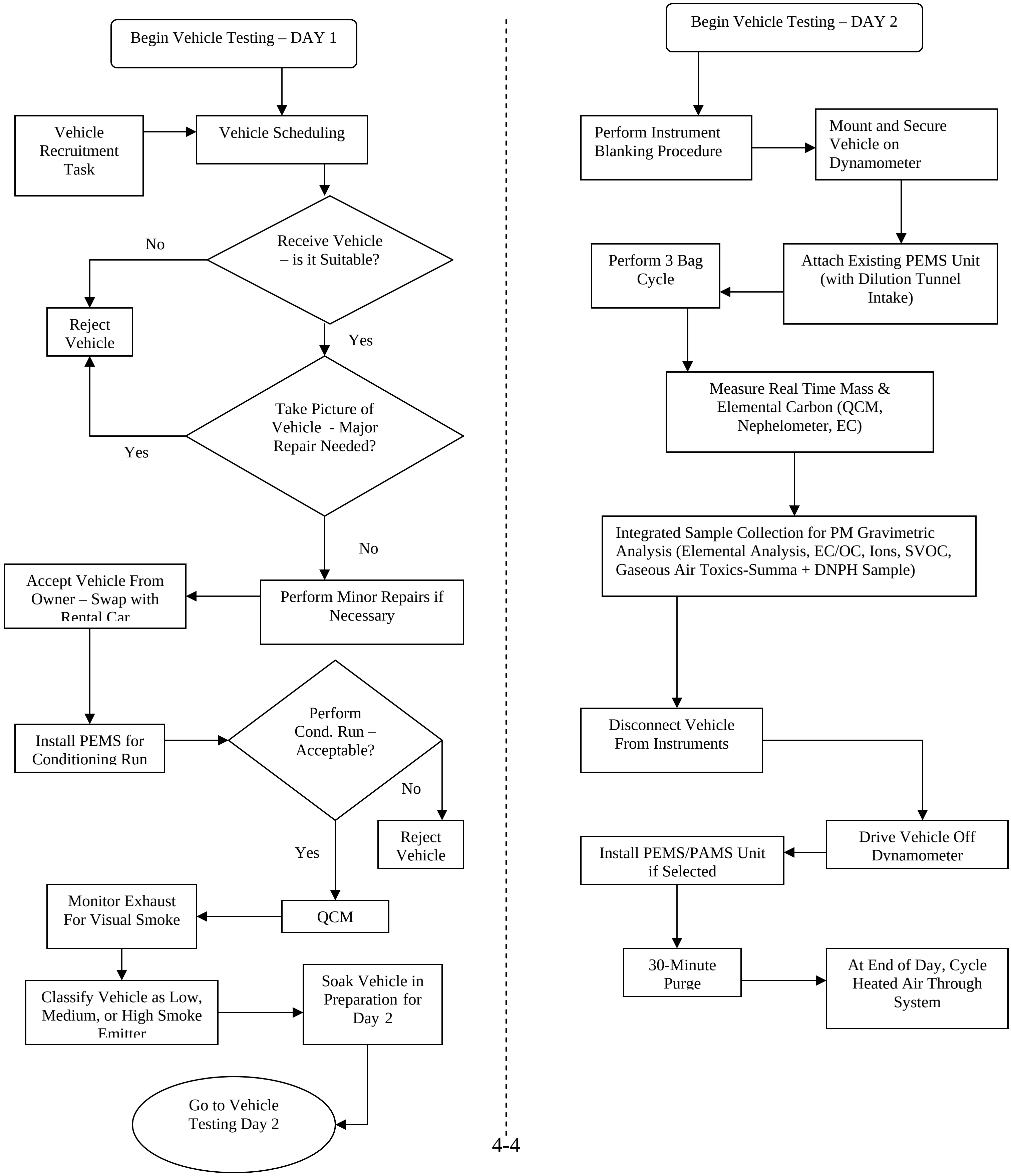


Figure 4-2. Kansas City Exhaust Measurement Flowchart

Figure 4-3. Daily Testing Flowchart



At the conclusion of vehicle testing, the vehicle was unloaded, disconnected from the PEMS and dynamometer sampling systems and removed from the dynamometer. Figure 4-3 presents a flowchart of daily vehicle testing activities.

4.2 Collection and Validation of Data from the Chassis Dynamometer

Round 1 and Round 2 regulated emission results for the participants' vehicles, along with detailed calculation methods, are presented in Appendices G and H. In addition, much more comprehensive data files, containing additional emissions and test data, have been transmitted to EPA. Summaries and graphs of the regulated emission results can be found elsewhere in this report. The following sub-sections describe the data file structures, data validation, and known data quality issues associated with the chassis dynamometer regulated emission data collected in the Kansas City study.

Dynamometer/Regulated Emission Modal Data

In addition to the calculated emission data described above, modal data that were collected from the dynamometer and regulated emissions bench were uploaded to the project FTP site. The modal data for each test were collected at a rate of 1 sample-per-second and were archived as a tab-delimited text file, named with its test number and a PRN extension. A total of 14 data fields are archived in the modal files, as listed in Table 4-1. Four of the data fields, AmbHC, PAU TEM, Torque, and Frt Spd, are not used in our emission rate calculations and were collected for QA/QC purposes. Unusual conditions that could have an influence on emissions measurements are discussed in the subsequent data validation section.

Table 4-1. Dynamometer Modal File Data Fields

Field Name	Units	Description
PDPTEMP	Centigrade	Temperature of PDP inlet
Hi CO	ppm	Diluted exhaust CO concentration from the high range CO analyzer
HotHC	ppmC	Diluted exhaust HC concentration from the Heated FID
NOx	ppm	Diluted exhaust NOx concentration from the NOx analyzer
CO_2	Percent	Diluted exhaust CO2 concentration from the high range CO2 analyzer
AMBTEMP	Centigrade	Ambient temperature (measured at the test cell)
REL HUM	Percent	Ambient relative humidity (measured at the test cell)
LoCO	ppm	Diluted exhaust CO concentration from the low range CO analyzer
AmbHC	ppmC	Ambient HC concentration from the ambient HC analyzer
Rr Spd	MPH	Dynamometer rear roll speed
PBAR	mmHg	Barometric Pressure (measured at the test cell)
PAU TEM	Centigrade	Temperature of the dynamometer's water-cooled Power Absorption Unit
Torque	Ft-Lbs	Instantaneous torque measured by the Dynamometer's torque cell
Frt Spd	MPH	Dynamometer front roll speed

Gaseous data contained in these files have been time aligned to account for sample transport delay times. Real time data acquisition and control (DAC) for the dynamometer was started manually via keyboard stroke. Once started, the DAC sent a start signal to the driver's aid to begin the driver's trace, and simultaneously began second-by-second data acquisition. The same signal that started the driver's aid was also sent to peripheral PM sampling equipment operated by DRI. Hence, all real time data and the start of peripheral sampling equipment were initially automatically aligned to the start of the driving trace. Real-time data from those sensors that have essentially instantaneous response, such as speed, torque, temperatures, and pressures, required no further time alignment. However, to account for normal sample transport time and instrument response times, real time gas data was time aligned with the vehicle speed. This was accomplished during post-processing of the collected real time data file. As described in Section 2.2, sample delays were measured for each analyzer during the pilot study.

There are two considerations to be given to the time alignment of gaseous data. The first is simply a delay time for sample transport; that is, the time it takes the leading edge of an emission spike leaving the engine to reach the analyzer. Transport of the sample through the dilution tunnel and sample lines is constant. However, travel time through the vehicle's exhaust system is variable due to the transient nature of exhaust flows and exhaust system configuration differences between manufacturers. So, the total sample transport delay time is somewhat variable from vehicle to vehicle, and from within different portions of the transient driving cycle. Unfortunately, it is not possible to account for this variability (which amounts to probably up to 3 seconds) during the time alignment process. Therefore, an average delay time (8-12 seconds) as measured during the pilot study was used to time align data from each gas analyzer.

Secondly, resolution of emission spikes is lost in the sampling and analysis process. For instance, what may be a 0.5 second engine out emission event may show up as a 5-10 second spike in the real time data. The loss of resolution is due to sample dilution and diffusion, as well as instrument response times (analyzer cell flushing). There is no way to regain resolution through data manipulation, so, although data are sampled and reported at a rate of 1 sample per second, the "real" resolution is actually on the order of 5-10 seconds. A choice must be made when time aligning this data: whether to align to the leading edge of an emission spike, or to the emission spike's maximum value, or somewhere in between. In determining the average delay times above, the leading edge of the emission spike was chosen. Specifically, the leading edge of the emission spike from the vehicle's first acceleration in Phase 1 was used as the alignment guide. The delay times for 10 different tests were determined in this manner, an average for these 10 tests was taken, and these average delay times were used for all of the remaining tests. Spot checks of a number of additional tests indicated that this process worked well.

Dynamometer load settings for 2000-2005 model year vehicles were found in the Certified Vehicle Test Result Report (http://www.epa.gov/otaq/crttst.htm). For 1999 and older vehicles, the Lookup Table Data for Inspection/Maintenance http://epa.gov/otaq/epg/techguid.htm) was used to determine dynamometer load settings. Inertias were generally rounded down in order to prevent overloading participant vehicles.

Edits were also made to several fields of the raw, real-time data for selected tests in order to correct known errors. A description of these edits is given in the following section.

Data Validation and Data Quality Issues for Dynamometer Generated Data

Data Validation

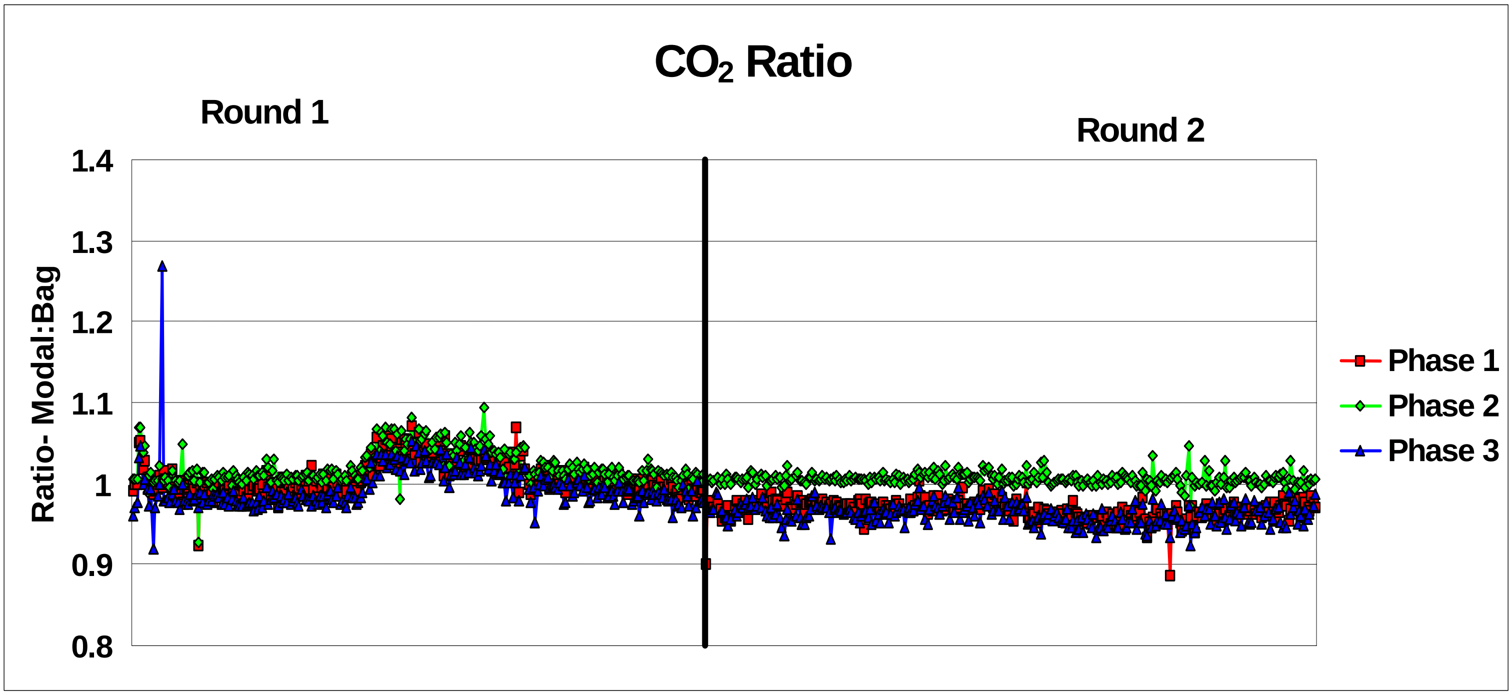
The contractor was responsible for gathering and conducting a review on the data as it pertains to data validation and to identify any data quality issues. The contractor has not conducted a full review and analysis of the data. EPA plans to conduct further analysis on the data to better determine its validity and its use in our modeling efforts.

At the conclusion of the study, all dynamometer and associated regulated emissions data were imported into summary spreadsheets. Numerical elements within each data field were then compared and checked, using control charts and graphs, for completeness and correctness. Text data elements were checked manually.

In the case of data input via keyboard by a technician, i.e., bag concentration values or vehicle and test information, errors that were detected during the data validation process were reconciled, whenever possible, with input bag concentration values, vehicle and test values entered on the handwritten test data form.

Collection of the modal data was automated through the use of a data acquisition system. In this case, data could be compromised due to a fault in the measurement system or with the measuring sensor itself. If possible, compromised modal data was corrected. This was possible in only a couple of cases, when it was known that inappropriate conversion factors were applied as a result of instrument range changes.

The data were also examined to determine if problems existed in the methodology. For instance, modal gaseous data were compared to bag gaseous data, and any differences found were cause for closer examination. For each test phase of each test, the ratio of modal-to-bag concentrations was computed and plotted. Figure 4-4 shows these plots for CO_2, CO, NOx, and HC concentrations for both rounds of the study (Round 1 data is to the left of the vertical line in each plot). Ratios that varied significantly from 1.0 were investigated. These plots were used initially to check for gross errors in keyboard input of the bag data, and the plots shown here have all keyboard errors corrected. For clarity, some invalid values resulting from test issues on several runs were removed from the plots shown in Figure 4-4, as listed in Table 4-2 below. Additional information on suspect dynamometer test data was investigated and is discussed in the following section and in Appendices S and V. In general, data was not eliminated or modified unless explicitly stated in this section or Appendices S or V.



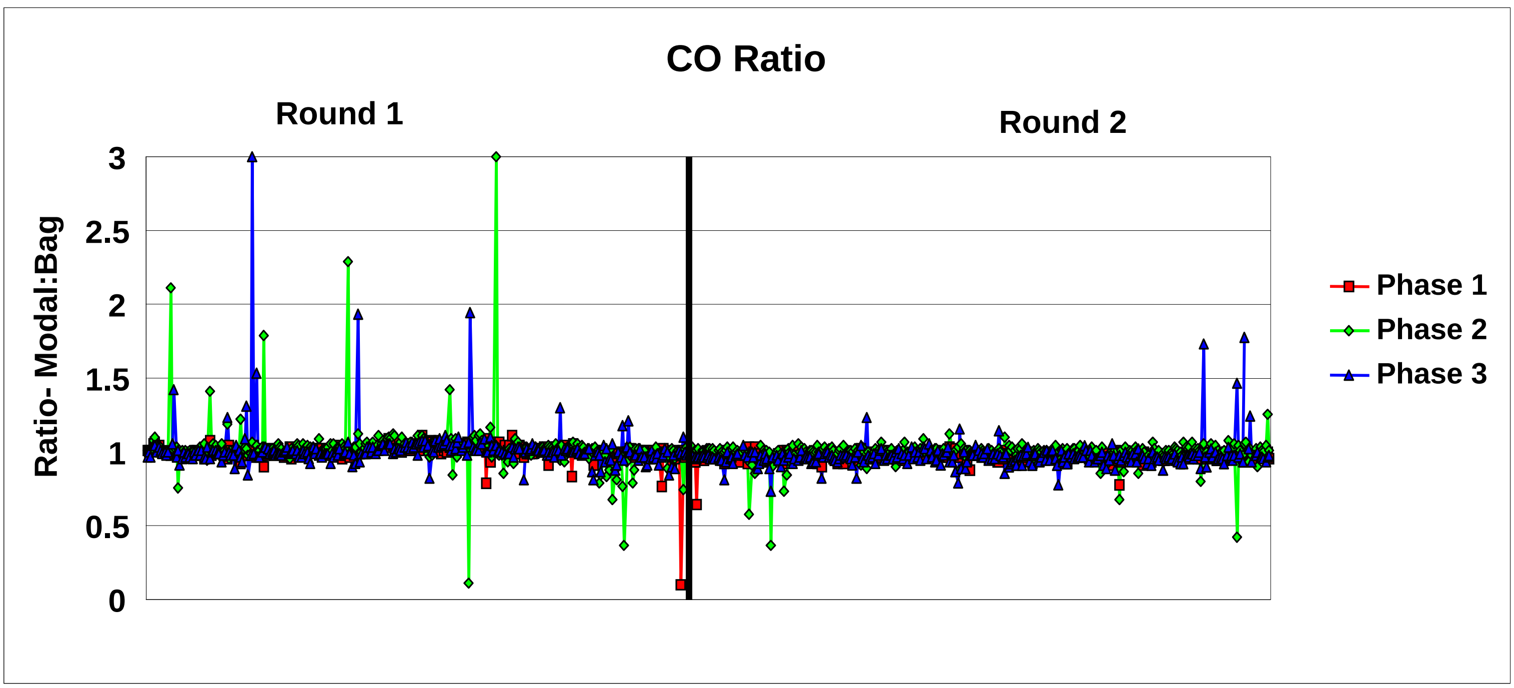
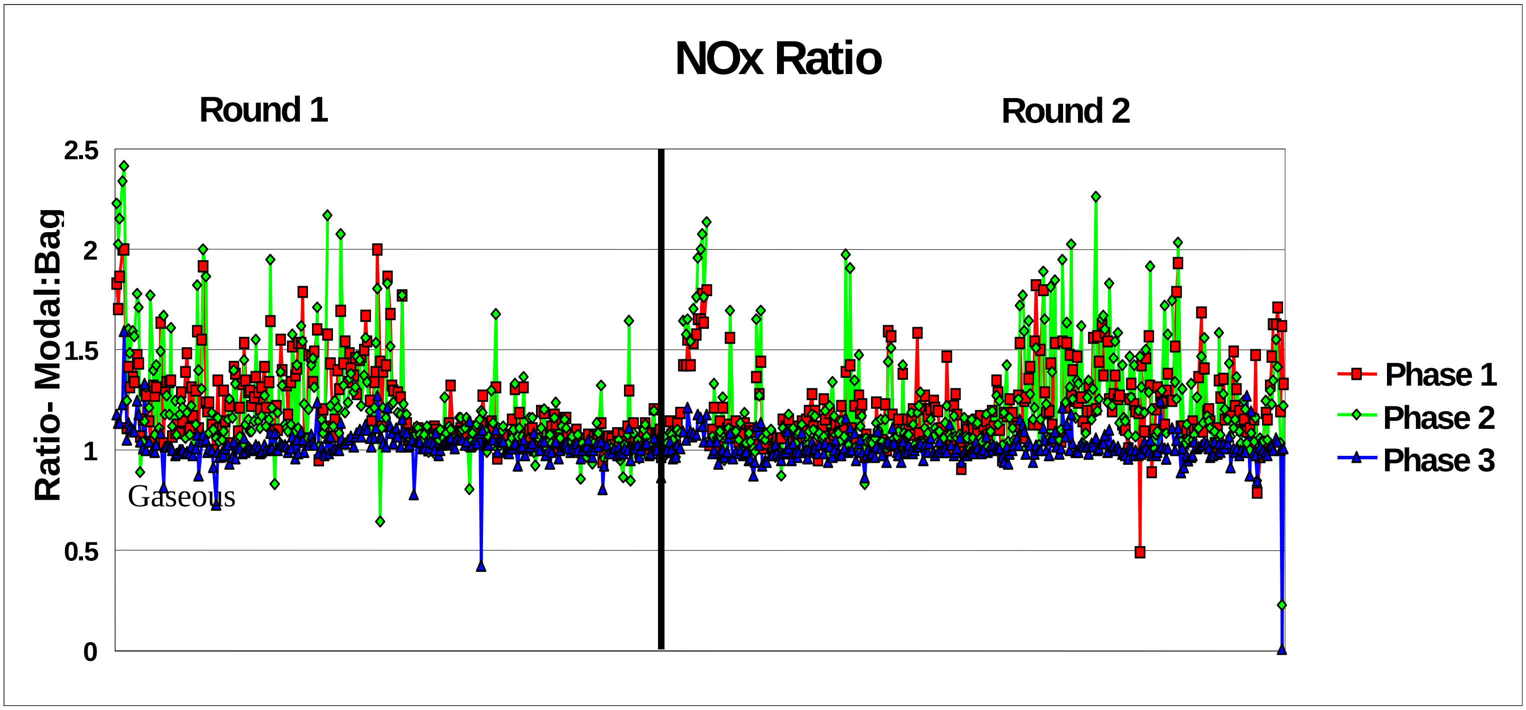


Figure 4-4. Modal to Bag Ratios for CO_2, CO, NOx, and THC



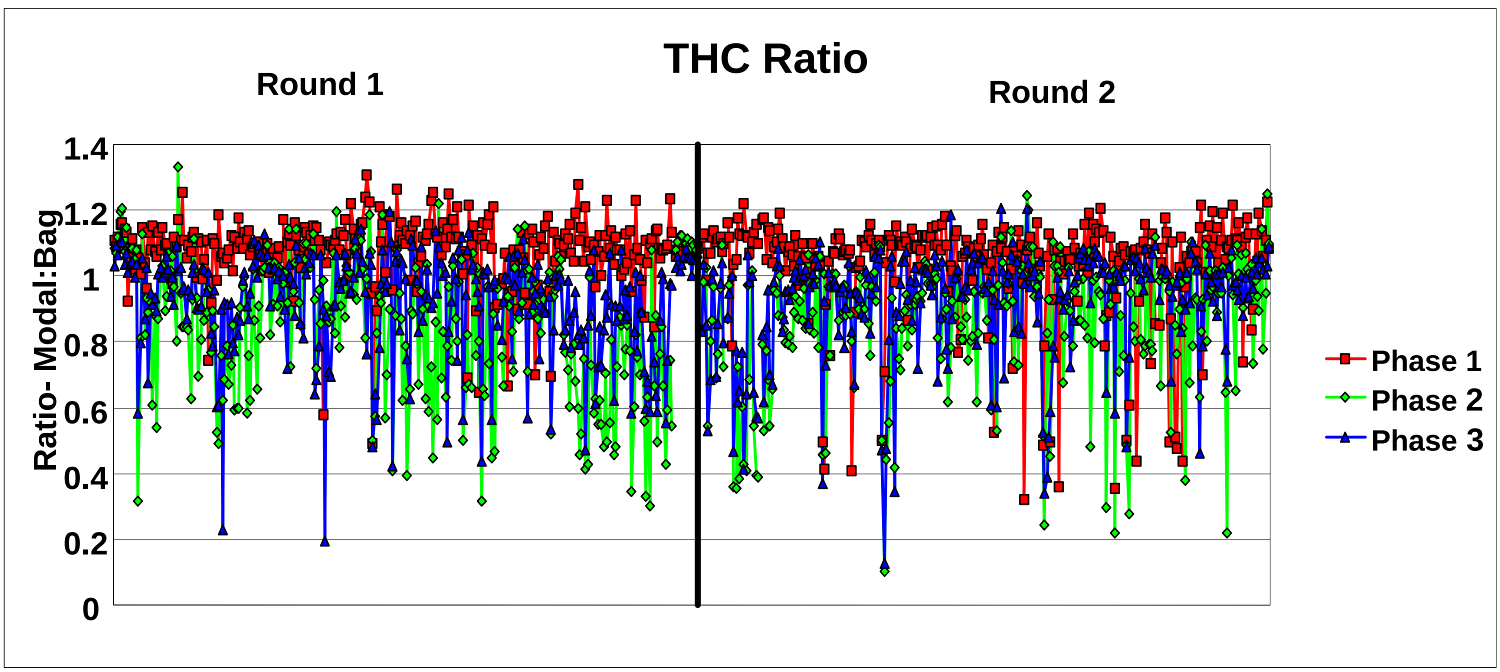


Figure 4-4. Modal to Bag Ratios for CO_2, CO, NOx, and THC (continued)

Table 4-2. Null Data Removed From Figures 4-4 through 4-6

Run #	Issue
84032	No Phase 3 bag NO_x data
84039	No Phase 3 bag NO_x data
84047	No Phase 3 bag NO_x data
84093	No Phase 1 bag NO_x data
84127	Bags were being evacuated for the first 30 seconds of Phase 1, Round 1 bag data voided
84140	No Phase 3 bag NO_x data
84149	No Phase 3 bag CO data
84156	No bag data for Phases 1 or 2
84192	No Phase 3 bag CO data
84201	No bag data for Phases 1 and 2
84235	Bag did not fill during Phase 1
84265	No Phase 3 bag CO data
84278	No bag data available for test
84297	No modal (real-time second-by-second) NO_x data for Phase 3
84334	No Phase 1 bag CO data
84343	No modal NO_x data for test
84349	No Phase 3 bag CO data
84393	Bags not fully evacuated prior to start of test, no bag data for any pollutant or phase
84408	No Phase 3 bag CO data
84409	Bags not fully evacuated prior to start of test, no bag data for any pollutant or phase
84414	No Phase 3 bag CO data
84430	Bags not fully evacuated prior to start of test, no bag data for any pollutant or phase
84438	No Phase 3 bag CO data
84444	No Phase 3 bag CO data
84464	No Phase 3 bag NO_x data
84536	Bags inadvertently evacuated during Phases 1 and 2, Phase 3 bag data is only phase available
84624	No bag CO_2 data for Phase 3
84766	No Phase 3 bag CO data
84773	No bag CO data for Phase 3
84777	Bags not fully evacuated prior to start of test, no bag data for any pollutant or phase

Known Data Quality Issues

The following section describes issues associated with the Kansas City data, along with corrective actions applied. Affected test numbers described in the following sections are summarized in the list of known test issues included in Appendices S and V.

Measurements:

While both modal and bag measurements were made for the regulated emissions, our intent was to provide the modal analysis as the primary source of emissions data, with the bag data to serve as a back-up and cross-check to the modal data. As shown in Tables 4-3 through 4-7, there generally was good agreement between the modal and bag data. The primary quality issue associated with the modal measurements is under-reporting of HC and CO emission rates for very high emitters due to concentrations higher than the instruments designed measuring range.

Table 4-3. HC Emissions for the EPA975 Control Vehicle during Rounds 1 and 2.

Test #	Odometer	Date	Amb. Temp	Ph1_Bag	Ph2_Bag	Ph3_Bag	Wtd_Bag	Ph1_Modal	Ph2_Modal	Ph3_Modal	Wtd_Modal
Rnd 1	*Miles*		*F*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*
84081	13139	07/26/2004	76.4	5.362	2.104	3.567	2.372	4.740	1.877	3.342	2.124
84114	13158	8/02/2004	93.5	5.367	2.208	4.040	2.495	4.824	2.009	3.618	2.263
84143	13170	08/07/2004	81.5	6.561	2.083	3.561	2.417	5.754	1.816	3.265	2.120
84177	13189	08/14/2004	74.1	5.351	2.082	3.602	2.355	4.529	1.711	3.159	1.955
84187	13208	08/18/2004	77.4	5.356	2.137	3.523	2.401	4.524	1.743	3.130	1.983
84218	13239	08/25/2004	81.0	5.451	2.263	3.813	2.534	4.682	2.074	3.619	2.314
84259	13250	09/08/2004	72.0	6.180	2.181	3.552	2.481	5.462	1.908	3.336	2.189
84290	13266	09/14/2004	87.7	5.222	2.160	3.499	2.411	5.607	1.938	3.370	2.227
84348	13303	09/24/2004	79.6	5.208	2.055	3.424	2.311	4.764	1.885	3.276	2.129
84360	13323	09/27/2004	77.6	5.448	2.059	3.534	2.338	4.798	1.855	3.316	2.110
84374	13352	09/29/2004	73.7	5.475	2.042	3.417	2.313	5.211	1.900	3.356	2.170
84387	13370	10/01/2004	72.0	5.932	2.173	3.501	2.463	5.414	1.989	3.341	2.262
		Average	*78.873*	*5.576*	*2.129*	*3.586*	*2.407*	*5.026*	*1.892*	*3.344*	*2.154*
		Standard Deviation		*0.403*	*0.066*	*0.167*	*0.070*	*0.419*	*0.100*	*0.142*	*0.104*
		Coeff of Var		*7.233*	*3.112*	*4.668*	*2.916*	*8.328*	*5.307*	*4.257*	*4.818*
Rnd 2											
84450	13729	01/22/2005	24.9	13.345	2.438	3.629	3.095	12.585	2.272	3.562	2.905
84461	13748	01/26/2005	43.9	7.749	2.230	3.397	2.601	7.192	2.020	3.233	2.376
84480	13768	01/31/2005	40.2	8.217	2.351	3.659	2.745	7.546	2.072	3.602	2.461
84507	13788	02/05/2005	58.9	6.805	2.179	3.434	2.509	6.261	1.915	3.286	2.239
84536	13809	02/11/2005	51.7	7.937	2.336	3.602	2.720				
84544	13828	02/14/2005	54.0	7.707	2.297	3.669	2.679	7.078	2.106	3.424	2.461
84578	13871	02/22/2005	43.8	7.475	2.340	3.760	2.708	6.697	2.073	3.473	2.413
84606	13936	03/03/2005	51.9	9.369	2.273	3.587	2.730	8.661	2.046	3.292	2.474
84624	14013	03/08/2005	44.6	8.379	2.166	3.262	2.565	7.793	1.939	3.181	2.330
84651	14033	03/14/2005	46.1	9.600	2.305	3.668	2.775	8.911	2.096	3.487	2.544
84697	14052	03/22/2005	42.6	8.255	2.416	3.925	2.829	7.684	2.148	3.599	2.541
84741	14072	03/31/2005	53.9	7.940	2.401	3.710	2.783	7.197	2.149	3.400	2.501
		Average	*46.354*	*8.565*	*2.311*	*3.608*	*2.728*	*7.964*	*2.076*	*3.413*	*2.477*
		Standard Deviation		*1.615*	*0.084*	*0.168*	*0.143*	*1.637*	*0.095*	*0.141*	*0.161*
		Coeff of Var		*18.854*	*3.644*	*4.663*	*5.227*	*20.560*	*4.565*	*4.133*	*6.505*

Table 4-4. NOx Emissions for the EPA975 Control Vehicle during Rounds 1 and 2.

Test #	Odometer	Date	Amb. Temp	Ph1_Bag	Ph2_Bag	Ph3_Bag	Wtd_Bag	Ph1_Modal	Ph2_Modal	Ph3_Modal	Wtd_Modal
Rnd 1	*Miles*		*F*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*
84081	13139	07/26/2004	76.4	6.900	5.623	6.962	5.780	3.704	2.490	5.824	2.778
84114	13158	8/02/2004	93.5	8.199	6.808	8.555	6.998	4.824	3.359	7.548	3.719
84143	13170	08/07/2004	81.5	7.543	5.755	6.973	5.931	4.044	2.674	6.152	2.985
84177	13189	08/14/2004	74.1	7.062	5.352	6.689	5.532	3.535	2.291	5.451	2.572
84187	13208	08/18/2004	77.4	7.543	6.351	8.092	6.533	3.776	2.634	5.079	2.862
84218	13239	08/25/2004	81.0	7.595	6.129	8.032	6.335	6.808	4.910	7.632	5.195
84259	13250	09/08/2004	72.0	7.745	5.918	7.173	6.098	5.481	3.704	6.316	3.974
84290	13266	09/14/2004	87.7	7.027	5.993	7.276	6.135	5.358	4.048	6.565	4.291
84348	13303	09/24/2004	79.6	7.152	5.498	6.832	5.675	5.246	3.457	6.207	3.739
84360	13323	09/27/2004	77.6	7.922	6.259	8.050	6.470	5.933	3.995	7.381	4.332
84374	13352	09/29/2004	73.7	6.872	5.470	6.841	5.637	4.594	3.045	5.441	3.290
84387	13370	10/01/2004	72.0	5.862	4.607	5.580	4.741	4.071	2.687	4.731	2.902
		Average	*78.873*	*7.285*	*5.814*	*7.255*	*5.989*	*4.781*	*3.274*	*6.194*	*3.553*
		Standard Dev		*0.589*	*0.543*	*0.779*	*0.558*	*0.970*	*0.751*	*0.918*	*0.761*
		Coeff of Var		*8.080*	*9.348*	*10.732*	*9.316*	*20.282*	*22.940*	*14.816*	*21.405*
Rnd 2											
84450	13729	01/22/2005	24.9	5.039	4.695	6.314	4.828	3.549	2.853	5.804	3.100
84461	13748	01/26/2005	43.9	5.928	4.958	6.030	5.084	4.160	3.149	5.764	3.385
84480	13768	01/31/2005	40.2	6.183	5.216	6.731	5.369	4.005	3.132	5.586	3.345
84507	13788	02/05/2005	58.9	5.959	4.993	6.289	5.134	4.201	3.238	5.782	3.467
84536	13809	02/11/2005	51.7	5.391	4.611	5.231	4.696				
84544	13828	02/14/2005	54.0	5.918	5.006	6.451	5.155	3.856	2.935	5.934	3.192
84578	13871	02/22/2005	43.8	6.208	4.999	5.909	5.126	3.953	2.838	5.508	3.082
84606	13936	03/03/2005	51.9	5.668	4.845	5.974	4.966	3.431	2.474	5.085	2.706
84624	14013	03/08/2005	44.6	4.715	4.301	5.640	4.416	2.844	2.139	4.848	2.366
84651	14033	03/14/2005	46.1	5.496	4.521	5.676	4.651	3.093	2.173	5.098	2.423
84697	14052	03/22/2005	42.6	5.998	4.799	5.914	4.940	3.671	2.726	5.711	2.985
84741	14072	03/31/2005	53.9	5.727	4.767	5.981	4.902	3.189	2.235	5.069	2.484
		Average	*46.354*	*5.686*	*4.809*	*6.012*	*4.939*	*3.632*	*2.717*	*5.472*	*2.958*
		Standard Dev		*0.437*	*0.240*	*0.383*	*0.251*	*0.432*	*0.385*	*0.359*	*0.382*
		Coeff of Var		*7.683*	*4.997*	*6.375*	*5.079*	*11.887*	*14.179*	*6.560*	*12.913*

Table 4-5. CO Emissions for the EPA975 Control Vehicle during Rounds 1 and 2.

Test #	Odometer	Date	Amb. Temp	Ph1_Bag	Ph2_Bag	Ph3_Bag	Wtd_Bag	Ph1_Modal	Ph2_Modal	Ph3_Modal	Wtd_Modal
Rnd 1	*Miles*		*F*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*
84081	13139	07/26/2004	76.4	34.977	13.353	20.406	14.950	34.747	13.245	21.056	14.887
84114	13158	8/02/2004	93.5	27.959	14.581	24.411	15.936	27.801	14.452	24.464	15.818
84143	13170	08/07/2004	81.5	32.694	13.242	20.255	14.734	32.347	13.122	20.911	14.655
84177	13189	08/14/2004	74.1	32.244	13.546	21.736	15.070	30.533	12.646	20.815	14.128
84187	13208	08/18/2004	77.4	31.351	15.365	20.090	16.526	29.486	14.030	19.173	15.191
84218	13239	08/25/2004	81.0	27.324	13.648	20.142	14.798	26.567	13.109	20.147	14.286
84259	13250	09/08/2004	72.0	38.321	13.538	21.472	15.358	36.865	12.916	20.854	14.694
84290	13266	09/14/2004	87.7	29.708	13.170	19.738	14.481	29.612	12.970	19.644	14.293
84348	13303	09/24/2004	79.6	31.081	12.899	20.405	14.348	31.314	12.846	20.663	14.331
84360	13323	09/27/2004	77.6	31.475	12.983	21.085	14.509	31.479	12.859	21.134	14.404
84374	13352	09/29/2004	73.7	32.212	13.858	20.318	15.245	32.493	13.682	20.880	15.143
84387	13370	10/01/2004	72.0	36.440	12.967	19.895	14.677	36.483	12.863	20.008	14.596
		Average	*78.873*	*32.149*	*13.596*	*20.830*	*15.053*	*31.644*	*13.228*	*20.812*	*14.702*
		Standard Dev		*3.080*	*0.695*	*1.230*	*0.614*	*3.058*	*0.524*	*1.248*	*0.468*
		Coeff of Var		*9.581*	*5.114*	*5.905*	*4.076*	*9.664*	*3.959*	*5.994*	*3.180*
Rnd 2											
84450	13729	01/22/2005	24.9	126.810	22.085	25.226	27.803	130.208	21.423	25.934	27.452
84461	13748	01/26/2005	43.9	69.908	15.115	20.550	18.372	75.064	14.980	21.365	18.581
84480	13768	01/31/2005	40.2	76.089	17.209	20.899	20.523	118.858	16.828	22.039	22.491
84507	13788	02/05/2005	58.9	55.299	13.618	20.626	16.293	56.276	13.385	21.347	16.191
84536	13809	02/11/2005	51.7	69.732	15.236	21.025	18.521				
84544	13828	02/14/2005	54.0	64.861	15.664	23.548	18.818	67.155	15.508	24.013	18.834
84578	13871	02/22/2005	43.8	66.274	15.972	21.851	19.023	70.433	15.730	22.697	19.087
84606	13936	03/03/2005	51.9	79.561	16.556	21.995	20.180	82.804	16.164	22.657	20.049
84624	14013	03/08/2005	44.6	88.814	17.962	22.438	21.948	92.296	17.599	23.072	21.854
84651	14033	03/14/2005	46.1	83.019	17.171	23.222	20.985	85.587	16.885	24.229	20.936
84697	14052	03/22/2005	42.6	73.603	17.594	24.529	21.024	75.408	17.236	25.317	20.859
84741	14072	03/31/2005	53.9	62.267	15.879	21.838	18.726	65.368	15.743	22.918	18.846
		Average	*46.354*	*76.353*	*16.672*	*22.312*	*20.185*	*83.587*	*16.498*	*23.235*	*20.471*
		Standard Dev		*17.617*	*2.006*	*1.470*	*2.726*	*21.655*	*1.919*	*1.429*	*2.770*
		Coeff of Var		*23.073*	*12.034*	*6.586*	*13.504*	*25.907*	*11.632*	*6.149*	*13.531*

Table 4-6. CO_2 Emissions for the EPA975 Control Vehicle during Rounds 1 and 2.

Test #	Odometer	Date	Amb. Temp	Ph1_Bag	Ph2_Bag	Ph3_Bag	Wtd_Bag	Ph1_Modal	Ph2_Modal	Ph3_Modal	Wtd_Modal
Rnd 1	*Miles*		*F*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*	*gm/mile*
84081	13139	07/26/2004	76.4	655.596	386.177	546.714	410.991	660.250	383.352	566.654	410.095
84114	13158	8/02/2004	93.5	701.022	401.557	573.925	428.644	702.250	399.921	593.783	428.619
84143	13170	08/07/2004	81.5	698.986	394.152	561.646	421.490	699.583	391.552	575.821	420.211
84177	13189	08/14/2004	74.1	668.594	385.104	537.781	410.177	633.353	358.689	518.947	383.831
84187	13208	08/18/2004	77.4	662.173	407.598	576.557	432.517	626.736	380.095	551.493	404.767
84218	13239	08/25/2004	81.0	671.201	400.773	582.138	427.151	660.720	385.876	584.863	413.690
84259	13250	09/08/2004	72.0	686.038	394.461	522.006	418.218	662.598	374.387	515.336	398.889
84290	13266	09/14/2004	87.7	641.921	382.460	535.629	406.503	637.310	387.625	540.899	411.169
84348	13303	09/24/2004	79.6	664.857	385.410	540.777	410.449	669.062	380.866	556.551	407.760
84360	13323	09/27/2004	77.6	660.165	383.192	540.884	408.592	658.169	378.604	544.969	404.744
84374	13352	09/29/2004	73.7	676.372	393.683	554.462	419.272	685.317	394.606	610.149	424.383
84387	13370	10/01/2004	72.0	666.596	386.881	533.293	411.738	670.909	385.451	549.878	411.871
		Average	*78.873*	*671.127*	*391.787*	*550.484*	*417.145*	*663.855*	*383.419*	*559.112*	*410.002*
		Standard Dev		*16.534*	*7.875*	*18.396*	*8.367*	*23.018*	*10.105*	*27.412*	*11.345*
		Coeff of Var		*2.464*	*2.010*	*3.342*	*2.006*	*3.467*	*2.636*	*4.903*	*2.767*
Rnd 2											
84450	13729	01/22/2005	24.9	714.152	400.129	539.755	426.560	736.229	399.200	560.667	428.396
84461	13748	01/26/2005	43.9	656.205	383.396	512.578	406.759	671.182	380.906	532.453	406.752
84480	13768	01/31/2005	40.2	720.258	410.801	551.668	436.486	740.207	408.635	573.823	437.125
84507	13788	02/05/2005	58.9	647.458	379.259	518.918	403.106	668.852	378.133	538.290	404.597
84536	13809	02/11/2005	51.7	690.058	393.408	517.852	417.783				
84544	13828	02/14/2005	54.0	661.944	390.467	535.082	414.876	684.845	389.656	547.342	416.227
84578	13871	02/22/2005	43.8	681.418	394.107	529.037	418.546	703.068	393.037	548.544	420.095
84606	13936	03/03/2005	51.9	681.971	392.582	512.840	415.889	716.592	389.410	533.069	416.298
84624	14013	03/08/2005	44.6	640.040	374.459	506.561	397.494	669.567	373.870	-	-
84651	14033	03/14/2005	46.1	694.395	390.042	516.104	414.465	727.570	386.607	541.654	414.925
84697	14052	03/22/2005	42.6	673.616	393.320	518.953	416.850	694.603	391.273	550.234	418.348
84741	14072	03/31/2005	53.9	631.061	386.203	513.754	408.001	665.312	387.348	540.866	412.708
		Average	*46.354*	*674.381*	*390.681*	*522.759*	*414.735*	*698.003*	*388.916*	*546.694*	*417.547*
		Standard Dev		*26.935*	*9.088*	*12.777*	*9.932*	*27.168*	*9.207*	*12.108*	*9.088*
		Coeff of Var		*3.994*	*2.326*	*2.444*	*2.395*	*3.892*	*2.367*	*2.215*	*2.177*

Table 4-7. Fuel Economy for the EPA975 Control Vehicle during Rounds 1 and 2.

Test #	Odometer	Date	Amb. Temp	Ph1_Bag	Ph2_Bag	Ph3_Bag	Wtd_Bag	Ph1_Modal	Ph2_Modal	Ph3_Modal	Wtd_Modal
Rnd 1	*Miles*		*F*	*mpg*	*mpg*	*mpg*	*mpg*	*mpg*	*mpg*	*mpg*	*Mpg*
84081	13139	07/26/2004	76.4	11.83	20.80	14.59	19.47	11.793	20.989	14.103	19.553
84114	13158	8/02/2004	93.5	11.30	19.95	13.77	18.65	11.308	20.065	13.372	18.686
84143	13170	08/07/2004	81.5	11.16	20.42	14.23	19.03	11.198	20.596	13.905	19.130
84177	13189	08/14/2004	74.1	11.69	20.84	14.76	19.50	12.373	22.417	15.325	20.881
84187	13208	08/18/2004	77.4	11.82	19.63	13.90	18.47	12.522	21.115	14.551	19.791
84218	13239	08/25/2004	81.0	11.77	20.05	13.75	18.78	12.000	20.840	13.707	19.410
84259	13250	09/08/2004	72.0	11.24	20.37	15.18	19.12	11.666	21.480	15.407	20.069
84290	13266	09/14/2004	87.7	12.21	20.99	14.90	19.70	12.268	20.784	14.778	19.533
84348	13303	09/24/2004	79.6	11.79	20.88	14.75	19.55	11.737	21.148	14.361	19.696
84360	13323	09/27/2004	77.6	11.84	20.99	14.71	19.62	11.908	21.270	14.622	19.831
84374	13352	09/29/2004	73.7	11.56	20.40	14.41	19.10	11.433	20.391	13.170	18.916
84387	13370	10/01/2004	72.0	11.59	20.78	14.95	19.45	11.548	20.894	14.542	19.476
		Average	*78.873*	*11.650*	*20.509*	*14.492*	*19.203*	*11.813*	*20.999*	*14.320*	*19.581*
		Standard Dev		*0.286*	*0.430*	*0.460*	*0.392*	*0.402*	*0.566*	*0.672*	*0.543*
		Coeff of Var		*2.459*	*2.096*	*3.171*	*2.040*	*3.406*	*2.693*	*4.691*	*2.773*
Rnd 2											
84450	13729	01/22/2005	24.9	9.02	19.46	14.58	17.94	8.788	19.570	14.057	17.916
84461	13748	01/26/2005	43.9	10.90	20.79	15.50	19.40	10.611	20.961	14.945	19.420
84480	13768	01/31/2005	40.2	9.95	19.34	14.45	18.04	9.059	19.499	13.894	17.932
84507	13788	02/05/2005	58.9	11.40	21.13	15.32	19.72	11.085	21.251	14.792	19.701
84536	13809	02/11/2005	51.7	10.45	20.28	15.32	18.91				
84544	13828	02/14/2005	54.0	10.93	20.39	14.76	19.02	10.599	20.471	14.452	18.986
84578	13871	02/22/2005	43.8	10.65	20.19	14.97	18.85	10.317	20.296	14.470	18.815
84606	13936	03/03/2005	51.9	10.30	20.23	15.41	18.88	9.856	20.442	14.872	18.902
84624	14013	03/08/2005	44.6	10.69	21.03	15.60	19.57	10.265	21.124	-	-
84651	14033	03/14/2005	46.1	10.08	20.30	15.27	18.88	9.678	20.515	14.579	18.892
84697	14052	03/22/2005	42.6	10.57	20.09	15.11	18.77	10.288	20.256	14.321	18.756
84741	14072	03/31/2005	53.9	11.43	20.57	15.39	19.30	10.894	20.559	14.656	19.128
		Average	*46.354*	*10.528*	*20.316*	*15.139*	*18.939*	*10.131*	*20.450*	*14.504*	*18.845*
		Standard Dev		*0.631*	*0.519*	*0.357*	*0.518*	*0.691*	*0.532*	*0.324*	*0.536*
		Coeff of Var		*5.993*	*2.552*	*2.357*	*2.733*	*6.821*	*2.602*	*2.235*	*2.845*

1.) **CO_2**: CO_2 ratios, shown in Figure 4-4, which includes both Round 1 and Round 2 data, typically showed the most consistency of all the regulated gaseous emissions and remained around 1.0. The primary exceptions are issues listed above (which have been removed from Figure 4-4).

2) **CO:** In the graph of modal:bag ratios for CO shown in Figure 4-4, quite a few more excursions away from a ratio of 1.0 are found. These excursions are primarily found at concentration levels below 10 ppm, as the minimum detectable limit of 0.5% of full scale (5 ppm) as specified by Horiba Instruments is approached. This can be seen in Figure 4-5, which shows the modal:bag ratios plotted as a function of concentration. Ratios also start to decrease as measured concentrations increase, in two cases markedly. This is the result of transient CO spikes occurring in the real time which are beyond the analytical capability of the analyzer (i.e., off-scale real time data). The more off-scale points occurring during a phase, the larger the decrease in the real time to bag ratio. Due to the use of two different CO analyzers covering different ranges (0-1,000 ppm and 0-10,000 ppm), this problem is minimized for CO measurement and only occurred in two instances as can be seen in Figure 4-5 Phase 1 data. Appendices S and V provide information on tests where instrument "pegging" may have occurred.

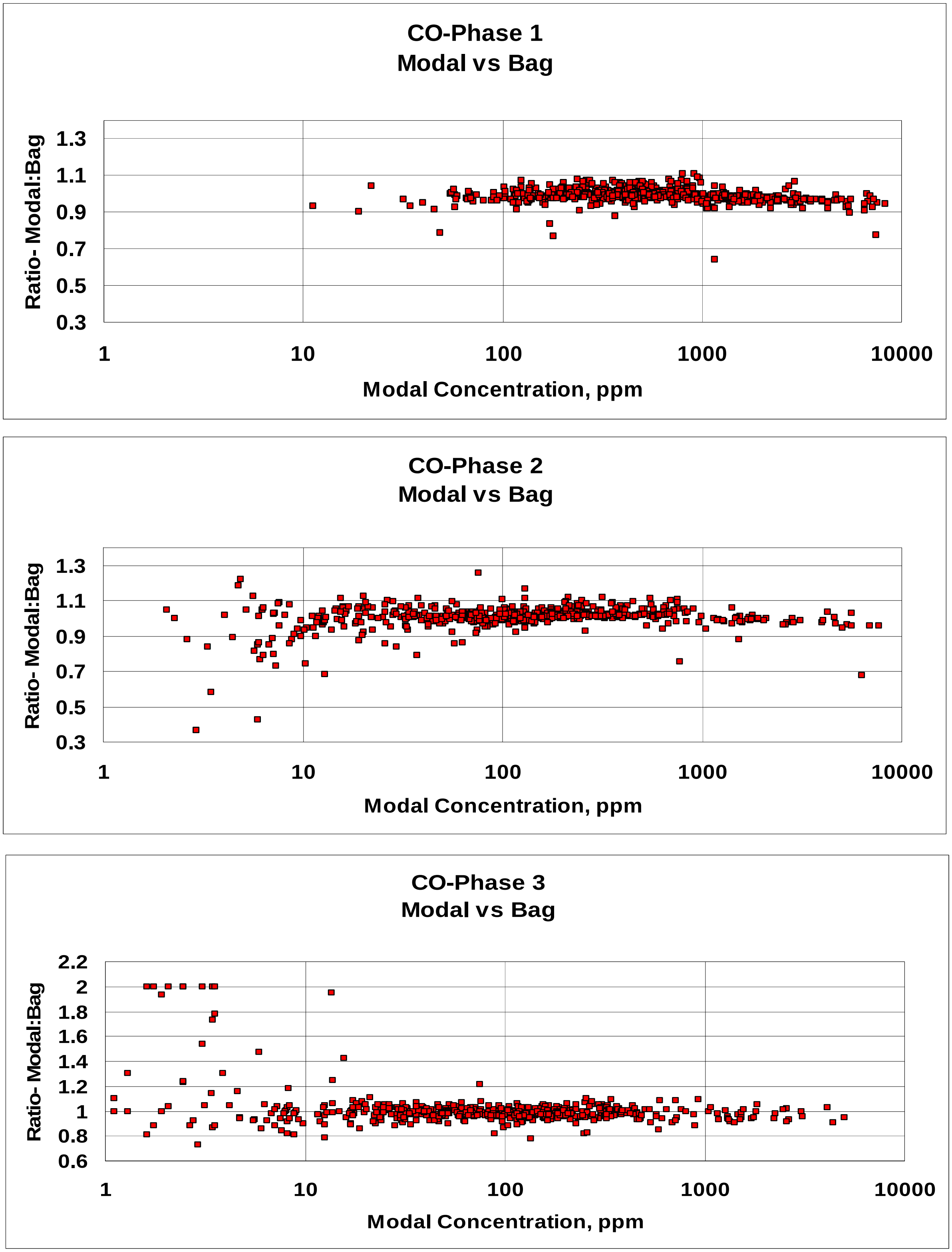


Figure 4-5. By-Phase Modal to Bag CO Ratios vs. Modal CO Concentration, both Rounds

3.) **HC:** As with CO measurements, agreement between the modal and bag HC measurements drops off for very low and very high HC concentrations. In Figure 4-6, the HC modal to bag ratios are plotted against HC concentration. For higher emitting vehicles, the modal data contains a larger number of off-scale data points (i.e., >1,250 ppmC), resulting in the modal data under-reporting HC. A couple of factors influenced the disagreement between modal and bag HC measurements on the lower end. First, bag HC measurements were recorded to ± 1 ppm, while modal HC measurements were recorded to ± 0.001 ppm. Secondly, CVS bags were not purged between the last (and dirtiest) test of one day and the first (and cleanest) test of the next day. HC desorbtion from the bag surfaces from an extremely high HC emitter could elevate HC bag concentrations from a lower emitter. Conversely, at higher concentration measurements, some HC could adsorb onto the bag surface, thereby decreasing the measured HC concentration. No correction was applied to the HC bag data to account for the potential absorption/adsorption in the bag. Likewise no correction was performed to the modal data to account for underreporting of HC data due to off-scale measurements. Since vehicles were generally tested from the "cleanest" to the "dirtiest" on a daily basis, Figure 4-6 compares the first test of the day (lowest emitting vehicle) to the last test of the day (highest emitting vehicle). This could help illustrate bag desorbtion influences on the modal to bag ratio results for the first test of the day.

AMBHC- An FID was dedicated to measuring the building background HC concentrations. These measurements are not used in the emission rate calculations, but were recorded to document building background HC levels. This instrument was functional only during portions of Round 1, and not at all during Round 2. During the last half of Round 1, the instrument was operated on the 0-1000 ppmC range instead of the 0-100 ppmC range. This resulted in a scaling factor error of 10. AMBHC measurements on all affected runs were edited by dividing by 10 to reflect true concentrations. In addition, the sampling valve for the AMBHC instrument was turned to the wrong position at the start of one run (84079), resulting in diluted exhaust, instead of building background air, being sampled during the first 630 seconds of this test. AMBHC for the first 630 seconds of this run are therefore void, as indicated in the edited PRN file for this run. This and other test issues, as well as data corrections performed, are listed in Appendices S and V.

4) **NOx:** NOx converter efficiency, affecting NOx bag measurements, is the culprit in the bad agreement between NOx modal and bag measurements, as seen in Figure 4-4. Due to the large differences seen, all NOx bag data for Rounds 1 and 2 have been invalidated, and should not be used. With the exception of the NOx bag data shown here in comparison with modal data, all dynamometer "by phase" results are based on real-time modal measurements, not bag measurements. Modal NO_x was lost on two runs (84343 and 84297) due to the instrument's ozonator air running out or being turned off. NO_x for the entire 84343 test was lost, while only Phase 2 and Phase 3 of 84297 were lost.

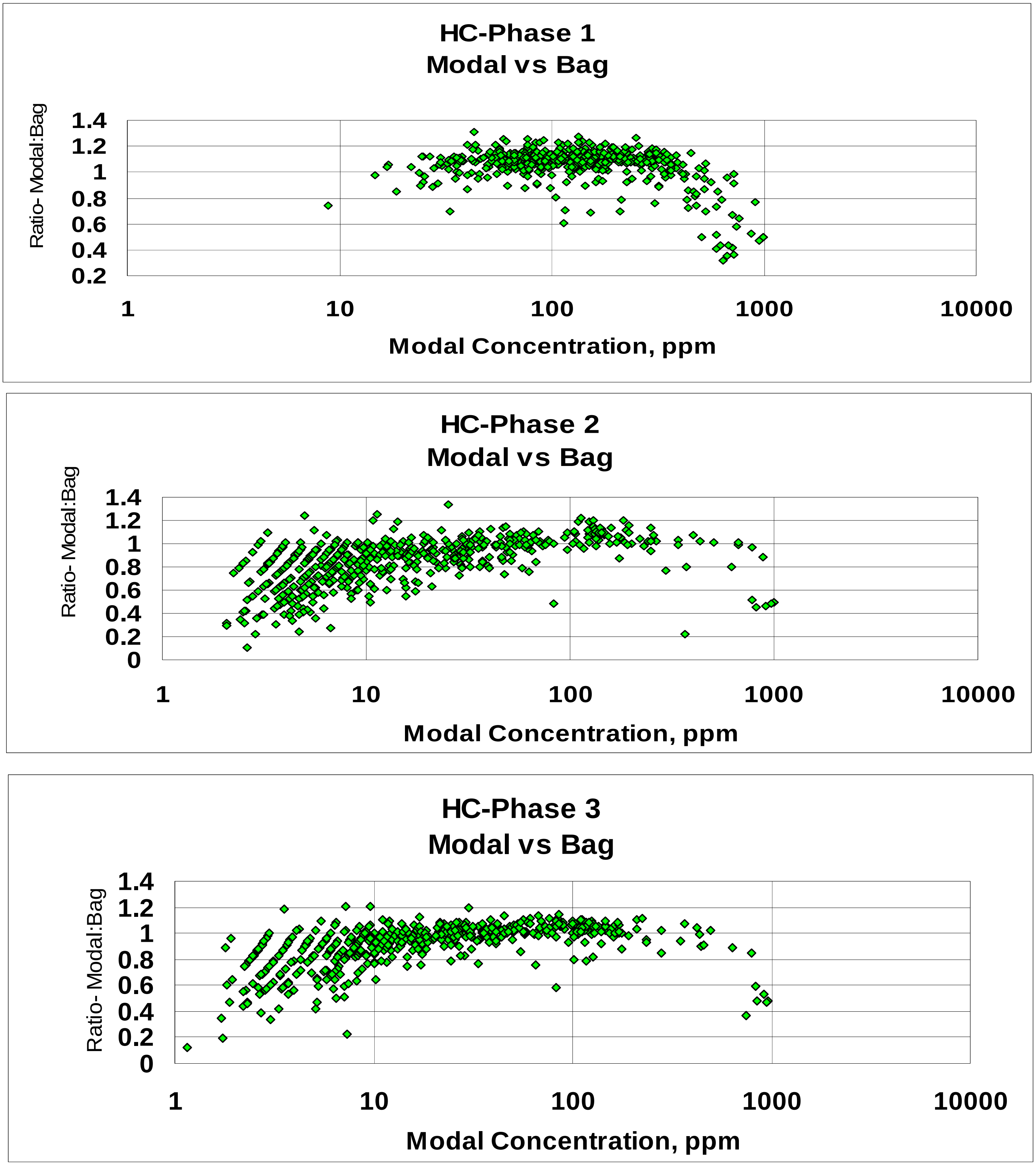


Figure 4-6. By-Phase Modal to Bag HC Ratios vs. Modal HC Concentration, both Rounds

One final note on the modal data, although it was collected and is being reported at the rate of 1 hertz (1 sample per second), the smallest mode that can be realistically resolved is probably on the order of 10 seconds. This is due to the effects of sample transport from the vehicle's exhaust system to the analyzer and inherent analyzer response times. The problem is twofold. First, transient engine-out emissions (spikes) may only last a half second or so. But once diluted and transported to the analyzer, the same emission spike will be recorded by the analyzer as a 5-10 second event. Secondly, exhaust transport times through the vehicle's exhaust system and transfer tube will be changing continuously due to the transient nature of the driving cycles. These effects must be considered when using the data for second-by-second analysis or emissions models. Both true bag and true modal data were collected during this study and are being provided to the EPA for a final determination regarding how the data should be used.

Dynamometer Measurements:

Torque- Zero offset in the torque measurement system was a noticeable, intermittent problem on ~ 25 runs during the first portion of Round 1 testing. The cause of the zero offsets was traced to a faulty connection on an in-line fuse holder within the torque measurement circuit. The fuse holder was replaced and no further problems were encountered. The torque zero offset was calculated for each run in Round 1 as the average torque signal obtained during the engine off portion of the test (T = 1500 to 2000 seconds). Corrections for zero offset were determined and applied only to the Round 1 torque data, as the Round 2 torque data were unaffected by the offset.

Torque data for one run (84141) was lost due to the extremely large offset (177ft-lbs.). The next 24 most affected runs had offsets ranging from 5.54 to 0.10 ft lbs, all of which were satisfactorily corrected. The remaining tests had zero offsets of less than 0.10 ft-lbs. On four runs (84073, 84109, 84214, 84215) only Phase 3 was baseline corrected as the baseline drift apparently began during the hot soak. Torque data from another run (84051) were voided due to negative baseline drift. In addition, the torque board became dislodged during Phase 2 of one test (84279), so only Phase 1 torque data are good for this run.

Torque measurement for another 25 runs in Round 1 was affected when a gain potentiometer was inadvertently adjusted. This affected the real time torque measurement only, not the dynamometer loading circuit nor the readout meter used to set load and display coastdown values. The tests affected by this were conducted from July 20 through July 24 (runs 84051-84076). The potentiometer was readjusted late on July 24, 2004 and from that point forward, was checked on a daily basis during the mid-day blank collection. No further adjustment was required for the remainder of the summer phase. Affected real time data were corrected by applying a correction factor to the second by second data. A correction factor was determined by noting that, on average, the dynamometer set point loading (Hp@ 50 mph) was 89% of the average torque measured during Phase 2 for unaffected runs, while only 55% on affected runs. The correction factor 89/55 = 1.62 was applied to torque for the affected runs.

Torque measurement on one test in Round 2 was affected as a result of the torque board dislodging during the test. The affected test was 84614. For this test, no valid torque measurement was made; however, the torque control system remained functional, maintaining the proper vehicle loading.

The affected runs described in this section are included in the list of known test issues provided in Appendices S and V. In addition, Appendix BB provides results from the pilot study, which shows a good correlation between EPA's dynamometer laboratory in Ann Arbor, Michigan and EPA's portable Clayton dynamometer used for this study.

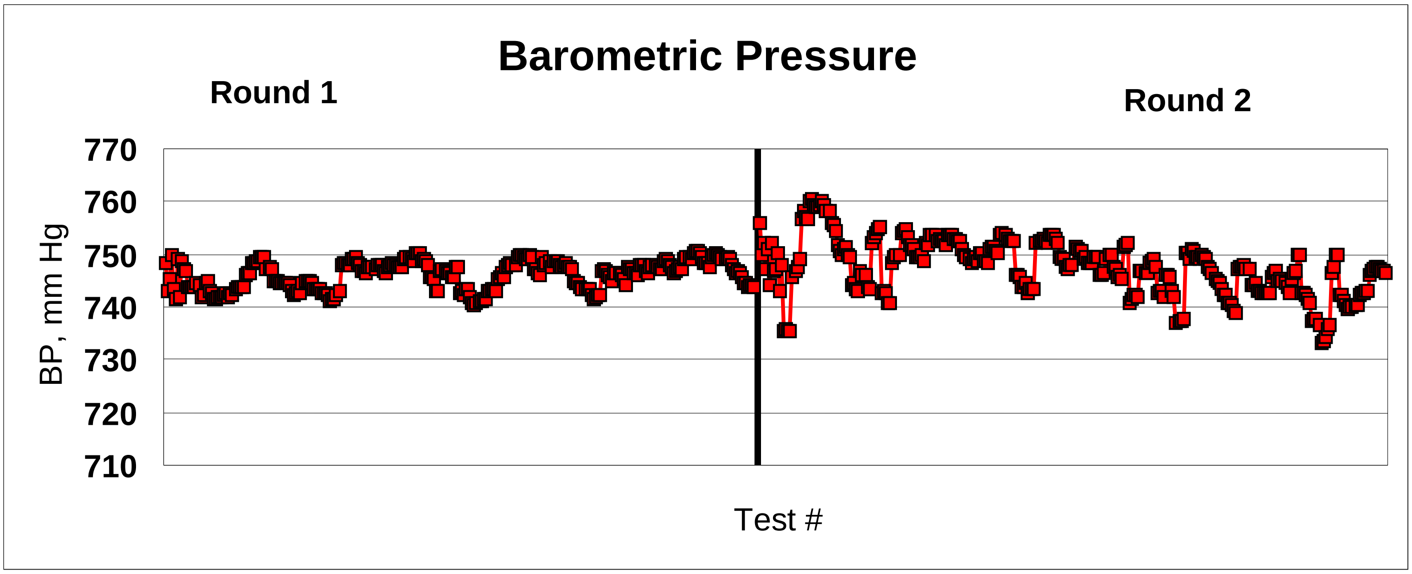
Relative humidity measurements- On a few occasions, the relative humidity sensor was operated on a dead 9 vdc battery, which resulted in invalid relative humidity measurements. The affected Round 2 tests include 84532-84534 on 2/11/05 and 84681-84687 on 3/19/05. The affected Round 1 test is 84258 on 9/8/04. In order to provide humidity/temperature corrected NOx values, the invalid relative humidity data for these tests was supplemented with relative humidity data from the KC airport. Details for all affected tests are provided in Appendices S and V.

Other Chassis Dynamometer Test Conditions

Round 1 and Round 2 test temperatures and barometric pressures are shown in Figure 4-7.

Dilution Tunnel Temperatures: As seen in Figure 4-8, dilution tunnel temperatures, as measured at the PDP inlet, remained fairly constant throughout Round 1 and Round 2 testing. Phase 1 and Phase 3 PDP inlet temperatures remained around 46^{o}C except for a couple of occasions during Round 1 (the dilution heater was not turned on) and also during Round 2 (the heater contactor failed) when temperatures remained near ambient. Phase 2 PDP inlet temperatures were also maintained around 46^{o}C, except for the larger vehicles, where dilution factors were low and raw exhaust temperatures were high, particularly during high vehicle speed and acceleration operation. On twenty of the larger vehicles, Phase 2 tunnel temperatures averaged over 50^{o}C. Tunnel air temperatures should not significantly affect gaseous regulated emission measurements. Temperature effects on particulate measurements are unknown. All tests where the average dilution tunnel temperatures exceeded 50C during any phase are included in the list of known test issues provided in Appendices S and V.

Driving violations- Numerous driving violations (as defined in the CFR for certification testing) were known to occur during the course of testing. Driving violations occurred mostly due to trouble stopping or slowing the test vehicles while following the aggressive deceleration rates of the LA92 driving cycle on the Clayton dynamometer. A few of the older, rear wheel drive vehicles had weak rear brakes to start off with which became weaker as they heated as the cycle proceeded. Many of the newer test vehicles would lose traction on the dynamometer's rolls while braking resulting in "skidding" of the stopped tires on the still moving dynamometer rolls. On the other hand, many of the older test vehicles ran poorly and had trouble maintaining the acceleration rates and higher speeds of the LA92 driving cycle. Driving violations were not quantified, although field notes indicate when obvious trace violations occurred. This information is provided in the list of known test issues provided in Appendices S and V. However, the modal data files contain the actual vehicle speed versus time trace for each test, so driving violations can be analyzed at a later date by comparing target vehicle speed for the LA92 test to that provided in the modal data. In the current presentation of the emissions data, no tests were invalidated due to driving violations.



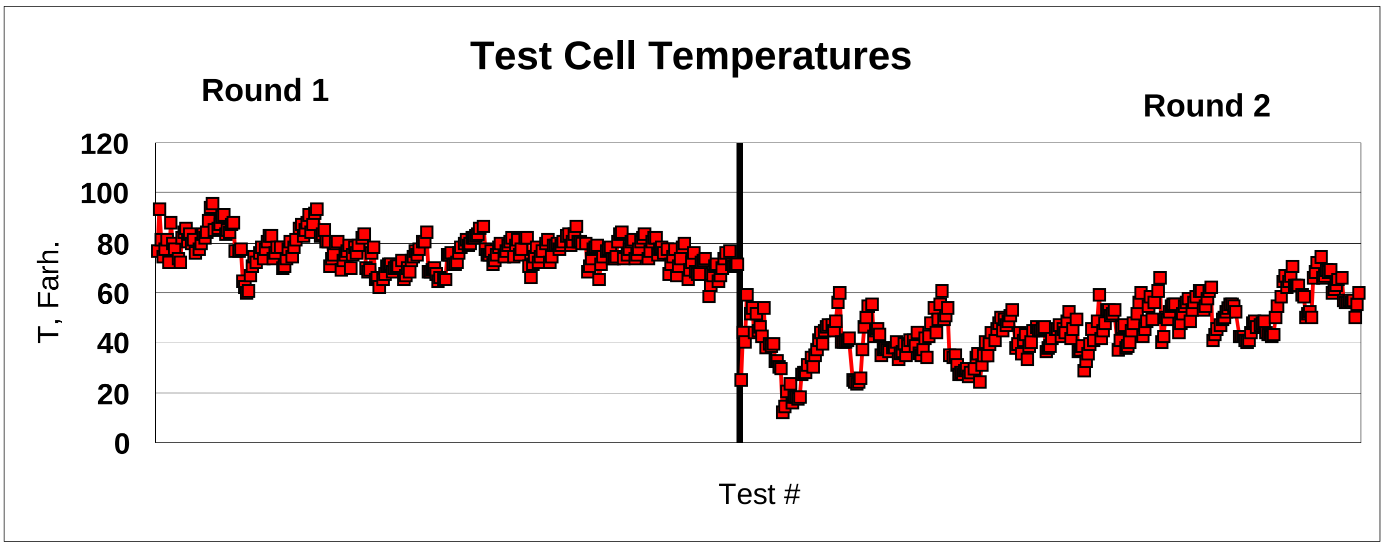


Figure 4-7. Rounds 1 and 2 Test Temperatures and Barometric Pressure

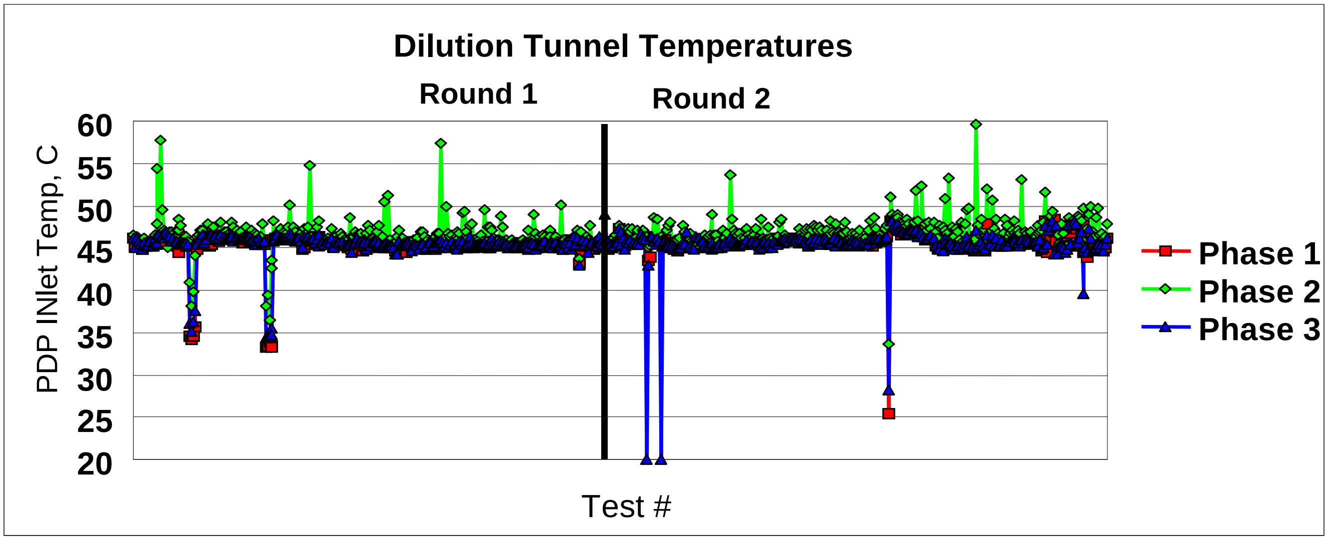


Figure 4-8. Rounds 1 and 2 Dilution Tunnel Temperatures.

HC Background Concentrations: Hydrocarbon background concentrations were measured through the dilution tunnel during the 10-minute engine-off period between Phase 2 and Phase 3. Background concentrations were low, indicating good ventilation through the test area. Average measured concentrations were over 10 ppmC on 4 occasions, as seen in Figure 4-9. These four incidents occurred while testing extremely high HC emitters with known exhaust leaks; however, the HC background could also be elevated due to other vehicles being operated in the area. The HC background as measured through the dilution tunnel during the 10 minute soak was used to perform HC bag/modal reading corrections for all tests, including those in which the background exceeded 10 ppmC. As no limits had been established for background levels, no tests were invalidated due to elevated background levels.

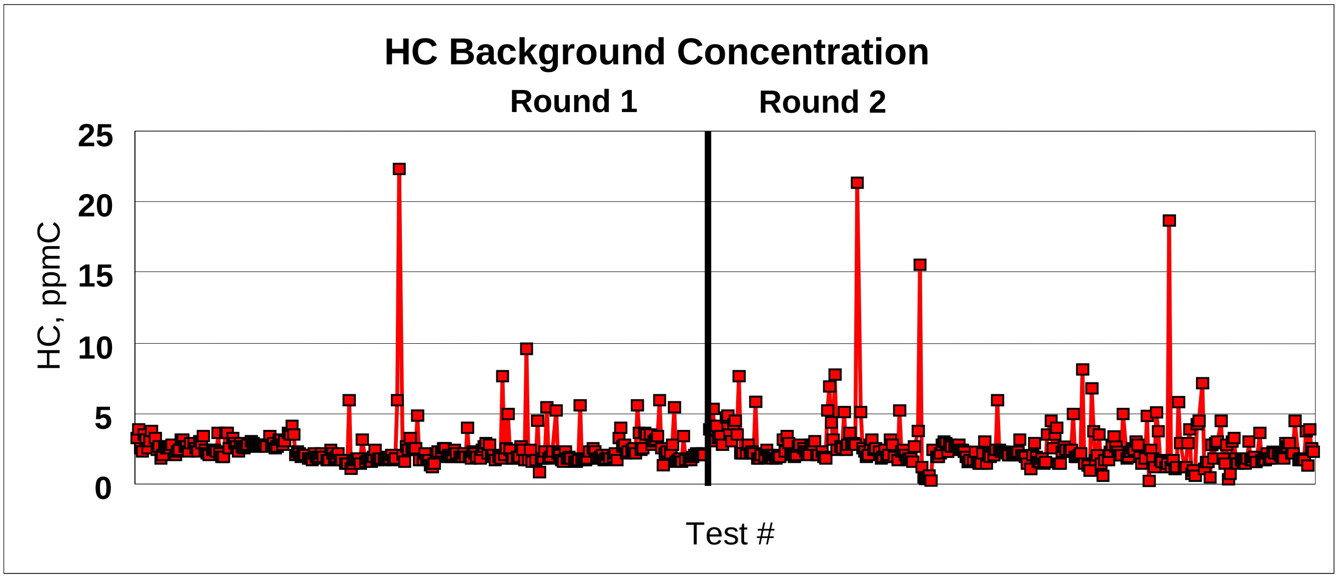


Figure 4-9. Rounds 1 and 2 Tunnel HC Levels With Engine Off Between Phase 2 and Phase 3.

Control Vehicle Tests

Several steps were taken to ensure precise and accurate emission test results were gathered during the Kansas City Study. As described in Appendix BB, a pilot study was conducted using vehicles tested both at EPA's dynamometer laboratory in Ann Arbor, Michigan and at the Kansas City test facility using EPA's portable Clayton dynamometer. After the pilot study was concluded, one of EPA's test vehicles (a 1988 Ford Taurus) was retained to use throughout the Kansas City study to use as a control test vehicle. This section presents regulated emission results from the Round 1 and Round 2 dynamometer testing conducted on the EPA provided control vehicle (EPA975). Additional details on the control vehicle testing, including PEMS results and results from dynamometer testing in Ann Arbor, can be found in Section 4.4.3, *Control Vehicle Results*. A total of 24 chassis dynamometer tests were conducted on the control vehicle in Kansas City using the transportable dynamometer. This included twelve tests in Round 1 and twelve tests in Round 2. Tests were conducted over the cold-start LA92 driving cycle. The control vehicle was fueled using an Indolene fuel provided by EPA. Phase 1, Phase 2, Phase 3, and weighted regulated emission rates and fuel economy results for these tests, along with average emission rates, standard deviations, and coefficients of variation (COV) are presented in Tables 4-3 (HC bag and modal results), 4-4 (NO_x bag and modal results), 4-5 (CO bag and modal results), 4-6 (CO_2 bag and modal results) and 4-7 (Fuel economy bag and modal results). Differences in emission rates and coefficients of variation can be seen from Round 1 to Round 2, particularly in Phase 1 HC and CO emission rates. These differences are more than likely due to ambient temperature effects. Average test temperatures for the control vehicle during Rounds 1 and 2 were 78.9^{o}F and 46.4^{o}F, respectively. The lowest test temperature encountered for the control vehicle during Round 2 was ~ 25 F. This test resulted in extremely high HC emissions for Phase 1 and high CO emission during all three Phases, which skewed Round 2 COVs upward for these compounds, as can be seen in Tables 4-3 and 4-5. Without results from this test included, COVs for Rounds 1 and 2 would be very similar. With the exception of NO_x (to which a humidity correction factor was applied), bag and modal results have not been corrected for temperature, barometric pressure or relative humidity.

With the exceptions noted above, Rounds 1 and 2 COVs for HC, CO, CO_2, and fuel economy were generally less than about 5% for the stabilized Phase 2 and warm-start transient Phase 3. Somewhat higher COVs occurred for the cold-start Phase 1 HC and CO emissions, again presumably the result of cold start ambient temperature conditions. Precision for NO_x was not as good, with the COV at just under 10 % for the humidity corrected NO_x emission rates. Although not shown in the table, the precision for the uncorrected NO_x was somewhat better, with a COV of 5.7 %. This suggests that applying the NO_x correction factor, with such diverse humidity and temperature conditions, is at least partially responsible for the decay in precision for the corrected NO_x emission rates. The NO_x correction factor used for both the PEMS and dynamometer systems is that defined in the Code of Federal Regulations, Title 40, part 86.1342-90. For gasoline combustion, this correction factor is specified as:

$$K_1 = \frac{1}{1 - 0.0047(H - 75)}$$

where H is the absolute humidity in grains of water per pound of dry air. Since this correction factor is based on a relatively small study conducted on pre-catalyst vehicles under limited conditions, it's applicability to extreme temperature and humidity conditions seen in Kansas City may be limited. Future analysis of NO_x emissions using a revised correction factor applicable to a wider temperature/humidity range may be of benefit.

Bag data were also collected on a routine basis as a backup and verification of modal results. Precision for bag HC, CO, CO_2, and fuel economy was similar to the modal results, with coefficients of variation in general less than 5 %. Excellent agreement was also found between modal and bag CO and CO_2 emissions, indicating that no flow/leak problems existed. Bag HC emissions were slightly less than modal HC emissions, probably as a result of some HC absorption on the unheated surfaces of the bag analysis system.

As can be seen in Table 4-4, Bag NO_x values were only ~50-80 % of the modal NO_x values. This is attributable to a known issue with the bag analysis, where older NO_x converters were used. Actually, two different NO_x converters were used over the course of the study. However, neither one maintained its converter efficiency for very long. The second converter, installed in the bag analysis system after the fifth test on the control vehicle, was considerably better than the first for a short period. Phase 1 NO_x values were most affected due to the longer time available for NO conversion to NO2 (all bags were read at the end of the test). Agreement between Phase 3 modal and bag NO_x values were quite good regardless of the NO_x converter issues, which indicates that most of the NO_x was originally emitted as NO. Again, however, the primary intent of collecting bag data was to provide a back-up and cross-check to the modal data. Modal data was collected as the primary source of emissions data, and all "by phase" emissions presented in the report for this study are based on modal data. The cumulative by-phase MSOD data submitted for this project is based on actual tedlar bag samples, as described in Section 5.

4.3 PEMS Test Procedures

PEMS testing was conducted on all vehicles entering the program. The general PEMS installation procedures used during the study are described in the following sections. The various types of PEMS testing conducted during the study are described in Sections 4.3.1.4 through 4.3.1.6.

4.3.1 PEMS Installation and Testing

4.3.1.1 Installation

Prior to the installation of the PEMS, OBDII scans were performed using a handheld scan tool, and readiness status along with pending and confirmed codes were recorded. Detailed information about each vehicle was also collected for future reference to be used in Mobile Source Observation Database (MSOD) table population, including vehicle make, model, model year, odometer, vehicle identification number (VIN), engine displacement, number of cylinders, engine and evaporative family identification numbers, transmission details, and emission control system information. Fuel and oil samples were collected for study vehicles (unless unavailable because of anti-siphon devices).

Once vehicle information was gathered, a warmed-up PEMS unit was installed, along with batteries in the trunk or truck bed of the test vehicle. Two batteries were used for all installations, to prevent system shutdown during conditioning runs and to maximize acquisition time during the driveaway. Flame ionization detector (FID) fuel pressure was checked, and the FID fuel bottle was replaced if under 200 PSI would be available for the conditioning run. A new (full) fuel bottle was always installed for all driveaways. FID exhaust and drainage tubes were connected to the PEMS unit and routed outside the vehicle. Various instruments and sensors were then connected to the PEMS unit, including a vehicle interface (VI) cable, a weather probe, an auxiliary thermocouple, and a Global Positioning System (GPS) antenna. A flowmeter and matching control box were also connected to the PEMS, purged with dry compressed nitrogen gas (flowmeter only), and powered on (all flowmeter boxes remained powered up throughout the day to minimize warm-up time). This flowmeter was attached to the rear of the vehicle using a common bicycle rack which had been slightly modified for use in this study. Vehicle exhaust was routed from the tailpipe to the flowmeter through a silicon tube with stainless-steel unions. A connection from a laptop computer to the PEMS was used to set system parameters and configuration settings, perform audits and calibrations, and control data acquisition.

4.3.1.2 Onsite Quality Assurance

Once the PEMS was physically installed in the test vehicle, several steps were taken to ensure that the PEMS was in proper working order and to ensure that complete accurate test results would be obtained. Prior to each use of the equipment, leak tests were performed for the FID fuel and PEMS systems, internal PEMS pressures and ambient conditions were recorded, and analyzer sample rates were verified. Once initial system checks were complete, and after full system warm-up, the vehicle was started (for conditioning runs only). The vehicle was turned on, allowed to slightly warm up, and the hydrocarbon reading from the road test screen was noted. This reading was used to determine the appropriate calibration range for the vehicle being tested. The unit was recalibrated, if needed and a zero and gas audit were performed. Spans and re-audits were performed if necessary. Additional checks were made to ensure that the equipment was collecting data for VI, GPS, flow, emissions, and other parameters – and that these parameters seemed reasonable upon inspection. The voltages of the two fully-charged batteries were verified. A test session was begun after successful completion of initial system checks, zeros, and audits. Copies of the installation checklists and data collection sheets are included in Appendix J for reference. Complete installation guidelines (details which supplement the installation checklists) are provided in Appendix I.

Once PEMS installation and setup was completed, a person other than the installer (generally the onsite manager) performed a review of the installation, to verify system parameters and confirm proper installation. A copy of this installation review checklist, along with other onsite data quality checks that were performed, is provided in Appendix N.

After every conditioning run, vehicle emissions and fuel economy values measured during the conditioning run were reviewed. If any suspect values were identified, the PEMS system and installation were reviewed to try to determine the source of the problem. If the problem was found, it was corrected (if possible), and the vehicle was given another conditioning run. If a problem was not found, or not correctable, the suspect or faulty equipment was taken out of service for repair. The vehicle was then outfitted with new equipment and another conditioning run was performed.

After onsite checks of the data were performed, the raw (XML) and processed (.csv) files were uploaded daily to the project FTP site for perusal by other project team members. Additional checks on the data were later performed by Austin ERG staff using SAS scripting, including confirmation of the presence of VI and flow data, verification of transport delays, test duration, vehicle speed, and test distance, analysis of audit and calibration data, and evidence of any system faults or warnings.

Further detail on specific PEMS QA procedures can be found in Appendix M: Off-site data quality and results analysis queries, and Appendix N: Onsite installation and data quality checks

4.3.1.3 PEMS Test Issues

The equipment downtime experienced during Round 1 was greatly reduced during Round 2 through the addition of an on-site PEMS repair and support person. Most repairs were minor, such as stuck solenoids, loose or dirty contacts and fittings, water in the system, or blown relays, and were able to be repaired quickly. Most larger repairs, such as system module and CPU board replacements, were also accomplished onsite (after necessary repair items were received onsite). This increase in equipment up-time allowed significantly more driveaways to be conducted in Round 2 than were possible during Round 1 of the study.

As mentioned in Section 2.4.1 (changes from Round 1), the hot-wire anemometer-style flowmeters used throughout the Round 1 summer portion of the study were replaced with pressure-differential style flowmeters for Round 2 of the study. Measurements from the original hot-wire anemometer flowmeters were adversely affected by heat radiation effects at low vehicle speeds and idle. Since convective cooling minimized these effects when vehicles were in motion, low-speed and idle flow measurements were biased low. This bias was eliminated with the use of pressure-differential style flowmeters provided for Round 2 of the study. These flowmeters relied on a bank of differential pressure sensors (as opposed to a hot-wire anemometer) in order to determine corrected mass exhaust flowrates. However, the orifices in the differential pressure sensors used in these new flowmeters were susceptible to PM clogging and moisture freezing. This condition was minimized as much as possible by thoroughly purging all orifices with high-pressure dry compressed nitrogen prior to each use, and by maintaining the flowmeters and tubing assemblies in above-freezing conditions.

Earlier in the study, problems were encountered with preventing moisture and exhaust fumes from entering vehicles during testing. The new flowmeters required additional tubing to be routed out of the trunk (generally requiring the trunk to be propped open wider). Standard household pipe insulation purchased at a hardware store was found to fairly effectively seal trunks. Carbon monoxide detectors were used to ensure vehicle exhaust was not entering the passenger compartment.

As mentioned in Section 2.4.1, Round 2 testing was conducted during the winter, as opposed to the Round 1 summer study. Operation of the PEMS units below freezing temperatures was occasionally necessary, and proved to be problematic because of water freezing in system components and measurement drift. Battery life seemed greatly reduced during Round 2 testing, perhaps due to battery cycle fatigue (these were the original batteries used since the start of the study) and also possibly due to operation in the cold temperatures.

In order to prevent trunks from inadvertently popping open, as would occasionally happen with the original vice-grip-devised trunk latches, heavy-duty zip-ties were used (with metal rings installed in the trunk latch assembly) to secure trunks. These zip ties, which are typically used for securing building ventilation and may be found at a typical hardware store, also prevented motorists from tampering with the PEMS units installed in trunks during driveaway tests.

Experience gained during Round 1 of the study helped streamline Round 2 testing. For example, installation procedures and sequences were modified in order to minimize lost time in the event of equipment malfunctions. Certain “tricks” and procedures for equipment software helped expedite installations and minimize system resets. The incorporation of a session manager into the host software also allowed consolidation of audit and test information into one test file, thereby expediting equipment setup and reducing time needed for test processing and analysis.

4.3.1.4 Conditioning Testing

PEMS units were installed to determine emissions and fuel economy on conditioning runs performed prior to dynamometer testing. After the installation and QC procedures were completed, the flowmeter installation was photographed, and the vehicle was driven on a “conditioning” route (similar in speed, acceleration, and distance to the LA-92 test). This conditioning drive allowed emissions and mileage data to be gathered on all vehicles driven in a consistent manner, and it also allowed all vehicles to be similarly conditioned prior to dynamometer testing. After the conditioning run was completed, a host laptop was connected to the PEMS and the vehicle's fuel economy over the conditioning drive was calculated by using cumulative grams/mile emissions estimates derived from the conditioning run segment of the test record. If the fuel economy estimate from the conditioning run seemed reasonable, the test was stopped, and a post-test audit and zero were performed to help gather information on instrument drift that may have occurred during the conditioning drive. If the fuel economy and/or emissions determined from the conditioning run were not reasonable, the problem was investigated and corrected as described in Section 4.3.1.2.

The overall travel distance for the standard conditioning run was approximately 8 miles over approximately 1300 seconds. Figure 4-10 shows a sample speed and acceleration plot for a typical conditioning run. The speed and acceleration profile for the drive is shown in Figure 4-11.

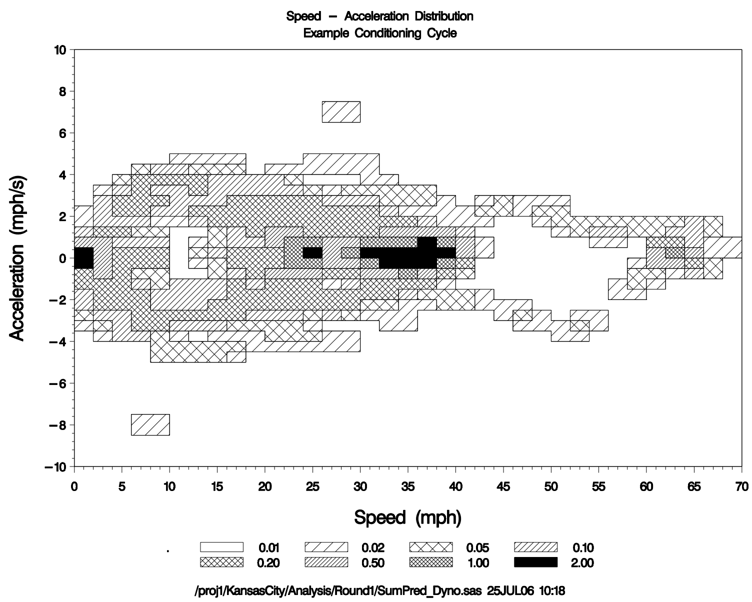


Figure 4-10. Sample Speed Trace for a Dynamometer Conditioning Run

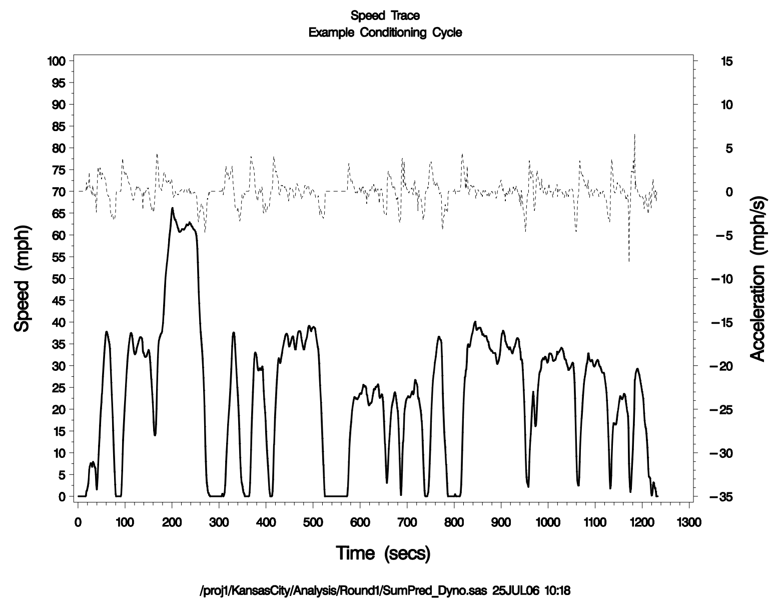


Figure 4-11. Sample Speed-Acceleration Distribution for A Dynamometer Conditioning Run

On occasion, some vehicles could not be tested on the dynamometer for various reasons. Some examples of untestable vehicles include those with four-wheel drive, certain exhaust leaks, rough running/stalling, tailpipe rust, transmission problems, or vehicles that were too large for the dynamometer to handle. For these vehicles, conditioning runs were still performed, but an extended conditioning route (approximately 18 miles) was used for the run. Details of the "standard" 8 mile conditioning route and also of this "extended" conditioning route are provided in Appendix K. Details pertaining to all conditioning runs are provided in Appendix K.

4.3.1.5 Drive-Away Testing

In addition to conditioning and dynamometer testing, some program participants were solicited for "driveaway" testing. This involved installing a PEMS unit on the participant's vehicle, driving the vehicle on the conditioning run, and then releasing the vehicle to the participant (after conditioning run fuel economy and emissions were reviewed, and the setup was independently verified). This conditioning drive allowed emissions and mileage data to be gathered on all vehicles driven in a consistent manner, and it also allowed all vehicles to be similarly conditioned prior to release to the owners. In order to maximize battery life, power supplies were connected to the PEMS units and batteries during troubleshooting and while waiting for motorists to return to pick up their driveaway test vehicles. Immediately before releasing the vehicle to the motorist for the driveaway test, the vehicle's trunk or hatch was sealed with standard household pipe insulation to prevent vehicle exhaust or moisture from entering the vehicle.

Prior to vehicle release, the participant was encouraged to drive the vehicle as much as possible (i.e., by running their weekly errands), and to drive the vehicle as they normally would. This allowed activity, emissions, and fuel economy information to be gathered under "real-world" on-road driving conditions. The PEMS unit continued to operate until the battery supply was depleted, typically 6 to 8 hours of operation. The flame ionization detector used for total hydrocarbon (THC) measurements continued to operate until the PEMS shut down or until FID fuel was depleted, resulting in a loss of THC measurements. Although a THC measurement loss could result in a slight error in fuel economy and THC emission values, this was generally not the case since FID shutdown usually occurred long after the vehicle was parked for the day.

Participants were generally scheduled to return the following day in order to have the PEMS unit removed. Upon their return, they were interviewed about their driving experience and also provided information on passenger pick-ups and drop-offs and any other significant driving events that occurred during testing. Vehicle miles traveled for driveaway runs varied from 13 miles to 66 miles, and the total number of recorded seconds also ranged from 576 seconds to 38,000 seconds.

Although eight PEMS units were provided for Round 1 of the study, equipment malfunctions generally prevented concurrent use of all eight units. This reduced the number of drive-away tests that could be performed during Round 1. Onsite PEMS repair and maintenance support provided during Round 2 greatly reduced equipment downtime, and allowed a significantly higher number of driveaway tests to be conducted.

4.3.1.6 PEMS Testing Concurrent with Dynamometer Testing

PEMS testing was performed in tandem with dynamometer testing, to provide dynamometer vs. PEMS comparative results. Some notable differences between use of the PEMS for dynamometer testing vs. in-vehicle testing (such as conditioning run and driveaway testing) include:

- Rather than exhausting to the environment, the PEMS' flowmeter/sample line assembly was attached directly to the vehicle's exhaust, after which the vehicle's exhaust was routed through the dynamometer's transfer tube to the CVS tunnel. The exhaust sample was drawn from the PEMS's sample port and flow meter tube into the transition tube feeding the dynamometer's CVS.
- Since the vehicle was stationary on the dynamometer, no GPS signal was collected
- An analog voltage signal proportional to dynamometer roller speed (ratio of 0.1 volt = 1 mph) was acquired through external analog input 3. For certain Round 1 tests, speed from external analog input 3 needed to be adjusted by a factor of 10 (tests 84242 – 84392). For still other Round 1 tests, the external analog input 3 was not usable because the voltage signal was found to be erratic during data analysis; in these cases (tests 84153 – 84241) the actual dynamometer speed as recorded by BKI was used. For the remainder of the Round 1 tests, as well as all tests in Round 2, the external analog input 3 signal was found to be accurate. Adjustment of speeds was performed during post-processing and QA of the data using SAS.
- An external event marker switch was used to indicate the start of a run, and also to distinguish between test Phases. However, for accuracy purposes, test-phase delineation was based on test timing rather than manually inserted markers during data analysis.

- Full quality control procedures, as described above in 4.3.1.2, were performed during PEMS/dynamometer testing, including leak checks, zeros, audits, and spans/reaudits as necessary. Emission readings derived from the conditioning testing previously performed were used to determine which concentration calibration gas should be used to calibrate the PEMS unit prior to vehicle testing.

4.4 Regulated Emissions Measurement Results

PEMS sampling was performed concurrently with all dynamometer testing. By-phase and total composite emission rates as measured using each system (PEMS / dynamometer) were then calculated and are presented in the following section. These results are based on time-aligned test data to which the necessary corrections (humidity, dilution, and flow) have been applied.

For each system, phase-specific grams/mile emission rates were calculated by dividing the total phase emissions by the distance the vehicle traveled during that phase. For all calculations, mileage was that as measured by the rear dynamometer rollers. Composite emission rates for the entire run were calculated using the following formula:

$$C = 0.43\left[\frac{Pol1 + Pol2}{D1 + D2}\right] + 0.57\left[\frac{Pol2 + Pol3}{D2 + D3}\right]$$

Where:

C = Composite emission rate for the run (grams/mile)
Pol1 = Total pollutant (HC, CO, CO_2, NO_x or $PM_{2.5}$) emissions for phase 1 (grams/mg)
Pol2 = Total pollutant (HC, CO, CO_2, NO_x or $PM_{2.5}$) emissions for phase 2 (grams/mg)
Pol3 = Total pollutant (HC, CO, CO_2, NO_x, or $PM_{2.5}$) emissions for phase 3 (grams/mg)
D1 = Phase 1 distance traveled (miles)
D2 = Phase 2 distance traveled (miles)
D3 = Phase 3 distance traveled (miles)

4.4.1 Summary of Round 1 Regulated Emissions Measurements

288 dynamometer tests were conducted from July 12, 2004 through October 2, 2004. 47 tests were performed using the new pitot-tube flowmeter, and 241 tests were performed with the hot-wire anemometer flowmeter. Table 4-8 provides a side-by-side comparison of Round 1 PEMS vs. dynamometer composite results aggregated from second-by-second (SBS) data. The PEMS data was obtained using the hot-wire anemometer. Control vehicle test results are not included in Table 4-8. The dynamometer test results are based on speed and emissions time-aligned second-by-second data, integrated for each phase. The PEMS test results were calculated by using speed and emissions time-alignment methodology developed by Sensors, Inc. Although EPA staff identified some incorrect flow rate readings as measured by the PEMS hot-wire anemometer flowmeters, the data presented in Table 4-8 are based on emission rate calculations corrected for these flow inaccuracies.

Table 4-8. By-Test Comparison of Round 1 PEMS vs. Dynamometer Composite Results

RunID	Temp (F)	RH (%)	Composite HC (g/mi)			Composite CO (g/mi)			Composite NO_x (g/mi)			Composite CO_2 (g/mi)			PM2.5 (mg/mi)	PEMS DATASuspect	Dyno DATASuspect
			PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff			
84032	82.3	55.9	0.05	0.12	62.14	0.49	0.43	12.9	0.09	0.1	8.1	358.89	359.64	0.21	2.667	x	
84034	84.1	59.4	0.1	0.12	15.75	3.12	2.15	45.04	0.54	0.46	17.11	553.22	502.92	10	2.735		
84035	85.6	58.1	0.26	0.29	11.34	4.84	3.47	39.47	0.58	0.51	12.41	829.64	697.48	18.95	5.943		
84036	80.5	65.7	0.2	0.2	2.59	7.48	6.64	12.7	1.64	1.63	1.07	343.57	347.55	1.15	1.861	x	
84037	83.2	58.5	2.18	1.55	40.93	54	32.34	66.98	1.86	1.25	48.88	999.49	659.41	51.57	9.205	x	
84039	79.5	79.7	0.17	0.22	22.77	2.42	2.05	17.72	0.23	0.18	31.51	687.53	668.97	2.77	2.705		
84042	76.0	75.6	0.32	0.31	2.08	5.54	4.74	17.02	0.67	0.63	6.23	322.05	318.2	1.21	2.717		
84043	77.5	70.5	0.63	0.57	11.74	12.34	10.41	18.57	2.43	2.31	5.14	328.11	288.37	13.78	3.551		
84047	79.9	66.2	0.12	0.14	16.4	1	0.87	15.61	0.07	0.07	0.31	426.67	437.27	2.42	1.735		
84048	83.2	63.9	0.95	1.1	13.26	9.77	9.04	8.1	3.36	3.41	1.35	404.66	419.55	3.55	60.070		
84050	82.0	80.3	0.07	0.08	7.8	3.35	2.88	16.55	0.07	0.06	30.9	422.82	365.13	15.8	1.589		
84051	84.0	71.8	0.17	0.18	4.48	5.25	5.15	1.92	0.83	0.86	3.59	340.36	359.84	5.42	0.580		
84052	89.1	60.0	0.48	0.47	3.12	6.28	5.22	20.17	2.13	2.1	1.38	496.24	457.68	8.42	5.563		
84054	94.1	47.5	0.19	0.21	7.45	3.16	2.83	11.69	1.17	1.1	5.74	520.38	507.74	2.49	2.641		
84055	95.8	50.1	1.1	1.06	3.37	11.62	9.7	19.79	5	4.13	20.92	598.08	504.1	18.64	4.883		
84056	85.4	70.3	0.1	0.1	0.79	3.86	3.43	12.43	0.31	0.3	5.07	532.78	531.17	0.3	1.468		
84057	85.9	69.2	0.51	0.51	1.8	16.55	16.17	2.34	0.1	0.09	6.16	274.9	280.47	1.99	1.213		
84058	87.3	65.2	0.12	0.13	10.7	0.97	0.92	5.39	0.29	0.33	10.84	453.18	459.34	1.34	1.123		
84060	90.3	63.8	0.1	0.1	0.5	1.11	1	10.46	0.96	0.93	3.1	454.28	472.34	3.82	1.080		
84061	91.5	57.7	0.59	0.53	10.71	5.9	4.87	21.29	1.11	1.06	4.17	408.73	350.69	16.55	1.573		
84062	83.9	80.3	0.07	0.07	5.39	0.71	0.64	11.19	0.86	0.92	6.37	442.69	479.74	7.72			
84063	85.3	72.5	0.13	0.13	0.83	0.71	0.78	9.57	0.54	0.55	1.53	310.08	340.02	8.8	2.144		
84064	84.7	72.3	0.27	0.28	2	4.1	3.36	22.28	1.23	1.27	2.51	426.96	441.66	3.33			
84066	87.4	66.1	1.12	0.46	**142.77**	27.96	15.44	81.07	0.59	0.37	58.1	672.38	434.73	54.66	6.465		x

RunID	Temp (F)	RH (%)	Composite HC (g/mi)			Composite CO (g/mi)			Composite NO_x (g/mi)			Composite CO_2 (g/mi)			PM2.5 (mg/mi)	PEMS DATASuspect	Dyno DATASuspect
			PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff			
84067	87.8	65.0	0.4	0.44	9.02	5.99	5.51	8.74	1.48	1.58	6.15	425.97	443.94	4.05	1.944		
84068	76.7	88.6	0.09	0.11	12.8	2.42	1.97	22.77	0.29	0.32	10.11	440.7	463.2	4.86	0.404		
84069	76.8	84.1	0.2	0.21	8.53	1.56	1.44	8.32	0.63	0.68	6.85	408.86	444.44	8	0.566		
84071	77.2	84.5	2.63	2.23	18.02	14.42	11.21	28.6	3.68	5.29	30.48	410.91	340	20.86	38.519		
84072	64.7	92.0	0.07	0.1	22.2	0.63	0.54	15.42	0.19	0.19	0.17	494.59	512.39	3.47	1.614		
84073	62.4	84.5	0.38	0.39	2.49	5.93	6.07	2.31	1.42	1.44	1.1	439.84	455.74	3.49	3.083		
84074	60.2	88.5	0.51	0.36	44.49	18.22	12.17	49.77	6.12	4.52	35.26	512.97	388.82	31.93	6.481		
84076	61.1	92.3	4.94	4.7	5.03	66.23	67.86	2.4	3.87	3.34	15.68	515.34	474.27	8.66	16.155		
84077	66.6	85.0	0.08	0.07	10.87	3.24	3.17	2.26	0.19	0.2	7.11	252.5	263.19	4.06	0.905		
84078	70.4	70.3	0.12	0.12	3.12	2.27	2.75	17.45	0.31	0.31	0.81	353.85	380.25	6.94	0.554		
84079	74.1	61.9	2.6	1.86	39.81	101.49	63.78	59.11	1.64	0.98	67.65	675.47	368.01	83.55	32.506	x	x
84082	71.9	53.0	0.05	0.06	9.09	0.55	0.44	23.56	0.11	0.11	0.15	446.18	456.78	2.32	1.068		
84083	76.1	42.5	0.09	0.09	1.94	2.89	3.12	7.35	0.2	0.18	12.17	365.09	366.75	0.45	0.850		
84084	78.0	38.4	0.11	0.12	9.68	1.07	1.02	4.93	0.74	0.65	14.28	396.86	413.29	3.98	0.711		
84086	73.7	49.4	0.1	0.1	1.81	1.36	1.33	2.29	0.1	0.11	7.94	535.43	505.9	5.84	2.760		
84087	77.4	44.1	0.12	0.11	7.06	1.26	1.11	13.23	0.4	0.35	13	382.21	394.33	3.07	1.757		
84088	80.1	40.8	0.22	0.23	7.24	2.23	2.32	3.99	1.35	0.53	**152.28**	413	446.05	7.41	1.304		
84090	83.1	40.5	0.11	0.13	15.49	1.31	1.21	8.47	0.36	0.35	3.65	458.94	467.92	1.92	0.693		
84091	82.9	43.9	0.26	0.28	8.13	5.61	5.52	1.59	0.84	0.72	17.69	521.32	519.31	0.39	1.053		
84092	73.9	58.1	0.05	0.07	19.16	0.54	0.5	6.86	0.97	0.88	10.15	285.43	313.93	9.08	1.452		
84093	75.7	51.1	0.15	0.19	21.33	1.54	1.5	2.46	0.68	0.6	14.23	334.93	366.35	8.58	1.327		
84094	78.0	47.1	0.28	0.3	6.74	9.66	8.4	14.93	2.47	1.89	31.06	522.59	510.49	2.37	2.055		
84096	78.6	45.7	0.95	1.04	8.92	10.44	10.25	1.87	1.89	1.62	16.79	507.19	486.87	4.17	5.146		
84097	69.9	65.0	0.06	0.08	20.46	0.31	0.2	57.76	0.09	0.09	0.47	429.7	435.3	1.29	0.809		
84098	70.8	63.5	0.16	0.16	1.04	1.61	1.38	16.51	0.41	0.36	13.31	468.78	483.86	3.12	0.603		
84099	73.4	57.6	0.3	0.32	5.93	1.85	1.74	6.45	0.42	0.38	10.93	376.14	411.83	8.67	3.350		

RunID	Temp (F)	RH (%)	Composite HC (g/mi)			Composite CO (g/mi)			Composite NO_x (g/mi)			Composite CO_2 (g/mi)			PM2.5 (mg/mi)	PEMS DATASuspect	Dyno DATASuspect
			PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff			
84101	77.4	49.9	0.56	0.55	1.79	26.29	22.72	15.69	2.58	2.16	19.71	380.55	381.24	0.18	10.186		
84102	80.8	44.5	0.18	0.19	4.99	7.23	7.13	1.4	0.67	0.59	13.13	246.24	252.93	2.64	0.717		
84103	74.6	60.7	0.16	0.17	7.42	1.08	1	7.8	0.56	0.48	16.35	423.43	424.34	0.22	0.459		
84104	78.1	55.7	0.18	0.18	3.6	2.16	2.16	0.01	0.86	0.71	20.27	470.87	490.8	4.06	1.640		
84105	81.1	51.7	0.31	0.32	2.72	4.77	4.36	9.47	0.59	0.54	8.46	286.23	300.67	4.8	1.264		
84107	86.0	39.4	0.25	0.27	6.89	4.06	3.78	7.31	0.86	0.73	17.14	454.52	451.4	0.69	3.963		
84108	87.6	38.7	0.68	0.64	5.63	14.14	12.21	15.81	3.15	2.65	18.8	349.93	323.96	8.01			
84109	83.0	59.1	0.16	0.17	6.63	2.07	1.96	5.52	0.88	0.75	18.46	468.47	475.23	1.42			x
84110	84.7	56.8	0.19	0.19	4.23	5.31	5.04	5.19	0.63	0.58	7.96	346.26	349	0.78	10.088		
84111	88.4	51.6	0.18	0.17	4.52	2.57	2.33	10.15	1.06	0.91	16.6	449.39	464.32	3.22	4.147		
84115	84.0	57.1	0.22	0.23	6.39	7.84	5.92	32.56	0.58	0.7	17.92	361.49	362.39	0.25		x	
84116	87.6	49.5	0.21	0.2	5.12	2.94	2.43	21.27	0.77	0.91	15.94	464.24	465.33	0.24		x	
84119	91.9	44.5	1.57	1.83	14.18	13.25	13.96	5.12	5.67	5.7	0.67	504.9	506.36	0.29		x	
84121	82.9	60.0	0.06	0.08	20.56	0.5	0.39	27.73	0.06	0.08	15.37	453.09	454.15	0.23	0.718	x	
84122	83.3	57.5	0.14	0.17	13.89	1.25	1.31	4.69	0.35	0.34	3.1	469.83	470.91	0.23	1.847	x	
84123	85.1	56.2	0.85	0.91	6.5	26.57	25.94	2.42	1.02	1.04	1.93	264.32	264.99	0.25		x	
84126	80.5	61.7	0.78	0.84	7.51	10.08	11.56	12.88	1.53	1.73	11.35	505.74	507.19	0.29	2.971	x	
84128	73.5	47.6	0.24	0.24	2.22	2.74	3.03	9.81	0.41	0.45	9.4	399.38	400.4	0.25	4.448	x	
84129	75.4	45.2	0.21	0.24	11.63	3.12	3.27	4.73	0.38	0.43	12.78	368.91	369.72	0.22	2.529	x	x
84131	79.4	38.8	0.14	0.15	7.94	4.41	3.73	18.33	0.55	0.59	7.26	361.6	362.3	0.19	2.209	x	
84132	80.3	38.3	0.99	1.08	8.73	12.24	11.43	7.08	2.3	2.47	6.87	460.73	461.58	0.18	4.399	x	
84133	68.8	53.0	0.15	0.15	2.19	1.25	1.25	0.42	0.3	0.35	12.62	438.83	439.81	0.22	0.901	x	
84134	72.9	43.6	0.25	0.28	12.29	9.34	8.29	12.66	1.66	1.61	2.72	525.48	519.88	1.08	2.051		
84135	75.2	38.3	0.4	0.43	7.05	4.7	5.02	6.4	0.59	0.57	4.34	352.89	386.86	8.78	2.257		
84137	76.9	34.9	0.4	1.04	61.57	4.17	10.16	58.92	0.58	2.37	75.53	176.3	463.33	61.95		x	
84140	75.1	44.9	0.08	0.09	13.19	1.02	1.01	1.01	0.23	0.21	6.14	460.13	505.35	8.95			

RunID	Temp (F)	RH (%)	Composite HC (g/mi)			Composite CO (g/mi)			Composite NO_x (g/mi)			Composite CO_2 (g/mi)			PM2.5 (mg/mi)	PEMS DATASuspect	Dyno DATASuspect
			PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff			
84145	79.2	49.2	1.12	1.15	2.78	14.79	13.71	7.86	2.39	2.07	15.48	281.88	279.58	0.82	1.344		
84146	82.4	46.6	1.51	1.18	28.04	12.94	9.78	32.24	1.97	1.62	21.4	453.86	376.33	20.6			
84148	83.8	43.5	1.91	1.16	64.14	17.53	7.67	**128.7**	4.42	3.43	28.97	533.7	429.21	24.35	46.326	x	
84149	69.6	49.4	0.07	0.08	15.79	0.71	0.71	0.26	0.07	0.09	19.64	293.88	341.68	13.99	0.959		
84150	68.3	48.5	0.16	0.16	1.45	4.6	4.44	3.59	0.38	0.37	2.67	511.06	511.43	0.07	4.786	x	
84151	69.4	46.8	0.08	0.09	11.95	1.92	3.32	42.29	0.21	0.21	1.84	373.98	399.82	6.46			
84153	76.0	38.1	0.11	0.12	5.19	0.83	0.66	25.32	0.49	0.4	22.15	573.64	569.86	0.66	6.948		
84154	78.4	33.7	23.02	12.04	91.22	177.32	112.41	57.75	6.65	4.58	45.36	932.19	563.62	65.39	80.266	x	x
84156	65.4	59.4	0.11	0.11	3.82	4.96	4.64	6.91	0.24	0.22	9.73	361.58	393.14	8.03			
84157	65.9	54.5	0.49	0.46	6.23	6.19	5.64	9.86	0.8	0.82	3.29	281.97	297.23	5.13	2.989		
84160	62.0	56.0	0.13	0.12	0.77	2.29	2.07	10.72	0.39	0.35	14.23	394.08	382.2	3.11	0.669		
84161	65.4	52.9	0.23	0.25	4.17	0.99	0.98	0.43	0.75	0.78	4.59	478.11	479.84	0.36	6.567	x	x
84162	67.3	41.7	0.65	0.47	38.08	27.86	23.98	16.2	1.34	0.81	65.95	711.57	422.92	68.25	25.586	x	
84164	70.8	36.6	0.18	0.19	3.14	1.54	1.46	5.88	0.27	0.26	1.46	408.6	454.16	10.03			
84165	71.6	37.5	3.57	3.39	5.25	14.02	12.96	8.11	4.75	4.4	7.82	323.41	313.81	3.06	19.417		
84166	71.5	39.2	0.36	0.34	5.63	7.82	7.07	10.63	1.35	1.24	8.26	431.62	435.04	0.78	0.690		
84168	70.1	46.7	0.12	0.14	14.74	2.11	1.97	6.92	0.76	0.78	2.48	445.32	446.85	0.34		x	
84169	70.7	44.0	0.26	0.27	4.8	6.02	4.8	25.56	1.1	1.28	14.48	424.72	426.15	0.33		x	
84171	70.8	44.8	2.77	1.18	**134.28**	29.06	14.79	96.46	2.09	1.37	52.59	451.7	277.37	62.85	40.870	x	
84172	73.0	39.6	0.39	0.45	13.06	6.75	5.72	18.14	0.78	0.93	16.32	472.75	428.61	10.3	13.510		
84173	65.2	57.5	0.45	0.47	4.29	5.38	5.18	3.74	1.16	1.12	3.38	357.56	376.71	5.08		x	
84174	66.9	54.6	0.36	0.37	2.69	2.16	1.65	31.23	1.54	1.29	19.17	538.76	532	1.27		x	
84175	70.1	47.8	1.31	1.26	4.34	8.27	7.75	6.76	2.05	1.71	19.83	460.86	446.42	3.23	3.696		
84178	68.7	54.4	0.22	0.23	2.79	2.96	2.67	10.79	0.65	0.61	7.03	363.72	396.68	8.31	1.165		
84179	72.9	43.5	0.48	0.49	1.71	7.4	6.67	10.93	1.57	1.28	23.06	509.54	498.51	2.21	1.972		
84180	74.6	44.4	1.32	1.33	1.24	10.27	9.09	12.97	2.34	2	17.34	461.23	465.02	0.82	9.349		

RunID	Temp (F)	RH (%)	Composite HC (g/mi)			Composite CO (g/mi)			Composite NO_x (g/mi)			Composite CO_2 (g/mi)			PM2.5 (mg/mi)	PEMS DATASuspect	Dyno DATASuspect
			PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff			
84182	76.7	45.1	0.71	0.47	53.35	20.37	12.04	69.1	2.55	1.4	82.37	900.91	562.68	60.11	12.074		
84183	74.8	58.9	0.15	0.14	5.73	1.89	1.54	22.3	0.57	0.59	3.95	297.19	332.35	10.58			
84184	77.6	53.1	0.16	0.15	7.12	8.19	7.05	16.2	0.13	0.11	23.91	303.94	320.72	5.23	1.944		
84185	80.5	50.6	0.34	0.36	3.75	5.31	4.85	9.42	0.78	0.68	15.72	299.76	309.48	3.14	3.319		
84188	80.2	45.7	6.68	4.67	42.96	86.71	65.36	32.66	2.69	2.1	27.66	626.1	499.83	25.26	40.325		
84189	84.4	41.4	2.25	18.42	87.79	252.9	198.38	27.48	1.98	1.51	31.4	429.35	347.12	23.69	287.856		x
84191	68.4	45.9	0.32	0.22	46.45	2.32	2.11	9.72	0.38	0.38	1.28	351.62	379.88	7.44	2.254		
84192	68.7	45.6	0.09	0.07	35.64	1.1	1.09	1.34	0.21	0.19	7.05	460.46	502.92	8.44	5.243		x
84193	68.9	45.0	0.09	0.1	13.08	3.52	2.97	18.87	0.56	0.56	0.21	405.09	434.16	6.7	5.842		
84195	70.2	44.1	0.09	0.13	36.08	1.1	1	10.13	0.51	0.4	28.1	407.91	448.15	8.98	0.572		
84196	68.0	51.4	1.23	2.06	40.51	15.75	14.98	5.15	3.5	3.03	15.73	485.34	475.38	2.09	8.027		
84197	64.3	66.6	0.32	0.35	9.46	6.51	6.51	0.04	2.09	2.07	1	360.07	420.63	14.4	0.969		
84198	65.8	63.2	0.41	0.42	2.91	4.07	4.92	17.18	0.58	0.58	1.46	289.04	346.82	16.66	2.165		
84200	65.2	68.8	0.46	0.48	3.51	5.45	6.26	12.82	0.67	0.66	1.89	294.91	355.58	17.06			
84201	65.0	67.6	5.95	5.66	5.24	72.76	78.19	6.94	3.97	3.47	14.3	433.29	413.92	4.68	12.512		
84205	75.1	68.8	0.15	0.14	4.07	4.38	3.49	25.59	0.77	0.56	38.59	610.43	601.46	1.49	8.527		
84206	75.2	67.1	0.87	0.8	8.76	13.89	13.02	6.65	0.89	0.65	37.54	576.25	574.84	0.25	1.392		
84208	75.7	66.8	2.23	2.21	1.11	31.08	28.44	9.28	4.68	3.9	20.15	513	500.58	2.48	54.502	x	
84209	71.7	71.1	0.48	0.52	6.43	11.52	12.33	6.55	4.41	3.77	17.09	401.39	404.63	0.8			
84210	71.3	69.7	0.7	0.82	14.17	12.51	11.52	8.56	3.24	2.87	12.82	340.46	338.87	0.47	12.448		
84211	71.9	69.1	0.45	0.46	3.6	11.18	9.59	16.52	1.22	1.04	17.35	431.67	416.66	3.6	31.956		
84213	75.7	54.3	0.68	0.59	14.07	31.47	23.22	35.57	1.25	0.97	28.56	564.77	551.42	2.42	6.098		
84214	78.6	61.5	0.05	0.15	67.84	2.09	1.92	8.58	0.85	0.63	34.34	479.04	490.94	2.42	6.799		
84215	79.8	58.5	0.1	0.19	48.08	2.46	2.03	21.23	0.84	0.63	33.49	440.71	450.1	2.09	3.811		
84242	79.2	10.4	0.15	0.25	38.71	1.37	1.34	2.3	0.62	0.43	44.75	425.81	452.08	5.81			
84244	80.8	45.4	0.95	1.56	38.78	23.32	20.15	15.7	3.09	2.98	3.82	365.96	327.95	11.59	22.176		

RunID	Temp (F)	RH (%)	Composite HC (g/mi)			Composite CO (g/mi)			Composite NO_x (g/mi)			Composite CO_2 (g/mi)			PM2.5 (mg/mi)	PEMS DATASuspect	Dyno DATASuspect
			PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff			
84245	81.8	24.3	1.13	2.97	61.82	26.69	18.05	47.81	3.44	2.13	61.27	576.97	382.58	50.81	48.725	x	
84246	74.7	49.7	0.58	0.73	20.6	12.84	10.54	21.79	1.68	1.21	38.9	505.35	493.75	2.35	23.560		
84250	81.1	46.2	0.95	2.93	67.72	33.67	27.26	23.51	2.68	2.57	4.44	342.18	316.52	8.11	10.171		
84252	75.1	34.4	0.12	0.16	24.56	1.33	1.24	7.77	0.11	0.06	88.23	462.3	467.93	1.2			
84253	77.7	35.8	0.14	0.21	33.92	5.88	5.04	16.59	1.08	0.92	17.17	451.6	444.32	1.64			
84256	81.7	36.9	0.23	0.42	45.76	9.99	8.86	12.77	1.54	1.44	7.5	432.05	445.46	3.01	6.269		
84257	82.1	37.1	0.4	0.55	27.24	6.47	5.69	13.76	2.56	2.19	17.01	476.04	464.02	2.59			
84258	70.8	1.5	0.26	0.29	9.59	3.96	4.23	6.46	2.04	1.49	36.95	458.31	483.61	5.23	4.880		x
84261	66.0	65.7	0.87	1.22	29	11.1	11.69	4.99	1.93	2	3.6	154.42	170.06	9.19	9.607	x	
84262	71.8	50.2	0.28	0.44	35.04	9.32	8.32	11.97	1.8	1.57	14.46	463.88	486.53	4.66			x
84263	74.5	41.8	0.86	1.2	28.65	52.41	42.59	23.04	2.68	2.58	3.75	387.27	396.37	2.3	19.701		
84265	78.4	37.2	0.92	11.11	91.69	57.84	132.78	56.43	0.73	1.23	40.73	320.45	515.74	37.87	153.506		
84266	72.3	54.8	0.05	0.09	37.52	0.4	0.3	34.39	0.13	0.14	7.02	320.85	359.95	10.86	2.271		
84267	74.3	47.5	0.24	0.34	27.99	5.95	5.56	6.85	1.28	1.19	7.27	367.62	374.95	1.96	3.600		
84268	76.7	39.8	0.5	0.72	31.29	3.31	2.72	21.6	4.59	3.81	20.52	629.69	586.28	7.41	25.712		
84270	79.6	30.6	0.71	0.94	25.05	12.16	11.1	9.56	1.89	1.71	10.38	504.6	497.67	1.39	24.542		
84271	81.5	30.2	0.86	1.28	32.45	13.26	11.8	12.31	9.17	7.51	22.18	540.77	505.67	6.94	5.753		
84272	72.3	65.2	0.08	0.08	1.08	1.03	1.14	9.7	0.08	0.08	2.01	409.29	424.22	3.52	1.957		
84274	74.4	49.6	0.53	0.5	7.01	8.24	7.29	13.03	2.14	1.87	14.07	292.09	305.88	4.51	5.607		
84276	78.7	33.8	0.2	0.21	0.92	2.67	2.48	7.48	1.38	1.12	22.71	474.2	465.55	1.86	1.967		
84277	79.3	30.4	19.51	14.49	34.62	304.96	149.22	**104.37**	1.19	1.02	16.46	507.06	265.49	90.99	260.854	x	
84278	79.9	33.7	0.61	0.57	7.23	11.29	10.73	5.18	0.74	0.63	18.02	440.4	424.36	3.78	11.551		
84279	77.1	47.2	0.09	0.11	18.12	5.48	4.02	36.29	0.2	0.18	12.26	443.29	467.22	5.12	4.789		x
84280	78.9	44.4	0.08	0.08	3	3.34	2.93	13.81	0.7	0.65	7.68	305.53	314.33	2.8	1.076		
84281	80.5	38.7	0.49	0.47	4.09	12.69	11.12	14.12	1.56	1.22	28.34	713.07	653.66	9.09	9.896		
84283	82.8	37.2	7.79	5.75	35.46	106.71	78.62	35.74	2.41	1.65	46.12	663.41	429.87	54.33	73.083	x	x

RunID	Temp (F)	RH (%)	Composite HC (g/mi)			Composite CO (g/mi)			Composite NO_x (g/mi)			Composite CO_2 (g/mi)			PM2.5 (mg/mi)	PEMS DATASuspect	Dyno DATASuspect
			PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff			
84284	83.9	35.6	1.46	1.31	12.04	40.52	29.33	38.13	5.71	4.58	24.63	556.28	516.67	7.67	72.460		
84285	79.2	56.1	0.12	0.13	11.01	5.94	5.7	4.24	0.12	0.14	11.81	295.44	337.93	12.57	2.000		
84286	80.7	53.0	0.2	0.23	11.64	5.43	5.15	5.41	2.72	2.21	23.1	547.65	531.74	2.99	2.888		
84287	83.5	49.8	1.2	0.64	87.61	12.12	7.57	60.15	2.67	1.55	72.17	721.21	488.37	47.68	48.349	x	
84289	86.7	41.2	5.66	4.96	14.21	79.72	69.04	15.46	5.56	4.96	12.17	514.29	456.03	12.77	163.729		x
84291	80.4	56.4	0.21	0.28	23.67	3.54	4.34	18.47	0.35	0.36	1.1	228.46	283.81	19.5	5.454		
84292	80.8	56.9	0.29	0.28	4.11	10.1	7.53	34.16	0.95	0.76	24.53	432.66	411.99	5.02	11.424		
84293	79.7	61.8	1.23	1.1	12.43	11.93	10.07	18.53	3.11	2.55	22.24	475.82	408.26	16.55	6.235		
84295	79.5	59.8	8.09	4	**102.05**	50.87	44.74	13.71	3.34	2.54	31.42	562.93	498.48	12.93	58.905		
84296	68.1	64.6	0.08	0.09	16.5	3.64	3.66	0.37	0.07	0.08	3.26	257.72	276.26	6.71	3.077		x
84297	70.9	50.9	0.37	0.36	2.48	9.17	8.5	7.9	0.86	.		410.81	387.82	5.93	1.762		x
84298	74.0	44.2	0.26	0.23	10.94	10.17	7.55	34.72	1.15	0.86	33.52	900.28	694.88	29.56	27.060		
84300	77.1	33.1	0.17	0.18	5.17	1.96	1.88	4.32	0.42	0.39	7.68	456.95	459.54	0.56	1.305		
84301	78.1	31.3	5.12	3.35	52.57	58.69	31.8	84.53	2.7	1.66	62.71	822.24	467.13	76.02	9.748	x	x
84302	79.1	32.1	0.5	0.53	6.83	6.81	6.14	10.94	2.16	1.9	13.65	573.72	535.35	7.17	7.079		
84303	65.1	63.6	0.06	0.07	21.51	0.88	0.75	16.98	0.32	0.25	30.28	581.99	516.09	12.77	2.529		
84304	71.2	47.3	0.04	0.05	25.73	1.17	1.07	8.75	0.15	0.15	3.37	311.6	328.26	5.08	2.158		
84305	74.2	42.5	0.12	0.13	5.26	1.72	1.7	1.1	0.58	0.52	10.08	403.45	409.78	1.55	1.305		
84307	76.8	41.1	0.2	0.22	8.96	3.81	3.6	5.71	0.6	0.6	0.31	385.04	392.86	1.99	1.710		
84308	77.4	42.3	0.25	0.27	6.61	8.39	8.04	4.39	2.32	2.04	13.88	405.69	409.38	0.9	4.001		
84309	78.2	42.1	11.96	9.21	29.91	234.68	173.08	35.59	2.44	2.14	14.08	690.72	502.38	37.49	43.598		
84310	73.6	63.3	0.09	0.07	27.48	1.05	0.82	27.29	0.3	0.22	34.41	636.26	530.59	19.92	5.962	x	
84311	74.0	62.2	0.36	0.39	9.02	11.17	11.45	2.46	1.13	1.13	0.58	277.29	331.19	16.27	9.175		
84312	74.3	61.1	0.21	0.22	4.73	7.96	7.76	2.63	2.32	2	16.06	402.17	404.4	0.55			
84314	80.6	48.3	0.79	0.69	13.99	23.95	18.81	27.31	2.88	2.38	21.11	385.99	360.73	7	3.767		
84315	83.4	46.4	0.88	0.99	11.19	7.13	6.7	6.41	2.21	1.93	14.38	357.28	369.35	3.27	60.851		

RunID	Temp (F)	RH (%)	Composite HC (g/mi)			Composite CO (g/mi)			Composite NO_x (g/mi)			Composite CO_2 (g/mi)			PM2.5 (mg/mi)	PEMS DATASuspect	Dyno DATASuspect
			PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff			
84316	84.6	46.3	0.83	0.86	2.62	9.04	7.9	14.41	0.92	0.76	20.16	367.52	347.47	5.77	49.626		
84318	75.3	36.7	0.21	0.28	26.15	2.95	3.83	22.89	0.96	1.08	11.24	264.34	339.2	22.07	3.564		
84319	77.5	35.3	0.21	0.21	1.06	2.99	2.58	15.97	0.66	0.62	6.2	398.4	387.87	2.71	4.143		
84321	80.5	33.3	0.19	0.2	1.78	1.14	0.97	17.9	0.5	0.48	4.48	433.83	430.66	0.74	1.449		
84322	81.4	31.5	0.3	0.3	1.49	8.67	7.44	16.44	1.5	1.28	16.88	365.19	313.03	16.66	9.987		
84324	75.4	45.1	0.25	0.25	3.45	5.57	4.86	14.64	0.46	0.47	1.07	405.25	403.8	0.36	3.141		
84325	77.6	43.7	0.38	0.41	6.72	2.12	2.14	0.99	0.42	0.41	2.52	396.19	404.01	1.94	3.101		
84327	80.8	41.5	0.12	0.12	0.84	2.17	1.85	16.82	0.31	0.26	17.08	445.01	441.46	0.81	0.610		
84328	82.0	40.7	0.21	0.21	1.98	1.14	0.94	21.26	0.68	0.47	45.11	429.3	425.13	0.98			
84329	83.2	38.3	0.23	0.2	12.65	3.49	2.19	58.98	0.44	0.27	61.91	694.82	505.63	37.42		x	
84355	65.4	55.0	0.05	0.07	25.03	0.92	1.05	12.95	0.25	0.23	6.55	414.86	450.2	7.85	1.136		
84356	69.1	54.6	0.17	0.19	10.65	4.85	5.07	4.35	1.34	1.36	1.24	355.85	370.06	3.84	3.879		
84357	72.4	51.9	0.96	1.06	9.69	41.62	44.14	5.71	0.55	0.56	2.45	302.17	302.85	0.22	8.001		
84359	76.0	51.8	0.24	0.2	18.58	3.75	3.13	19.82	1.11	1.1	0.79	422.94	337.8	25.2			
Average*					**17.95**			**18.06**			**17.6**			**10.37**			

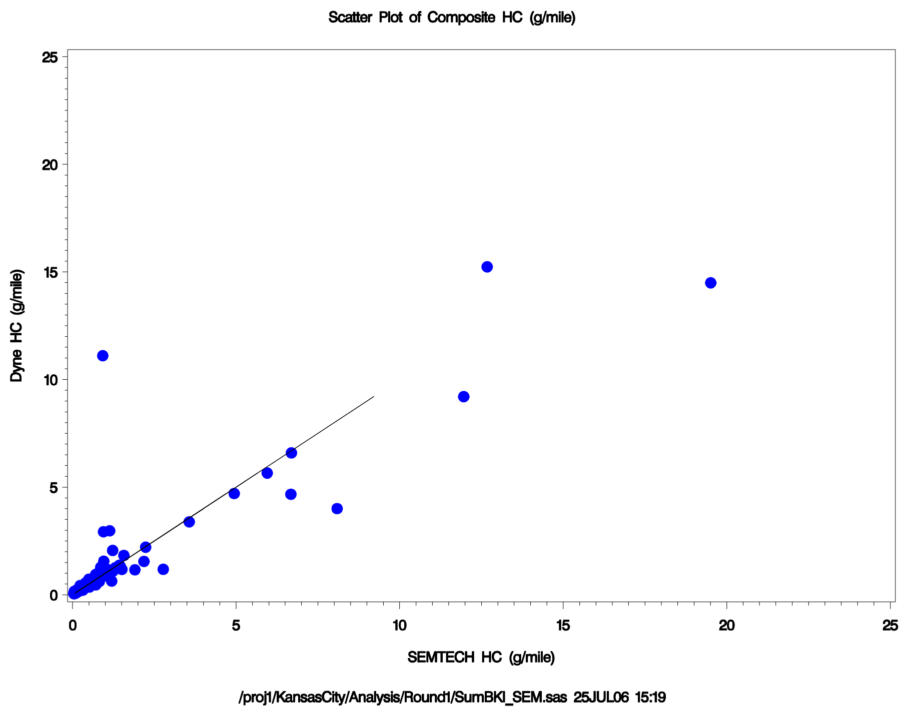
*The average percentage difference shown here is the average of the absolute value of the percentage difference for each run

In Table 4-8, percentage difference of gaseous emissions results between the PEMS and dynamometer two systems is shown for each run, and results with overall differences greater than 100% are indicated with bold font. Out of 220 tests, only six show a difference greater than 100% for a pollutant. Overall average percent differences are in the range of 10-18 percent for HC, CO, NO_x and CO_2. Comparison of phase-specific and total composite emission rates in the data shows a relatively good correlation between the PEMS and dynamometer methods of measurement. Complete (by-phase) results are provided in Appendices G and H. Analysis of results from the "Measurement Allowance for In-Use Testing" study being conducted in 2006 at Southwest Research Institute in San Antonio, Texas and also analysis of the dynamometer correlation results between the EPA dynamometer in Ann Arbor and the EPA portable Clayton dynamometer gathered during the Kansas City Pilot Study may provide insight into any possible bias issues between the two types of measurements systems. Results from DRI's gravimetrically-collected $PM_{2.5}$ measurements are also shown in Table 4-8 for reference. Additional information and results from particulate matter measurements are provided in Section 4.5.

The last two columns of Table 4-8 indicate dyno and PEMS records which may have suspicious regulated gaseous pollutant results, based on review of test data. For the dynamometer data, an "x" in the "dyno data suspect" column indicates either a test anomaly was noted in the onsite test log, or some issue was identified with the dynamometer data during subsequent data analysis, which could influence the overall test result. Some examples of data issues that would be noted include tests for which part or all of the real-time data was improperly collected or voided, tests where incorrect dynamometer loading was applied, tests where real-time sensors were saturated (pegged at maximum value), tests with equipment failures that would affect overall results, or tests where significant drive trace violations occurred. This review was only applied to dynamometer measurements collected during the study. Detailed notes pertaining to QC review of all dynamometer measurements are provided in Appendices S and V.

In addition to the dynamometer data review, all PEMS data was analyzed to identify missing information and indicators of potentially invalid results. This analysis involved performing a comparison of exhaust mass flow rates for each test with those of other vehicles with a similar engine displacement, comparison of exhaust temperatures of each tests with the exhaust temperatures of other vehicles of similar engine displacement, review of exhaust dilution levels (percentage $CO + CO_2$ in exhaust), review of ambient temperature measured during testing and review of test durations, distances, and measured fuel economy. PEMS tests with highly suspicious results are indicated with an "x" in the "PEMS data suspect" in Table 4-8, and detailed notes collected during review of Round 1 dyno PEMS tests are provided in Appendix O.

Figure 4-12 provides the same Round 1 PEMS vs. dyno comparison information graphically with a l:1 line for reference. HC, CO, NOx, and CO2 are depicted using dots, squares, triangles, and circle-crosses, respectively. Additional scatter plots of dynamometer results vs. the PEMS for each particular phase can be located in Appendices G and H. Results listed as "suspect" in Table 4-8 are not included in Figure 4-12.



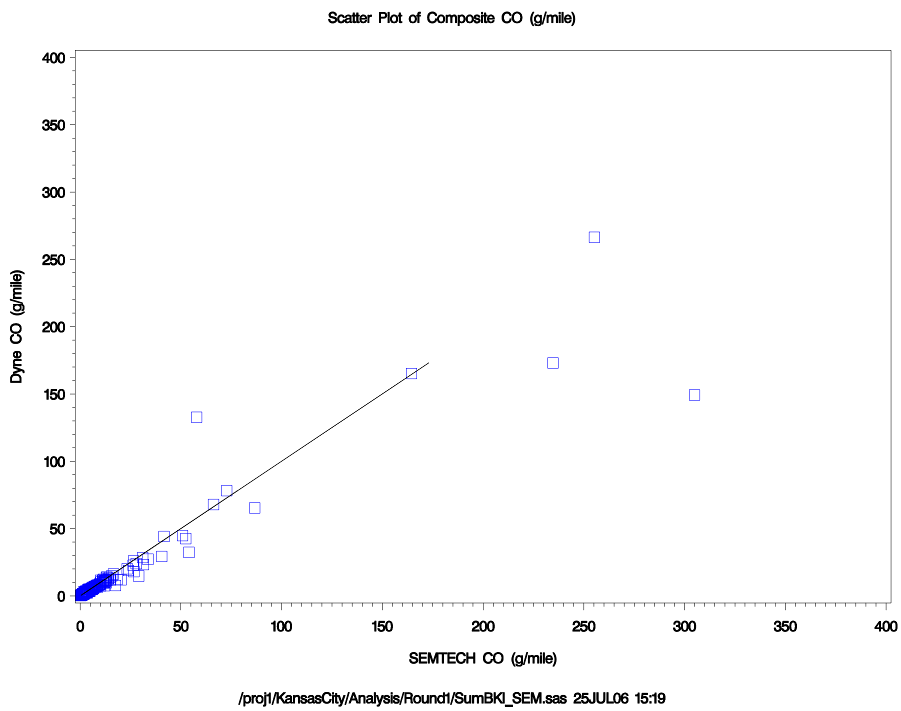
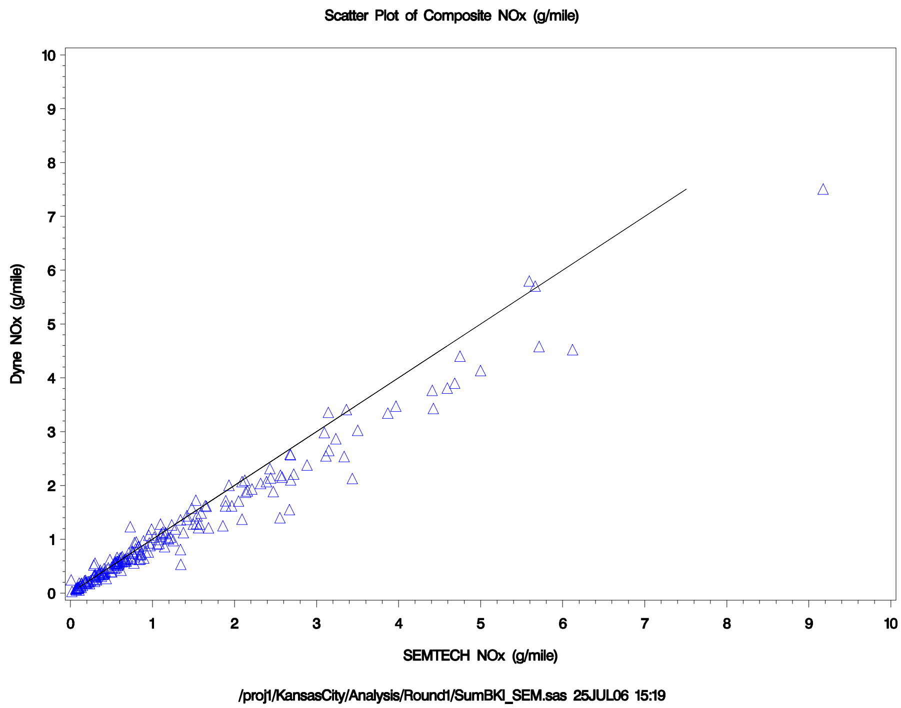


Figure 4-12. Plots of Round 1 Dyno vs. PEMS Measurements



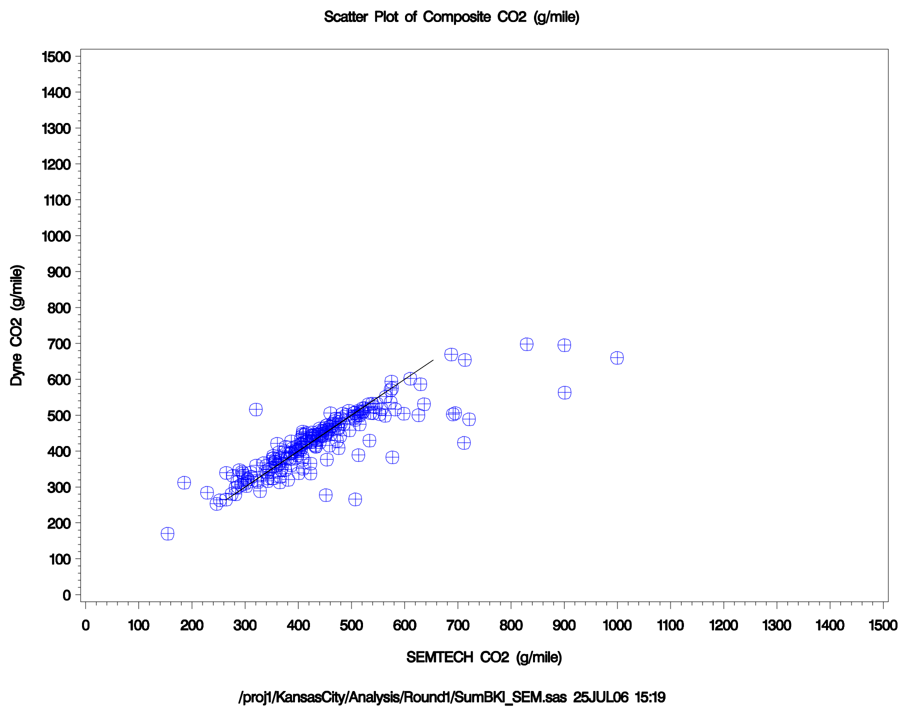


Figure 4-12 (Continued). Plots of Round 1 Dyno vs. PEMS Measurements

Table 4-9 provides results of all conditioning run tests conducted during Round 1, and Table 4-10 provides results of all driveaway tests conducted during Round 1. As with the PEMS data collected on the dynamometer, all conditioning run and driveaway results were reviewed to identify missing information and indicators of potentially invalid results, including an evaluation of exhaust mass flow rates, exhaust temperatures, dilution levels, ambient temperature measurements, test duration and distance and measured fuel economy. PEMS tests with highly suspicious results are indicated with an “x” in the “PEMS data suspect” column in Tables 4-9 and 4-10, and detailed notes collected during review of all Round 1 conditioning run and driveaway PEMS tests are provided in Appendices Q and R.

Table 4-9. Round 1 Conditioning Run Test Results

CTR_TST_ID	Make	Model	Model Year	Disp	Test Date	Test Duration (minutes)	Test Distance (miles)	Fuel Used (gal)	Test FE (mpg)	Composite CO2 (gpm)	Composite CO (gpm)	Composite NOx (gpm)	Composite THC (gpm)	Suspect Data
C_KS1_002_1	FORD	F150	1979	2.3	8/9/2004	23	.	1.39	N/A	N/A	N/A	N/A	N/A	x
C_KS1_003_1	DODGE	RAM250	1994	5.2	7/13/2004	22	7.8	0.84	9.3	929.9	14.47	3.22	0.84	
C_KS1_004_1	ISUZU	TROOPER	1999	3.5	7/13/2004	0	0.0	0.00	N/A	N/A	N/A	N/A	N/A	x
C_KS1_004_2	ISUZU	TROOPER	1999	3.5	7/13/2004	21	8.0	0.46	17.3	506.7	3.05	0.85	0.19	
C_KS1_005_1	GMC	YUKON XL	2001	5.3	7/13/2004	22	8.0	0.76	10.5	845.4	2.66	0.47	0.18	
C_KS1_006_1	FORD	ESCORT LX	1995	1.9	7/14/2004	21	8.0	0.30	26.5	327.3	5.75	0.91	0.20	
C_KS1_007_1	FORD	F-250	1979	5.7	7/14/2004	52	8.0	0.76	10.6	728.4	74.79	1.00	1.73	
C_KS1_009_1	TOYOTA	RAV4	2000	2.2	7/14/2004	23	8.0	0.39	20.4	427.9	5.40	0.69	0.26	
C_KS1_010_1	DODGE	SPIRIT	1990	2.5	7/15/2004	25	8.1	0.34	23.9	360.1	7.50	1.41	0.49	
C_KS1_011_1	FORD	F-150 XLT	2001	5.4	7/15/2004	22	8.0	0.65	12.3	713.5	6.29	0.38	0.32	
C_KS1_013_1	HONDA	CIVIC	1996	1.6	7/16/2004	21	8.0	0.26	30.4	269.5	14.14	0.67	0.59	
C_KS1_017_1	MAZDA	626	2001	2.5	7/17/2004	23	8.6	0.34	25.5	348.2	0.67	0.07	0.09	
C_KS1_018_1	DODGE	CARAVAN SE	1989	3	7/17/2004	23	8.1	0.40	20.3	423.1	7.69	3.37	1.62	
C_KS1_020_1	CHEVROLET	CORSICA	1996	2.2	7/19/2004	23	7.8	0.32	24.5	352.7	5.68	0.84	0.36	
C_KS1_021_1	HONDA	CIVIC SI	2002	2	7/19/2004	18	8.0	0.31	26.1	336.7	3.12	0.04	0.07	
C_KS1_022_1	GMC	JIMMY	1995	4.2	7/19/2004	21	8.0	0.57	14.0	623.5	5.78	1.48	0.34	
C_KS1_023_1	OLDSMOBILE	CUTLASS CIERA	1988	3.8	7/19/2004	28	8.0	0.33	24.2	357.0	5.94	1.05	0.55	
C_KS1_024_1	JEEP	CHEROKEE SPORT	1998	4	7/19/2004	0	.	0.00	N/A	N/A	N/A	N/A	N/A	x
C_KS1_024_2	JEEP	CHEROKEE SPORT	1998	4	7/19/2004	20	6.8	0.48	14.3	592.5	14.02	4.28	2.39	
C_KS1_025_1	CHEVROLET	CAVALIER	1990	2.2	7/20/2004	24	8.4	0.41	20.6	422.9	4.58	1.02	0.58	
C_KS1_026_1	CHRYSLER	300	1999	3.5	7/20/2004	21	7.7	0.41	18.8	468.1	2.83	0.41	0.40	
C_KS1_027_1	GMC	SATURN	2001	1.9	7/20/2004	20	8.1	0.23	34.5	257.2	0.71	0.24	0.04	
C_KS1_028_1	BUICK	LESABRE	1998	3.8	7/21/2004	19	7.5	0.41	18.2	487.3	0.65	1.30	0.13	
C_KS1_028_2	BUICK	LESABRE	1998	3.8	7/20/2004	22	8.1	0.41	19.5	460.6	0.34	0.66	0.10	
C_KS1_028_3	BUICK	LESABRE	1998	3.8	7/20/2004	1	0.0	0.00	N/A	N/A	N/A	N/A	N/A	x
C_KS1_030_1	NISSAN	FRONTIER	2002	3.3	7/20/2004	21	8.0	0.56	14.5	608.5	2.96	0.37	0.07	
C_KS1_032_1	SATURN	SATURN	1996	1.9	7/21/2004	21	8.0	0.41	19.7	447.9	1.26	0.66	0.20	
C_KS1_033_1	DODGE	CARAVAN	1995	3.3	7/21/2004	21	8.0	0.53	15.0	577.5	7.38	2.21	0.64	
C_KS1_035_1	MERCURY	VILLAGER LS	1994	2.5	7/21/2004	23	7.7	0.50	15.5	567.2	2.46	1.58	0.43	
C_KS1_036_1	JEEP	WRANGLER	1995	2.5	7/21/2004	19	6.3	0.45	14.0	617.8	9.87	0.68	0.47	
C_KS1_037_1	GMC	PONTIAC GRAND AM	1989	2.3	7/22/2004	19	7.7	0.39	19.7	419.0	16.07	6.88	2.54	
C_KS1_040_1	TOYOTA	SOLARA SLE	2001	3	7/22/2004	21	7.7	0.41	18.7	471.1	1.98	0.33	0.16	
C_KS1_041_1	DODGE	GRAND CARAVAN SPORT	1997	3.3	7/22/2004	20	8.0	0.52	15.4	573.6	1.35	1.31	0.16	
C_KS1_043_1	CHEVROLET	BLAZER	1995	4.3	7/23/2004	22	6.5	0.44	14.7	595.2	5.50	1.68	0.25	
C_KS1_044_1	CHEVROLET	S-10	2003	4.3	7/23/2004	22	7.7	0.50	15.5	570.7	1.27	0.84	0.18	

CTR_TST_ID	Make	Model	Model Year	Disp	Test Date	Test Duration (minutes)	Test Distance (miles)	Fuel Used (gal)	Test FE (mpg)	Composite CO2 (gpm)	Composite CO (gpm)	Composite NOx (gpm)	Composite THC (gpm)	Suspect Data
C_KS1_049_1	LINCOLN	TOWNCAR	1990	5	7/26/2004	20	8.0	0.55	14.7	560.5	23.42	2.11	4.62	x
C_KS1_050_1	HONDA	CIVIC EX	1999	1.6	7/24/2004	21	.	0.20	N/A	N/A	N/A	N/A	N/A	x
C_KS1_051_1	HONDA	ACCORD	1997	2.2	7/24/2004	23	8.0	0.32	25.3	352.3	1.23	0.37	0.09	
C_KS1_052_1	HONDA	ACCORD LX	1989	2	7/24/2004	20	7.6	0.47	16.3	420.7	80.42	1.08	2.31	x
C_KS1_056_1	HONDA	ACCORD EX	2000	2.2	7/26/2004	22	8.0	0.43	18.8	471.9	2.14	0.39	0.09	
C_KS1_056_2	HONDA	ACCORD EX	2000	2.2	7/26/2004	4	.	0.00	N/A	N/A	N/A	N/A	N/A	x
C_KS1_057_1	FORD	TAURUS SES	2003	3	7/26/2004	20	8.0	0.36	21.9	408.7	0.10	0.07	0.02	
C_KS1_057_2	FORD	TAURUS SES	2003	3	7/26/2004	6	.	0.00	N/A	N/A	N/A	N/A	N/A	x
C_KS1_058_1	CHEVROLET	MALIBU LS	1998	3.1	7/26/2004	19	8.0	0.38	21.0	424.4	1.02	0.68	0.18	
C_KS1_061_1	HONDA	ODYSSEY	2004	3.5	7/27/2004	20	8.0	0.48	16.6	538.0	1.14	0.12	0.18	
C_KS1_062_1	NISSAN	PATHFINDER LE	2003	3.5	7/27/2004	18	.	0.51	N/A	N/A	N/A	N/A	N/A	x
C_KS1_063_1	CHEVROLET	LUMINA	1998	3.1	7/27/2004	21	8.5	0.38	22.2	399.7	1.11	0.55	0.18	
C_KS1_064_1	FORD	MUSTANG	1999	4.6	7/27/2004	19	7.7	0.30	26.2	334.5	4.25	0.38	0.17	
C_KS1_065_1	HYUNDAI	TIBURON	2000	2	7/27/2004	20	7.7	0.31	24.9	408.7	1.32	0.33	0.06	
C_KS1_066_1	CADILLAC	SEVILLE	1991	4.9	7/27/2004	21	8.0	0.55	14.5	602.0	8.63	0.85	0.53	
C_KS1_067_1	SATURN	SL1	1999	1.9	7/28/2004	26	8.0	0.36	22.5	392.0	3.03	1.49	0.20	
C_KS1_067_2	SATURN	SL1	1999	1.9	7/28/2004	1	.	0.00	N/A	N/A	N/A	N/A	N/A	x
C_KS1_068_1	FORD	EXPLORER	1993	4	7/28/2004	42	8.0	0.56	14.4	608.5	8.47	2.76	0.33	
C_KS1_069_1	ISUZU	RODEO SL	1999	3.2	7/28/2004	21	8.0	0.46	17.4	501.5	6.92	1.67	0.70	
C_KS1_071_1	TOYOTA	RAV4	2000	2	7/28/2004	22	7.9	0.43	18.4	478.4	3.78	0.82	0.41	
C_KS1_072_1	NISSAN	SENTRA GXE	1997	1.6	7/28/2004	19	8.0	0.37	21.4	414.5	1.06	1.12	0.14	
C_KS1_073_1	FORD	RANGER	1999	3	7/29/2004	23	8.1	0.47	17.0	521.7	0.87	0.24	0.06	
C_KS1_074_1	MERCURY	SABLE LS	2002	3	7/29/2004	22	8.0	0.33	24.1	370.5	0.20	0.09	0.02	
C_KS1_075_1	TOYOTA	CAMRY	1994	2.2	7/29/2004	21	7.8	0.43	18.4	456.7	17.73	2.99	0.41	
C_KS1_076_1	HONDA	CIVIC	1984	1.5	8/3/2004	24	8.6	0.23	37.3	217.0	12.52	1.19	0.48	
C_KS1_076_2	HONDA	CIVIC	1984	1.5		0		0.27	0.0	N/A	N/A	N/A	N/A	x
C_KS1_077_1	TOYOTA	AVALON	1999	3	7/29/2004	21	8.0	0.31	25.7	344.9	1.19	0.46	0.23	
C_KS1_078_1	HONDA	CIVIC DX	1991	1.5	7/30/2004	23	8.0	0.40	19.9	429.5	11.05	2.87	1.03	
C_KS1_078_2	HONDA	CIVIC DX	1991	1.5	7/30/2004	0	.	0.00	N/A	N/A	N/A	N/A	N/A	x
C_KS1_080_1	JEEP	GRAND CHEROKEE	1995	4	8/2/2004	23	7.4	0.19	38.6	217.1	6.61	3.86	0.85	x
C_KS1_081_1	DODGE	RAM LE	1991	5.2	8/2/2004	22	8.0	0.56	14.4	585.1	17.71	3.36	1.31	
C_KS1_082_1	TOYOTA	COROLLA	1997	1.6	7/30/2004	21	7.8	0.28	28.3	311.7	1.92	0.68	0.32	
C_KS1_083_1	NISSAN	MAXIMA	2000	3	7/30/2004	20	8.0	0.38	21.3	416.4	1.03	0.89	0.20	
C_KS1_085_1	FORD	F-150	1995	5	7/31/2004	21	8.0	0.47	17.2	507.4	6.55	1.41	0.27	
C_KS1_086_1	FORD	CONTOUR	1995	2	7/31/2004	21	8.0	0.34	23.4	372.7	4.91	0.45	0.23	
C_KS1_088_1	CHEVROLET	S-10	1996	4.3	7/31/2004	21	8.0	0.32	25.1	351.1	2.48	0.50	0.18	
C_KS1_090_1	PONTIAC	GRAND PRIX	1993	3.1	7/31/2004	22	8.0	0.38	20.9	413.3	7.11	1.82	0.66	
C_KS1_092_1	FORD	EXPLORER	2000	4	8/2/2004	19	8.0	0.30	26.6	332.4	1.14	0.28	0.02	
C_KS1_093_1	CHEVROLET	SILVERADO	2002	5.3	8/2/2004	33	9.4	0.45	20.6	429.2	0.78	0.36	0.11	

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C_KS1_094_1	PLYMOUTH	VOYAGER	1998	3.3	8/3/2004	21	.	0.46	N/A	N/A	N/A	N/A	N/A	x
C_KS1_094_2	PLYMOUTH	VOYAGER	1998	3.3	7/30/2004	22	8.0	0.40	20.1	441.3	1.60	0.63	0.17	
C_KS1_095_1	BUICK	LESABRE	1989	3.8	7/30/2004	19	7.9	0.41	19.2	459.9	2.08	0.87	0.30	
C_KS1_096_1	SUBARU	OUTBACK LEGACY	1996	2.2	7/29/2004	21	8.1	0.43	18.9	453.9	11.09	1.12	0.48	
C_KS1_097_1	FORD	THUNDERBIRD	1988	3.8	8/3/2004	47	8.5	0.55	15.5	542.5	18.36	1.91	1.43	x
C_KS1_098_1	FORD	EXPLORER XLT	1995	4	8/3/2004	21	8.1	0.56	14.5	603.6	6.07	2.85	0.25	
C_KS1_099_1	VOLVO	S80	2001	2.9	8/3/2004	18	8.0	0.30	26.4	335.0	0.74	0.22	0.10	
C_KS1_100_1	MAZDA	PROTÉGÉ	1991	1.8	8/11/2004	29	8.0	0.34	23.8	343.9	14.04	3.75	3.77	x
C_KS1_1012_1	NISSAN	MAXIMA	1992	3	8/24/2004	22	8.0	0.00	N/A	0.0	0.00	0.00	0.00	x
C_KS1_102_1	DODGE	GRAND CARAVAN SE	1999	3.3	8/3/2004	20	8.0	0.30	26.3	335.0	1.21	0.45	0.15	
C_KS1_103_1	CHRYSLER	TOWN & COUNTRY	2000	3.3	8/4/2004	21	8.0	0.46	17.4	509.4	1.17	0.59	0.11	
C_KS1_104_1	TOYOTA	CELICA	1999	2.2	8/4/2004	20	8.0	0.35	22.7	1023.5	2.71	0.04	0.17	x
C_KS1_105_1	JEEP	CHEROKEE SPORT	1993	4	8/6/2004	23	7.8	0.48	16.2	531.9	11.73	2.89	1.41	
C_KS1_105_2	JEEP	CHEROKEE SPORT	1993	4	8/4/2004	31	8.6	0.32	26.4	321.6	7.84	2.03	0.90	
C_KS1_107_1	TOYOTA	CAMRY LE	2000	2.2	8/4/2004	21	7.9	0.27	29.1	298.9	3.75	0.41	0.14	
C_KS1_108_1	CHEVROLET	CAVALIER	1997	2.2	8/4/2004	21	8.0	0.24	33.1	264.4	2.46	0.49	0.11	
C_KS1_109_1	MERCURY	GRAND MARQUIS GS	1997	4.6	8/5/2004	22	8.0	0.35	22.6	386.2	6.01	0.76	0.13	
C_KS1_110_1	BUICK	CENTURY LIMITED	1998	3.1	8/5/2004	22	7.7	0.25	30.5	288.9	3.01	0.26	0.19	
C_KS1_110_2	BUICK	CENTURY LIMITED	1998	3.1	8/5/2004	0	.	0.00	N/A	N/A	N/A	N/A	N/A	x
C_KS1_112_1	FORD	PROBE	1993	2.5	8/5/2004	23	8.0	0.43	18.5	458.3	15.39	0.94	1.06	
C_KS1_113_1	FORD	BRONCO	1995	5.8	8/5/2004	17	7.5	0.56	13.5	644.1	12.05	2.47	0.44	
C_KS1_114_1	CHRYSLER	CONCORD	2000	2.7	8/5/2004	20	8.0	0.39	20.4	433.8	2.56	0.94	0.39	
C_KS1_116_1	FORD	ESCORT ZX2	1999	2	8/6/2004	27	8.0	0.32	25.3	342.4	7.43	0.73	0.16	
C_KS1_117_1	CHEVROLET	BLAZER LS	2002	4.3	8/6/2004	22	8.0	0.48	16.6	537.6	1.12	0.33	0.14	
C_KS1_118_1	LINCOLN	TOWNCAR	1987	4.3	8/6/2004	22	8.0	0.53	15.0	567.8	15.95	4.96	1.35	
C_KS1_120_1	HONDA	ACCORD	1990	2.2	8/6/2004	20	8.0	0.31	25.6	328.7	12.17	1.04	0.80	
C_KS1_121_1	DODGE	DYNASTY	1988	3.3	8/7/2004	21	8.0	0.22	36.1	237.0	4.86	1.68	0.96	
C_KS1_123_1	JEEP	CHEROKEE	1990	4	8/7/2004	21	8.1	0.26	31.6	272.6	5.61	2.62	0.63	x
C_KS1_124_1	FORD	ESCORT	2002	2	8/9/2004	22	7.9	0.36	22.2	401.7	0.43	0.06	0.05	
C_KS1_126_1	PLYMOUTH	VOYAGER	1993	3	8/7/2004	21	.	0.31	N/A	N/A	N/A	N/A	N/A	x
C_KS1_127_1	HONDA	ODYSSEY	2000	3.5	8/9/2004	21	8.0	0.46	17.3	510.6	3.27	0.47	0.19	
C_KS1_128_1	HONDA	ACCORD	2000	2.3	8/9/2004	20	8.0	0.31	25.9	339.6	3.09	0.28	0.10	
C_KS1_129_1	FORD	F150	2000	4.2	8/9/2004	22	7.8	0.41	18.9	462.2	6.28	0.33	0.35	
C_KS1_132_1	FORD	RANGER XLT	1988	2.3	8/7/2004	24	7.6	0.55	13.8	607.5	21.17	2.31	2.46	
C_KS1_133_1	HONDA	ACCORD LX	2001	2.3	8/10/2004	24	8.0	0.44	18.3	488.6	0.67	0.10	0.03	
C_KS1_134_1	NISSAN	SENTRA	1994	2.3	8/10/2004	30	7.7	0.00	N/A	0.0	0.00	0.00	0.00	x
C_KS1_134_2	NISSAN	SENTRA	1994	1.6	8/11/2004	24	7.8	0.26	30.4	281.7	8.25	0.65	0.36	
C_KS1_138_1	CHRYSLER	LEBARON	1983	2.6	8/10/2004	30	8.1	0.62	13.0	646.8	24.88	1.83	0.68	x
C_KS1_139_1	VOLVO	850	1997	2.4	8/11/2004	20	7.8	0.31	25.3	352.7	0.52	0.38	0.16	

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C_KS1_140_1	MERCURY	TOPAZ GS	1994	2.3	8/13/2004	21	6.8	0.30	22.4	394.1	3.37	0.61	0.28	
C_KS1_140_2	MERCURY	TOPAZ GS	1994	2.3	8/11/2004	21	8.0	0.24	33.9	258.5	3.09	0.58	0.19	
C_KS1_141_1	FORD	FOCUS SE	2001	2	8/11/2004	20	8.0	0.28	28.0	315.4	3.33	0.17	0.08	
C_KS1_142_1	PLYMOUTH	VOYAGER	1999	3.3	8/11/2004	24	8.0	0.49	16.5	540.9	0.91	0.36	0.17	
C_KS1_147_1	HONDA	CIVIC DX	1988	1.5	8/12/2004	22	8.0	0.33	24.4	336.1	17.24	1.32	1.61	
C_KS1_148_1	BUICK	REGAL	1996	3.8	8/12/2004	23	8.0	0.30	26.7	333.5	1.05	0.47	0.10	
C_KS1_149_1	CADILLAC	CIMMARON	1986	2.8	8/12/2004	25	8.1	0.37	21.5	405.0	5.94	0.69	0.88	
C_KS1_150_1	FORD	RANGER	1999	3	8/12/2004	20	8.0	0.32	25.2	348.3	3.43	0.63	0.48	
C_KS1_151_1	PONTIAC	BONNEVILLE	1988	3.8	8/14/2004	29	.	0.31	N/A	N/A	N/A	N/A	N/A	x
C_KS1_152_1	MERCURY	TOPAZ	1994	2.3	8/13/2004	34	8.0	0.45	18.0	493.3	1.72	0.59	0.35	
C_KS1_153_1	MERCURY	SABLE	1996	3	8/13/2004	29	8.0	0.11	75.6	115.5	1.76	0.29	0.12	x
C_KS1_154_1	JEEP	CHEROKEE	1998	4	8/14/2004	34	8.0	0.42	19.1	461.5	4.10	1.41	0.47	
C_KS1_159_1	FORD	THUNDERBIRD LX	1995	4.6	8/14/2004	48	8.0	0.15	52.0	165.6	4.20	0.44	0.20	x
C_KS1_160_1	TOYOTA	CAMRY	1997	2.2	8/14/2004	59	8.1	0.29	27.5	322.3	2.05	0.53	0.18	
C_KS1_164_1	TOYOTA	COROLLA	1996	1.8	8/16/2004	66	7.8	0.22	35.4	251.0	2.15	0.52	0.23	x
C_KS1_165_1	HONDA	CIVIC	2000	1.6	8/16/2004	33	8.0	0.26	30.8	287.2	1.88	0.11	0.05	
C_KS1_166_1	TOYOTA	CAMRY	2000	2.2	8/18/2004	25	8.0	0.33	24.2	366.9	1.58	0.45	0.15	
C_KS1_167_1	TOYOTA	COROLLA	2000	1.8	8/16/2004	20	8.0	0.29	27.7	320.7	1.25	0.51	0.12	
C_KS1_167_2	TOYOTA	COROLLA	2000	1.8	8/16/2004	17	.	0.00	N/A	N/A	N/A	N/A	N/A	x
C_KS1_171_1	SUBARU	OUTBACK	2000	2.5	8/17/2004	32	18.6	0.88	21.1	418.5	2.38	0.07	0.05	x
C_KS1_171_2	SUBARU	OUTBACK	2000	2.5	8/17/2004	2	0.0	0.00	N/A	N/A	N/A	N/A	N/A	x
C_KS1_173_1	CHEVROLET	MONTE CARLO	1977	5	8/17/2004	20	8.2	0.48	17.1	444.2	43.08	11.58	3.85	
C_KS1_175_1	HYUNDAI	SANTA FE	2001	2.4	8/18/2004	21	8.0	0.47	17.0	521.4	1.93	0.63	0.08	
C_KS1_178_1	CHEVROLET	LUMINA	1999	2.2	8/18/2004	22	8.0	0.48	16.7	533.3	3.97	0.52	0.11	x
C_KS1_179_1	GMC	SAFARI	1993	4.3	8/18/2004	34	8.0	0.34	23.6	360.2	8.22	0.91	2.00	
C_KS1_180_1	GMC	SONOMA SLS	2001	4.3	8/18/2004	0	.	0.00	N/A	N/A	N/A	N/A	N/A	x
C_KS1_180_2	GMC	SONOMA SLS	2001	4.3	8/18/2004	26	8.0	0.34	23.7	375.8	0.16	0.11	0.02	
C_KS1_181_1	SATURN	SL1	1994	3.1	8/20/2004	23	8.0	0.34	23.3	365.4	11.24	0.85	0.48	
C_KS1_182_1	BUICK	REGAL	1990	3.1		0		0.31	0.0	N/A	N/A	N/A	N/A	x
C_KS1_187_1	CHEVROLET	ASTRO VAN	1991	4.3	8/20/2004	59	18.6	1.12	16.6	513.3	17.66	1.24	1.01	
C_KS1_189_1	CHEVROLET	S-10 TRUCK	1985	2.8	8/20/2004	23	8.0	0.49	16.3	415.3	79.13	1.64	5.37	
C_KS1_193_1	FORD	ECONOLINE	1983	5.8	8/21/2004	33	18.6	0.33	55.9	116.0	26.67	1.11	1.21	x
C_KS1_194_1	LINCOLN	TOWNCAR	1989	5	8/21/2004	30	8.0	0.39	20.4	397.2	24.38	2.59	0.96	x
C_KS1_195_1	FORD	F150 TRUCK	1998	4.2	8/21/2004	24	8.0	0.48	16.8	529.1	1.10	0.44	0.15	
C_KS1_196_1	FORD	WINDSTAR	1999	4.2	8/21/2004	21	8.0	0.37	21.9	404.6	1.78	0.40	0.05	
C_KS1_197_1	CHEVROLET	C 1500	1994	5.7	8/21/2004	40	8.0	0.59	13.5	637.3	15.08	0.60	0.61	
C_KS1_199_1	DODGE	STRATUS ES	1996	2.4	8/23/2004	25	8.0	0.40	20.2	421.8	10.72	5.63	0.48	
C_KS1_201_1	MAZDA	MX-6	1988	2.2	8/23/2004	42	8.1	0.36	22.6	374.4	10.92	3.34	0.71	
C_KS1_203_1	OLDSMOBILE	NINETY EIGHT	1985	3.8	8/23/2004	35	8.0	0.58	13.7	587.1	42.08	1.09	0.68	

CTR_TST_ID	Make	Model	Model Year	Disp	Test Date	Test Duration (minutes)	Test Distance (miles)	Fuel Used (gal)	Test FE (mpg)	Composite CO2 (gpm)	Composite CO (gpm)	Composite NOx (gpm)	Composite THC (gpm)	Suspect Data
		REGENCY												
C_KS1_204_1	LINCOLN	TOWNCAR	1987	5	8/23/2004	25	8.0	0.07	116.3	73.5	1.21	0.27	0.38	x
C_KS1_207_1	PONTIAC	BONNEVILLE	1994	3.8	8/25/2004	20	8.0	0.34	23.5	374.6	1.93	0.47	0.18	
C_KS1_208_1	FORD	F150	1990	4.9	8/25/2004	22	8.0	0.00	N/A	0.0	0.00	0.00	0.00	x
C_KS1_210_1	FORD	TAURUS	2002	3	8/26/2004	48	8.0	0.47	17.1	518.1	0.29	0.26	0.12	
C_KS1_212_1	CHRYSLER	CONCORD	1994	3.5	8/25/2004	21	8.0	0.30	26.3	324.1	6.77	2.38	0.70	x
C_KS1_212_2	CHRYSLER	CONCORD	1994	3.5	8/25/2004	21	8.0	0.30	26.3	324.1	6.77	2.38	0.70	x
C_KS1_213_1	OLDSMOBILE	EIGHTY-EIGHT	1994	3.8	8/27/2004	30	8.0	0.37	21.4	411.7	1.98	0.51	0.14	
C_KS1_215_1	FORD	CROWN VICTORIA	1985	5	8/26/2004	20	8.0	0.70	11.4	686.8	56.07	1.38	1.31	
C_KS1_219_1	HONDA	CIVIC	2000	1.6	8/26/2004	30	8.0	0.27	29.7	292.0	4.33	0.09	0.00	
C_KS1_221_1	BUICK	CENTURY	1997	3.1	8/26/2004	22	8.0	0.00	N/A	0.0	0.00	0.00	0.00	x
C_KS1_222_1	PONTIAC	GRAND AM	1992	2.3	8/26/2004	25	8.0	0.32	25.2	321.6	19.60	5.32	0.48	
C_KS1_223_1	DODGE	GRAND CARAVAN	2005	3.8	8/26/2004	46	8.1	0.42	19.2	459.7	0.83	0.17	0.07	
C_KS1_225_1	TOYOTA	COROLLA	1989	1.6	8/27/2004	23	8.0	0.34	23.9	334.2	24.47	1.42	0.54	
C_KS1_226_1	NISSAN	SENTRA	1993	1.3	8/27/2004	21	8.0	0.26	30.4	275.5	10.41	0.20	0.28	
C_KS1_226_2	NISSAN	SENTRA	1993	1.3	8/27/2004	0	.	0.00	N/A	N/A	N/A	N/A	N/A	x
C_KS1_228_1	OLDSMOBILE	SILHOUETTE	2000	3.4	8/27/2004	49	8.0	0.33	24.3	363.4	0.90	0.49	0.10	
C_KS1_233_1	FORD	TAURUS	1987	3	8/28/2004	8	0.0	0.00	4.3	378.4	12.97	0.00	0.00	x
C_KS1_233_2	FORD	TAURUS	1987	3	8/28/2004	20	8.0	0.37	21.7	402.6	5.35	1.48	0.20	
C_KS1_234_1	FORD	F150 4X2	1987	4.9	8/28/2004	32	18.6	1.31	14.2	502.3	68.81	6.03	7.19	
C_KS1_235_1	PONTIAC	6000	1988	2.8	8/28/2004	23	8.0	0.28	28.9	298.4	4.89	1.36	0.69	
C_KS1_236_1	OLDSMOBILE	ACHIEVA	1992	2.3	8/28/2004	27	8.0	0.45	17.8	489.8	6.54	3.02	0.45	
C_KS1_236_2	OLDSMOBILE	ACHIEVA	1992	1.9		0		0.33	0.0	N/A	N/A	N/A	N/A	x
C_KS1_237_1	GEO	PRISM	1990	1.6	8/28/2004	22	8.0	0.19	41.1	200.4	7.26	3.19	1.79	
C_KS1_239_1	FORD	ESCORT	1993	1.8	8/30/2004	20	8.0	0.08	98.4	75.1	9.28	0.72	0.58	x
C_KS1_240_1	FORD	CONTOUR	1998	2.5	8/30/2004	23	8.0	0.34	23.4	351.6	18.41	0.35	0.68	x
C_KS1_241_1	CADILLAC	SEDAN DE VILLE	1993	4.9	8/30/2004	21	8.0	0.45	17.7	460.5	26.00	2.12	1.05	
C_KS1_243_1	HONDA	ACCORD	1987	2	8/30/2004	20	8.0	0.40	20.1	408.4	21.92	3.11	0.72	
C_KS1_244_1	INFINITI	I30	1998	3	8/30/2004	19	8.0	0.15	52.0	171.1	0.29	0.19	0.07	x
C_KS1_245_1	PLYMOUTH	VOYAGER	1997	3.3	8/30/2004	18	8.0	0.30	26.4	336.5	1.14	0.82	0.18	
C_KS1_246_1	EAGLE	TALON	1994	1.8	8/31/2004	24	8.0	0.23	34.1	259.7	0.88	1.05	0.24	
C_KS1_247_1	FORD	RANGER	1987	2.9	8/31/2004	22	8.0	0.51	15.8	541.4	11.63	2.26	1.63	
C_KS1_248_1	VOLVO	240 GL	1983	2.3	8/31/2004	23	8.0	0.30	26.6	329.8	3.34	1.46	0.33	
C_KS1_249_1	CHEVROLET	S-10	1989	4.3	8/31/2004	20	8.0	0.41	19.7	440.2	6.66	1.22	0.39	
C_KS1_250_1	FORD	ESCORT	1987	1.9	8/31/2004	17	5.2	0.15	35.6	178.7	44.12	1.05	3.20	x
C_KS1_253_1	BUICK	REGAL	1992	3.8	9/1/2004	22	8.0	0.44	18.2	479.7	5.40	2.67	0.39	
C_KS1_254_1	MERCURY	SABLE	1997	3	9/1/2004	24	8.0	0.18	45.5	192.7	1.88	0.42	0.10	x
C_KS1_255_1	FORD	TAURUS	2001	3	9/1/2004	20	8.0	0.40	20.1	443.5	0.55	0.03	0.05	
C_KS1_259_1	PLYMOUTH	ACCLAIM	1990	2.5	9/1/2004	41	18.7	0.34	55.5	94.4	40.45	0.58	2.47	x

CTR_TST_ID	Make	Model	Model Year	Disp	Test Date	Test Duration (minutes)	Test Distance (miles)	Fuel Used (gal)	Test FE (mpg)	Composite CO2 (gpm)	Composite CO (gpm)	Composite NOx (gpm)	Composite THC (gpm)	Suspect Data
C_KS1_282_1	OLDSMOBILE	DELTA 88	1991	3.8	9/8/2004	19	8.0	0.35	23.3	377.8	4.19	1.19	0.29	
C_KS1_290_1	DODGE	RAM 50	1989	2.3	9/8/2004	20	8.0	0.32	24.5	356.4	5.01	3.88	0.52	
C_KS1_294_1	BUICK	CENTURY	1984	3	9/8/2004	22	8.0	0.75	10.7	623.4	118.30	0.96	12.33	x
C_KS1_297_1	KIA	SEPHIA	2000	1.8	9/9/2004	23	8.0	0.19	42.0	212.9	0.28	0.07	0.01	
C_KS1_298_1	CHEVROLET	CAVALIER	1989	2	9/9/2004	18	8.0	0.14	58.9	149.3	1.44	0.39	0.18	
C_KS1_299_1	BUICK	LESABRE	1979	4.9	9/9/2004	19	8.0	0.45	17.6	492.6	5.37	8.08	2.11	
C_KS1_300_1	FORD	F150	1994	5	9/9/2004	19	8.0	0.58	13.8	645.4	2.41	4.53	0.74	x
C_KS1_301_1	MERCURY	GRAND MARQUIS	1986	5	9/9/2004	23	8.0	0.46	17.5	492.8	10.37	1.26	1.25	
C_KS1_302_1	BUICK	ELECTRA PARK AVE	1989	3.8	9/10/2004	22	8.0	0.42	19.0	465.2	2.97	0.63	0.33	
C_KS1_304_1	FORD	ASPIRE	1995	1.3	9/10/2004	21	8.0	0.31	26.2	330.0	6.29	1.77	0.64	
C_KS1_305_1	HONDA	ACCORD	2001	3.8	9/10/2004	23	8.0	0.47	17.0	525.1	1.41	0.20	0.14	
C_KS1_306_1	JEEP	GRAND CHEROKEE	1995	4	9/11/2004	33	18.7	1.11	16.7	525.9	4.57	2.82	0.44	x
C_KS1_307_1	GMC	JIMMY	1990	4.3	9/10/2004	31	8.0	0.41	19.4	450.0	7.01	0.62	0.43	
C_KS1_308_1	MG	MG	1978	1.8	9/10/2004	35	8.1	0.66	12.3	363.6	230.00	1.14	16.16	x
C_KS1_309_1	OLDSMOBILE	SILHOUETTE	1997	3.4		0		0.52	0.0	N/A	N/A	N/A	N/A	x
C_KS1_312_1	HONDA	CIVIC	2000	1.6	9/14/2004	24	8.0	0.29	27.2	322.3	2.68	0.34	0.17	
C_KS1_314_1	GMC	SIERRA	1995	4.3	9/13/2004	21	8.0	0.68	11.8	683.7	39.96	2.33	4.45	x
C_KS1_316_1	HONDA	CIVIC	1997	1.6	9/14/2004	20	8.0	0.33	24.4	332.7	20.20	0.61	0.66	
C_KS1_317_1	OLDSMOBILE	CUSTOM CRUISER STATI	1984	5	9/13/2004	18	8.0	0.57	14.1	518.6	60.87	5.89	7.79	
C_KS1_318_1	VOLVO	GL	1984	2.3	9/14/2004	21	8.0	0.41	19.7	432.3	10.52	3.69	1.19	
C_KS1_319_1	CHEVROLET	CAPRICE	1987	5	9/14/2004	22	8.0	0.60	13.4	519.4	88.36	2.32	4.89	
C_KS1_321_1	DODGE	RAM	1997	5.9	9/14/2004	35	18.6	1.66	11.2	780.5	10.80	3.32	0.29	x
C_KS1_322_1	FORD	F150	1993	4.9	9/15/2004	25	8.0	0.52	15.3	569.1	7.45	1.62	0.81	
C_KS1_323_1	PONTIAC	GRAND PRIX	1989	3.1	9/15/2004	20	8.0	0.62	12.9	604.7	38.84	1.85	8.45	x
C_KS1_324_1	BUICK	LESABRE	1990	3.8	9/15/2004	20	8.0	0.48	16.7	531.6	1.08	0.95	0.15	
C_KS1_325_1	DODGE	STRATUS	1996	2.4	9/15/2004	21	8.0	0.42	19.3	448.2	7.32	0.86	0.41	
C_KS1_326_1	TOYOTA	CAMRY	1997	2.5	9/14/2004	20	8.0	0.37	21.4	409.2	3.96	0.89	0.24	
C_KS1_327_1	DODGE	DURANGO	1999	5.9	9/15/2004	22	8.0	0.82	9.8	904.5	4.62	1.03	0.06	
C_KS1_328_1	HONDA	CIVIC	1998	1.6	9/15/2004	22	8.0	0.25	32.2	270.1	3.72	0.11	0.06	
C_KS1_329_1	HONDA	CIVIC	2001	1.7	9/15/2004	34	18.6	0.55	33.9	260.0	2.01	0.17	0.01	
C_KS1_329_2	HONDA	CIVIC	2001	1.7	9/15/2004	34	18.6	0.55	33.9	260.0	2.01	0.17	0.01	
C_KS1_330_1	HONDA	ACCORD	1992	2.2	9/16/2004	25	8.0	0.43	18.6	476.4	2.88	0.64	0.32	
C_KS1_331_1	PONTIAC	GRAND AM	1994	2.3	9/16/2004	29	8.0	0.37	21.9	397.2	7.18	1.93	0.44	
C_KS1_332_1	CHEVROLET	MALIBU	1999	3.1	9/16/2004	27	8.0	0.40	20.2	443.0	0.85	0.48	0.07	
C_KS1_333_1	OLDSMOBILE	SILHOUETTE	2002	3.4	9/16/2004	23	8.0	0.51	15.7	568.7	0.87	0.26	0.01	
C_KS1_335_1	M.BENZ	280 SE	1973	4.5	9/16/2004	23	8.0	0.77	10.4	564.1	180.28	1.45	10.18	
C_KS1_336_1	CHEVROLET	G-20	1993	5.7	9/16/2004	45	14.1	0.43	32.6	197.2	42.55	0.38	3.22	x
C_KS1_337_1	FORD	F150	1997	4.6	9/20/2004	31	18.6	1.21	15.4	566.4	10.16	0.52	0.24	x

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C_KS1_338_1	CHEVROLET	VENTURE	2003	3.4	9/17/2004	20	8.0	0.42	19.1	468.7	0.61	0.19	0.09	
C_KS1_339_1	PLYMOUTH	VOYAGER	1991	3	9/17/2004	23	8.0	0.36	22.3	385.2	7.40	1.91	1.30	
C_KS1_341_1	DODGE	AVENGER	1996	2	9/17/2004	16	8.0	0.26	31.0	263.5	14.83	0.78	1.00	
C_KS1_343_1	TOYOTA	COROLLA	1989	1.6	9/17/2004	20	8.0	0.28	28.7	305.7	3.18	1.18	0.35	
C_KS1_344_1	NISSAN	SENTRA	1997	3	9/18/2004	14	5.6	0.19	29.6	293.5	4.44	0.71	0.22	
C_KS1_346_1	TOYOTA	CAMRY	1990	2	9/18/2004	21	8.0	0.29	27.7	296.6	14.58	0.98	0.83	
C_KS1_347_1	NISSAN	ALTIMA	2000	2.4	9/18/2004	25	8.0	0.47	17.0	512.2	7.61	1.30	0.14	
C_KS1_348_1	PLYMOUTH	SUNDANCE	1989	2.3	9/17/2004	21	8.0	0.41	19.6	436.4	12.70	1.56	0.62	
C_KS1_349_1	FORD	WINDSTAR	2001	3.8	9/29/2004	22	8.0	0.42	19.1	470.5	0.56	0.11	0.04	
C_KS1_350_1	TOYOTA	AVALON	1996	3	9/18/2004	19	8.0	0.38	21.1	416.6	2.43	0.94	0.35	
C_KS1_350_2	TOYOTA	AVALON	1996	3	9/20/2004	18	8.0	0.40	20.1	443.5	1.24	0.70	0.25	
C_KS1_351_1	NISSAN	MAXIMA	1997	3	9/20/2004	20	8.0	0.33	24.7	359.9	1.77	0.29	0.36	
C_KS1_352_1	TOYOTA	CAMRY	1999	2.2	9/20/2004	20	8.0	0.37	21.8	406.6	2.85	0.48	0.17	
C_KS1_354_1	FORD	TAURUS	1998	3	9/20/2004	22	8.0	0.42	19.3	456.3	4.61	0.21	0.05	
C_KS1_355_1	JEEP	WRANGLER	1997	4	9/20/2004	21	8.0	0.49	16.3	540.0	5.97	0.37	0.24	
C_KS1_356_1	KIA	RIO	2004	1.6	9/20/2004	19	7.8	0.25	31.8	281.0	0.38	0.08	0.04	
C_KS1_358_1	CHEVROLET	CAPRICE-ESTATE	1990	5	9/21/2004	22	7.9	0.52	15.1	530.1	34.66	1.32	3.28	
C_KS1_359_1	MERCURY	GRAND MARQUIS	1988	5	9/21/2004	22	8.0	0.13	63.8	135.8	1.87	0.26	0.51	x
C_KS1_360_1	TOYOTA	PICKUP	1987	2.4	9/20/2004	25	8.0	0.44	18.3	485.7	2.04	4.57	0.77	
C_KS1_361_1	CHEVROLET	CAVALIER	2004	2.2	9/21/2004	18	8.0	0.36	22.3	399.5	0.77	0.04	0.04	
C_KS1_363_1	PONTIAC	GRAND AM SE	1997	2.4	9/22/2004	21	7.7	0.37	20.9	419.9	4.90	0.88	0.15	
C_KS1_363_2	PONTIAC	GRAND AM SE	1997	2.4	9/21/2004	23	8.0	0.37	21.6	403.1	6.52	0.79	0.19	
C_KS1_364_1	SATURN	SEDAN	2001	2.4	9/21/2004	20	8.0	0.36	22.0	404.9	0.49	0.22	0.02	
C_KS1_364_2	SATURN	SEDAN	2001	2.4	9/21/2004	23	8.1	0.32	25.4	337.1	9.29	0.30	0.18	
C_KS1_367_1	PLYMOUTH	VOYAGER	1999	3.8	9/22/2004	22	9.4	0.48	19.7	451.1	1.80	0.56	0.13	
C_KS1_368_1	TOYOTA	CAMRY	1994	3	9/22/2004	21	8.0	0.31	25.8	337.9	5.23	0.31	0.33	x
C_KS1_369_1	FORD	RANGER	2003	4	9/22/2004	19	8.0	0.47	16.9	527.2	0.77	0.22	0.05	
C_KS1_369_2	FORD	RANGER	2003	4	9/22/2004	21	8.0	0.46	17.3	513.6	2.98	0.20	0.06	
C_KS1_372_1	KIA	SEDONA	2004	3.5	9/23/2004	20	8.0	0.49	16.2	547.3	3.38	0.00	0.02	
C_KS1_373_1	TOYOTA	COROLLA	1995	1.6	9/23/2004	21	8.0	0.27	29.2	302.2	2.18	0.86	0.21	
C_KS1_373_2	TOYOTA	COROLLA	1995	1.6	9/23/2004	23	8.0	0.27	29.6	292.0	5.50	0.75	0.38	
C_KS1_374_1	TOYOTA	SIENNA	2000	3	9/23/2004	21	7.5	0.46	16.2	545.3	2.14	0.86	0.43	
C_KS1_377_1	OLDSMOBILE	CUTLASS	1987	2.5	9/23/2004	25	8.0	0.74	10.8	699.5	58.28	5.92	12.94	
C_KS1_379_1	CHEVROLET	LUMINA	1997	3.1	9/24/2004	22	8.0	0.47	17.0	513.0	9.89	0.80	0.25	
C_KS1_381_1	FORD	CONTOUR	1996	2	9/24/2004	23	8.0	0.27	29.4	295.8	5.83	0.27	0.20	x
C_KS1_381_2	FORD	CONTOUR	1996	2	9/24/2004	22	8.0	0.27	29.2	297.6	5.37	0.20	0.26	x
C_KS1_383_1	FORD	F150	1989	4.9	9/24/2004	20	8.0	0.54	14.9	580.9	8.89	6.34	2.05	
C_KS1_383_2	FORD	F150	1989	4.9	9/24/2004	25	8.0	0.57	14.1	612.4	10.78	5.55	3.12	
C_KS1_384_1	SATURN	WAGON	1993	1.9	9/24/2004	37	22.1	0.72	30.7	270.7	12.36	0.82	0.87	

CTR_TST_ID	Make	Model	Model Year	Disp	Test Date	Test Duration (minutes)	Test Distance (miles)	Fuel Used (gal)	Test FE (mpg)	Composite CO2 (gpm)	Composite CO (gpm)	Composite NOx (gpm)	Composite THC (gpm)	Suspect Data
C_KS1_385_1	CHEVROLET	TRACKER	2003	2.5	9/24/2004	19	8.0	0.40	20.2	442.0	0.98	0.23	0.14	
C_KS1_386_1	CHEVROLET	CAPRICE CLASSIC WAGO	1987	5	9/11/2004	17	8.0	0.45	17.8	455.1	29.95	5.03	1.15	
C_KS1_386_2	CHEVROLET	CAPRICE CLASSIC WAGO	1987	5	9/11/2004	19	8.0	0.56	14.2	563.5	39.83	5.99	1.68	
C_KS1_387_1	FORD	ESCORT	1999	2	9/11/2004	19	8.0	0.32	25.0	351.2	4.03	0.93	0.07	
C_KS1_388_1	TOYOTA	CAMRY	2001	3	9/11/2004	20	8.0	0.40	20.0	443.8	2.90	0.13	0.07	
C_KS1_389_1	DODGE	RAM	1986	3.7	9/11/2004	19	8.0	0.48	16.6	396.3	79.53	2.15	7.92	
C_KS1_390_1	CHEVROLET	SUBURBAN	1995	5.7	9/11/2004	20	8.0	0.75	10.7	806.3	18.40	1.66	0.51	
C_KS1_394_1	TOYOTA	COROLLA	1992	1.6	9/25/2004	24	8.0	0.37	21.8	404.6	3.78	1.13	0.26	
C_KS1_394_2	TOYOTA	COROLLA	1992	1.6	9/25/2004	21	7.7	0.36	21.2	413.2	5.41	0.92	0.39	
C_KS1_395_1	PONTIAC	GRAND AM	1997	2.4	9/25/2004	22	8.0	0.28	28.7	306.6	3.16	1.12	0.18	
C_KS1_398_1	MERCURY	TRACER	1995	1.9	9/25/2004	22	8.0	0.19	43.1	200.6	4.18	0.94	0.14	
C_KS1_399_1	CHEVROLET	LUMINA	2001	3.1	9/25/2004	23	7.7	0.33	23.3	382.9	0.90	0.21	0.16	
C_KS1_416_1	FORD	TAURUS SE	1998	3	9/27/2004	22	8.0	0.44	18.3	486.8	1.86	0.29	0.15	
C_KS1_417_1	TOYOTA	COROLLA	1996	1.8	9/27/2004	20	8.0	0.28	28.8	301.8	5.27	1.73	0.50	
C_KS1_419_1	NISSAN	MAXIMA	2002	3.5	9/27/2004	21	8.0	0.35	22.9	389.6	0.94	0.21	0.12	
C_KS1_420_1	M.BENZ	SEL	1980	4.5	9/27/2004	21	8.0	0.80	10.0	392.8	331.04	0.03	17.80	
C_KS1_420_2	M.BENZ	SEL	1980	4.5	9/27/2004	20	8.0	0.73	10.9	376.3	294.59	0.18	15.19	
C_KS1_421_1	FORD	TAURUS	1993	3.8	9/27/2004	22	7.1	0.48	14.7	597.2	6.86	0.94	0.56	
C_KS1_424_1	CHEVROLET	ASTRO	1990	4.3	9/28/2004	38	8.0	0.68	11.8	633.5	73.24	1.50	6.18	
C_KS1_424_2	CHEVROLET	ASTRO	1990	4.3	9/28/2004	25	8.0	0.68	11.8	579.6	107.72	1.47	6.84	
C_KS1_425_1	VOLVO	850 TURBO	1996	2.3	9/28/2004	24	8.0	0.20	39.2	225.7	1.61	0.67	0.06	x
C_KS1_425_2	VOLVO	850 TURBO	1996	2.3	9/28/2004	24	8.0	0.21	38.2	231.2	1.85	0.77	0.12	x
C_KS1_426_1	TOYOTA	CAMRY	1994	3	9/28/2004	22	8.0	0.32	25.3	338.3	10.78	0.24	0.39	x
C_KS1_427_1	SATURN	SL1	1997	1.9	9/28/2004	21	8.0	0.24	33.0	266.7	2.40	0.36	0.28	
C_KS1_428_1	FORD	TAURUS	1995	3	9/28/2004	19	7.6	0.36	21.1	420.1	2.19	0.89	0.23	
C_KS1_429_1	OLDSMOBILE	CUTLASS WAGON	1989	3.3	9/27/2004	19	8.0	0.46	17.2	503.1	11.31	0.85	0.36	
C_KS1_429_2	OLDSMOBILE	CUTLASS WAGON	1989	3.3	9/27/2004	23	8.0	0.52	15.2	564.7	14.11	1.26	0.86	
C_KS1_430_1	HONDA	ODYSSEY	2000	3.5	9/29/2004	24	8.0	0.44	18.2	482.7	6.07	0.81	0.59	
C_KS1_432_1	LINCOLN	CONTINENTAL	1995	4.6	9/29/2004	19	8.0	0.37	21.5	410.0	4.55	1.26	0.65	x
C_KS1_433_1	FORD	F-150	1989	4.9	9/29/2004	34	18.6	1.12	16.5	487.6	30.52	2.24	2.95	x
C_KS1_434_1	MERCURY	MARQUIS	1994	4.6	9/29/2004	21	8.0	0.43	18.7	464.4	8.24	0.97	1.04	
C_KS1_436_1	PONTIAC	GRAND AM GT	1998	2.4	9/29/2004	27	8.1	0.29	27.4	320.0	4.69	0.63	0.19	x
C_KS1_437_1	TOYOTA	CAMRY	1996	2.2	9/30/2004	22	8.0	0.26	30.7	291.0	0.69	0.22	0.03	
C_KS1_437_2	TOYOTA	CAMRY	1996	2.2	9/30/2004	8	.	0.00	N/A	N/A	N/A	N/A	N/A	x
C_KS1_438_1	CHEVROLET	AVALANCHE	2002	2.2	9/30/2004	34	18.6	1.42	13.1	680.9	1.74	0.46	0.12	x
C_KS1_439_1	GEO	PRISM	1996	1.6	9/30/2004	22	8.0	0.26	30.6	281.3	6.55	0.91	0.66	
C_KS1_440_1	FORD	BRONCO	1990	5	9/30/2004	36	18.5	1.12	16.6	504.0	20.91	1.87	1.37	x

CTR_TST_ID	Make	Model	Model Year	Disp	Test Date	Test Duration (minutes)	Test Distance (miles)	Fuel Used (gal)	Test FE (mpg)	Composite CO2 (gpm)	Composite CO (gpm)	Composite NOx (gpm)	Composite THC (gpm)	Suspect Data
C_KS1_441_1	HONDA	ACCORD	1997	2.1	9/29/2004	23	8.0	0.32	25.2	351.8	2.71	0.47	0.15	
C_KS1_442_1	NISSAN	MAXIMA	1990	3	9/30/2004	21	8.0	0.30	26.4	330.2	4.23	0.89	0.96	
C_KS1_443_1	VW	CABRIO	1999	2	9/30/2004	20	7.7	0.25	30.9	287.5	1.18	0.29	0.09	
C_KS1_982_1	TOYOTA	CAMRY	1998	2.2	9/18/2004	23	8.0	0.47	16.9	512.4	8.35	1.10	0.53	

Table 4-10. Round 1 Driveaway Test Results

CTR_TST_ID	Make	Model	Model Year	Disp	Test Date	Test Duration (minutes)	Test Distance (miles)	Fuel Used (gal)	Test FE (mpg)	Composite CO2 (gpm)	Composite CO (gpm)	Composite NOx (gpm)	Composite THC (gpm)	Suspect Data
D_KS1_036_1	JEEP	WRANGLER	1995	2.5	7/23/2004	556	64.5	3.70	17.5	503.02	4.25	0.40	0.15	
D_KS1_095_1	BUICK	LESABRE	1989	3.8	8/2/2004	550	17.8	0.86	20.7	416.51	7.66	1.09	0.54	
D_KS1_096_1	SUBARU	OUTBACK LEGACY	1996	2.2	7/29/2004	421	23.8	0.77	30.7	275.02	9.44	0.91	0.24	
D_KS1_097_1	FORD	THUNDERBIRD	1988	3.8	8/5/2004	371	35.8	1.05	34.2	253.07	4.95	0.84	0.42	
D_KS1_124_1	FORD	ESCORT	2002	2	8/10/2004	523	42.4	1.58	26.9	326.00	4.43	0.15	0.05	
D_KS1_134_1	NISSAN	SENTRA	1994	1.6	8/11/2004	347	30.4	0.85	35.8	245.41	3.13	0.17	0.14	
D_KS1_138_1	CHRYSLER	LEBARON	1983	2.6	8/12/2004	362	13.5	0.80	16.9	491.50	23.78	1.51	0.49	x
D_KS1_149_1	CADILLAC	CIMMARON	1986	2.8	8/13/2004	366	59.4	2.21	26.9	326.98	2.74	0.74	0.40	
D_KS1_200_1	FORD	TEMPO	1986	2.3	8/24/2004	426	28.3	1.32	21.5	393.78	13.22	1.19	0.35	
D_KS1_203_1	OLDSMOBILE	NINETY EIGHT REGENCY	1985	3.8	8/24/2004	150	29.6	0.39	75.1	116.41	1.14	0.38	0.06	x
D_KS1_254_1	MERCURY	SABLE	1997	3	9/2/2004	298	66.8	3.13	21.3	408.45	6.59	1.19	0.19	
D_KS1_282_1	OLDSMOBILE	DELTA 88	1991	3.8	9/10/2004	229	41.3	1.39	29.7	296.47	2.49	1.17	0.21	
D_KS1_317_1	OLDSMOBILE	CUSTOM CRUISER STATI	1984	5	9/15/2004	492	23.0	1.44	16.0	478.21	38.73	5.48	6.21	
D_KS1_386_1	CHEVROLET	CAPRICE CLASSIC WAGO	1987	5	9/14/2004	602	26.8	1.49	18.0	449.92	26.56	7.85	1.64	
D_KS1_1012_1	NISSAN	MAXIMA	1992	3	8/25/2004	449	33.5	0.02	2009.8	2.20	0.02	0.00	0.00	x

A fuel economy comparison of Round 1 conditioning runs and LA92 drive cycle tests performed on the dynamometer is presented in Figure 4-13 (with a 1:1 line shown for reference). Appendices F and L provides formulas for calculating fuel economy from both the dynamometer and the PEMS. Results identified as “suspicious” in Tables 4-8 and 4-9 are excluded from Figure 4-13.

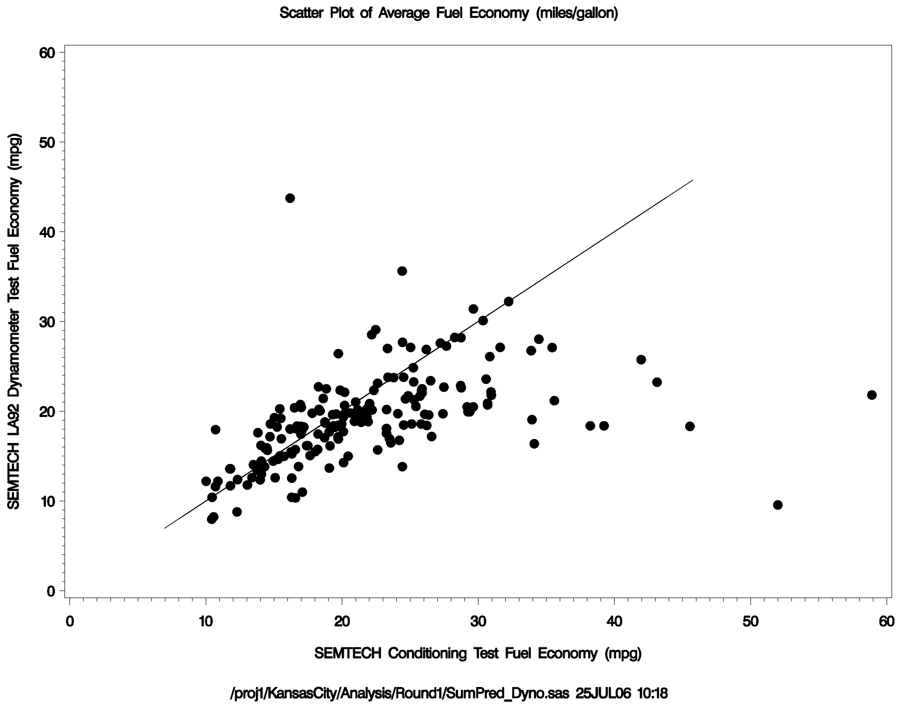


Figure 4-13. By-Vehicle Comparison of Conditioning Run vs. Dynamometer Testing Fuel Economy for Round 1

A fuel economy comparison of the driveaway tests and the LA92 dynamometer tests performed during Round 1 is shown in Figure 4-14, and Figure 4-15 provides a by-vehicle comparison of Round 1 condition run vs. driveaway test fuel economy. Again, 1:1 lines are provided for reference, and all “suspect” results are excluded from these figures. These figures tend to reveal lower fuel economy determinations as measured by the PEMS in comparison with dynamometer measurements. This difference could be attributed to testing discrepancies such as how closely the laboratory LA92 drive cycle approximates the driving pattern and loads encountered with real-word driving. The difference could also be in part due to measurement discrepancies between the two systems, such as errors or bias in determining the true exhaust mass flow rate or errors or bias in the exhaust gas concentration measurements. Examination of comparison of results of tests using similar measurement systems but different driving patterns (such as shown in Figure 4-15) helps illustrate the influence of testing variations, and examination of comparison of results of tests using identical driving patterns but different measurement systems (such as shown in Figures 4-12 and 4-16) helps illustrate the difference in results as measured by two different systems (PEMS vs. dynamometer).

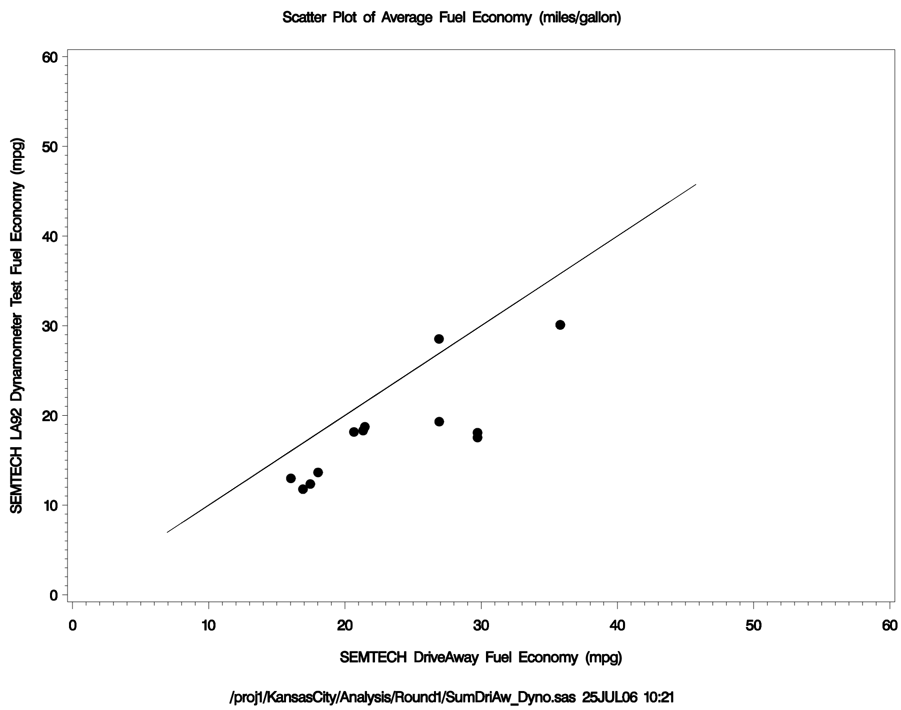


Figure 4-14. By-Vehicle Comparison of Driveaway vs. Dynamometer Testing Fuel Economy for Round 1

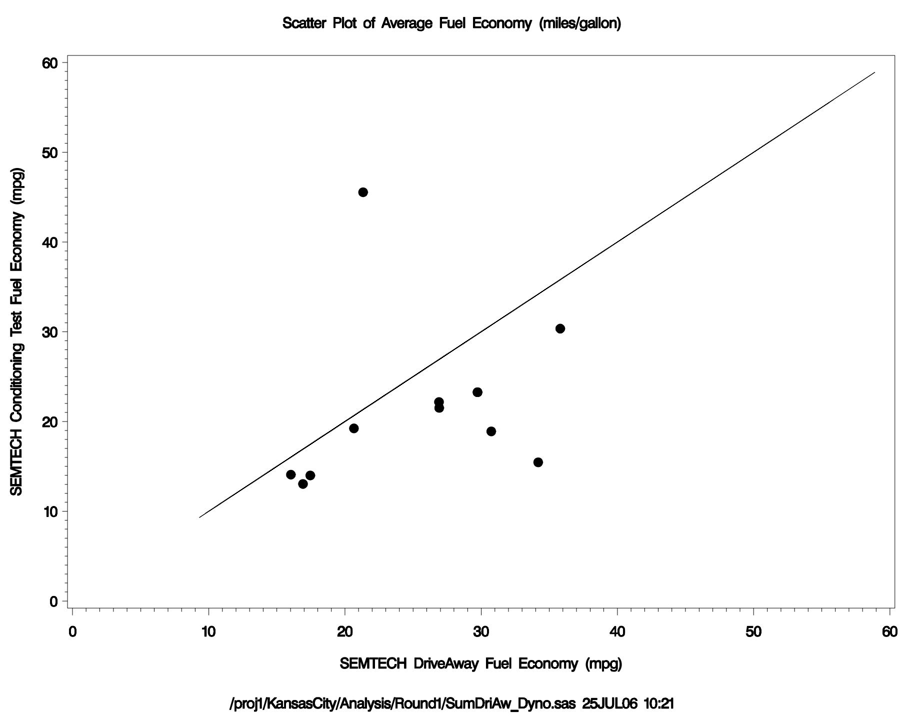


Figure 4-15. By-Vehicle Comparison of Driveaway vs. Conditioning Run Fuel Economy for Round 1

As previously indicated, an attempt was made to collect fuel and oil samples from all study vehicles. Occasionally, anti-siphon devices prevented collection of fuel samples from certain study vehicles. All fuel and oil samples were sent to the USEPA's National Vehicle and Fuel Emissions Laboratory for analysis. No oil samples were analyzed during the study (subsequent analysis is expected). Results of all fuel analysis performed prior to April 2006 were included in the MSOD data submission for this study and are shown in Table 4-11. Results of fuels analysis performed after April 2006 were not included in the MSOD submission (and are not shown in Table 4-11) but are included in Appendix FF (KC_fuels_analysis_complete.pdf) for reference.

Table 4-11. Fuel Analysis Results from Round 1 Vehicle Samples

Laboratory Fuel Batch ID	Vehicle ID	Sulfur (ppm)	Initial Boiling Point (F)	10% Distillation Point (F)	50% Distillation Point (F)	90% Distillation Point (F)	End Point (F)	Specific Gravity at 60 F	Degrees API at 60 F	Oxygen Weight %	Oxygenate Type	Total Recovery (mL)	Residue (mL)	Loss (mL)	Reid Vapor Pressure (psi)	Olefins (Vol %)	Saturates (Vol %)	Aromatics (Vol %)
13619	KS1_181	175	102		228	329	419	0.7588	54.98	0	NONE	97.8	0.8	1.4	6.3	7.6	56.9	35.5
13620	KS1_068	73	100	138	218	341	431	0.7504	57.08	0	NONE	98.2	0.7	1.1	6.8	12.7	57.2	30.1
13621	KS1_003	210	94	127	206	333	431	0.7381	60.21	0	NONE	97.7	0.8	1.5	8.1	8.3	65	26.7
13622	KS1_330	75	101	148	225	346	435	0.7566	55.53	0	NONE	97.9	0.8	1.3	6.1	10	57.6	32.4
13623	KS1_148	150	102	143	223	334	424	0.7578	55.22	0	NONE	98.1	0.8	1.1	6.6	9.5	55.6	34.9
13624	KS1_044	199	100	133	222	332	416	0.7541	56.15	0.47	ETHANOL	97.7	0.8	1.5	7.8	8	58.6	33.4
13625	KS1_151	166	99	143	222	340	445	0.7506	57.02	0	NONE	97.8	1	1.2	6.5	9.7	60.8	29.5
13626	KS1_082	107	100	141	223	339	422	0.7621	54.16	0.2	NONE	97.7	0.9	1.4	6.9	8	56	36
13627	KS1_189	94	102	142	223	338	426	0.7576	55.27	0	NONE	97.5	0.9	1.6	6.7	8.7	57.4	33.9
13632	KS1_132	79						0.7574	55.33	11.47	ETHANOL				8.2	6.9	74	19.1
13633	KS1_432	83	95	129	217	343	426	0.7491	57.4	0	NONE	97.3	0.8	1.9	8.2	9.3	60.3	30.4
13634	KS1_439	130	92	123	221	341	429	0.7507	57	0	NONE	97.3	0.7	2	8.4	9.1	58.6	32.3
13636	KS1_051	215	102	145	226	329	413	0.7581	55.15	0	NONE	97.7	0.8	1.5	6.5	8.3	57.7	34
13649	KS1_160	159	99	138	223	331	414	0.7541	56.14	0	NONE	97.6	0.8	1.6	7.4	8.4	59.6	32
13652	KS1_121	73	102	145	231	355	427	0.7653	53.41	0	NONE	97.9	0.7	1.4	6.1	10.4	52.9	36.7
13653	KS1_369	138	104	145	227	332	419	0.7599	54.7	0	NONE	97.8	0.8	1.4	6.1	8.1	56	35.9
13654	KS1_355	23	103	161	228	318	399	0.7496	57.28	0	NONE	97.5	0.9	1.6	5.9	2.4	69.6	28
13655	KS1_024	112	100	142	224	338	424	0.7542	56.12	0	NONE	97.7	0.8	1.5	6.3	10.1	58.5	31.4
13656	KS1_430	38						0.7485	57.55	0	NONE				10.7	3.7	63.3	33
13657	KS1_108	159	101	146	223	337	442	0.7524	56.56	0	NONE	97.8	0.7	1.5	6.4	10.3	59.5	30.2
13658	KS1_297	106	102	146	225	347	451	0.7573	55.35	0	NONE	97.7	0.9	1.5	6.2	10	57.3	32.7
13659	KS1_389	174	100	142	224	330	423	0.7566	55.53	0	NONE	97.9	0.7	1.4	6.9	8	58.1	33.9
13661	KS1_335	67	103	141	222	342	435	0.7539	56.2	0	NONE	97.5	0.8	1.7	6.5	10.7	57.1	32.2
13662	KS1_399	153	97	129	212	329	426	0.7421	59.17	0	NONE	98.1	0.8	1.1	8.1	9.4	62.6	28

Laboratory Fuel Batch ID	Vehicle ID	Sulfur (ppm)	Initial Boiling Point (F)	10% Distillation Point (F)	50% Distillation Point (F)	90% Distillation Point (F)	End Point (F)	Specific Gravity at 60 F	Degrees API at 60 F	Oxygen Weight %	Oxygenate Type	Total Recovery (mL)	Residue (mL)	Loss (mL)	Reid Vapor Pressure (psi)	Olefins (Vol %)	Saturates (Vol %)	Aromatics (Vol %)
13663	KS1_139	115	102	140	224	343	412	0.75	57.18	0	NONE	97.9	0.8	1.3	6.6	7.6	62.6	29.8
13726	KS1_083	43	98	151	227	322	406	0.7468	57.97	0	NONE	98	0.9	1.1	7	2.3	69.8	27.9
13727	KS1_123	313	94	131	213	334	411	0.7348	61.08	0	NONE	97.6	0.9	1.5	8.6	10	68.8	21.2
13728	KS1_005	70	102	141	225	348	428	0.7518	56.71	0	NONE	97.8	0.9	1.3	6.8	12.1	58.5	29.5
13729	KS1_306	154	101	144	226	330	415	0.761	54.46	0	NONE	98.2	0.8	1	6.8	9.7	55.1	35.2
13730	KS1_109	117	104	148	225	335	432	0.7536	56.26	0	NONE	98.2	0.9	0.9	6.4	8.6	61.4	30
13731	KS1_107	146	102	145	222	332	426	0.7552	55.87	0	NONE	98.1	0.9	1	6.5	8.6	59.6	31.8
13732	KS1_153	133	102	142	224	336	423	0.7584	55.09	0	NONE	98.1	0.9	1	6.9	8.3	56.4	35.3
13733	KS1_033	106	102	141	225	340	438	0.7554	55.81	0.14	ETHANOL	97.8	0.8	1.4	6.7	9.6	59.4	31.1
13734	KS1_384	134	96	134	219	331	416	0.7505	57.05	0	NONE	97.9	0.8	1.3	8.2	8	61.5	30.5
13738	KS1_419	41	93	139	226	318	406	0.7416	59.31	0	NONE	97.5	0.8	1.7	8.2	2.1	71.6	26.3
13823	KS1_173	170	101	147	226	342	433	0.7585	55.06	0	NONE	98	0.8	1.2	6.3	9.5	57.4	33.1
13824	KS1_169	166	99	143	225	340	453	0.7526	56.51	0	NONE	97.7	0.8	1.5	6.6	9.5	61	29.5
13825	KS1_367	141	98	132	221	341	433	0.7543	56.09	0	NONE	98.2	0.8	1	7.3	9.4	58.4	32.2
13826	KS1_002	179	106	148	226	332	422	0.7575	55.3	0	NONE	98.2	0.8	1	6.5	7.8	57.9	34.3
13839	KS1_358	149	102	141	225	334	418	0.7555	55.8	0	NONE	98	0.9	1.1	7.2	8.9	58.1	33
13840	KS1_308	174	99	146	227	331	418	0.7603	54.62	0	NONE	97.6	0.8	1.6	6.2	7.7	56.6	35.7
13841	KS1_317	98	105	144	230	350	420	0.7708	52.07	0	NONE	98.1	0.8	1.1	6.4	10.6	48.6	40.8
13842	KS1_319	48	103	140	223	350	437	0.7538	56.21	0	NONE	98.2	0.7	1.1	6.8	11.7	58	30.3
14277	KS1_299	13	99	155	227	319	402	0.745	58.43	0	NONE	97.5	0.9	1.6	6.4	2.1	70.7	27.2
14284	KS1_007	55	98	144	232	339	428	0.7614	54.36	0	NONE	97.5	1	1.5	6.5	10.5	54.1	35.5
14289	KS1_004	321	103	147	227	334	422	0.7506	57.03	0	NONE	97.5	1	1.5	6.4	8.7	63.4	27.9

4.4.2 Summary of Round 2 Regulated Emissions Measurements

As with the Round 1 data, regulated pollutant measurements from the dynamometer are based on speed and emissions time-aligned second-by-second data, integrated for each phase. The PEMS test results were calculated by using speed and emissions time-alignment methodology developed by Sensors, Inc. Table 4-12 provides a side-by-side comparison of Round 2 PEMS vs. dynamometer composite results for each test (excluding control runs). Percentage difference between the two systems is shown for each run, and results with overall differences greater than 100% are indicated with bold-faced font. Out of 279 tests, six report a difference greater than 100% for at least one pollutant. Results from DRI's gravimetrically-collected $PM_{2.5}$ measurements are also shown in Table 4-12 for reference. Additional information and results from particulate matter measurements are provided in Section 4.5

Comparison of phase-specific and total composite emission rates in the data shows a relatively good correlation between the PEMS and dynamometer methods of measurement. A composite emission comparison is provided in this section, and complete (by-phase) results are provided in Appendices G and H for both Rounds 1 and 2 of the study. As with the Round 1 PEMS vs. dynamometer comparison data shown in Table 4-8, analysis of results of future studies, such as the "Measurement Allowance for In-Use Testing" study being conducted in 2006 at Southwest Research Institute in San Antonio, Texas, may help illustrate any discrepancies between results measured using these two systems.

As with the Round 1 data, the last two columns of Table 4-12 indicate dyno and PEMS records which may have suspicious regulated gaseous pollutant results, based on review of test data. For the dynamometer data, an "x" in the "dyno data suspect" column indicates either a test anomaly was noted in the onsite test log, or some issue was identified with the dynamometer data during subsequent data analysis, which could influence the overall test result. Some examples of data issues that would be noted include tests for which part or all of the real-time data was improperly collected or voided, tests where incorrect dynamometer loading was applied, tests where real-time sensors were saturated (pegged at maximum value), tests with equipment failures that would affect overall results, or tests where significant drive trace violations occurred. This review was only applied to dynamometer measurements collected during the study. Detailed notes pertaining to QC review of all dynamometer measurements are provided in Appendices S and V.

All Round 2 PEMS data was also analyzed to identify missing information and indicators of potentially invalid results. This analysis involved performing a comparison of exhaust mass flow rates for each test with those of other vehicles with a similar engine displacement, comparison of exhaust temperatures of each tests with the exhaust temperatures of other vehicles of similar engine displacement, review of exhaust dilution levels (percentage $CO + CO_2$ in exhaust), review of ambient temperature measured during testing and review of test durations, distances, and measured fuel economy. PEMS tests with highly suspicious results are indicated with an "x" in the "PEMS data suspect" in Table 4-12, and detailed notes collected during review of all Round 2 dyno PEMS tests are provided in Appendix P.

Table 4-12. By-Test Comparison of Round 2 PEMS vs. Dynamometer Composite Results

RunID	Temp (F)	RH (%)	HC (g/mi)			CO (g/mi)			NOx (g/mi)			CO2 (g/mi)			PM2.5 (mg/mi)	PEMS DATASuspect	Dyno DATASuspect
			PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff			
84393	37.9	70.6	0.58	0.34	41.85	6.07	3.17	47.69	0.33	0.30	8.13	768.10	449.54	41.47	2.48	x	
84394	39.2	69.1	0.51	0.31	39.74	9.95	5.26	47.13	0.47	0.30	36.07	855.25	530.00	38.03	21.09	x	
84396	39.1	65.5	0.27	0.30	-9.58	9.56	8.69	9.11	1.34	1.38	-3.43	371.92	385.82	-3.74	10.49		
84397	39.3	65.8	8.56	4.94	42.28	123.99	73.51	40.71	4.28	3.54	17.35	808.69	559.58	30.80	80.42	x	
84398	32.8	45.7	0.38	0.20	47.50	5.30	3.11	41.34	0.27	0.16	42.16	717.85	402.69	43.90	5.41	x	
84399	32.7	43.4	0.46	0.25	46.16	12.26	6.68	45.54	0.49	0.29	40.47	720.62	399.66	44.54	2.82	x	
84401	30.1	41.3	0.59	0.34	42.21	8.18	4.57	44.13	1.39	0.95	31.21	811.75	495.01	39.02	4.75	x	
84402	29.4	39.2	1.12	1.02	9.08	20.92	17.36	17.01	2.85	2.61	8.24	379.47	337.87	10.96	20.31		
84403	12.2	41.7	1.90	0.60	68.17	9.31	5.20	44.18	0.45	0.33	26.27	789.19	474.11	39.93	7.52	x	
84407	23.9	32.5	1.27	2.90	**-128.74**	39.00	24.18	38.01	5.20	4.58	11.91	557.01	367.97	33.94	151.32	x	
84409	17.9	43.5	0.61	0.50	18.80	7.85	8.41	-7.24	0.94	1.15	-22.43	434.76	432.62	0.49	4.54		
84411	18.4	43.9	0.52	0.53	-1.01	2.42	5.39	**-122.96**	0.54	0.84	-55.84	166.12	384.08	**-131.21**	83.29	x	
84412	17.8	44.8	0.28	0.56	**-100.49**	6.64	9.57	-44.23	0.21	0.47	**-123.70**	171.91	305.99	-78.00	3.09	x	
84413	18.4	47.0	.	1.87	N/A	.	33.86	N/A	.	1.40	N/A	.	700.36	N/A	140.91	x	
84414	27.2	40.1	0.09	0.12	-22.41	1.48	1.59	-7.25	0.20	0.11	45.32	452.20	449.79	0.53	2.56		x
84415	28.4	33.7	0.29	0.33	-13.68	7.68	8.11	-5.65	1.47	1.62	-10.27	696.66	713.39	-2.40	27.03		
84416	28.2	36.0	0.19	0.19	-3.82	7.44	6.63	10.81	0.10	0.08	16.95	321.06	281.73	12.25	3.84		
84419	34.1	30.8	0.44	0.44	-0.92	6.61	6.88	-4.12	0.60	0.52	12.90	470.93	442.39	6.06	4.29		
84420	30.4	39.4	0.19	0.25	-31.96	5.40	5.15	4.66	0.39	0.35	10.31	469.59	379.66	19.15	17.05		
84421	34.9	36.4	0.23	0.24	-5.06	2.45	2.28	7.00	0.43	0.41	5.54	394.82	363.08	8.04	4.21		
84422	37.4	38.5	1.69	1.50	11.37	19.07	16.83	11.73	5.74	5.25	8.63	547.06	522.20	4.54	18.68		x
84424	41.3	41.5	0.27	0.24	9.70	4.69	4.02	14.20	2.43	2.37	2.62	597.83	579.49	3.07	13.91	x	
84425	43.9	39.3	2.40	2.21	7.81	18.67	16.01	14.26	6.07	5.47	9.85	574.97	532.63	7.36	28.28	x	
84426	39.4	61.8	0.20	0.22	-9.28	6.68	6.48	3.04	0.11	0.10	15.51	346.19	306.34	11.51	6.91		
84427	45.2	58.3	0.10	0.11	-14.50	0.92	0.86	6.70	0.14	0.13	6.31	378.39	353.87	6.48	1.45		
84428	46.3	56.5	0.35	0.38	-9.34	5.61	5.57	0.78	0.80	0.71	11.21	429.14	418.70	2.43	17.01		
84430	46.7	56.0	0.80	0.63	21.14	20.97	16.13	23.09	1.78	1.74	1.94	449.98	390.15	13.30	23.64		

RunID	Temp (F)	RH (%)	HC (g/mi)			CO (g/mi)			NOx (g/mi)			CO2 (g/mi)			PM2.5 (mg/mi)	PEMS DATASuspect	Dyno DATASuspect
			PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff			
84431	47.1	54.9	0.86	1.15	-34.14	10.00	12.64	-26.42	1.25	1.36	-8.23	487.00	510.38	-4.80	27.39		x
84432	44.7	60.5	0.41	0.41	-0.90	3.05	2.91	4.60	0.32	0.29	11.88	337.72	300.92	10.90	6.55		
84433	48.3	57.4	0.30	0.28	8.12	4.68	3.58	23.62	0.35	0.32	9.64	537.00	486.68	9.37	27.54		
84436	56.3	50.5	0.38	0.36	4.63	10.11	9.28	8.18	0.77	0.64	16.89	540.07	491.97	8.91	3.87		
84437	60.1	47.0	0.27	0.30	-11.63	2.61	2.58	1.23	0.35	0.34	2.37	431.28	430.76	0.12	2.08		
84438	40.3	60.9	0.11	0.11	-6.65	2.10	2.13	-1.58	0.13	0.10	24.91	469.97	439.08	6.57	2.68		
84439	40.6	60.1	0.37	0.39	-5.50	6.03	5.65	6.25	1.71	1.63	4.60	479.21	463.43	3.29	7.32		x
84442	40.7	59.6	0.28	0.30	-7.82	2.61	2.62	-0.41	0.38	0.35	5.88	451.12	471.80	-4.59	2.53		
84443	41.5	61.0	0.59	0.60	-1.63	6.72	6.60	1.78	2.15	1.93	10.21	348.42	331.88	4.75	19.00		
84444	25.0	32.6	0.27	0.31	-16.88	1.21	1.19	1.52	0.19	0.20	-7.26	439.68	449.71	-2.28	18.07		
84445	24.1	33.4	0.26	0.24	7.93	2.37	2.18	8.06	0.11	0.24	**-114.00**	252.55	424.38	-68.03	3.24	x	
84446	23.6	35.8	0.80	0.76	5.05	5.09	5.17	-1.45	0.73	0.62	14.44	537.87	509.89	5.20	30.30		
84448	24.7	38.9	0.44	0.44	-0.74	5.98	6.21	-3.83	0.44	0.41	7.77	535.31	522.17	2.45	22.75		
84449	25.8	39.0	0.44	0.44	-1.09	8.05	7.91	1.77	1.15	1.13	2.12	493.77	473.77	4.05	10.15		
84450	24.9	41.1	3.30	3.09	6.52	30.51	27.69	9.24	5.37	4.81	10.33	454.71	424.96	6.54	20.88		
84452	46.3	49.6	0.28	0.27	1.54	6.99	6.26	10.43	1.04	1.09	-4.82	472.58	459.17	2.84	6.07		x
84453	50.1	47.8	0.46	0.53	-14.69	3.80	4.07	-7.28	0.95	1.07	-12.76	382.63	429.73	-12.31	6.53		
84455	54.9	42.7	0.23	0.24	-5.82	5.13	4.62	9.90	0.45	0.44	1.86	439.62	427.58	2.74	1.83		
84456	55.4	44.1	2.36	1.46	37.99	41.02	25.46	37.94	1.57	1.53	2.49	598.07	487.81	18.44	37.30	x	
84457	42.2	59.8	0.49	0.49	0.82	10.07	6.93	31.18	1.68	2.02	-20.25	494.92	492.17	0.56	22.22		
84458	45.0	52.6	0.71	0.68	3.84	17.01	16.79	1.34	1.38	1.30	6.03	511.47	489.03	4.39	19.93		
84459	45.4	51.6	0.45	0.43	5.22	9.34	8.73	6.54	2.01	1.84	8.16	500.59	468.54	6.40	4.70		
84462	42.9	50.9	3.56	3.32	6.67	99.70	99.11	0.59	1.19	1.15	3.20	393.09	391.90	0.30	38.05		
84463	34.7	62.5	0.25	0.25	-2.61	9.23	7.51	18.65	0.66	0.77	-17.10	378.72	366.52	3.22	101.18		
84464	37.2	61.2	0.61	0.61	-0.08	6.11	5.93	2.89	0.84	0.88	-4.78	470.42	445.46	5.31	32.94		x
84465	37.9	56.0	0.21	0.23	-6.50	3.35	3.32	0.89	0.88	0.92	-3.81	506.96	523.56	-3.28	188.71		
84467	37.2	55.0	2.11	1.61	23.58	21.89	17.60	19.61	1.83	1.81	0.88	408.71	360.11	11.89	23.32		
84468	36.6	46.3	0.22	0.23	-6.20	3.57	3.54	0.69	0.73	0.78	-6.68	485.25	498.02	-2.63	5.22		
84469	37.6	43.0	1.44	1.38	3.90	17.70	15.24	13.89	2.62	2.58	1.46	454.60	441.30	2.93	138.65		x

RunID	Temp (F)	RH (%)	HC (g/mi)			CO (g/mi)			NOx (g/mi)			CO2 (g/mi)			PM2.5 (mg/mi)	PEMS DATASuspect	Dyno DATASuspect
			PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff			
84470	38.0	42.9	61.47	16.14	73.74	237.74	210.51	11.46	2.08	2.09	-0.45	571.61	509.39	10.88	332.68	x	x
84472	40.0	40.9	8.72	4.26	51.17	82.10	59.14	27.96	1.91	2.02	-5.95	544.44	489.49	10.09	91.37	x	
84473	33.3	72.6	0.20	0.19	6.29	3.63	3.17	12.64	0.87	0.83	4.29	590.07	574.45	2.65	13.22		
84474	35.9	67.1	1.32	1.08	18.73	14.67	10.62	27.61	1.30	1.22	5.99	322.60	268.88	16.65	63.87		
84475	36.8	65.2	1.75	1.61	7.93	31.84	31.35	1.54	0.84	0.85	-1.29	408.81	398.80	2.45	43.59		
84477	39.4	59.8	1.45	1.49	-2.81	57.06	58.25	-2.07	1.98	1.80	9.30	439.23	421.54	4.03	74.32		
84479	35.0	78.3	0.38	0.39	-2.92	5.78	5.43	6.13	0.78	0.76	2.12	499.39	492.78	1.32	7.99		
84482	39.0	70.1	1.11	1.11	0.20	13.01	12.75	2.06	8.32	6.97	16.17	520.14	510.14	1.92	14.10		
84483	41.1	58.3	0.41	0.38	7.15	4.48	3.99	11.06	0.43	0.41	4.39	386.15	352.43	8.73	5.01		
84484	40.7	56.8	1.06	1.04	1.84	12.85	12.39	3.61	8.43	7.05	16.31	511.04	506.80	0.83	8.66		
84485	38.9	59.2	1.28	1.10	14.03	28.15	25.09	10.90	1.04	1.02	2.08	624.86	571.32	8.57	20.05		
84487	44.1	46.8	1.01	0.96	5.16	50.98	45.73	10.31	2.86	2.86	-0.07	432.14	420.65	2.66	22.53		
84488	35.4	65.4	0.19	0.19	0.06	3.56	3.00	15.59	0.79	0.84	-7.20	482.94	472.03	2.26	2.58		
84489	34.9	63.0	0.73	0.67	7.05	3.44	3.12	9.30	3.34	3.12	6.51	414.93	385.26	7.15	15.40		
84490	36.9	55.0	1.13	0.97	14.34	28.26	24.95	11.74	1.00	1.02	-1.61	609.41	556.44	8.69	3.84		
84492	41.4	39.7	2.83	1.46	48.50	23.16	20.95	9.54	1.70	1.63	4.18	581.85	544.35	6.44	52.72		
84493	34.5	58.9	0.05	0.06	-21.26	0.63	0.51	19.16	0.03	0.03	-15.71	473.60	462.63	2.32	1.09		
84494	42.9	52.4	0.21	0.22	-7.65	5.27	4.58	13.00	1.22	1.19	2.01	398.22	375.23	5.77	2.75		
84495	47.9	49.4	0.38	0.32	15.36	7.18	5.67	20.96	0.55	0.52	5.29	390.95	363.23	7.09	2.08		
84497	53.8	43.3	0.36	0.37	-1.41	8.60	7.42	13.72	0.61	0.55	10.10	593.97	564.85	4.90	24.40	x	
84498	43.7	55.8	0.32	0.28	11.39	4.33	3.33	23.08	0.43	0.42	2.91	491.62	470.13	4.37	10.10		
84499	49.7	51.9	0.41	0.47	-14.08	8.72	8.90	-1.98	0.34	0.32	4.16	349.35	348.21	0.32	4.66		
84500	55.1	46.1	0.51	0.53	-4.52	6.67	6.06	9.13	1.98	1.89	4.34	401.17	409.04	-1.96	4.82		
84503	49.2	45.0	0.11	0.11	-4.57	1.07	0.74	30.79	0.19	0.20	-5.28	477.64	476.38	0.26	2.80		
84504	51.3	43.9	0.37	0.38	-2.73	3.07	2.82	8.40	0.42	0.38	10.24	442.28	434.87	1.67	2.46		
84505	54.3	40.1	0.62	0.62	0.45	7.69	6.63	13.74	1.73	1.69	2.18	465.15	439.47	5.52	8.63		
84507	58.9	27.1	2.80	2.51	10.61	20.14	16.15	19.79	5.83	5.12	12.15	443.27	401.66	9.39	2.44		
84508	34.6	63.0	0.45	0.47	-3.24	11.38	11.61	-2.02	0.60	0.59	0.72	263.38	273.72	-3.93	2.69		
84509	34.0	60.4	2.37	2.13	10.23	19.49	17.24	11.56	4.05	3.49	13.71	586.33	516.86	11.85	14.08		

RunID	Temp (F)	RH (%)	HC (g/mi)			CO (g/mi)			NOx (g/mi)			CO2 (g/mi)			PM2.5 (mg/mi)	PEMS DATASuspect	Dyno DATASuspect
			PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff			
84510	34.9	55.5	3.04	2.74	10.01	34.42	31.65	8.03	4.06	3.75	7.74	648.26	625.32	3.54	22.33		
84512	31.0	57.6	72.24	17.97	75.13	226.14	179.00	20.84	0.68	0.70	-3.27	437.15	374.06	14.43	181.76		x
84514	27.0	56.1	0.29	0.21	27.96	1.49	1.26	15.78	0.26	0.21	20.71	478.55	470.46	1.69	3.85		x
84515	28.2	58.1	0.41	0.33	18.12	9.98	8.38	16.04	0.80	0.71	11.55	485.14	403.43	16.84	5.43		
84517	27.7	62.7	0.40	0.40	1.17	3.58	3.62	-1.16	0.70	0.65	6.72	508.30	511.52	-0.63	21.76		
84518	28.7	62.8	0.60	0.58	3.37	9.81	9.26	5.58	0.74	0.75	-0.43	441.86	435.76	1.38	2.69		
84519	29.6	61.7	1.41	1.13	19.81	15.74	11.19	28.88	3.67	3.19	13.21	553.44	465.20	15.95	23.01		
84520	26.8	52.3	0.13	0.13	2.15	1.20	1.07	11.02	0.18	0.18	1.34	482.03	474.17	1.63	2.68		
84521	28.2	85.1	0.24	0.25	-3.02	5.12	5.04	1.47	0.47	0.48	-1.58	400.40	404.90	-1.12	2.60		
84522	29.3	103.1	0.32	0.29	8.16	3.42	2.88	15.74	0.41	0.41	-0.57	536.22	505.22	5.78	5.74		
84524	33.8	94.9	0.41	0.41	1.08	6.75	6.58	2.45	1.22	1.27	-4.58	361.99	351.43	2.92	4.26		
84526	35.7	86.6	0.77	0.79	-2.02	9.82	9.29	5.38	1.08	1.20	-10.74	507.29	506.58	0.14	52.17		
84527	24.3	35.3	0.80	0.65	18.63	12.57	10.28	18.22	0.67	0.55	17.53	743.67	650.11	12.58	15.39		
84528	31.4	24.0	0.63	0.61	3.21	10.91	8.79	19.44	1.50	1.58	-5.22	526.88	526.18	0.13	133.10		
84529	35.2	20.7	1.41	1.10	21.71	22.32	20.87	6.53	1.55	1.46	5.80	390.26	386.18	1.05	56.52		
84531	40.3	17.3	0.88	0.73	17.71	22.05	22.00	0.20	1.70	1.71	-0.63	354.69	351.92	0.78	18.61		
84532	34.9	2.4	0.21	0.21	2.88	3.57	3.84	-7.34	0.28	0.26	5.17	500.88	507.07	-1.24	5.81		x
84533	39.8	1.3	0.34	0.31	7.48	4.98	4.21	15.51	1.15	1.07	7.11	693.60	670.09	3.39	6.46		
84534	44.1	5.1	0.59	0.58	2.46	5.45	5.20	4.59	0.73	0.71	2.91	402.44	412.17	-2.42	28.13		x
84537	40.9	63.8	0.30	0.30	0.41	5.61	4.48	20.10	0.82	0.73	10.01	587.41	533.31	9.21	3.18		x
84538	45.6	58.5	0.14	0.14	1.19	3.56	2.77	22.15	1.11	1.10	0.86	499.99	509.84	-1.97	1.07		
84539	47.9	57.4	0.63	0.61	3.38	8.76	7.49	14.54	0.82	0.75	7.89	612.67	589.85	3.73	3.95		
84541	49.8	68.3	0.79	0.70	11.03	16.98	13.57	20.10	1.29	1.05	18.26	542.43	467.28	13.85	6.33		
84542	44.6	61.3	0.73	0.74	-1.63	15.74	14.81	5.91	1.06	1.08	-2.29	462.55	478.70	-3.49	4.91		
84543	49.5	52.5	0.24	0.24	3.65	5.25	4.03	23.30	0.85	0.75	11.28	587.66	534.29	9.08	3.98		
84546	47.0	63.1	0.44	0.37	16.37	7.32	5.51	24.78	0.74	0.72	3.25	533.03	500.90	6.03	2.72		
84547	48.6	59.8	0.34	0.38	-11.72	3.87	3.78	2.40	0.42	0.42	0.45	299.57	305.26	-1.90	17.67		
84548	50.5	53.6	0.45	0.47	-4.13	4.20	3.79	9.87	0.63	0.63	-0.47	424.38	427.29	-0.68	2.84		
84550	53.3	42.2	2.54	2.50	1.96	18.43	17.53	4.88	2.07	2.07	0.06	509.46	524.94	-3.04	22.27		

RunID	Temp (F)	RH (%)	HC (g/mi)			CO (g/mi)			NOx (g/mi)			CO2 (g/mi)			PM2.5 (mg/mi)	PEMS DATASuspect	Dyno DATASuspect
			PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff			
84551	37.9	56.4	0.23	0.25	-5.13	4.64	4.14	10.93	0.25	0.24	5.00	509.68	520.95	-2.21	5.64		
84552	39.5	51.8	0.16	0.17	-4.75	3.13	3.27	-4.44	0.24	0.20	15.25	488.16	483.63	0.93	2.04		
84554	44.3	38.0	0.76	0.67	12.19	10.46	9.22	11.84	1.44	1.44	0.05	639.27	609.71	4.62	13.76		
84556	35.8	54.9	0.27	0.27	0.01	4.32	4.12	4.69	0.83	0.83	-0.83	481.60	493.01	-2.37	4.63		
84557	40.7	42.4	0.20	0.21	-6.60	2.07	2.06	0.85	0.36	0.34	5.28	511.55	503.02	1.67	2.70		
84558	43.5	36.3	0.96	0.65	32.26	6.70	5.77	13.78	0.40	0.37	8.26	569.08	547.54	3.79	36.01		x
84560	48.8	36.1	0.32	0.24	26.41	4.01	2.59	35.41	0.45	0.31	31.46	450.99	316.54	29.81	6.10		x
84562	33.3	47.8	0.11	0.10	8.87	0.95	0.78	18.04	0.12	0.10	18.30	543.05	503.15	7.35	4.39		
84563	38.5	39.6	0.17	0.17	-1.58	2.27	1.87	17.50	0.14	0.14	-3.94	524.23	527.05	-0.54	0.92		
84564	40.1	36.7	0.25	0.26	-4.02	3.44	3.46	-0.66	0.71	0.67	5.01	477.35	483.15	-1.21	5.44		
84566	44.8	32.7	0.50	0.51	-3.48	7.86	7.98	-1.52	0.47	0.49	-5.61	452.12	466.10	-3.09	36.75		
84567	46.6	30.4	12.49	12.44	0.40	260.54	246.30	5.47	0.25	0.40	-60.56	413.85	400.09	3.32	44.26		
84568	45.0	61.8	0.74	0.61	17.42	11.84	9.03	23.74	1.43	1.39	2.55	400.19	391.76	2.11	4.11		
84569	45.1	62.4	0.32	0.30	5.85	7.14	6.38	10.61	0.88	0.88	-0.74	444.84	430.50	3.22	3.37		
84570	45.4	64.5	0.46	0.33	28.04	12.20	9.09	25.52	0.54	0.49	9.15	447.77	392.10	12.43	1.00		
84572	46.6	65.6	0.39	0.42	-6.51	7.76	8.00	-3.08	1.07	1.10	-2.23	397.89	408.23	-2.60	3.64		
84573	36.5	71.8	0.22	0.22	1.08	3.37	3.08	8.58	1.04	1.01	3.09	526.77	519.34	1.41	5.03		
84574	37.7	67.3	0.34	0.35	-1.62	8.06	7.80	3.24	0.91	0.89	2.57	413.90	416.33	-0.59	1.05		
84575	39.0	65.5	0.92	0.89	2.90	19.86	18.51	6.79	1.55	1.54	1.06	446.92	439.91	1.57	5.78		
84577	42.0	62.2	0.21	0.22	-2.95	8.18	7.16	12.48	2.10	1.67	20.48	521.50	503.33	3.48	5.97		
84580	45.3	45.8	.	0.19	N/A	.	3.12	N/A	.	0.61	N/A	.	510.78	N/A	8.98	x	
84581	45.5	45.8	0.47	0.40	15.18	7.08	6.24	11.87	0.79	0.78	1.06	429.74	414.46	3.56	1.09		
84582	47.2	40.4	2.09	2.07	0.99	26.27	24.39	7.16	1.44	1.37	4.99	377.35	377.87	-0.14	15.57		
84584	42.5	53.9	0.32	0.31	1.39	5.25	4.62	11.96	0.36	0.32	12.05	395.96	390.46	1.39	5.82		
84587	43.9	45.7	0.68	0.64	5.01	4.86	4.85	0.08	1.04	1.12	-7.43	471.10	486.39	-3.25	12.14		
84588	48.3	40.6	2.35	1.78	24.39	49.00	44.23	9.74	1.51	1.53	-1.78	656.38	634.10	3.39	19.30		
84589	52.6	36.0	0.12	0.14	-14.05	1.51	1.50	0.90	0.18	0.17	4.87	305.59	305.68	-0.03	32.80		
84591	41.4	51.6	0.36	0.36	-0.37	7.94	7.16	9.78	1.74	1.63	6.52	546.21	549.47	-0.60	21.79		
84592	45.5	46.2	11.23	5.76	48.72	83.51	75.85	9.18	2.31	1.89	18.29	379.45	344.28	9.27	79.12		

RunID	Temp (F)	RH (%)	HC (g/mi)			CO (g/mi)			NOx (g/mi)			CO2 (g/mi)			PM2.5 (mg/mi)	PEMS DATASuspect	Dyno DATASuspect
			PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff			
84593	49.5	43.0	0.14	0.13	5.29	3.48	3.30	5.05	0.16	0.16	-2.91	365.10	369.05	-1.08	3.38		
84595	36.7	43.7	0.15	0.15	-0.69	4.76	4.15	12.90	1.14	1.13	0.18	331.06	339.68	-2.60	2.13		x
84597	38.4	40.9	0.87	0.87	0.52	17.46	17.55	-0.53	0.46	0.46	0.15	355.75	354.16	0.45	.		
84599	29.1	43.9	0.58	0.57	1.69	3.35	3.28	2.22	0.28	0.28	-1.57	422.68	427.98	-1.25	12.22		
84600	32.3	37.6	0.44	0.42	4.94	9.23	8.50	7.91	1.29	1.24	4.14	594.55	570.58	4.03	22.84		
84601	35.8	31.4	5.73	4.53	20.97	81.91	61.33	25.13	2.89	2.79	3.50	529.17	478.50	9.58	47.94		
84603	39.4	42.0	3.78	2.85	24.43	12.84	13.40	-4.30	3.13	3.33	-6.20	298.54	309.04	-3.52	7.46		
84605	45.9	44.8	2.69	1.70	37.00	27.17	16.19	40.41	2.38	2.57	-7.82	519.96	498.77	4.07	50.99	x	
84609	48.8	65.2	5.69	3.64	36.09	56.98	44.72	21.52	3.05	2.92	4.23	589.28	488.40	17.12	25.56		
84611	59.2	41.0	0.40	0.43	-8.39	5.58	6.11	-9.52	1.57	1.54	2.16	434.32	446.87	-2.89	5.42		
84612	42.1	55.2	0.03	0.14	**-314.48**	1.19	2.08	-75.15	0.23	0.55	**-140.82**	376.53	488.62	-29.77	0.75		
84616	52.9	47.8	0.13	0.15	-14.61	1.17	0.98	16.13	0.25	0.25	-0.92	457.91	466.89	-1.96	1.05		
84617	53.1	46.5	0.35	0.34	3.65	6.11	4.92	19.46	1.15	1.07	6.88	667.77	617.99	7.45	5.67		
84618	50.6	47.7	0.95	0.66	30.44	25.04	19.55	21.93	3.70	4.04	-9.00	594.72	447.57	24.74	6.31		
84620	51.8	42.1	5.25	2.76	47.46	42.57	21.38	49.77	2.00	3.09	-55.00	478.64	416.35	13.01	8.05		
84621	52.8	35.1	0.56	0.51	8.09	8.29	7.47	9.90	1.12	1.14	-1.67	476.73	451.38	5.32	4.56		
84622	37.4	45.9	0.83	0.47	43.58	6.99	4.09	41.50	0.61	0.43	30.43	609.37	395.53	35.09	7.62		
84623	41.1	39.1	1.66	0.82	50.60	37.82	18.40	51.36	3.75	3.43	8.55	564.77	357.33	36.73	27.09		
84626	46.2	35.5	1.21	1.20	1.14	35.85	36.13	-0.76	1.89	1.69	10.64	454.01	429.85	5.32	19.60		
84627	47.0	34.9	36.53	14.84	59.37	86.27	68.54	20.55	3.75	3.72	0.70	638.02	547.12	14.25	232.12		
84628	37.9	44.0	0.46	0.41	11.27	4.92	4.74	3.59	0.32	0.31	5.04	576.61	582.37	-1.00	14.58		
84629	38.9	38.6	0.40	0.40	-0.86	6.58	6.78	-2.98	0.19	0.17	12.66	432.73	421.14	2.68	5.16		
84630	40.4	36.1	1.28	1.14	10.63	30.95	29.30	5.34	0.50	0.51	-0.93	400.17	371.43	7.18	10.56		
84632	45.0	30.4	40.53	15.16	62.60	108.94	88.15	19.09	3.73	3.63	2.53	659.57	567.58	13.95	99.41		
84633	47.8	46.9	1.42	1.29	9.42	63.89	59.03	7.59	1.29	1.23	4.64	433.92	392.32	9.59	.		
84634	51.9	43.8	1.10	1.06	3.03	12.48	11.56	7.40	3.77	3.14	16.54	473.99	464.05	2.10	23.18		
84635	56.5	33.1	1.67	1.51	9.17	19.13	16.34	14.58	1.45	1.53	-5.37	481.67	469.67	2.49	65.85		
84637	59.7	23.7	4.13	3.78	8.64	73.58	69.22	5.92	4.08	3.89	4.81	462.42	465.32	-0.63	146.94		
84638	42.5	36.3	1.39	1.29	6.71	24.27	22.69	6.52	1.27	1.34	-5.69	468.83	471.90	-0.65	2.57		

RunID	Temp (F)	RH (%)	HC (g/mi)			CO (g/mi)			NOx (g/mi)			CO2 (g/mi)			PM2.5 (mg/mi)	PEMS DATASuspect	Dyno DATASuspect
			PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff			
84639	45.6	33.5	0.35	0.32	9.48	6.37	5.41	15.01	0.71	0.75	-5.27	357.61	327.89	8.31	1.80		
84640	48.7	32.4	0.27	0.26	4.74	9.53	7.92	16.84	1.30	1.32	-1.21	531.04	526.67	0.82	.		
84642	55.0	29.7	0.60	0.54	10.79	22.01	19.15	12.97	1.55	1.49	3.95	426.25	393.81	7.61	5.78		
84643	58.5	24.2	1.98	1.81	8.41	33.33	29.75	10.75	2.78	2.63	5.24	368.63	341.79	7.28	146.04		
84644	49.7	42.3	0.23	0.21	8.80	3.30	3.17	4.12	0.38	0.36	6.70	539.31	528.40	2.02	5.05		
84645	56.5	34.2	0.48	0.48	-0.24	5.28	4.82	8.72	0.46	0.48	-5.01	448.69	438.10	2.36	6.37		
84646	60.7	31.4	0.84	0.70	16.37	19.91	15.70	21.14	1.42	1.41	0.61	437.79	369.17	15.67	6.27		x
84648	65.7	24.2	1.11	1.09	1.27	21.77	22.08	-1.42	1.84	1.71	7.14	530.95	515.29	2.95	37.11		
84649	40.2	43.9	0.91	0.73	19.74	9.82	7.07	28.05	0.81	0.71	11.96	562.10	463.40	17.56	6.49		
84650	42.5	38.7	0.69	0.60	12.45	13.19	11.24	14.73	1.51	1.55	-2.14	481.95	455.82	5.42	7.63		
84653	50.2	27.1	5.79	3.91	32.47	89.24	71.68	19.68	5.81	5.10	12.17	737.72	688.25	6.71	111.61	x	
84655	49.4	26.0	0.38	0.39	-1.98	4.75	4.79	-0.74	1.28	1.28	0.03	484.11	472.30	2.44	5.35		
84656	52.0	25.2	0.50	0.43	14.22	10.14	7.96	21.48	1.28	1.31	-2.76	452.44	426.19	5.80	7.84		
84658	54.8	24.0	0.85	0.86	-1.59	12.34	11.18	9.41	3.00	2.85	4.92	401.29	381.53	4.92	6.65		x
84659	55.5	23.7	2.98	1.73	41.88	36.83	31.08	15.61	2.99	2.72	9.13	437.14	420.67	3.77	15.53		
84660	55.6	23.6	1.34	1.27	5.39	8.20	7.09	13.50	2.85	3.00	-5.11	466.47	457.67	1.89	157.13		
84661	44.3	50.7	0.32	0.29	11.31	4.71	3.67	22.00	1.31	1.34	-2.20	448.87	428.46	4.55	4.07		
84662	47.8	48.7	2.49	2.17	12.94	45.92	41.43	9.79	5.32	5.01	5.98	558.34	520.33	6.81	19.07		x
84663	51.4	42.8	1.13	0.91	19.30	16.97	12.60	25.76	1.57	1.60	-1.56	441.54	376.29	14.78	22.22		x
84665	54.9	34.2	0.61	0.58	5.18	12.99	12.07	7.12	2.86	2.79	2.52	544.58	505.47	7.18	10.04		
84666	56.4	28.3	1.04	1.07	-2.43	12.48	12.56	-0.68	2.85	2.89	-1.38	590.71	600.24	-1.61	12.77		
84667	57.8	22.8	7.77	6.88	11.45	69.05	65.68	4.88	3.27	3.29	-0.44	632.92	605.14	4.39	12.39		x
84668	48.9	37.3	0.17	0.17	5.37	2.26	1.92	15.33	1.46	1.36	6.90	487.41	459.26	5.78	2.45		
84669	53.0	30.7	1.25	1.03	17.60	23.53	20.32	13.62	2.56	2.70	-5.53	426.87	397.18	6.96	27.15		x
84670	55.9	27.3	0.76	0.70	8.01	15.52	14.10	9.15	1.22	1.25	-1.75	428.30	388.45	9.30	10.56		
84672	58.3	24.1	0.42	0.41	0.99	7.05	5.91	16.20	0.88	0.91	-2.93	294.79	265.97	9.78	4.91		
84673	60.5	21.4	12.67	6.47	48.93	305.06	213.11	30.14	2.63	0.65	75.22	703.78	674.27	4.19	83.99	x	x
84674	60.7	20.1	3.19	2.49	21.91	48.33	42.38	12.30	2.56	2.70	-5.16	545.13	500.75	8.14	8.98		
84675	52.9	28.9	0.33	0.34	-3.81	5.00	4.86	2.74	1.88	1.99	-5.81	400.47	395.88	1.15	4.11		

RunID	Temp (F)	RH (%)	HC (g/mi)			CO (g/mi)			NOx (g/mi)			CO2 (g/mi)			PM2.5 (mg/mi)	PEMS DATASuspect	Dyno DATASuspect
			PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff			
84676	54.8	25.6	0.99	0.89	10.20	19.21	17.58	8.51	2.16	2.29	-5.93	540.03	513.65	4.88	8.78		
84677	57.9	24.1	0.28	0.27	2.88	4.52	4.14	8.52	0.64	0.60	5.61	478.77	448.88	6.24	2.03		
84679	60.5	25.4	1.42	1.20	15.12	18.60	14.41	22.55	1.31	1.36	-3.76	390.69	341.77	12.52	7.87		
84680	62.1	24.2	53.89	16.94	68.56	148.84	111.35	25.19	1.82	2.34	-28.55	606.50	527.49	13.03	417.10		
84681	41.3	68.7	0.29	0.31	-4.74	4.02	4.09	-1.77	1.88	2.15	-14.10	406.11	401.57	1.12	.		x
84682	43.1	33.1	2.30	2.39	-3.95	46.58	46.27	0.65	0.90	0.90	0.01	430.75	436.33	-1.29	20.09		x
84683	45.5	39.4	1.18	1.04	11.69	15.28	12.86	15.80	2.74	2.87	-4.53	423.70	404.59	4.51	9.18		x
84685	46.9	22.6	1.69	1.21	28.30	7.12	5.50	22.73	1.83	1.90	-4.11	641.39	603.75	5.87	66.01		x
84686	49.3	14.1	6.62	3.27	50.61	26.05	18.29	29.80	4.61	3.90	15.33	537.08	439.63	18.15	27.30		x
84687	49.9	3.2	2.33	1.90	18.58	51.55	43.90	14.85	1.65	1.58	4.14	681.37	622.69	8.61	32.52	x	x
84688	52.1	38.9	0.42	0.41	2.27	6.86	6.47	5.77	1.30	1.28	1.77	490.93	459.18	6.47	10.36		
84689	54.2	38.2	0.26	0.26	-3.14	7.26	6.72	7.44	0.67	0.67	0.20	327.55	308.20	5.91	2.43		
84690	55.2	38.3	0.70	0.68	2.68	9.95	9.29	6.64	1.05	1.26	-20.81	372.43	378.31	-1.58	2.00		
84692	55.8	35.3	7.05	7.62	-8.09	161.33	158.99	1.45	0.22	0.26	-21.20	290.43	284.65	1.99	19.12		
84693	54.7	43.3	1.06	1.00	4.95	16.73	15.58	6.88	1.83	1.91	-4.70	557.86	543.17	2.63	5.66		
84694	52.1	51.9	2.91	1.91	34.14	27.93	20.69	25.93	5.11	4.43	13.28	596.16	492.64	17.36	26.68		
84695	42.4	67.6	0.71	0.63	10.57	9.06	7.38	18.61	1.00	1.20	-20.87	385.47	390.72	-1.36	2.12		
84696	42.2	67.7	6.17	3.73	39.51	31.60	25.23	20.15	3.35	3.60	-7.49	473.70	391.13	17.43	51.72		
84699	42.6	71.1	8.22	5.18	36.98	76.51	61.85	19.16	2.03	2.48	-21.68	560.64	514.41	8.25	158.21		
84700	40.8	72.9	8.22	6.11	25.70	78.09	65.54	16.07	3.31	3.38	-1.90	669.95	613.09	8.49	68.99		
84701	40.2	66.9	0.51	0.49	3.56	3.85	3.39	11.91	2.07	2.21	-6.72	399.99	394.25	1.44	11.59		
84702	41.2	64.8	1.38	1.27	8.35	15.46	12.60	18.51	1.61	1.69	-4.46	653.84	587.59	10.13	8.53		
84703	43.7	60.9	1.23	1.09	11.50	29.87	26.32	11.91	5.69	5.33	6.36	528.25	505.96	4.22	11.19		
84705	48.1	54.2	2.37	2.25	4.91	72.01	75.48	-4.81	0.76	0.78	-3.02	496.27	486.48	1.97	27.23		
84707	48.6	52.8	4.63	2.75	40.63	45.21	38.52	14.81	1.95	2.10	-7.36	713.34	669.72	6.11	78.06	x	
84708	46.0	60.0	0.10	0.10	0.32	1.28	1.11	13.36	0.55	0.51	5.63	485.14	460.99	4.98	11.19		
84709	47.0	60.4	1.49	1.12	24.75	21.79	18.00	17.39	1.32	1.33	-0.37	430.60	365.17	15.20	3.37		
84710	48.2	59.3	2.33	1.29	44.55	22.28	21.31	4.33	0.62	0.66	-5.45	414.17	412.37	0.43	39.89		x
84712	48.8	61.3	12.63	6.36	49.65	80.06	75.65	5.51	1.79	2.09	-17.25	413.05	396.93	3.90	30.98		

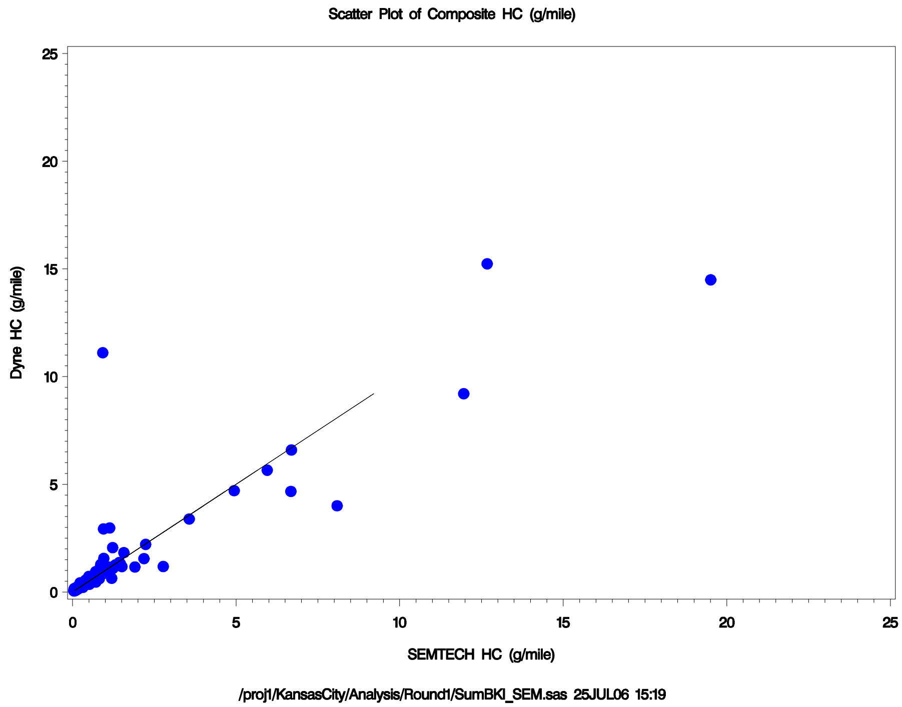
RunID	Temp (F)	RH (%)	HC (g/mi)			CO (g/mi)			NOx (g/mi)			CO2 (g/mi)			PM2.5 (mg/mi)	PEMS DATASuspect	Dyno DATASuspect
			PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff			
84713	44.1	74.1	0.41	0.36	12.60	7.34	6.16	16.09	0.57	0.60	-6.30	512.17	508.62	0.69	2.45		
84714	43.2	71.4	0.35	0.34	2.79	4.99	5.23	-4.93	0.22	0.27	-22.71	318.77	302.51	5.10	10.46		
84715	43.2	72.6	2.46	2.08	15.41	39.40	37.92	3.75	1.61	1.76	-9.56	390.35	361.07	7.50	59.26		
84719	42.7	62.0	0.43	0.32	25.36	8.49	6.92	18.45	1.09	1.12	-3.08	489.94	434.34	11.35	1.24		
84720	43.6	59.9	2.05	1.81	11.68	19.36	17.63	8.96	2.95	2.97	-0.59	685.23	614.65	10.30	9.57		
84722	50.5	47.4	0.21	0.18	14.42	2.50	2.15	14.04	1.69	1.45	13.97	530.69	498.32	6.10	2.87		
84723	54.7	43.2	2.40	1.95	19.09	18.95	14.48	23.57	3.33	3.71	-11.45	400.78	353.94	11.69	11.05		
84724	58.8	35.3	0.76	0.52	30.67	8.91	6.40	28.20	1.48	1.51	-1.76	477.91	408.42	14.54	4.31		
84726	64.4	29.1	0.73	0.59	18.40	18.88	15.75	16.58	1.49	1.42	4.68	541.37	453.30	16.27	2.86		
84727	66.5	26.5	0.80	0.77	3.16	13.76	13.98	-1.54	1.11	1.14	-2.90	528.49	511.19	3.27	34.79	x	
84728	62.5	43.4	0.16	0.14	9.01	0.95	0.67	29.19	0.09	0.14	-63.59	466.10	443.83	4.78	5.89		
84729	64.6	41.5	0.18	0.18	2.58	3.09	2.86	7.50	0.29	0.29	1.90	319.05	387.32	-21.40	2.13		
84730	66.6	39.6	1.40	1.04	25.55	13.25	9.79	26.06	0.59	0.58	1.38	535.18	479.25	10.45	6.57		
84732	70.6	37.1	4.86	3.75	22.91	84.37	69.27	17.90	4.02	4.59	-14.20	480.18	440.96	8.17	7.78		
84733	63.4	42.7	0.28	0.25	10.90	2.39	2.20	7.81	0.67	0.64	4.59	481.69	449.98	6.58	1.44		x
84734	63.0	42.9	0.65	0.58	9.42	8.48	7.86	7.28	1.58	1.61	-1.71	497.26	457.62	7.97	3.61		
84737	59.5	49.5	0.25	0.26	-2.33	10.72	10.58	1.38	0.93	0.89	3.68	419.50	378.23	9.84	10.10		
84738	58.2	50.7	5.53	4.62	16.54	159.32	145.23	8.84	1.81	2.17	-20.15	652.37	614.61	5.79	15.24		
84739	50.1	52.1	0.51	0.53	-3.58	7.99	7.71	3.56	0.68	0.78	-15.28	305.08	350.72	-14.96	22.84		
84740	51.6	48.7	0.68	0.57	15.80	9.94	8.11	18.39	0.85	0.86	-1.32	532.50	488.72	8.22	6.71		
84743	52.4	42.3	.	0.20	N/A	.	5.39	N/A	.	1.09	N/A	.	295.12	N/A	1.19		
84745	50.2	38.5	0.72	0.66	8.26	15.11	12.51	17.23	2.00	1.97	1.37	298.20	277.54	6.93	16.61		
84747	63.6	36.9	0.08	0.03	60.96	1.27	-0.93	**173.07**	0.49	0.48	0.49	519.53	382.85	26.31	.		x
84748	66.1	36.9	0.10	0.10	3.55	2.49	1.85	25.75	0.73	0.75	-2.59	535.67	489.93	8.54	1.62		
84749	68.0	37.3	0.15	0.13	12.28	2.43	1.64	32.55	0.25	0.25	1.00	470.47	429.24	8.76	1.13		
84751	72.3	35.9	0.16	0.16	4.56	6.72	5.96	11.34	1.14	1.31	-14.18	308.51	332.03	-7.62	2.92		
84752	74.1	33.5	0.41	0.45	-10.32	2.80	2.57	8.29	1.56	1.52	2.21	253.43	246.05	2.91	6.38	x	
84753	66.0	59.6	0.14	0.13	6.17	1.36	1.04	23.14	0.22	0.20	9.77	520.58	485.51	6.74	6.15		
84754	67.0	58.3	0.08	0.08	-0.09	0.78	0.51	35.11	0.36	0.34	5.38	516.47	481.02	6.86	3.38		

RunID	Temp (F)	RH (%)	HC (g/mi)			CO (g/mi)			NOx (g/mi)			CO2 (g/mi)			PM2.5 (mg/mi)	PEMS DATASuspect	Dyno DATASuspect
			PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff	PEMS	Dyno	% Diff			
84755	69.1	54.7	0.10	0.10	4.16	2.45	2.40	2.20	0.14	0.12	13.63	509.45	501.79	1.51	2.88		
84757	68.2	50.0	0.18	0.19	-4.18	1.98	1.52	23.33	0.49	0.46	4.98	531.78	498.01	6.35	2.02		
84758	68.9	49.1	3.59	3.19	11.24	54.92	53.57	2.45	1.38	1.53	-11.05	665.06	624.18	6.15	16.66		
84759	60.2	73.3	0.05	0.05	-2.94	1.21	1.02	16.05	0.03	0.03	6.95	351.05	357.69	-1.89	0.79		
84760	61.8	68.6	0.09	0.09	-6.08	1.23	1.03	15.83	0.05	0.06	-12.22	477.75	454.34	4.90	1.46		
84761	62.9	62.5	0.08	0.09	-10.00	1.23	1.03	16.63	0.08	0.07	8.14	518.77	529.55	-2.08	2.51		
84763	65.4	56.1	0.13	0.12	5.78	2.04	1.74	14.75	0.13	0.14	-8.14	512.35	511.31	0.20	3.51		
84765	66.2	53.9	6.11	4.27	30.12	113.55	103.26	9.06	1.27	1.52	-19.74	511.56	465.69	8.97	101.74		
84766	56.8	64.8	0.16	0.14	10.28	1.78	1.49	16.34	0.33	0.35	-4.91	513.45	488.72	4.82	1.76		
84767	56.5	64.2	0.51	0.36	30.72	14.16	9.77	31.05	2.31	2.09	9.52	549.19	408.99	25.53	3.03		
84768	56.2	63.7	0.81	0.70	13.82	3.34	3.20	4.29	1.30	1.37	-5.62	602.31	577.16	4.18	7.08		
84770	56.9	63.4	0.60	0.56	7.16	5.90	5.69	3.56	2.17	2.26	-4.31	632.53	605.50	4.27	23.63		
84771	56.4	64.5	3.57	3.05	14.65	27.01	22.49	16.73	2.66	2.92	-9.57	500.77	467.51	6.64	45.02		
84772	56.7	64.1	0.56	0.49	12.72	8.13	6.79	16.46	2.48	2.50	-0.69	467.98	470.37	-0.51	6.41		
84773	50.0	72.9	0.22	0.18	16.27	2.09	1.65	21.33	0.57	0.59	-3.32	530.19	477.23	9.99	1.55		
84774	55.6	60.3	0.43	0.38	11.70	5.07	3.55	29.92	0.87	0.29	66.48	506.34	454.49	10.24	3.95		
84775	60.0	40.1	1.38	1.19	13.66	14.56	12.12	16.75	2.67	2.58	3.32	687.87	616.25	10.41	3.76		
84777	63.8	29.3	0.91	0.88	2.66	16.56	15.58	5.91	3.38	3.48	-2.86	473.78	462.83	2.31	3.65		
Average*					**15.70**			**14.76**			**10.21**			**8.27**			

*The average percentage difference shown here is the average of the absolute value of the percentage difference for each run

Figure 4-16 provides a by-pollutant comparison of dynamometer vs. PEMS emissions with a 1:1 reference line. HC, CO, NOx, and CO2 are depicted using dots, squares, triangles, and circle-crosses, respectively. Additional scatter plots of dynamometer results vs. the PEMS for each particular phase can be located in Appendices G and H. Results listed as "suspect" in Table 4-12 are not included in Figure 4-16.

Table 4-13 provides results of all conditioning run tests conducted during Round 2, and Table 4-14 provides results of all driveaway tests conducted during Round 2. All conditioning run and driveaway results were reviewed to identify missing information and indicators of potentially invalid results, including an evaluation of exhaust mass flow rates, exhaust temperatures, dilution levels, ambient temperature measurements, test duration and distance and measured fuel economy. PEMS tests with highly suspicious results are indicated with an "x" in the "PEMS data suspect" column in Tables 4-13 and 4-14, and detailed notes collected during review of all PEMS tests are provided in Appendices T and U.



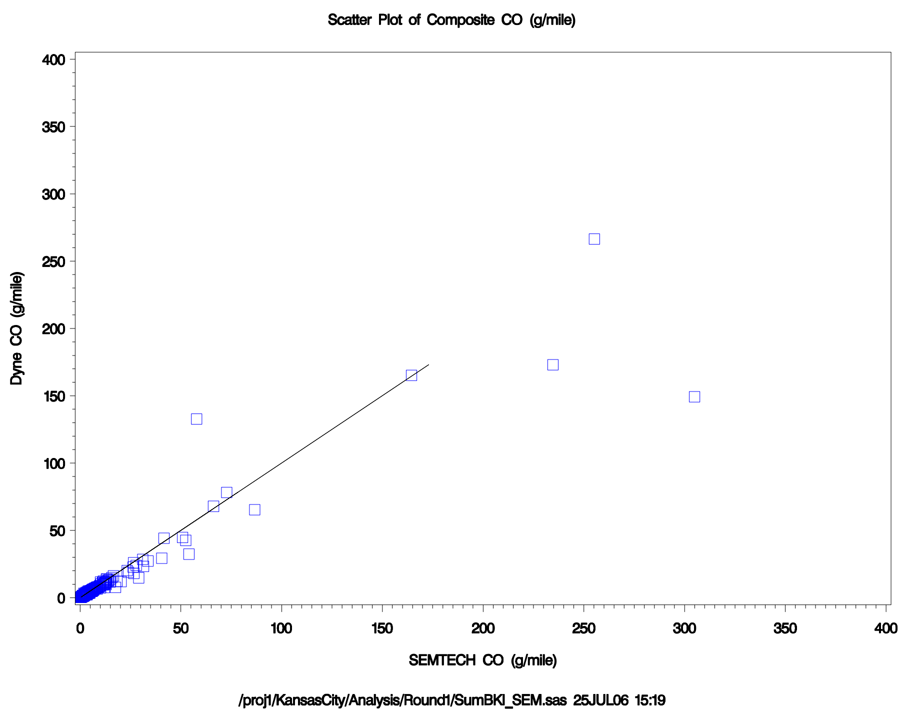
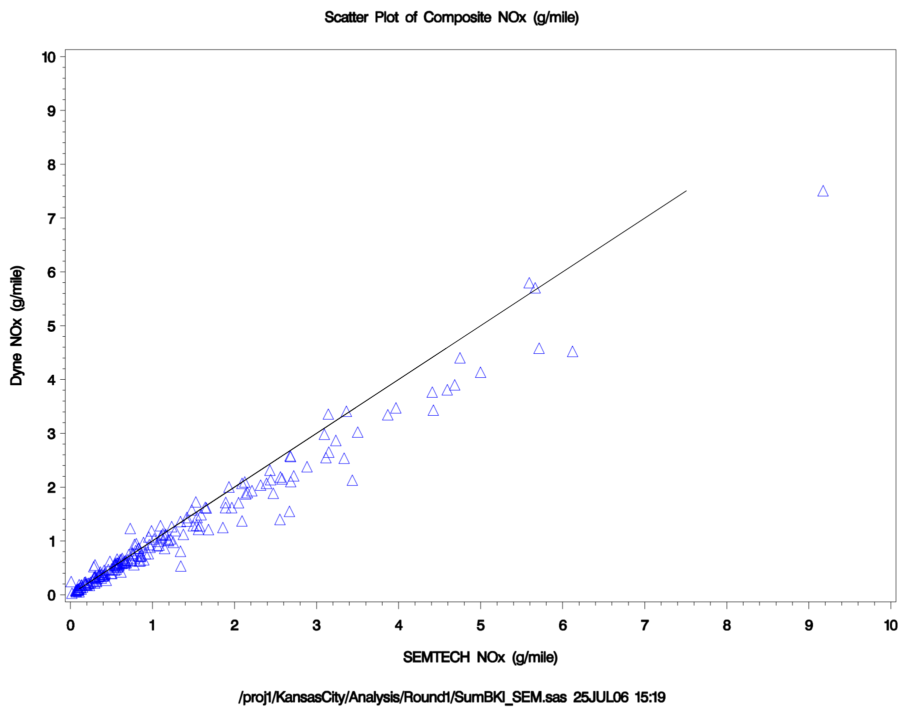


Figure 4-16. Plots of Round 2 Dynamometer vs. PEMS Measurements



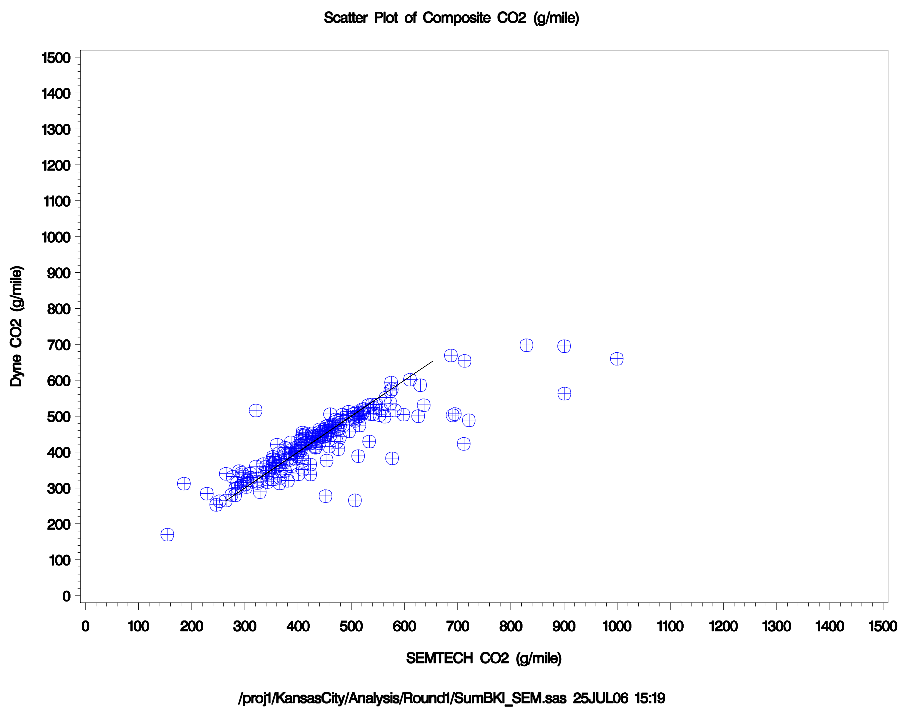


Figure 4-16 (Continued). Plots of Round 2 Dynamometer vs. PEMS Measurements

Table 4-13. Round 2 Conditioning Run Test Results

CTR_TST_ID	Make	Model	Model Year	Disp	Test Date	Test Duration (minutes)	Test Distance (miles)	FuelUsed (gal)	Test FE (mpg)	Composite CO2 (gpm)	Composite CO (gpm)	Composite NOx (gpm)	Composite THC (gpm)	Suspect Data
C_KS2_453_1	HONDA	ODYSSEY	2002	3.5	4/4/2005	20	8.0	0.51	15.6	567.0	4.22	0.21	0.05	
C_KS2_462_1	KIA	SEDONA	2004	3.5	4/5/2005	22	8.0	0.42	18.9	472.3	0.55	0.01	0.02	
C_KS2_484_1	CHRYSLER	TOWN & COUNTRY	2002	3.8	2/22/2005	22	8.1	0.42	19.0	469.4	2.53	0.51	0.07	
C_KS2_491_1	HONDA	ODYSSEY	2003	3.5	4/5/2005	29	8.0	0.41	19.5	456.7	0.87	0.18	0.03	
C_KS2_495_1	JEEP	CHEROKEE 4X4	2001	4	4/4/2005	24	8.0	0.60	13.3	667.0	5.05	0.85	0.23	
C_KS2_511_1	TOYOTA	SIENNA LE	2001	3	4/2/2005	26	8.0	0.38	21.0	425.3	2.99	0.19	0.07	
C_KS2_518_1	DODGE	GRAND CARAVAN	2002	3.3	4/2/2005	42	8.0	0.39	20.3	439.6	2.14	0.83	0.10	
C_KS2_521_1	MITSUBISHI	MONTERO	2003	3.8	2/7/2005	63	8.3	0.97	8.6	1038.1	6.02	1.51	0.21	
C_KS2_530_1	FORD	ESCORT LX	1995	1.9	1/11/2005	25	8.0	0.39	20.4	425.6	9.31	1.13	0.35	
C_KS2_531_1	CHEVROLET	SILVERADO	1976	3.5	1/11/2005	31	8.0	1.34	6.0	1201.3	168.71	7.46	12.88	x
C_KS2_532_1	CHRYSLER	300M	1999	3.5	1/11/2005	29	8.0	0.42	18.9	475.2	1.01	0.21	0.12	
C_KS2_533_1	HONDA	ODYSSEY	2000	3.5	1/11/2005	36	8.0	0.47	17.3	515.1	3.17	0.33	0.30	
C_KS2_534_1	HONDA	ACCORD	1997	2.2	1/12/2005	27	8.0	0.37	21.8	408.9	2.22	0.46	0.14	
C_KS2_537_1	PLYMOUTH	VOYAGER	1998	3.3	1/12/2005	24	8.0	0.44	18.3	487.4	2.17	0.85	0.22	
C_KS2_538_1	HONDA	ACCORD	2001	2.3	1/12/2005	37	8.2	0.43	19.3	465.2	0.87	0.10	0.10	
C_KS2_539_1	HONDA	CIVIC	1991	1.5	1/12/2005	30	8.0	0.42	19.1	442.6	16.13	3.04	1.29	
C_KS2_540_1	TOYOTA	COROLLA	1995	1.6	1/13/2005	51	8.0	0.40	20.3	439.1	2.74	0.98	0.41	
C_KS2_541_1	DODGE	CARAVAN	1997	3.3	1/13/2005	27	8.0	0.43	18.9	475.6	1.24	0.75	0.14	
C_KS2_542_1	PONTIAC	GRAND AM	1989	2.3	1/13/2005	32	8.0	0.47	17.0	492.2	17.93	4.34	3.37	
C_KS2_543_1	DODGE	CARAVAN	2000	3	1/13/2005	26	8.0	0.81	9.8	912.2	2.49	0.49	0.57	x
C_KS2_544_1	MERCURY	SABLE	2002	3	1/14/2005	34	8.0	0.45	17.7	507.5	0.75	0.12	0.06	
C_KS2_545_1	FORD	F250	1979	5.7	1/14/2005	31	8.0	1.32	6.1	1268.6	124.93	2.27	9.81	
C_KS2_546_1	CHEVROLET	MALIBU	1999	3.1	1/14/2005	49	8.0	0.40	20.0	439.7	6.75	0.85	0.68	
C_KS2_547_1	HONDA	CIVIC	1996	1.6	1/14/2005	31	8.0	0.31	26.1	331.7	7.70	0.70	0.50	
C_KS2_548_1	SATURN	NULL	1996	1.9	1/14/2005	46	8.0	0.35	22.8	390.5	2.84	0.90	0.32	

CTR_TST_ID	Make	Model	Model Year	Disp	Test Date	Test Duration (minutes)	Test Distance (miles)	FuelUsed (gal)	Test FE (mpg)	Composite CO2 (gpm)	Composite CO (gpm)	Composite NOx (gpm)	Composite THC (gpm)	Suspect Data
C_KS2_549_1	CHEVROLET	LUMINA	1998	3.1	1/15/2005	39	8.1	0.36	22.5	394.7	2.76	0.51	0.40	
C_KS2_550_1	PONTIAC	GRAND AM	1997	2.4	1/15/2005	35	8.0	0.38	20.8	428.3	2.82	0.88	0.23	
C_KS2_551_1	CHEVROLET	IMPALA	2003	3.8	1/15/2005	58	8.0	0.39	20.4	434.3	4.28	0.09	0.17	
C_KS2_552_1	DODGE	DURANGO	1999	5.9	1/15/2005	46	8.0	1.20	6.7	1304.4	26.02	1.13	1.27	x
C_KS2_553_1	HONDA	CIVIC	1998	1.6	1/15/2005	36	8.0	0.25	32.5	267.8	5.71	0.11	0.28	
C_KS2_555_1	JEEP	GRAND CHEROKEE	1995	4	1/17/2005	35	8.0	0.95	8.5	1006.1	28.26	7.25	4.09	
C_KS2_556_1	HONDA	ACCORD	2000	2.3	1/17/2005	32	8.0	0.35	22.8	392.1	2.44	0.31	0.20	
C_KS2_557_1	FORD	EXPLORER	1995	4	1/17/2005	48	8.0	0.89	9.0	986.5	9.56	3.14	0.58	
C_KS2_558_1	SATURN	LS1	2000	2.2	1/17/2005	37	8.1	0.33	24.6	361.9	2.33	0.40	0.22	
C_KS2_559_1	JEEP	CHEROKEE	1998	4	1/17/2005	35	8.0	0.85	9.5	883.4	36.42	7.77	4.38	x
C_KS2_562_1	CHEVROLET	MALIBU	1998	3.1	1/18/2005	45	8.1	0.36	22.5	395.6	3.11	0.89	0.37	
C_KS2_563_1	DODGE	SPIRIT	1990	2.5	1/18/2005	36	8.0	0.45	17.8	487.4	11.76	1.66	0.66	
C_KS2_564_1	SATURN	SC2	2001	1.9	1/18/2005	33	8.6	0.30	28.3	315.9	1.38	0.12	0.08	
C_KS2_565_1	MITSUBISHI	GALANT	2001	2.4	1/18/2005	51	8.1	0.36	22.3	402.0	0.59	0.18	0.09	
C_KS2_566_1	MERCURY	GRAND MARQUIS STATIO	1991	5	1/18/2005	160	8.1	0.82	9.9	882.3	13.34	2.31	2.90	x
C_KS2_567_1	JEEP	WRANGLER	1997	4	1/19/2005	57	8.0	0.85	9.4	930.2	15.62	0.87	1.21	
C_KS2_567_2	JEEP	WRANGLER	1997	4	1/19/2005	53	8.2	0.80	10.2	869.1	7.20	0.68	0.77	
C_KS2_567_3	JEEP	WRANGLER	1997	4	1/19/2005	35	8.1	0.70	11.5	769.9	6.66	0.60	0.63	
C_KS2_568_1	TOYOTA	CAMRY	1994	3	1/20/2005	51	8.5	0.34	25.3	352.7	1.18	0.36	0.23	
C_KS2_569_1	CHEVROLET	S-10	1995	4.3	1/19/2005	26	8.0	0.78	10.2	870.5	6.56	1.50	0.59	
C_KS2_570_1	SATURN	SEDAN	1999	1.9	1/19/2005	56	8.2	0.29	28.5	307.6	4.25	0.34	0.44	
C_KS2_571_1	BUICK	PARK AVENUE	1995	3.8	1/19/2005	40	8.1	0.71	11.4	771.9	8.57	0.93	0.81	
C_KS2_572_1	CHEVROLET	SILVERADO	2002	5.3	1/20/2005	24	8.0	0.73	11.0	808.5	6.49	0.47	0.64	
C_KS2_574_1	BUICK	CENTURY	2001	3.1	1/20/2005	25	8.0	0.40	20.1	445.8	1.16	0.10	0.06	
C_KS2_575_1	FORD	F150	2001	4.6	1/20/2005	31	8.0	0.81	9.9	905.6	3.13	0.52	0.30	
C_KS2_576_1	GEO	PRIZM	1991	1.6	1/20/2005	74	8.0	0.35	23.1	373.1	8.26	2.14	0.92	
C_KS2_577_1	PONTIAC	BONNEVILLE	1995	3.8	1/20/2005	39	10.7	1.05	10.2	862.7	9.01	2.04	0.81	

CTR_TST_ID	Make	Model	Model Year	Disp	Test Date	Test Duration (minutes)	Test Distance (miles)	FuelUsed (gal)	Test FE (mpg)	Composite CO2 (gpm)	Composite CO (gpm)	Composite NOx (gpm)	Composite THC (gpm)	Suspect Data
C_KS2_579_1	TOYOTA	SIENNA	2000	3	1/21/2005	37	8.1	0.83	9.7	918.9	3.36	1.20	0.48	x
C_KS2_580_1	PLYMOUTH	VOYAGER	1999	3.8	1/21/2005	34	8.1	0.74	11.0	795.4	12.02	0.89	0.53	
C_KS2_581_1	SATURN	SEDAN	2001	2.2	1/21/2005	33	8.0	0.42	19.0	470.5	2.12	0.32	0.12	
C_KS2_582_1	CHEVROLET	TRACKER	2003	2.5	1/21/2005	73	8.1	0.39	20.8	428.8	1.36	0.21	0.13	
C_KS2_583_1	BUICK	REGAL	1994	3.1	1/22/2005	43	8.0	0.73	11.0	798.9	9.23	2.09	1.50	
C_KS2_583_2	BUICK	REGAL	1994	3.1	1/21/2005	46	8.1	0.76	10.6	835.9	7.52	1.34	0.88	
C_KS2_584_1	NISSAN	MAXIMA	1995	3	1/22/2005	36	8.0	0.36	22.0	401.0	3.58	0.82	0.58	
C_KS2_585_1	FORD	TAURUS	1995	3	1/22/2005	48	8.0	0.41	19.7	451.0	4.28	0.91	0.24	
C_KS2_586_1	PONTIAC	GRAND PRIX LE	1993	3.1	1/22/2005	77	8.2	1.02	8.1	918.5	116.66	1.57	6.43	x
C_KS2_593_1	FORD	AEROSTAR	1993	3	1/25/2005	84	8.1	0.44	18.6	469.2	7.32	1.32	0.59	
C_KS2_594_1	PLYMOUTH	VOYAGER	1989	3	1/25/2005	41	8.1	0.78	10.4	745.7	79.40	2.49	3.67	
C_KS2_595_1	FORD	RANGER	1988	2.3	1/26/2005	59	8.0	0.48	16.7	500.8	17.32	1.45	2.77	
C_KS2_596_1	FORD	CROWN VICTORIA	1995	4.6	1/25/2005	44	8.1	0.88	9.1	958.0	16.52	2.13	1.39	
C_KS2_597_1	FORD	AEROSTAR	1992	3	1/25/2005	32	8.1	0.46	17.6	497.5	8.32	2.07	0.70	
C_KS2_599_1	CHEVROLET	LUMINA LS	1994	3.8	1/27/2005	40	8.0	0.73	11.0	813.3	1.87	0.84	0.65	
C_KS2_599_2	CHEVROLET	LUMINA LS	1994	3.8	1/26/2005	43	8.1	0.43	18.8	472.6	3.27	0.43	0.44	
C_KS2_600_1	FORD	CONTOUR	1995	2	1/26/2005	34	8.0	0.33	24.3	357.9	6.96	0.59	0.29	
C_KS2_602_1	DODGE	INTREPID	1994	3.3	1/26/2005	32	8.0	0.69	11.6	761.0	9.32	1.66	1.16	x
C_KS2_605_1	DODGE	CARAVAN	1989	3	1/27/2005	25	8.1	0.37	21.7	398.9	7.81	2.16	1.16	
C_KS2_606_1	CHEVROLET	SILVERADO 1500	1996	5	1/27/2005	55	18.6	1.60	11.6	765.2	5.44	1.08	0.26	x
C_KS2_607_1	FORD	TEMPO	1986	2.3	1/28/2005	44	8.0	0.50	16.2	382.3	112.27	1.98	7.43	
C_KS2_608_1	M.BENZ	280 SE	1973	4.5	1/27/2005	52	8.1	1.13	7.2	560.3	313.91	1.75	96.52	
C_KS2_609_1	CHEVROLET	MONTE CARLO	1977	5	1/27/2005	39	8.0	0.67	11.9	629.1	71.09	2.73	8.01	
C_KS2_611_1	FORD	EXPLORER	1996	4	1/28/2005	65	8.0	0.90	8.9	993.1	7.28	1.51	0.67	
C_KS2_612_1	DODGE	RAM	1989	2	1/28/2005	45	8.1	0.39	21.0	404.1	14.14	2.66	1.53	
C_KS2_614_1	HONDA	CIVIC	1988	1.5	1/28/2005	29	8.0	0.39	20.6	382.9	29.94	1.76	2.95	
C_KS2_616_1	JEEP	CHEROKEE	1998	4	1/29/2005	34	18.6	1.60	11.6	763.8	7.17	1.22	0.30	x

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C_KS2_617_1	DODGE	NEON	1996	2	1/29/2005	55	8.1	0.37	21.9	402.8	4.97	0.71	0.35	
C_KS2_618_1	BUICK	LASABRE	1979	4.9	1/29/2005	36	8.0	1.06	7.6	1156.9	7.52	14.17	8.16	
C_KS2_619_1	DODGE	CARAVAN	1996	3.3	1/29/2005	29	8.0	0.82	9.8	910.7	5.20	1.36	0.83	x
C_KS2_622_1	MAZDA	B2200	1992	2.1	1/31/2005	26	8.1	0.44	18.6	434.1	31.64	3.00	0.65	
C_KS2_623_1	CADILLAC	FLEETWOOD	1991	4.9	2/1/2005	31	8.0	1.00	8.0	1077.0	26.95	1.38	1.20	
C_KS2_623_2	CADILLAC	FLEETWOOD	1991	4.9	1/31/2005	26	8.1	0.57	14.1	609.9	16.37	0.66	1.31	x
C_KS2_624_1	FORD	RANGER	1990	2.3	1/31/2005	26	8.2	0.50	16.4	489.2	35.45	4.30	1.52	
C_KS2_624_2	FORD	RANGER	1990	2.3	1/31/2005	26	8.0	0.49	16.3	465.5	48.16	3.98	3.82	
C_KS2_625_1	BUICK	RAINER	2004	4.2	2/2/2005	51	8.1	1.02	8.0	1127.0	2.37	0.09	0.38	x
C_KS2_626_1	TOYOTA	TRUCK	1987	2.4	2/2/2005	46	8.0	0.44	18.1	493.3	1.62	2.90	1.32	
C_KS2_627_1	BUICK	LESABRE	1995	3.8	2/2/2005	53	8.0	0.40	19.8	451.1	2.18	0.81	0.10	
C_KS2_627_2	BUICK	LESABRE	1995	3.8	2/2/2005	37	8.0	0.46	17.5	507.4	4.23	0.54	0.14	
C_KS2_627_3	BUICK	LESABRE	1995	3.8	2/1/2005	24	8.0	0.76	10.5	852.1	3.78	0.88	0.27	
C_KS2_628_1	CHEVROLET	C10 SILVERADO	1984	5	2/1/2005	27	7.9	0.95	8.3	1021.0	32.63	2.60	4.03	x
C_KS2_631_1	FORD	RANGER XLT	1997	2.3	2/2/2005	32	8.0	0.41	19.5	451.4	6.99	1.52	0.25	
C_KS2_632_1	GMC	SONOMA	1996	2.2	2/2/2005	25	8.0	0.43	18.6	474.6	6.19	0.72	0.30	
C_KS2_633_1	FORD	FREESTAR SEL	2004	4.2	2/2/2005	25	8.0	0.49	16.4	550.8	0.32	0.02	0.04	
C_KS2_634_1	TOYOTA	4RUNNER SR5	1995	3	2/2/2005	88	8.0	0.92	8.7	993.0	24.62	0.86	1.61	x
C_KS2_635_1	CHEVROLET	SUBURBAN	1995	5.7	2/2/2005	45	18.6	1.18	15.7	554.3	9.75	1.56	1.06	
C_KS2_638_1	TOYOTA	SIENNA XLE	2001	3	2/3/2005	53	8.0	0.68	11.8	759.2	3.90	0.60	0.14	
C_KS2_639_1	ACURA	INTEGRA	1995	1.8	2/3/2005	79	8.0	0.31	26.2	331.8	6.76	0.34	0.52	
C_KS2_640_1	NISSAN	FRONTIER	1998	2.4	2/3/2005	27	8.0	0.45	18.0	489.2	6.11	1.88	0.71	
C_KS2_641_1	CHRYSLER	CONCORD	1996	3.5	2/3/2005	25	8.0	0.42	19.1	467.4	2.41	0.63	0.13	
C_KS2_642_1	FORD	TAURUS	2002	3	2/4/2005	27	8.0	0.40	20.2	444.0	0.76	0.29	0.03	
C_KS2_643_1	CHRYSLER	CONCORD LXI	2000	3.2	2/4/2005	37	8.0	0.76	10.5	845.5	7.39	0.54	0.55	x
C_KS2_644_1	DODGE	INTREPID	1993	3.3	2/4/2005	33	8.0	0.36	22.2	395.0	5.16	1.97	0.76	
C_KS2_644_2	DODGE	INTREPID	1993	3.3	2/4/2005	35	8.1	0.37	21.9	401.0	6.03	2.00	0.12	

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C_KS2_645_1	FORD	F150	1989	5	2/4/2005	36	18.6	1.26	14.8	594.6	8.04	1.24	0.41	x
C_KS2_646_1	CHEVROLET	ASTROVAN	1992	4.3	2/5/2005	39	8.0	0.90	8.9	968.3	21.28	7.52	4.44	
C_KS2_647_1	CHEVROLET	SUBURBAN	1994	5.7	2/5/2005	27	8.0	0.65	12.3	679.2	27.32	5.41	2.93	
C_KS2_648_1	FORD	F150	2001	5.4	2/5/2005	44	18.6	1.12	16.6	540.1	1.41	0.09	0.14	
C_KS2_649_1	HONDA	CIVIC	1992	1.5	2/5/2005	30	8.0	0.88	9.1	947.2	22.91	1.87	1.33	x
C_KS2_651_1	CHEVROLET	CAPRICE	1982	4.4	2/6/2005	28	8.0	0.97	8.3	483.8	272.91	0.61	80.71	
C_KS2_653_1	CHRYSLER	CONCORDE	2002	3.5	2/7/2005	41	8.0	0.50	16.0	555.6	4.24	0.26	0.66	
C_KS2_654_1	BUICK	SKYLARK	1994	3.1	2/7/2005	33	8.0	0.36	22.5	354.4	29.35	0.32	0.58	
C_KS2_655_1	CHEVROLET	ASTRO VAN	1993	4.3	2/8/2005	51	8.2	0.74	11.0	749.9	37.70	2.05	3.53	
C_KS2_656_1	DODGE	CARAVAN	1992	3	2/7/2005	40	8.0	0.82	9.7	888.3	19.72	5.04	2.71	x
C_KS2_660_1	DODGE	GRAND CARAVAN	1998	3.3	2/7/2005	123	8.0	0.02	507.0	4.1	0.11	0.00	0.00	x
C_KS2_661_1	LINCOLN	TOWNCAR	1991	4.6	2/10/2005	30	8.0	0.48	16.6	511.4	18.57	1.06	1.55	
C_KS2_662_1	ISUZU	PICKUP	1995	2.3	2/8/2005	35	8.0	0.45	17.7	493.5	8.22	1.62	1.00	
C_KS2_663_1	FORD	TAURUS	2001	3	2/8/2005	37	8.8	0.45	19.4	462.0	1.01	0.14	0.07	
C_KS2_664_1	HONDA	ACCORD	1997	2.2	2/9/2005	26	8.0	0.38	21.0	423.2	3.18	0.39	0.09	
C_KS2_665_1	DODGE	GRAND CARAVAN	2003	3	4/2/2005	22	8.0	0.44	18.4	489.4	0.47	0.43	0.03	
C_KS2_667_1	CHEVROLET	C1500	1996	4.3	2/8/2005	30	8.1	0.50	16.0	561.3	1.73	0.29	0.15	
C_KS2_668_1	DODGE	RAM PU	1995	5.9	2/9/2005	31	8.1	0.79	10.1	862.2	17.01	1.08	0.60	x
C_KS2_670_1	GEO	TRACKER	1992	1.6	2/9/2005	30	8.0	0.38	21.2	387.8	22.02	1.67	0.99	
C_KS2_671_1	PLYMOUTH	SUNDANCE	1992	2.5	2/9/2005	37	8.0	0.38	21.0	409.7	12.20	1.41	0.39	
C_KS2_674_1	HONDA	CRV	1998	2	2/10/2005	42	18.6	1.08	17.2	513.6	4.15	0.25	0.09	x
C_KS2_675_1	CHEVROLET	SUBURBAN	1999	5.7	2/10/2005	28	8.0	0.74	10.8	819.3	8.30	1.32	0.52	
C_KS2_676_1	SUBARU	LEGACY WAGON	1993	2.2	2/10/2005	49	8.0	0.42	18.9	463.6	7.19	1.00	0.64	
C_KS2_677_1	PONTIAC	MONTANA	2003	3.4	2/10/2005	24	8.0	0.38	20.9	427.4	2.02	0.19	0.07	
C_KS2_677_2	PONTIAC	MONTANA	2003	3.4	2/10/2005	29	8.1	0.39	20.8	431.5	0.61	0.14	0.03	
C_KS2_679_1	FORD	RANGER	1998	4	2/11/2005	29	8.0	0.42	19.2	465.2	2.17	0.72	0.16	
C_KS2_680_1	CHEVROLET	TAHOE	1996	5.7	2/11/2005	78	8.3	0.67	12.3	710.5	12.01	1.07	1.21	

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C_KS2_681_1	DODGE	GRAND CARAVAN	1996	3.3	2/12/2005	34	8.0	0.47	17.2	493.8	16.61	1.24	0.70	
C_KS2_681_2	DODGE	GRAND CARAVAN	1996	3.3	2/11/2005	25	8.0	0.37	21.5	401.8	10.31	0.95	0.51	
C_KS2_681_3	DODGE	GRAND CARAVAN	1996	3.3	2/11/2005	35	8.0	0.00	53605.6	0.0	0.00	0.00	0.00	x
C_KS2_682_1	JEEP	CHEROKEE SPORT	2000	4	2/12/2005	22	8.0	0.53	15.0	580.9	10.82	1.15	0.31	
C_KS2_682_2	JEEP	CHEROKEE SPORT	2000	4	2/11/2005	28	8.0	0.52	15.3	578.7	6.12	0.71	0.19	
C_KS2_685_1	DODGE	DAKOTA	1999	3.9	2/14/2005	22	8.0	0.46	17.4	503.2	6.81	0.99	0.60	
C_KS2_686_1	TOYOTA	COROLLA	1995	1.8	2/14/2005	19	8.0	0.28	28.9	306.0	2.95	0.45	0.23	
C_KS2_689_1	LINCOLN	TOWN CAR	1988	5	2/14/2005	33	8.0	0.48	16.6	512.2	14.16	1.64	2.79	
C_KS2_689_2	LINCOLN	TOWN CAR	1988	5	2/14/2005	0	0.0	0.00	N/A	.	.	.	.	x
C_KS2_693_1	ISUZU	AXIOM	2002	3.5	2/15/2005	38	8.0	0.50	16.2	550.4	2.42	0.27	0.12	
C_KS2_694_1	OLDS	SILHOUTTE	2002	3.4	2/15/2005	56	8.0	0.41	19.6	455.5	1.07	0.37	0.08	
C_KS2_695_1	FORD	F150	1992	4.9	2/15/2005	31	8.0	0.60	13.4	664.7	3.79	1.08	0.65	
C_KS2_698_1	CHRYSLER	TOWN & COUNTRY LX	2001	3.3	2/16/2005	28	8.0	0.44	18.2	487.4	4.21	0.91	0.21	
C_KS2_700_1	BUICK	PARK AVENUE	2000	3.8	2/16/2005	31	8.0	0.39	20.7	429.0	4.46	0.17	0.13	
C_KS2_701_1	DODGE	DAKOTA	1998	3.9	2/16/2005	35	8.2	0.51	16.0	548.9	8.35	0.63	0.31	
C_KS2_702_1	CHEVROLET	S-10	2001	4.3	2/16/2005	45	8.0	0.52	15.4	581.1	1.89	0.24	0.07	
C_KS2_703_1	FORD	COUNTRY SQUIRE	1986	5	2/16/2005	38	8.0	0.50	16.0	504.2	28.96	2.16	4.87	
C_KS2_704_1	CADILLAC	SEDAN DEVILLE	1992	4.9	2/17/2005	62	8.1	0.78	10.3	451.6	266.45	0.14	14.30	
C_KS2_705_1	DODGE	DAKOTA	2004	3.7	2/17/2005	37	8.0	0.47	16.9	523.8	4.38	0.06	0.33	
C_KS2_706_1	HONDA	ODYSSEY	1995	2.2	2/17/2005	33	8.0	0.84	9.5	925.5	9.61	0.81	0.74	x
C_KS2_707_1	DODGE	GRAND CARAVAN	1998	3.3	2/17/2005	43	8.2	0.44	18.8	472.4	4.60	0.63	0.21	
C_KS2_709_1	FORD	RANGER	2002	4	2/17/2005	30	8.0	0.00	N/A	0.0	0.00	0.00	0.00	x
C_KS2_709_2	FORD	RANGER	2002	4	2/17/2005	28	8.0	0.53	15.2	591.7	2.21	0.18	0.11	x
C_KS2_711_1	MERCURY	TOPAZ	1994	2.3	2/18/2005	37	11.5	0.46	25.1	356.0	1.49	0.77	0.15	
C_KS2_712_1	FORD	RANGER	1996	2.3	2/18/2005	38	8.0	0.41	19.3	453.8	7.04	1.26	0.69	
C_KS2_713_1	FORD	TAURUS	1995	2.2	2/18/2005	47	8.0	1.04	7.7	1125.7	13.71	1.30	1.04	x
C_KS2_715_1	CHEVROLET	SILVERADO	1994	5.7	2/19/2005	29	8.1	0.62	12.9	681.5	6.90	1.00	0.91	

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C_KS2_716_1	FORD	TAURUS	1993	3.8	2/19/2005	49	8.0	0.00	N/A	0.0	0.00	0.00	0.00	x
C_KS2_716_2	FORD	TAURUS	1993	3.8	2/19/2005	14	3.9	0.20	19.2	442.6	15.66	1.21	0.35	
C_KS2_718_1	BUICK	PARK AVENUE	1993	3.8	2/19/2005	35	8.0	0.46	17.4	507.7	6.13	0.95	0.19	
C_KS2_719_1	CHEVROLET	LUMINA	1994	3.1	2/19/2005	39	8.0	0.44	18.2	466.3	16.04	1.63	0.92	
C_KS2_721_1	FORD	WINDSTAR	1998	3.8	2/21/2005	36	8.0	0.47	17.2	509.7	7.59	1.73	0.20	
C_KS2_721_2	FORD	WINDSTAR	1998	3.8	2/21/2005	35	8.0	0.42	19.2	459.5	5.61	1.50	0.10	
C_KS2_722_1	VOLVO	960	1993	2.9	3/11/2005	25	8.0	0.41	19.8	451.6	2.08	0.38	0.10	
C_KS2_722_2	VOLVO	960	1993	2.9	3/11/2005	25	8.0	0.53	15.0	590.7	6.44	0.32	0.42	
C_KS2_723_1	FORD	TEMPO	1993	2.3	3/17/2005	31	8.0	0.34	23.5	377.6	2.87	1.93	0.20	
C_KS2_723_2	FORD	TEMPO	1993	2.3	3/18/2005	25	8.0	0.37	21.4	412.5	4.64	2.19	0.21	
C_KS2_724_1	CHEVROLET	BLAZER	1996	4.3	3/24/2005	24	8.0	0.52	15.4	572.3	6.08	0.55	0.25	
C_KS2_725_1	CHRYSLER	TOWN & COUNTRY	2002	3.8	4/5/2005	22	8.0	0.44	18.1	491.6	2.33	0.61	0.08	
C_KS2_726_1	CHEVROLET	S-10 LS	1995	4.3	3/28/2005	26	8.0	0.52	15.3	570.2	9.94	0.59	0.67	
C_KS2_727_1	BMW	528E	1988	2.7	2/22/2005	8	0.0	0.01	0.0	.	.	.	.	x
C_KS2_727_2	BMW	528E	1988	2.7	2/22/2005	24	8.0	0.48	16.8	458.9	41.53	1.55	3.93	
C_KS2_728_1	CHEVROLET	CORSICA	1995	3.1	2/22/2005	30	8.0	0.33	24.1	370.0	1.82	0.43	0.15	
C_KS2_728_2	CHEVROLET	CORSICA	1995	3.1	2/22/2005	43	3.5	0.15	23.4	369.4	8.02	0.85	0.65	x
C_KS2_729_1	CHRYSLER	TOWN & COUNTRY	1996	3.8	3/10/2005	34	8.0	0.44	18.1	466.8	17.02	1.39	0.93	
C_KS2_731_1	FORD	ESCORT	1993	1.9	2/23/2005	25	7.8	0.31	24.9	353.0	5.32	1.99	0.14	
C_KS2_733_1	NISSAN	PICKUP XE	1995	2.4	2/23/2005	28	8.1	0.50	16.0	539.8	12.83	0.43	0.64	
C_KS2_734_1	PLYMOUTH	VOYAGER	1993	3	3/29/2005	33	4.7	0.27	17.3	498.3	10.91	2.24	0.57	
C_KS2_736_1	MERCURY	VILLAGER	1997	3	2/25/2005	33	8.0	0.38	21.0	415.1	8.41	0.80	0.20	
C_KS2_737_1	BUICK	LESABRE	1978	5.7	2/24/2005	27	8.0	0.64	12.4	621.9	60.96	1.43	3.70	
C_KS2_738_1	SATURN	SL 2	2001	1.9	2/24/2005	27	8.0	0.30	27.1	331.6	0.76	0.19	0.05	
C_KS2_738_2	SATURN	SL 2	2001	1.9	2/24/2005	47	8.0	18.07	0.4	20238.6	9.92	2.66	0.72	x
C_KS2_739_1	FORD	TAURUS	1993	3	3/19/2005	25	8.0	0.39	20.6	426.8	5.28	1.22	0.50	
C_KS2_740_1	FORD	ESCAPE	2002	3	3/21/2005	27	7.9	0.42	18.9	472.9	1.59	0.18	0.08	

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C_KS2_743_1	FORD	LTD	1979	5	2/26/2005	77	5.8	0.16	37.2	209.8	17.30	1.75	1.39	x
C_KS2_743_2	FORD	LTD	1979	5	2/26/2005	5	0.0	0.00	2.2	2578.9	590.65	0.33	130.07	x
C_KS2_743_3	FORD	LTD	1979	5	2/28/2005	15	4.8	0.35	13.4	577.7	50.45	3.30	5.49	
C_KS2_743_4	FORD	LTD	1979	5	2/28/2005	30	8.0	0.50	16.1	516.2	25.29	4.44	1.79	
C_KS2_744_1	HONDA	ACCORD EX	1998	2.3	2/25/2005	48	8.1	0.29	27.4	323.9	2.67	0.30	0.11	
C_KS2_747_1	TOYOTA	4 RUNNER	1993	3	2/25/2005	23	8.0	0.47	17.2	498.0	16.46	1.12	0.36	
C_KS2_749_1	PONTIAC	SUNBIRD	1994	2	2/26/2005	28	8.1	0.78	10.3	826.3	25.46	0.43	1.87	x
C_KS2_750_1	FORD	ESCORT SE	1998	2	2/26/2005	31	8.0	0.28	28.3	312.7	3.14	0.87	0.06	
C_KS2_751_1	FORD	TAURUS GL	1997	3	2/26/2005	32	8.0	0.64	12.5	710.0	6.71	0.65	0.77	
C_KS2_753_1	FORD	WINDSTAR	1998	3.8	3/25/2005	36	8.1	0.46	17.6	504.5	4.00	1.96	0.32	
C_KS2_757_1	BUICK	REGAL	1979	3.8	2/28/2005	33	8.0	0.58	13.7	531.7	74.72	3.08	4.96	
C_KS2_760_1	MAZDA	PROTÉGÉ	1998	1.5	3/30/2005	26	8.0	0.29	28.2	312.3	3.86	0.56	0.18	
C_KS2_761_1	DATSUN	210 WAGON	1979	1.4	3/1/2005	15	0.0	0.01	2.9	2672.3	228.98	3.25	18.59	x
C_KS2_761_2	DATSUN	210 WAGON	1979	1.4	3/1/2005	21	8.0	0.26	30.2	281.4	8.86	2.48	1.23	x
C_KS2_761_3	DATSUN	210 WAGON	1979	1.4	3/1/2005	26	8.0	0.24	33.1	259.4	6.11	2.20	1.35	x
C_KS2_764_1	BUICK	SKYLARK	1998	3.1	3/29/2005	34	8.0	0.39	20.4	433.6	3.74	0.39	0.41	
C_KS2_767_1	DATSUN	280Z	1977	2.8	3/2/2005	26	8.0	0.63	12.7	697.2	5.67	1.18	0.59	
C_KS2_770_1	TOYOTA	CAMRY	1989	2.5	3/3/2005	27	8.2	0.24	33.7	257.8	5.51	0.93	0.19	x
C_KS2_772_1	BUICK	REGAL	1978	3.8	3/3/2005	30	8.0	0.42	19.2	393.6	42.86	2.91	3.18	
C_KS2_774_1	NISSAN	QUEST	1996	3	3/4/2005	30	8.0	0.39	20.5	435.6	1.59	0.42	0.13	
C_KS2_774_2	NISSAN	QUEST	1996	3	3/4/2005	32	8.1	0.41	19.5	448.4	6.79	0.64	0.67	
C_KS2_775_1	OLDSMOBILE	DELTA 88	1990	3.8	3/4/2005	22	8.0	0.53	15.0	564.8	16.33	1.26	3.06	
C_KS2_776_1	FORD	F-150	1987	4.9	3/4/2005	36	8.0	0.57	14.1	510.2	80.96	3.06	1.49	
C_KS2_777_1	FORD	RANGER XLT	2000	4	3/4/2005	37	.	0.47	N/A	.	.	.	.	x
C_KS2_778_1	FORD	F-250	1989	7.5	3/4/2005	58	8.0	0.69	11.6	753.1	14.88	2.87	1.07	
C_KS2_779_1	OLDSMOBILE	DELTA 88	1978	5.7	3/4/2005	39	8.1	0.51	15.8	504.7	34.27	1.51	4.31	
C_KS2_780_1	CHEVROLET	SUBURBAN	1997	5.7	3/5/2005	30	8.0	0.66	12.1	731.1	8.02	1.24	0.66	

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C_KS2_782_1	PLYMOUTH	VOYAGER	1999	3.3	3/5/2005	32	8.0	0.40	20.1	444.9	1.18	0.29	0.13	
C_KS2_782_2	PLYMOUTH	VOYAGER	1999	3.3	3/5/2005	36	8.1	0.44	18.4	482.6	3.77	0.44	0.25	
C_KS2_783_1	PLYMOUTH	VOYAGER	1992	2.5	3/5/2005	42	8.0	0.45	18.0	469.8	17.66	4.30	0.86	
C_KS2_784_1	FORD	RANGER XLT	1992	2.3	3/5/2005	31	8.0	0.49	16.4	461.5	52.65	1.40	1.52	
C_KS2_785_1	FORD	RANGER	1992	3	3/5/2005	50	8.3	0.63	13.0	668.7	12.27	0.78	0.77	
C_KS2_787_1	VW	BEETLE	1973	1.3	3/7/2005	21	8.1	0.36	22.4	325.8	43.05	2.27	3.57	x
C_KS2_788_1	PLYMOUTH	ACCLAIM	1989	2.5	3/7/2005	24	8.0	0.20	40.5	213.8	4.97	1.81	0.34	x
C_KS2_788_2	PLYMOUTH	ACCLAIM	1989	2.5	3/7/2005	22	8.0	0.19	41.7	206.6	5.58	1.72	0.29	x
C_KS2_788_3	PLYMOUTH	ACCLAIM	1989	2.5	3/8/2005	30	0.0	0.00	N/A	0.0	0.00	0.00	0.00	x
C_KS2_789_1	DODGE	RAM PICKUP	1987	3.7	3/7/2005	38	8.1	0.52	15.5	510.7	42.52	1.58	1.30	
C_KS2_791_1	TOYOTA	CAMRY	1999	2.2	3/7/2005	26	8.1	0.36	22.7	390.5	2.79	0.51	0.24	
C_KS2_792_1	CHEVROLET	TRAIL BLAZER	2002	4.2	3/8/2005	45	8.0	0.50	15.9	556.5	5.46	0.33	0.25	
C_KS2_795_1	FORD	CROWN VICTORIA LTD	1989	5	3/9/2005	37	8.1	0.49	16.4	518.6	16.16	1.94	1.94	
C_KS2_796_1	HONDA	ACCORD SEI	1989	2	3/8/2005	25	8.0	0.35	23.0	375.9	9.43	0.92	0.36	
C_KS2_797_1	ACURA	2.5 TL	1996	2.5	3/8/2005	33	8.1	0.40	20.4	430.3	6.70	0.31	0.62	
C_KS2_800_1	OLDSMOBILE	CUTLASS	1990	3.3	3/14/2005	32	8.0	0.40	20.3	436.3	4.64	1.11	0.27	
C_KS2_801_1	PLYMOUTH	VOYAGER SE	1988	3	3/9/2005	25	8.0	0.43	18.6	459.9	16.11	2.68	0.60	
C_KS2_802_1	VOLVO	740 TURBO	1987	2.3	3/9/2005	24	8.0	0.86	9.3	562.8	274.94	0.58	5.37	
C_KS2_805_1	CHEVROLET	CAVALIER	1995	2.2	3/10/2005	0	0.0	0.00	0.0	.	.	.	.	x
C_KS2_805_2	CHEVROLET	CAVALIER	1995	2.2	3/10/2005	23	8.0	0.29	27.7	317.4	4.73	0.71	0.19	
C_KS2_806_1	DODGE	SPIRIT	1989	2.5	3/10/2005	51	8.1	0.65	12.3	710.1	12.16	1.18	0.42	x
C_KS2_807_1	FORD	ESCORT	1987	1.9	3/10/2005	27	6.6	0.78	8.4	972.3	56.03	4.17	3.75	x
C_KS2_808_1	FORD	EXPLORER	1994	4	3/10/2005	22	8.0	0.55	14.5	607.1	9.31	1.20	0.27	
C_KS2_809_1	NISSAN	PATHFINDER	2001	3.5	3/11/2005	29	8.0	0.50	16.0	558.9	2.30	0.46	0.12	
C_KS2_809_2	NISSAN	PATHFINDER	2001	3.5	3/12/2005	32	8.1	0.81	10.0	720.5	100.14	6.01	10.28	x
C_KS2_811_1	DODGE	SE DAKOTA	1987	3.9	3/11/2005	31	8.1	0.56	14.3	566.5	40.08	1.75	1.06	
C_KS2_813_1	HONDA	ACCORD LXI	1988	2	3/11/2005	33	8.0	0.43	18.7	455.2	15.80	1.68	0.89	

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C_KS2_815_1	GMC	SONOMA	1995	4.3	3/12/2005	38	8.0	0.45	17.9	496.8	4.40	1.16	0.38	
C_KS2_816_1	NISSAN	PICKUP	1988	2.2	3/14/2005	32	8.0	0.31	25.8	327.9	12.76	1.42	0.59	
C_KS2_818_1	CHEVROLET	LUMINA APV	1990	3.1	3/12/2005	41	8.0	0.41	19.6	444.6	8.15	1.69	0.54	
C_KS2_820_1	BUICK	PARK AVENUE ELECTRA	1990	3.8	3/14/2005	28	8.0	0.46	17.5	510.5	2.96	1.51	0.26	
C_KS2_821_1	CHRYSLER	LEBARON	1988	2.5	3/16/2005	31	8.0	0.00	266963.9	0.0	0.00	0.00	0.00	x
C_KS2_821_2	CHRYSLER	LEBARON	1988	2.5	3/16/2005	22	8.1	0.36	22.5	382.0	10.34	1.98	0.63	
C_KS2_822_1	CADILLAC	ELDORADO	1990	4.5	3/15/2005	31	8.0	0.49	16.3	522.1	17.93	5.48	1.31	
C_KS2_823_1	CHEVROLET	LUMINA	1990	3.1	3/14/2005	65	8.2	0.44	18.7	468.9	7.51	1.57	0.31	
C_KS2_824_1	CHEVROLET	ASTROVAN	1989	4.3	3/14/2005	32	8.1	0.44	18.4	472.8	10.01	4.27	0.95	
C_KS2_825_1	DODGE	CARAVAN SE	1988	3	3/14/2005	37	8.0	0.46	17.3	503.5	7.43	2.92	1.72	
C_KS2_826_1	FORD	F250 PICKUP	1982	5.3	3/15/2005	36	8.0	0.74	10.9	665.5	87.86	3.52	9.59	
C_KS2_826_2	FORD	F250 PICKUP	1982	5.3	3/15/2005	13	4.8	0.49	9.7	663.0	147.90	2.99	14.97	
C_KS2_827_1	BUICK	CENTURY	1990	3.3	3/15/2005	26	8.0	0.43	18.7	469.0	7.06	1.20	0.41	
C_KS2_827_2	BUICK	CENTURY	1990	3.3	3/15/2005	1	0.0	0.00	0.0	.	.	.	.	x
C_KS2_828_1	FORD	F-150	1988	5	3/15/2005	36	8.0	0.62	12.9	678.3	10.90	2.10	1.29	
C_KS2_829_1	TOYOTA	PICKUP	1989	3	3/15/2005	0	0.0	0.00	N/A	.	.	.	.	x
C_KS2_829_2	TOYOTA	PICKUP	1989	3	3/15/2005	30	8.1	0.51	15.8	556.4	8.01	3.49	0.64	
C_KS2_829_3	TOYOTA	PICKUP	1989	3	3/15/2005	33	8.1	0.05	161.1	45.6	5.83	0.24	0.47	x
C_KS2_830_1	CHEVROLET	CORSICA	1989	2	3/15/2005	28	8.0	0.39	20.8	419.1	7.75	1.63	1.03	
C_KS2_833_1	MERCURY	TOPAZ	1989	2.3	3/16/2005	25	8.0	0.40	19.8	436.6	10.73	1.36	0.72	
C_KS2_834_1	TOYOTA	TERCEL SR5	1983	1.6	3/16/2005	28	8.1	0.30	26.7	322.2	8.45	0.93	0.80	
C_KS2_835_1	DODGE	SPIRIT	1990	2.5	3/16/2005	29	8.0	0.35	22.9	369.2	13.75	2.14	1.07	
C_KS2_836_1	HONDA	ACCORD	1988	2	3/29/2005	31	8.1	0.34	23.7	363.4	8.88	1.30	0.51	
C_KS2_836_2	HONDA	ACCORD	1988	2	3/30/2005	44	.	0.51	N/A	.	.	.	.	x
C_KS2_837_1	PONTIAC	FIREBIRD	1979	6.6	3/16/2005	27	10.1	0.75	13.4	530.1	86.32	2.73	4.26	
C_KS2_838_1	OLDSMOBILE	DELTA 88	1991	3.8	3/17/2005	55	8.1	0.46	17.5	510.2	1.57	1.43	0.17	
C_KS2_839_1	GMC	VANDURA	1983	5	3/16/2005	33	8.1	0.97	8.3	773.2	194.47	1.29	5.87	

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C_KS2_840_1	FORD	BRONCO	1990	5	3/17/2005	29	8.1	0.62	13.0	644.0	29.58	2.72	0.98	
C_KS2_842_1	TOYOTA	PICKUP	1983	2.2	3/17/2005	40	8.0	0.39	20.5	414.7	12.77	1.52	1.74	
C_KS2_844_1	CADILLAC	FLEETWOOD	1989	5	3/17/2005	24	8.0	0.24	34.0	94.3	93.04	0.03	21.29	x
C_KS2_846_1	CHEVROLET	CHEYENNE PICKUP	1973	5	3/17/2005	28	8.0	0.00	133122.7	0.0	0.00	0.00	0.01	x
C_KS2_846_2	CHEVROLET	CHEYENNE PICKUP	1973	5	3/17/2005	22	8.0	0.65	12.4	448.2	113.56	1.99	38.27	x
C_KS2_848_1	CHEVROLET	EL CAMINO	1976	5.7	3/18/2005	28	8.0	0.61	13.0	612.7	45.64	1.97	2.89	
C_KS2_849_1	FORD	F-150	1986	4.9	3/18/2005	25	8.0	0.57	14.2	575.2	22.51	7.28	8.35	
C_KS2_850_1	FORD	RANGER	1990	2.9	3/19/2005	42	8.0	0.52	15.3	559.4	15.93	4.35	1.74	
C_KS2_851_1	FORD	F-150	1988	4.9	3/18/2005	24	8.1	0.57	14.0	633.6	3.16	1.95	1.64	
C_KS2_855_1	TOYOTA	CAMRY	1990	2.5	3/18/2005	26	8.1	0.41	19.9	406.4	26.64	0.72	1.61	
C_KS2_856_1	OLDSMOBILE	CUTLASS	1989	2.8	3/21/2005	40	8.1	0.38	21.4	400.3	11.48	1.32	1.05	
C_KS2_856_2	OLDSMOBILE	CUTLASS	1989	2.8	3/19/2005	40	8.4	0.45	18.6	460.0	12.92	1.21	1.30	
C_KS2_857_1	CHEVROLET	C-10	1983	4.1	3/19/2005	33	8.0	0.64	12.6	664.3	28.53	6.00	3.00	
C_KS2_858_1	FORD	F-150	1988	5	3/19/2005	26	8.1	0.47	17.1	512.8	6.48	1.41	0.98	
C_KS2_859_1	BUICK	CENTURY	1988	2.8	3/19/2005	31	8.0	0.45	17.7	255.5	175.28	0.11	1.08	
C_KS2_862_1	GMC	JIMMY	1992	4.3	3/19/2005	23	8.0	0.30	26.7	326.1	6.60	0.76	0.25	
C_KS2_862_2	GMC	JIMMY	1992	4.3	3/19/2005	0	.	0.00	N/A	.	.	.	.	x
C_KS2_866_1	CHEVROLET	CAPRICE	1985	5	3/21/2005	30	8.0	0.70	11.5	588.8	112.48	2.83	6.42	
C_KS2_867_1	FORD	F-150	1978	6.5	3/21/2005	28	8.2	1.06	7.7	886.4	165.92	4.14	7.51	
C_KS2_868_1	TOYOTA	PICKUP 4X4 TURBO	1987	2.4	3/21/2005	30	8.0	0.52	15.6	513.0	30.59	4.19	5.75	
C_KS2_870_1	OLDSMOBILE	CUTLASS SUPREME	1987	5	4/7/2005	32	8.0	0.46	17.4	501.4	7.82	4.18	0.87	
C_KS2_870_2	OLDSMOBILE	CUTLASS SUPREME	1987	5	4/7/2005	13	4.2	0.28	14.7	560.2	29.01	4.72	1.75	
C_KS2_871_1	CHEVROLET	NOVA	1976	4.1	3/22/2005	29	8.0	0.49	16.3	448.3	57.10	1.87	5.54	
C_KS2_872_1	CHEVROLET	IMPALA	1973	5.7	3/22/2005	37	8.1	1.03	7.9	942.4	120.90	2.60	5.05	
C_KS2_873_1	FORD	F-150	1990	4.9	3/23/2005	33	8.1	0.42	19.3	460.2	2.63	3.44	0.48	
C_KS2_875_1	CHEVROLET	MALIBU	1980	3.8	3/22/2005	33	8.0	0.52	15.5	467.6	70.80	0.66	1.75	
C_KS2_876_1	CHEVROLET	G20 VAN	1989	5.7	3/22/2005	33	8.1	0.62	13.0	661.8	14.80	2.62	1.52	

CTR_TST_ID	Make	Model	Model Year	Disp	Test Date	Test Duration (minutes)	Test Distance (miles)	FuelUsed (gal)	Test FE (mpg)	Composite CO2 (gpm)	Composite CO (gpm)	Composite NOx (gpm)	Composite THC (gpm)	Suspect Data
C_KS2_876_2	CHEVROLET	G20 VAN	1989	5.7	3/22/2005	36	7.1	0.60	11.7	728.4	20.20	3.19	2.16	
C_KS2_877_1	CHEVROLET	BLAZER 4X4	1987	2.8	3/22/2005	27	7.9	0.47	17.0	503.0	14.06	6.77	0.95	
C_KS2_878_1	DODGE	CARAVAN ES	2003	3.8	3/23/2005	36	8.0	0.49	16.5	545.0	0.82	0.67	0.06	
C_KS2_878_2	DODGE	CARAVAN ES	2003	3.8	3/23/2005	27	8.0	0.45	17.7	507.4	0.96	0.60	0.07	
C_KS2_881_1	FORD	RANGER XLT	1989	2.3	3/23/2005	27	8.0	0.43	18.5	464.6	12.42	1.68	0.99	
C_KS2_883_1	CHEVROLET	MONTE CARLO	1984	5	3/23/2005	30	8.1	0.38	21.2	392.4	19.70	0.65	0.69	
C_KS2_885_1	SATURN	STATION WAGON	1994	1.9	3/24/2005	33	8.0	0.33	24.2	352.9	10.49	0.45	0.88	
C_KS2_887_1	FORD	MUSTANG	1979	2.3	3/24/2005	33	8.1	0.67	12.2	524.5	118.91	1.18	13.37	
C_KS2_888_1	VW	THING	1974	1.6	3/24/2005	35	8.1	0.35	23.2	275.1	60.08	2.59	7.88	
C_KS2_889_1	MAZDA	B2200	1988	2.2	3/24/2005	26	8.0	0.42	18.9	350.4	76.13	0.97	4.05	
C_KS2_891_1	MAZDA	PROTÉGÉ	1999	1.6	4/1/2005	24	8.1	0.28	28.3	306.8	6.59	1.16	0.14	
C_KS2_894_1	CHEVROLET	SILVERADO 1500	1989	5	3/25/2005	29	8.0	0.59	13.7	617.3	20.74	3.42	1.84	
C_KS2_894_2	CHEVROLET	SILVERADO 1500	1989	5	3/25/2005	35	8.0	0.58	13.7	613.0	22.23	3.10	2.22	
C_KS2_895_1	OLDSMOBILE	CUTLASS	1990	3.1	3/25/2005	36	8.1	0.39	20.6	421.5	9.50	1.21	0.27	
C_KS2_897_1	JEEP	CJ-7	1979	4.2	3/28/2005	69	8.3	0.70	11.7	581.1	108.97	6.31	7.34	
C_KS2_898_1	CHEVROLET	CAVALIER	1991	2.2	3/26/2005	30	8.0	0.43	18.7	423.5	32.23	3.53	2.85	
C_KS2_901_1	OLDSMOBILE	CUTLASS CIERRA	1990	3.3	3/26/2005	56	8.1	0.42	19.0	455.3	10.83	1.69	0.80	
C_KS2_902_1	FORD	GRANADA	1982	3.3	3/26/2005	39	8.1	0.49	16.4	525.5	12.71	1.35	0.69	
C_KS2_903_1	FORD	AEROSTAR	1990	3	3/26/2005	51	8.0	0.49	16.6	509.8	19.66	1.98	0.79	
C_KS2_905_1	TOYOTA	CAMRY	2001	2.2	3/28/2005	25	8.0	0.41	19.6	447.5	7.07	0.53	0.21	
C_KS2_906_1	FORD	ESCAPE	2002	3	3/28/2005	32	8.0	0.37	21.7	413.7	0.55	0.09	0.05	
C_KS2_910_1	PONTIAC	GRAND PRIX	1976	5.7	3/29/2005	35	8.1	0.85	9.5	672.8	168.62	1.49	7.23	x
C_KS2_911_1	CHEVROLET	CELEBRITY	1984	2.5	3/29/2005	28	8.1	0.37	21.5	402.5	8.83	1.07	0.46	
C_KS2_915_1	HONDA	CIVIC	1990	1.5	4/1/2005	42	8.3	0.33	24.8	346.7	9.11	2.45	0.60	
C_KS2_916_1	CHEVROLET	VAN 20	1986	5	4/1/2005	35	8.1	0.93	8.7	695.4	189.94	1.34	20.51	
C_KS2_917_1	FORD	F 100 RANGER	1978	4.9	4/2/2005	21	8.0	0.24	33.6	260.0	4.42	2.37	0.61	x
C_KS2_918_1	FORD	ESCORT	1998	2	4/2/2005	25	0.0	0.00	0.0	.	.	.	.	x

CTR_TST_ID	Make	Model	Model Year	Disp	Test Date	Test Duration (minutes)	Test Distance (miles)	FuelUsed (gal)	Test FE (mpg)	Composite CO2 (gpm)	Composite CO (gpm)	Composite NOx (gpm)	Composite THC (gpm)	Suspect Data
C_KS2_918_2	FORD	ESCORT	1998	2	4/2/2005	15	.	0.01	N/A	.	.	.	.	x
C_KS2_918_3	FORD	ESCORT	1998	2	4/2/2005	22	8.0	0.31	25.4	349.7	2.74	0.56	0.14	
C_KS2_922_1	CHEVROLET	BEAUVILLE 10	1979	5.7	4/4/2005	22	8.1	0.71	11.3	676.2	64.80	2.54	5.24	
C_KS2_923_1	FORD	ESCAPE	2005	3	4/5/2005	29	8.1	0.39	20.5	434.9	0.74	0.08	0.12	
C_KS2_924_1	FORD	FOCUS	2005	2	4/5/2005	39	8.1	0.38	21.5	412.1	2.65	0.06	0.09	
C_KS2_925_1	DODGE	CARAVAN SE	1992	3.3	4/6/2005	39	8.0	0.49	16.5	528.6	8.63	3.64	0.54	
C_KS2_926_1	FORD	F-150 XL	1995	4.9	4/6/2005	40	8.0	0.51	15.7	545.7	4.50	75.58	0.91	x
C_KS2_927_1	CHEV	ASTRO VAN	1994	4.3	4/6/2005	29	8.0	0.55	14.7	557.9	28.99	2.97	4.33	x
C_KS2_927_2	CHEV	ASTRO VAN	1994	4.3	4/6/2005	1	0.0	0.00	N/A	.	.	.	.	x
C_KS2_928_1	DODGE	GRAND CARAVAN SPORT	2000	3.3	4/6/2005	52	8.0	0.54	14.9	591.7	4.30	0.73	0.41	
C_KS2_929_1	CHEVROLET	SUBURBAN	1997	5.7	4/7/2005	31	8.1	0.63	12.8	677.6	13.41	3.62	1.14	
C_KS2_929_2	CHEVROLET	SUBURBAN	1997	5.7	4/7/2005	35	8.0	0.72	11.1	777.3	17.76	3.87	1.25	
C_KS2_930_1	TOYOTA	FORERUNNER	1998	3.4	4/6/2005	32	8.0	0.43	18.8	475.0	1.13	0.61	0.09	
C_KS2_935_1	FORD	F-250	1995	4.9	4/6/2005	24	8.0	0.58	13.9	638.1	4.12	2.10	0.65	
C_KS2_937_1	DODGE	CARAVAN	1995	3	4/7/2005	52	8.1	0.04	225.4	39.0	0.19	0.03	0.02	x
C_KS2_937_2	DODGE	CARAVAN	1995	3	4/7/2005	47	8.0	0.42	19.2	456.8	6.69	1.04	0.31	
C_KS2_939_1	CHEVROLET	ASTROVAN	1992	3	4/9/2005	38	18.6	1.12	16.5	503.8	21.19	7.33	1.94	
C_KS2_941_1	PLYMOUTH	VOYAGER	1992	3.3	4/8/2005	38	8.0	0.47	17.2	499.4	13.58	3.69	1.14	
C_KS2_944_1	CHEVROLET	BLAZER 4X4	1993	4.3	4/8/2005	41	18.6	1.06	17.6	499.3	6.56	1.22	0.40	
C_KS2_945_1	CHRYSLER	VOYAGER	2002	3.3	4/8/2005	50	18.7	0.92	20.4	439.0	0.82	0.43	0.05	
C_KS2_946_1	JEEP	CHEROKEE	1996	2.5	4/8/2005	41	8.1	0.51	15.7	562.8	5.07	0.42	0.42	
C_KS2_950_1	FORD	CLUB WAGON E150	1989	5	4/9/2005	51	18.6	0.64	29.2	240.6	34.20	0.41	4.45	
C_KS2_984_1	DODGE	STRATUS	1999	2.4	2/7/2005	36	8.0	0.43	18.8	460.8	10.60	0.91	0.32	
C_KS2_985_1	DODGE	INTREPID	1995	3.3	2/14/2005	40	8.0	0.39	20.7	425.5	4.28	0.88	0.67	
C_KS2_986_1	TOYOTA	AVALON	1998	3	2/28/2005	49	8.1	0.36	22.5	397.0	1.59	0.33	0.13	
C_KS2_987_1	FORD	EXPLORER	1993	4	2/28/2005	26	8.0	0.48	16.7	528.0	7.13	1.33	0.51	
C_KS2_989_1	DODGE	GRAND CARAVAN	2003	3.3	4/4/2005	30	8.1	0.41	19.5	455.3	0.66	0.50	0.07	

CTR_TST_ID	Make	Model	Model Year	Disp	Test Date	Test Duration (minutes)	Test Distance (miles)	FuelUsed (gal)	Test FE (mpg)	Composite CO2 (gpm)	Composite CO (gpm)	Composite NOx (gpm)	Composite THC (gpm)	Suspect Data
C_KS2_989_2	DODGE	GRAND CARAVAN	2003	3.3	4/4/2005	30	8.0	0.43	18.6	480.6	1.07	0.20	0.07	
C_KS2_1013_1	TOYOTA	CAMRY	1994	3	1/19/2005	59	8.0	0.29	28.1	317.2	1.08	0.33	0.32	
C_KS2_1014_1	MERCURY	GRAND MARQUIS	1994	4.6	2/9/2005	43	8.0	0.51	15.8	555.7	7.03	0.99	1.29	

Table 4-14. Round 2 Driveaway Test Results

CTR_TST_ID	Make	Model	Model Year	Disp	Test Date	Test Duration (minutes)	Test Distance (miles)	Fuel Used (gal)	Test FE (mpg)	Composite CO2 (gpm)	Composite CO (gpm)	Composite NOx (gpm)	Composite THC (gpm)	Suspect Data
D_KS2_618_1	BUICK	LASABRE	1979	4.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	x
D_KS2_677_1	PONTIAC	MONTANA	2003	3.4	2/11/2005	285	48.8	2.10	23.3	383.601	2.019	0.23	0.053	
D_KS2_679_1	FORD	RANGER	1998	4	2/12/2005	164	40.7	2.18	18.7	474.869	2.661	1.081	0.353	
D_KS2_689_1	LINCOLN	TOWN CAR	1988	5	2/15/2005	139	10.9	0.89	12.2	684.39	28.495	3.263	3.16	
D_KS2_689_2	LINCOLN	TOWN CAR	1988	5	2/15/2005	101	18.7	1.07	17.5	443.557	41.189	2.339	1.981	
D_KS2_698_1	CHRYSLER	TOWN & COUNTRY LX	2001	3.3	2/17/2005	49	18.6	0.88	21.1	418.766	4.529	0.785	0.129	
D_KS2_698_2	CHRYSLER	TOWN & COUNTRY LX	2001	3.3	2/17/2005	190	13.8	0.14	96.7	81.49	1.048	0.14	0.264	x
D_KS2_703_1	FORD	COUNTRY SQUIRE	1986	5	2/17/2005	76	20.8	1.03	20.2	403.008	22.486	2.773	3.185	
D_KS2_704_1	CADILLAC	SEDAN DEVILLE	1992	4.9	2/18/2005	259	21.1	1.58	13.4	342.322	207.497	0.173	8.368	
D_KS2_705_1	DODGE	DAKOTA	2004	3.7	2/18/2005	215	32.1	1.42	22.6	395.931	1.725	0.059	0.096	
D_KS2_711_1	MERCURY	TOPAZ	1994	2.3	2/19/2005	240	47.7	2.46	19.4	433.667	5.067	1.028	0.072	
D_KS2_722_1	VOLVO	960	1993	2.9	2/21/2005	215	40.8	1.60	25.5	351.182	1.015	0.311	0.105	
D_KS2_723_1	FORD	TEMPO	1993	2.3	2/21/2005	263	37.7	2.12	17.8	460.366	7.451	1.715	0.54	
D_KS2_724_1	CHEVROLET	BLAZER	1996	4.3	2/21/2005	280	40.8	2.11	19.4	457.864	3.737	0.647	0.201	
D_KS2_726_1	CHEVROLET	S-10 LS	1995	4.3	2/22/2005	316	50.7	2.65	19.2	454.78	8.917	0.612	0.428	
D_KS2_729_1	CHRYSLER	TOWN & COUNTRY	1996	3.8	2/22/2005	230	32.9	1.63	20.3	414.799	17.42	2.008	0.631	
D_KS2_730_1	FORD	RANGER	1994	3	2/23/2005	241	33.2	1.26	26.3	N/A	N/A	N/A	N/A	x
D_KS2_730_2	FORD	RANGER	1994	3	2/23/2005	48	18.6	0.72	26.0	339.502	4.116	0.364	0.299	
D_KS2_734_1	PLYMOUTH	VOYAGER	1993	3	2/23/2005	109	19.6	0.86	22.8	381.814	7.238	1.864	0.371	
D_KS2_735_1	DODGE	CARAVAN SE	1995	3.3	2/23/2005	169	30.4	1.14	26.6	334.906	1.171	0.269	0.067	
D_KS2_739_1	FORD	TAURUS	1993	3	2/24/2005	75	18.6	0.92	20.3	435.753	3.534	0.768	0.364	
D_KS2_739_2	FORD	TAURUS	1993	3	2/24/2005	194	11.3	0.84	13.5	648.561	6.817	1.414	0.932	
D_KS2_745_1	FORD	ECONOLINE E 150	2001	5.4	2/25/2005	472	55.4	3.67	15.1	589.838	3.393	0.4	0.14	
D_KS2_753_1	FORD	WINDSTAR	1998	2	2/26/2005	110	11.3	0.68	16.7	531.102	4.094	2.467	0.275	
D_KS2_759_1	JEEP	CHEROKEE	1988	4	2/28/2005	178	35.3	1.87	18.8	464.985	7.652	1.591	0.521	
D_KS2_760_1	MAZDA	PROTÉGÉ	1998	1.5	2/28/2005	374	32.8	3.27	10.1	878.367	9.696	0.988	0.649	
D_KS2_764_1	BUICK	SKYLARK	1998	3.1	3/1/2005	293	60.2	1.95	30.8	291.559	0.605	0.259	0.07	
D_KS2_766_1	JEEP	GRAND CHEROKEE	1993	5.2	3/1/2005	323	33.2	1.86	17.8	488.76	8.861	1.528	0.47	
D_KS2_769_1	HONDA	CIVIC	1999	1.8	3/2/2005	232	40.2	0.93	43.4	195.673	7.41	0.191	0.051	

CTR_TST_ID	Make	Model	Model Year	Disp	Test Date	Test Duration (minutes)	Test Distance (miles)	Fuel Used (gal)	Test FE (mpg)	Composite CO2 (gpm)	Composite CO (gpm)	Composite NOx (gpm)	Composite THC (gpm)	Suspect Data
D_KS2_770_1	TOYOTA	CAMRY	1989	2.5	3/5/2005	677	62.6	2.25	27.8	319.434	2.198	1.142	0.068	
D_KS2_773_1	FORD	E-150	1991	4.9	3/3/2005	293	52.9	3.59	14.7	564.493	21.576	4.39	4.149	
D_KS2_774_1	NISSAN	QUEST	1996	3	3/5/2005	129	31.5	1.29	24.4	364.925	2.103	0.347	0.128	
D_KS2_783_1	PLYMOUTH	VOYAGER	1992	2.5	3/7/2005	310	42.7	1.77	24.2	347.368	14.897	3.646	0.457	
D_KS2_786_1	FORD	ECONOLINE	1996	4.9	3/8/2005	440	34.1	2.03	16.8	532.548	2.257	1.861	0.127	
D_KS2_788_1	PLYMOUTH	ACCLAIM	1989	2.5	3/8/2005	510	78.8	2.81	28.1	307.99	7.963	2.552	0.206	
D_KS2_791_1	TOYOTA	CAMRY	1999	2.2	3/8/2005	156	42.6	1.78	23.9	371.101	3.413	0.387	0.19	
D_KS2_792_1	CHEVROLET	TRAIL BLAZER	2002	4.2	3/9/2005	348	56.9	3.05	18.7	479.503	2.272	0.255	0.047	
D_KS2_795_1	FORD	CROWN VICTORIA LTD	1989	5	3/10/2005	115	7.5	0.53	14.0	619.052	10.784	1.509	1.996	
D_KS2_801_1	PLYMOUTH	VOYAGER SE	1988	3	3/10/2005	52	8.1	0.45	17.9	484.622	9.561	3.658	1.201	
D_KS2_805_1	CHEVROLET	CAVALIER	1995	2.2	3/11/2005	331	18.7	0.66	28.3	306.899	6.14	0.763	0.393	
D_KS2_808_1	FORD	EXPLORER	1994	4	3/11/2005	393	27.5	1.64	16.8	518.482	9.847	1.449	0.253	
D_KS2_813_1	HONDA	ACCORD LXI	1988	2	3/13/2005	531	35.7	1.61	22.2	380.369	15.321	1.718	0.565	
D_KS2_818_1	CHEVROLET	LUMINA APV	1990	3.1	3/14/2005	222	38.8	1.36	28.5	307.7	4.722	0.928	0.276	
D_KS2_820_1	BUICK	PARK AVENUE ELECTRA	1990	3.8	3/16/2005	187	58.1	2.51	23.1	384.258	2.652	1.637	0.214	
D_KS2_824_1	CHEVROLET	ASTROVAN	1989	4.3	3/15/2005	20	3.0	0.28	10.7	804.307	21.621	6.235	0.845	
D_KS2_825_1	DODGE	CARAVAN SE	1988	3	3/16/2005	305	38.9	1.78	21.9	397.207	6.27	2.16	1.452	
D_KS2_830_1	CHEVROLET	CORSICA	1989	2	3/17/2005	405	13.5	0.73	18.4	466.347	10.08	1.605	1.427	
D_KS2_835_1	DODGE	SPIRIT	1990	2.5	3/17/2005	103	30.2	1.20	25.1	337.901	11.944	2.231	0.686	
D_KS2_836_1	HONDA	ACCORD	1988	2	3/31/2005	562	44.1	1.78	24.8	343.804	10.172	1.04	0.392	
D_KS2_847_1	GMC	1500 SLE SIERRA	1988	5.7	3/18/2005	353	31.5	2.10	15.0	578.631	11.976	1.583	0.763	
D_KS2_859_1	BUICK	CENTURY	1988	2.8	3/21/2005	235	39.8	1.84	21.7	203.899	138.646	0.2	5.81	
D_KS2_904_1	SUBARU	FORESTER	2001	2.5	3/28/2005	109	23.4	0.96	24.4	362.232	3.774	5.764	0.136	
D_KS2_910_1	PONTIAC	GRAND PRIX	1976	5.7	3/30/2005	317	32.6	3.12	10.5	667.948	117.053	2.47	4.294	
D_KS2_913_1	BUICK	LESABRE	1990	3.8	3/31/2005	453	42.6	1.88	22.7	380.574	9.196	0.656	0.327	

A fuel economy comparison of Round 2 conditioning runs and LA92 drive cycle tests performed on the dynamometer is shown with a 1:1 reference line in Figure 4-17. Appendices F and L provide formulas for calculating fuel economy from both the dynamometer and the PEMS. Results listed as “suspicious” in Tables 4-12 and 4-13 are excluded from Figure 4-17.

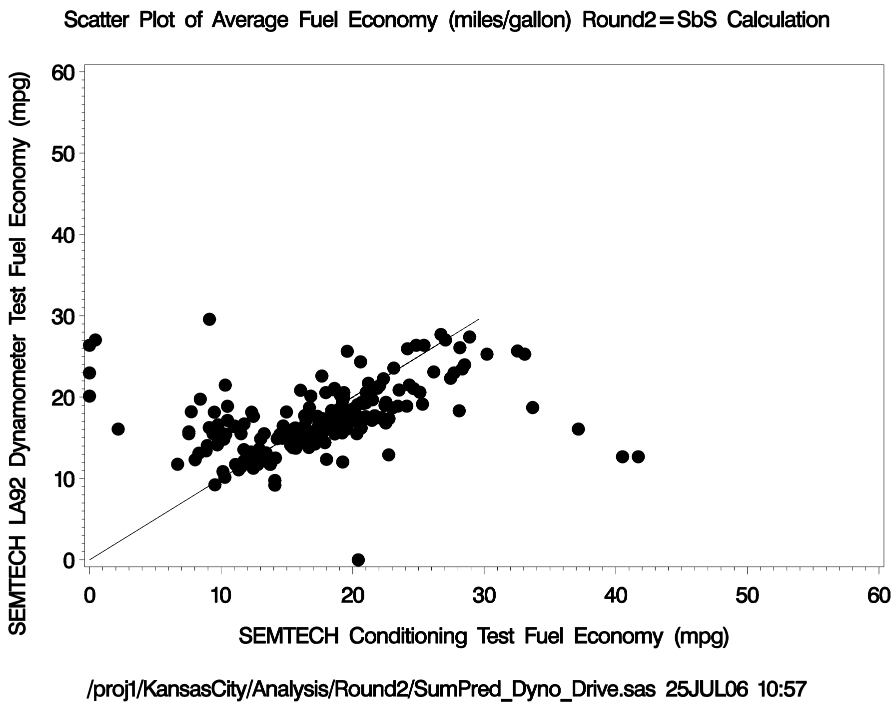


Figure 4-17. By-Vehicle Comparison of Conditioning Run vs. Dynamometer Testing Fuel Economy for Round 2

A fuel economy comparison of the 51 vehicles that received driveaway tests and LA92 dynamometer tests performed during Round 2 is shown in Figure 4-18. Figure 4-19 provides a by-vehicle comparison of Round 2 condition run vs. driveaway test fuel economy. 1:1 lines are provided for reference. As previously discussed, these figures reveal differences in results using the same test system (PEMS) but different tests (dynamometer LA-92 vs. standardized conditioning route vs. “real-world driving”).

Table 4-15 contains results of the Round 2 fuel samples that were analyzed during the study. Results of all fuel analysis performed prior to April 2006 were included in the MSOD data submission for this study and are shown in Table 4-15. Results of fuels analysis performed after April 2006 were not included in the MSOD submission (and are not shown in Table 4-15) but are included in Appendix FF (KC_fuels_analysis_complete.pdf) for reference.

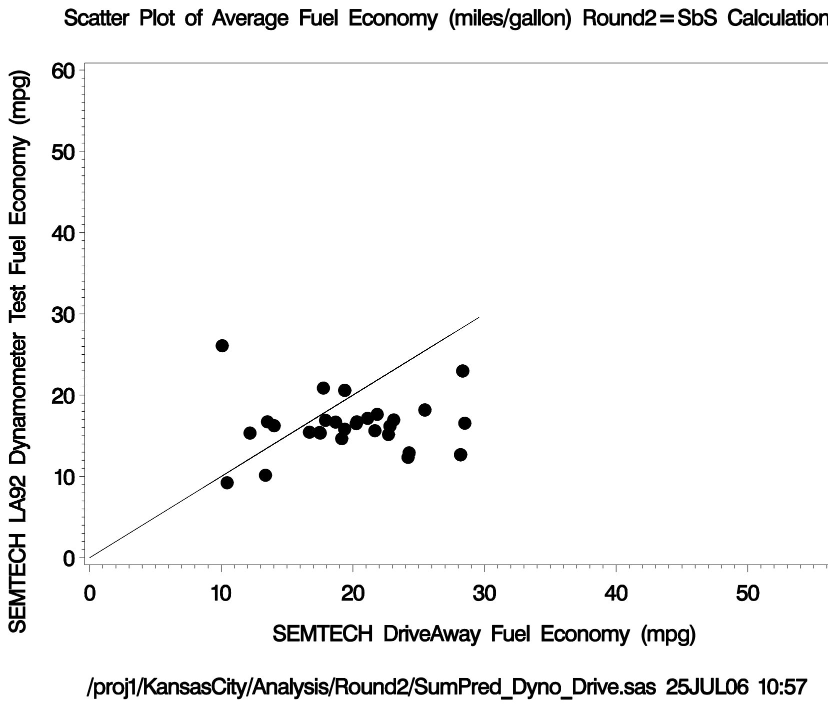


Figure 4-18. By-Vehicle Comparison of Driveaway vs. Dynamometer Testing Fuel Economy for Round 2

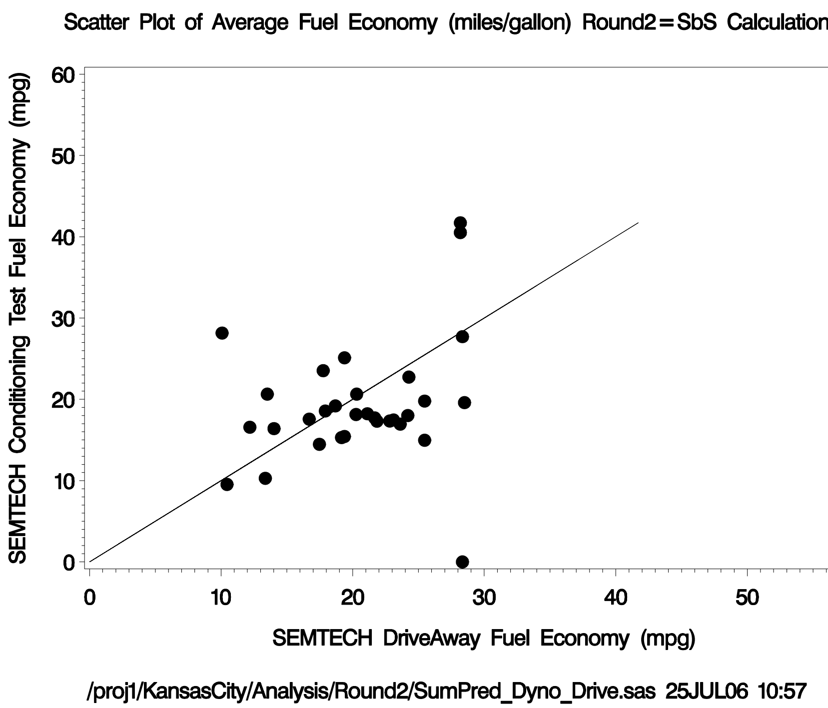


Figure 4-19. By-Vehicle Comparison of Driveaway vs. Conditioning Run Fuel Economy for Round 2

Table 4-15. Fuel Analysis Results from Round 2 Vehicle Samples

Laboratory Fuel Batch ID	Vehicle ID	Sulfur (ppm)	Initial Boiling Point (F)	10% Distillation Point (F)	50% Distillation Point (F)	90% Distillation Point (F)	End Point (F)	Specific Gravity at 60 F	Degrees API at 60 F	Oxygen Weight %	Oxygenate Type	Total Recovery (mL)	Residue (mL)	Loss (mL)	Reid Vapor Pressure (psi)	Olefins (Vol %)	Saturates (Vol %)	Aromatics (Vol %)
13629	KS2_533	134	78	95	193	327	421	0.7251	63.64	0	NONE	96.3	0.4	3.3	14	9.9	68.7	21.4
13720	KS2_685	258	79	101	199	320	402	0.7276	62.97	0	NONE	96.4	0.7	2.9	13.6	9.5	68.7	21.8
13721	KS2_575	330	82	100	196	320	399	0.7282	62.81	0	NONE	96.7	0.9	2.4	14.1	8.8	68.8	22.4
13722	KS2_634	214	79	98	198	323	407	0.7276	62.97	0	NONE	96.3	0.7	3	14.5	9.2	69.3	21.5
13723	KS2_622	153	80	99	198	328	427	0.7263	63.33	0	NONE	96.8	0.8	2.4	14.5	10.5	67.7	21.8
13724	KS2_579	129	78	97	199	328	433	0.7243	63.85	0	NONE	97	0.5	2.5	14.5	10	69.5	20.5
13725	KS2_568	103	82	105	215	321	410	0.7313	62.01	0	NONE	96.9	0.8	2.3	12.8	5.3	70.2	24.5
13736	KS2_670	255	80	96	193	319	401	0.7266	63.25	0	NONE	96.9	0.9	2.2	14.3	8.9	68.7	22.4
13739	KS2_679	346	82	102	196	318	403	0.7268	63.2	0	NONE	96.8	0.7	2.5	13.8	9.7	67.6	22.7
13827	KS2_605	310	80	102	201	322	412	0.7276	62.98	0	NONE	96.8	0.8	2.4	13.3	9.6	68.6	21.8
13828	KS2_756	163	83	104	196	328	406	0.7323	61.73	0	NONE	96.3	0.8	2.9	12.2	10.5	65.1	24.4
13829	KS2_675	235	82	101	197	323	405	0.7299	62.37	0	NONE	96.9	0.7	2.4	13.5	10.7	65.2	24.1
13830	KS2_569	101	82	99	193	322	412	0.7278	62.93	0	NONE	96.8	0.8	2.4	14.1	11.4	63	25.6
13831	KS2_596	206	79	100	200	324	430	0.7282	62.82	0	NONE	96.6	0.8	2.6	13.8	9.4	68.9	21.7
13832	KS2_572	292	81	96	199	321	406	0.7257	63.49	0	NONE	96.4	0.6	3	14.2	9.7	69	21.3
13833	KS2_556	373	81	100	199	318	403	0.7272	63.07	0	NONE	96.8	0.8	2.4	14.2	10.2	67.5	22.3
13834	KS2_594	130	80	99	201	329	425	0.727	63.13	0	NONE	96.6	0.9	2.5	13.3	10.8	67.5	21.7
13835	KS2_786	177	88	109	159	321	408	0.7366	60.61	3.33	ETHANOL	97.6	0.7	1.7	12.8	9.3	68.3	22.4
13836	KS2_626	350	80	100	198	319	401	0.7259	63.43	0	NONE	96.8	0.9	2.3	13.5	10.6	65.4	24
13837	KS2_582	351	84	100	195	319	405	0.7262	63.34	0	NONE	96.7	0.8	2.5	14.2	9.4	68.7	21.9
13838	KS2_740	273	81	103	202	321	411	0.7275	63.01	0	NONE	96.7	0.9	2.4	13.1	9.8	69	21.2
13843	KS2_757	129	84	107	197	332	413	0.7335	61.42	0	NONE	97.3	0.8	1.9	12.2	10.3	63.8	25.9
13844	KS2_872	131	84	108	199	330	423	0.7346	61.12	0	NONE	96.6	0.8	2.6	11.3	9.5	65.8	24.7
13845	KS2_773	128	86	112	203	328	411	0.7357	60.84	0	NONE	97.5	0.8	1.7	12.3	9.7	64.7	25.6
13846	KS2_917	197	91	127	214	329	408	0.7416	59.3	0	NONE	97.7	0.9	1.4	9.2	8.9	64.6	26.5
13847	KS2_910	143	84	111	200	330	419	0.7332	61.49	0	NONE	96.8	0.9	2.3	11	11.7	64.4	23.9
13848	KS2_776	121	86	113	204	332	426	0.7323	61.73	0	NONE	97.6	0.7	1.7	11.6	7.2	70.5	22.3
13850	KS2_623	84	83	108	219	323	409	0.7338	61.34	0	NONE	97.3	0.7	2	12.2	5	69.5	25.5
14276	KS2_782	119	82	105	192	323	414	0.7265	63.26	0	NONE	96.8	0.9	2.3	12.6	7.8	70.4	21.8
14278	KS2_725	195	83	103	199	322	407	0.7288	62.67	0	NONE	96.7	0.9	2.4	12.7	9.4	68.2	22.4
14279	KS2_736	230	83	104	195	321	408	0.7285	62.73	0	NONE	96.8	0.8	2.4	12.4	9.7	67.7	22.6
14280	KS2_618	172	81	98	199	329	425	0.7238	63.99	0	NONE	96.6	0.9	2.5	14	10.7	68.8	20.5
14281	KS2_727	139	84	104	194	331	413	0.7295	62.47	0	NONE	96.9	1	2.1	12.7	13.1	62.9	24

Laboratory Fuel Batch ID	Vehicle ID	Sulfur (ppm)	Initial Boiling Point (F)	10% Distillation Point (F)	50% Distillation Point (F)	90% Distillation Point (F)	End Point (F)	Specific Gravity at 60 F	Degrees API at 60 F	Oxygen Weight %	Oxygenate Type	Total Recovery (mL)	Residue (mL)	Loss (mL)	Reid Vapor Pressure (psi)	Olefins (Vol %)	Saturates (Vol %)	Aromatics (Vol %)
14282	KS2_632	347	79	98	198	318	401	0.7234	64.12	0	NONE	96.7	0.9	2.4	14	9.2	70.2	20.6
14283	KS2_619	389	79	99	198	317	397	0.7245	63.82	0	NONE	96.7	0.9	2.4	13.7	9.8	69.6	20.6
14285	KS2_640	86	81	103	218	322	408	0.7329	61.58	0	NONE	96.8	0.9	2.3	12.7	5.2	69.1	25.7
14286	KS2_633	77	84	108	221	315	408	0.7383	60.16	0	NONE	96.9	0.8	2.3	12.1	3.7	68.5	27.8
14287	KS2_819	146	85	110	198	329	416	0.7312	62.02	0	NONE	97.1	1	1.9	11.4	8.9	67.1	24
14288	KS2_801	94	80	102	196	323	416	0.7231	64.18	0	NONE	96.7	1	2.3	13.1	8.9	70.9	20.2
14290	KS2_721	290	81	101	197	320	400	0.7287	62.68	0.89	NONE	96.8	0.9	2.3	13.7	9	68.2	22.8
	Min	77.00	78.00	95.00	159.00	315.00	397.00	0.72	59.30	0.00	N/A	96.30	0.40	1.40	9.20	3.70	62.90	20.20
	Mean	202.50	82.03	103.18	199.20	323.63	411.23	0.73	62.55	0.11	N/A	96.84	0.81	2.36	13.08	9.27	67.76	22.97
	Median	174.50	82.00	102.00	198.00	322.50	408.50	0.73	62.88	0.00	N/A	96.80	0.80	2.40	13.30	9.55	68.55	22.40
	Max	389.00	91.00	127.00	221.00	332.00	433.00	0.74	64.18	3.33	N/A	97.70	1.00	3.30	14.50	13.10	70.90	27.80
	Std Dev	93.67	2.74	6.00	9.68	4.65	9.15	0.00	1.13	0.54	N/A	0.34	0.13	0.37	1.15	1.82	2.14	1.89

4.4.3 Control vehicle results

4.4.3.1 Round 1 Control Vehicle Test Results

Five LA92 dynamometer tests were performed for a 1988 Ford Taurus control vehicle at EPA's testing facility in Ann Arbor, MI. Results for these tests are presented in Table 4-16.

Table 4-16. Emissions Summary for Ann Arbor Control Vehicle Testing

Test ID	Phase	HC (g/mi)	CO (g/mi)	NO_x (g/mi)	CO_2 (g/mi)	PM (mg/mi)
VETS012378	1	4.058	25.897	5.875	617.341	32.016
VETS012378	2	1.93	13.328	3.947	370.998	10.093
VETS012378	3	3.076	20.455	6.1	527.129	5.219
VETS012380	1	3.881	28.92	6.191	622.316	11.46
VETS012380	2	1.799	13.73	3.927	369.915	6.39
VETS012380	3	3.015	21.487	5.994	525.609	6.164
VETS012384	1	3.853	29.673	5.782	602.62	11.964
VETS012384	2	1.847	13.126	3.83	365.109	8.815
VETS012384	3	2.952	20.811	6.198	523.356	6.434
VETS012395	1	4.07	29.92	5.722	619.329	22.228
VETS012395	2	1.867	13.004	3.65	367.479	5.846
VETS012395	3	3.015	22.147	5.602	524.237	4.193
VETS012398	1	3.887	29.82	5.896	609.913	13.908
VETS012398	2	1.897	13.153	3.7	365.632	4.814
VETS012398	3	2.982	21.39	5.605	522.037	6.354

A total of twelve LA92 dynamometer tests were performed for the same 1988 Ford Taurus control vehicle on site in Kansas City. Nine of the tests used a hot-wire flow meter and the remaining three tests were performed using a new pitot-tube flow meter for the PEMS measurements. Table 4-17 shows an emission summary of the dynamometer control tests performed in Kansas City measured with the PEMS in comparison with emissions measured by the dynamometer bench, by phase and composite (comp) measurements. Highlighted emission values (in blue) represent measurements taken with the newer pitot-tube flowmeter. In order to eliminate any opportunity for pitot-tube orifices to become blocked with particulate matter or ice, pitot-tube flowmeters were purged with high-pressure dry nitrogen gas prior to each test, and the flowmeters were stored in above-freezing temperatures when not in use.

Table 4-17. Round 1 by Phase Emissions Summary for Control Vehicle Testing in Kansas City

RunID	Phase	Temp (F)	RH (%)	HC (g/mi)		CO (g/mi)		NO_x (g/mi)		CO_2 (g/mi)		PM2.5 (mg/mi)	Distance (miles)	PEMS DATA Suspect	Dyno DATA Suspect
				PEMS	Dyno	PEMS	Dyno	PEMS	Dyno	PEMS	Dyno				
84081	1				5.35	36.9	34.95	7.23	6.88	658.16	653.31	5.45	1.18		
84081	2			2.07	2.1	14.75	13.29	6.61	5.54	400.34	384.22	1.28	8.64		
84081	3			5.04 3.3	3.55	21.86	20.33	7.1	7.07	556.98	544.6	0.54	1.17		
84081	Comp	76.4	40.6	2.31	2.36	16.38	14.89	6.67	5.71	424.33	409.04	1.44	10.99		
84114	1				5.35	.	27.88	.	8.1	.	699.36	2.55	1.17		
84114	2		.		2.2	.	14.49	.	6.78	.	399.54	0.73	8.61		
84114	3		.		4.03	.	24.31	.	8.39	.	572.8	0.9	1.17		
84114	Comp	93.5	45.0 .	.	2.49	.	15.85	.	6.96	.	426.75	0.84	10.95	x	
84143	1				6.55	.	32.54	.	7.49	.	697.04	13.53	1.19		
84143	2		.		2.08	.	13.18	.	5.72	.	392.47	0.87	8.64		
84143	3		.		3.55	.	20.18	.	6.98	.	560.04	1.42	1.19		
84143	Comp	81.5	38.2 .	.	2.41	.	14.67	.	5.9	.	419.84	1.56	11.02	x	
84177	1			5.13	5.34	33.65	32.11	7.16	7.07	629	666.3	5.31	1.17		
84177	2			2.06	2.07	14.02	13.48	6	5.38	372.86	383.39	1	8.64		
84177	3			3.33	3.59	21.98	21.63	6.52	6.58	510.4	535.89	1.2	1.19		
84177	Comp	74.1	35.0	2.31	2.35	15.58	15	6.09	5.55	395.52	408.46	1.24	11		
84187	1			5.09	5.34	32.64	31.23	7.2	7.57	621.04	659.96	5.14	1.2		
84187	2			2.06	2.13	15.98	15.26	6.67	6.37	387.53	405.57	1.47	8.66		
84187	3			3.28	3.51	20.42	20	7.59	7.97	544.32	574.61	1.34	1.19		
84187	Comp	77.4	54.2	2.3	2.39	17.16	16.43	6.76	6.54	410.54	430.52	1.66	11.05		x
84218	1			1.3	5.43	7.36	27.19	3.74	7.27	214.91	668.85	4.59	1.18		
84218	2			0.41	2.26	2.92	13.58	1.3	6.14	78.14	398.89	0.61	8.61		
84218	3				3.8	2.97	20.05	1.54	8.01	95.97	580.22	1.4	1.18		
84218	Comp	81.0	60.8	0.46	2.53	3.15	14.72	1.44	6.33	86.17	425.28	0.87	10.96	x	
84259	1			0.51	6.17	.	38.12	.	7.74	.	684.21	7.58	1.18		
84259	2		.		2.17	.	13.47	.	5.95	.	392.9	0.8	8.65		
84259	3		.		3.54	.	21.39	.	7.12	.	520.83	2	1.18		
84259	Comp	72.0	47.9 .	.	2.47	.	15.28	.	6.12	.	416.7	1.23	11.01		
84290	1			5.07	5.2	35.33	29.58	7.05	6.95	677.75	639.47	8.01	1.18		
84290	2			2.1	2.15	15.05	13.11	6.64	6.03	411.65	380.71	4.01	8.62		
84290	3				3.48	23.7	19.62	7.52	7.2	586.5	533.41	36.51	1.2		
84290	Comp	87.7	39.0	2.34	2.4	16.7	14.42	6.73	6.16	437.55	404.72	6.47	10.99		
84348	1			3.43 5.39	5.2	34.48	30.89	6.44	7.04	718.31	662.79	6.11	1.16		
84348	2			2.22	2.05	14.51	12.85	4.85	5.5	413.2	383.73	0.21	8.61		
84348	3			3.75	3.42	23.95	20.37	6.09	6.77	616.86	539.02	9.37	1.19		
84348	Comp	79.6	26.8	2.49	2.3	16.19	14.29	5.01	5.66	442.89	408.78	1.15	10.96		
84360	1			5.36	5.44	32.75	31.28	5.93	7.86	683.84	658.38	6.38	1.2		

RunID	Phase	Temp (F)	RH (%)	HC (g/mi)		CO (g/mi)		NO_x (g/mi)		CO_2 (g/mi)		PM2.5 (mg/mi)	Distance (miles)	PEMS DATA Suspect	Dyno DATA Suspect
				PEMS	Dyno	PEMS	Dyno	PEMS	Dyno	PEMS	Dyno				
84360	2			2.17	2.05	14	12.91	4.8	6.24	398.71	381.41	0.63	8.74		
84360	3			3.68	3.52	23.58	20.96	6.22	7.98	592.59	538.64	1.42	1.22		
84360	Comp	77.6	51.5	2.44	2.33	15.65	14.43	4.96	6.45	427.2	406.81	0.98	11.17		
84374	1			5.25	5.47	32.01	32.02	5.96	6.86	671.99	674.8	3.13	1.17		
84374	2			2.1	2.04	14.49	13.79	4.71	5.45	394.49	392.19	0.37	8.6		
84374	3			3.47	3.41	22.04	20.23	5.82	6.82	575.84	553.01	0.32	1.19		
84374	Comp	73.7	17.5	2.35	2.31	15.91	15.17	4.85	5.61	421.23	417.81	0.51	10.95		
84387	1			5.34	5.92	33.13	36.26	5.75	5.84	630.52	663.77	4.97	1.21		
84387	2			2.25	2.17	13.3	12.9	4.48	4.58	375.99	385.07	1.06	8.76		
84387	3			3.44	3.49	21.07	19.78	5.43	5.56	533.35	531.4	0.99	1.23		
84387	Comp	72.0	14.1	2.5	2.45	14.9	14.6	4.61	4.72	400.57	409.91	1.26	11.21		

Table 4-18 presents a composite emissions summary for Round 1 control testing. Average and standard deviation of the reported emission values were calculated and are listed at the bottom of Table 4-18, both including an excluding Run 84218.

Table 4-18. Round 1 Composite Emission Summary for Control Vehicle Testing in Kansas City

RunID	**Composite HC (g/mi)**			**Composite CO (g/mi)**			**Composite NO_x (g/mi)**			**Composite CO_2 (g/mi)**			**PM2.5 (mg/mi)**
	PEMS	**Dyno**	**%Diff**	**PEMS**	**Dyno**	**%Diff**	**PEMS**	**Dyno**	**%Diff**	**PEMS**	**Dyno**	**%Diff**	
84081	2.31	2.36	2.36	16.38	14.89	10.00	6.67	5.71	16.85	424.33	409.04	3.74	1.44
84114	.	2.49		.	15.85		.	6.96		.	426.75		0.84
84143	.	2.41		.	14.67		.	5.90		.	419.84		1.56
84177	2.31	2.35	1.65	15.58	15.00	3.87	6.09	5.55	9.89	395.52	408.46	3.17	1.24
84187	2.30	2.39	3.85	17.16	16.43	4.45	6.76	6.54	3.39	410.54	430.52	4.64	1.66
84218	0.46	2.53	81.72	3.15	14.72	78.58	1.44	6.33	77.33	86.17	425.28	79.74	0.87
84259	.	2.47		.	15.28		.	6.12		.	416.70		1.23
84290	2.34	2.40	2.45	16.70	14.42	15.81	6.73	6.16	9.22	437.55	404.72	8.11	6.47
84348	2.49	2.30	7.88	16.19	14.29	13.24	5.01	5.66	11.50	442.89	408.78	8.35	1.15
84360	2.44	2.33	4.67	15.65	14.43	8.41	4.96	6.45	23.15	427.20	406.81	5.01	0.98
84374	2.35	2.31	2.04	15.91	15.17	4.87	4.85	5.61	13.57	421.23	417.81	0.82	0.51
84387	2.50	2.45	1.83	14.90	14.60	2.03	4.61	4.72	2.25	400.57	409.91	2.28	1.26
All Avg	2.17	2.40	12.05	14.62	14.98	15.70	5.24	5.98	18.57	382.89	415.39	12.87	1.60
All Std	0.64	0.07	26.20	4.35	0.63	24.02	1.68	0.58	22.94	112.37	8.70	25.20	1.57
Avg*	2.38	2.39	3.34	16.06	15.00	7.84	5.71	5.94	11.23	419.98	414.49	4.51	1.67
Std*	0.08	0.06	2.11	0.71	0.66	4.89	0.94	0.60	6.84	16.78	8.52	2.64	1.63

* Statistic values were compiled from all runs except run 84218.

4.4.3.2 Round 2 Control Vehicle Test Results

A total of twelve LA92 dynamometer tests were performed for the same 1988 Ford Taurus control vehicle that was used for Round 1 control testing in Kansas City and Ann Arbor. All Round 2 testing was conducted using pressure-differential flow meter for the PEMS exhaust flow measurements. Table 4-19 shows an emissions summary of the dynamometer control tests performed in Kansas City measured with the PEMS in comparison with emissions measured by the dynamometer bench.

Table 4-19. Round 2 by Phase Emissions Summary for Control Vehicle Testing in Kansas City

RunID	Phase	Temp (F)	RH (%)	HC (g/mi)		CO (g/mi)		NO_x (g/mi)		CO_2 (g/mi)		PM2.5 (mg/mi)	Distance (miles)	PEMS DATASuspect	Dyno DATASuspect
				PEMS	Dyno	PEMS	Dyno	PEMS	Dyno	PEMS	Dyno				
84451	1			5.23	5.52	75.65	80.77	2.99	3.27	777.86	751.03	39.06	1.19		
84451	2			0.10	0.10	3.33	2.85	1.03	1.10	452.31	435.12	2.84	8.68		
84451	3			0.26	0.31	6.49	5.75	1.30	1.49	604.31	578.39	1.46	1.20		
84451	Comp	37.6	61.3	0.38	0.40	7.35	7.10	1.15	1.24	480.06	461.47	4.62	11.08		x
84461	1			7.98	7.73	84.41	69.40	5.90	5.92	701.86	653.87	46.54	1.21		
84461	2			2.46	2.22	17.97	15.05	5.49	4.94	404.78	382.08	2.98	8.72		
84461	3			3.80	3.39	27.29	20.43	7.82	6.00	587.57	510.60	3.06	1.22		
84461	Comp	43.9	50.6	2.85	2.59	22.12	18.28	5.67	5.07	433.21	405.38	5.26	11.16		
84480	1			7.81	8.20	85.63	75.59	6.61	6.15	766.18	717.55	49.90	1.20		
84480	2			2.45	2.35	18.92	17.11	5.70	5.20	424.64	409.46	3.99	8.68		
84480	3			3.98	3.66	28.17	20.85	7.61	6.71	620.07	550.38	4.83	1.18		
84480	Comp	40.2	69.6	2.84	2.74	23.02	20.41	5.88	5.36	455.89	435.12	6.44	11.05		x
84536	1			8.04	7.93	82.15	69.75	6.30	5.38	758.84	688.07	48.30	1.22		
84536	2			2.52	2.33	17.32	15.13	5.40	4.59	409.04	391.94	3.88	8.66		
84536	3			3.99	3.59	28.41	20.91	6.82	5.21	590.62	515.45	2.49	1.21		
84536	Comp	51.7	1.2	2.91	2.71	21.50	18.43	5.54	4.68	440.18	416.26	6.14	11.09		x
84544	1			8.25	7.68	83.95	64.55	6.00	5.88	725.71	658.37	47.00	1.23		
84544	2			2.46	2.29	18.37	15.56	5.49	4.98	404.19	388.53	5.28	8.74		
84544	3			4.04	3.66	32.66	23.39	7.37	6.43	599.19	532.41	5.65	1.21		
84544	Comp	54.0	49.7	2.87	2.67	22.81	18.70	5.64	5.13	434.62	412.84	7.52	11.18		
84578	1			7.93	7.45	84.77	66.25	6.42	6.17	758.51	678.12	32.10	1.21		
84578	2			2.57	2.33	18.67	15.86	5.26	4.98	414.82	392.47	3.74	8.65		
84578	3			4.36	3.75	30.48	21.70	6.75	5.89	624.20	527.04	4.60	1.20		
84578	Comp	43.8	55.9	2.97	2.70	22.94	18.92	5.42	5.10	447.29	416.83	5.29	11.06		
84596	1			2.61	2.76	43.96	44.56	2.58	2.43	798.00	740.10	1.67	1.21		
84596	2			0.08	0.07	3.41	3.28	0.64	0.67	438.02	437.63	1.89	8.68		
84596	3			0.32	0.26	4.70	3.33	1.12	1.14	591.70	542.37	0.77	1.21		
84596	Comp	37.4	41.9	0.23	0.22	5.63	5.46	0.77	0.80	467.60	460.89	1.80	11.11		
84606	1			9.23	9.35	96.47	79.62	5.91	5.62	748.72	679.46	51.20	1.18		
84606	2			2.35	2.26	18.53	16.45	5.15	4.82	402.34	391.20	3.23	8.66		
84606	3			3.96	3.58	31.44	21.77	6.88	5.96	602.65	510.53	3.62	1.21		

RunID	**Phase**	Temp (F)	RH (%)	**HC (g/mi)**		**CO (g/mi)**		**NO_x (g/mi)**		**CO_2 (g/mi)**		**PM2.5 (mg/mi)**	**Distance (miles)**	**PEMS DATASuspect**	**Dyno DATASuspect**
				PEMS	**Dyno**	**PEMS**	**Dyno**	**PEMS**	**Dyno**	**PEMS**	**Dyno**				
84606	Comp	51.9	40.9	2.82	2.72	23.48	20.08	5.31	4.94	434.25	414.42	5.73	11.05		
84624	1			9.02	8.36	109.72	88.34	4.85	4.68	709.87	636.64	46.80	1.20		
84624	2			2.44	2.16	20.53	17.89	4.74	4.28	394.42	372.95	1.55	8.77		
84624	3			3.78	3.26	31.09	22.20	6.68	5.62	587.65	503.89	2.22	1.23		
84624	Comp	44.6	35.0	2.87	2.56	25.89	21.85	4.88	4.40	424.38	395.84	3.93	11.21		
84651	1			9.77	9.58	101.18	82.64	5.13	5.48	766.92	691.08	71.62	1.18		
84651	2			2.55	2.30	19.61	17.09	4.41	4.50	407.49	388.32	4.27	8.67		
84651	3			4.16	3.66	32.27	23.05	5.90	5.65	599.09	513.51	5.51	1.20		
84651	Comp	46.1	34.2	3.03	2.77	24.70	20.88	4.55	4.63	439.31	412.64	7.82	11.06		
84697	1			2.26	8.23	101.79	73.10	5.89	5.96	815.75	670.52	35.40	1.21		
84697	2			1.19	2.41	22.34	17.52	4.67	4.78	458.85	391.96	3.14	8.66		
84697	3			1.73	3.91	37.67	24.26	6.25	5.88	654.52	516.64	4.33	1.22		
84697	Comp	42.6	69.4	1.28	2.82	27.62	20.92	4.85	4.92	491.50	415.37	4.92	11.09		
84741	1			8.69	7.92	85.84	62.04	5.44	5.69	740.86	627.60	38.55	1.21		
84741	2			2.92	2.39	20.09	15.78	4.63	4.75	440.52	384.35	2.71	8.71		
84741	3			4.32	3.70	31.00	21.66	6.21	5.95	619.51	511.17	3.11	1.23		
84741	Comp	53.9	43.0	3.32	2.77	24.33	18.62	4.79	4.88	469.02	406.04	4.61	11.16		

Table 4-20 presents a composite emissions summary for Round 2 control testing. Average and standard deviation values are reported at the bottom of Table 4-20, both for all runs, and also for all runs except Run numbers 84451 and 84697. In general, the dynamometer (BKI) emission measurements appear to be lower than those measured by the PEMS (SMT). Additional investigation may be warranted to identify the source of this discrepancy. Results from the "Measurement Allowance for In-Use Testing" study being conducted in 2006 at Southwest Research Institute in San Antonio, Texas may provide insight into any possible PEMS bias issues. Additional analysis of the dynamometer correlation results between the EPA dynamometer in Ann Arbor and the EPA portable Clayton dynamometer gathered during the Kansas City Pilot Study may provide insight into any possible dynamometer bias issues.

Table 4-20. Round 2 Composite Emission Summary for Control Vehicle Testing in Kansas City

RunID	Composite HC (g/mi)			Composite CO (g/mi)			Composite NO_x (g/mi)			Composite CO_2 (g/mi)			PM2.5 (mg/mi)
	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	PEMS	Dyno	%Diff	
84451	0.38	0.40	-5.22	7.35	7.10	3.40	1.15	1.24	-7.67	480.06	461.47	3.87	4.62
84461	2.85	2.59	8.82	22.12	18.28	17.34	5.67	5.07	10.65	433.21	405.38	6.43	5.26
84480	2.84	2.74	3.37	23.02	20.41	11.34	5.88	5.36	8.85	455.89	435.12	4.56	6.44
84536	2.91	2.71	6.80	21.50	18.43	14.30	5.54	4.68	15.63	440.18	416.26	5.43	6.14
84544	2.87	2.67	7.03	22.81	18.70	18.01	5.64	5.13	9.21	434.62	412.84	5.01	7.52
84578	2.97	2.70	9.29	22.94	18.92	17.54	5.42	5.10	5.93	447.29	416.83	6.81	5.29
84596	0.23	0.22	2.60	5.63	5.46	3.01	0.77	0.80	-2.88	467.60	460.89	1.43	1.80
84606	2.82	2.72	3.44	23.48	20.08	14.47	5.31	4.94	6.93	434.25	414.42	4.57	5.73
84624	2.87	2.56	10.83	25.89	21.85	15.60	4.88	4.40	9.88	424.38	395.84	6.73	3.93
84651	3.03	2.77	8.71	24.70	20.88	15.44	4.55	4.63	-1.84	439.31	412.64	6.07	7.82
84697	1.28	2.82	-119.56	27.62	20.92	24.26	4.85	4.92	-1.48	491.50	415.37	15.49	4.92
84741	3.32	2.77	16.48	24.33	18.62	23.49	4.79	4.88	-1.97	469.02	406.04	13.43	4.61
All Avg	2.36	2.31	-3.95	20.95	17.47	14.85	4.54	4.26	4.27	451.44	421.09	6.65	5.34
All Std	1.08	0.94	36.79	6.97	5.37	6.55	1.72	1.54	7.13	21.21	20.85	3.96	1.61
average*	2.46	2.26	6.56	20.34	17.16	13.99	4.51	4.20	4.79	447.80	421.61	5.85	5.38
st dev*	1.08	0.97	5.55	6.97	5.51	6.12	1.80	1.60	7.24	17.88	21.78	2.95	1.69

* Statistic values were compiled from all runs except run 84697

4.4.4 Comparison of Emissions from Vehicles Measured in Both Rounds of the Study

Forty-one vehicles were tested in both Rounds 1 and 2 for the purpose of comparing summer and winter vehicle emissions. Four of these vehicles were tested twice for a total of forty-five valid retest pairs across Rounds 1 and 2 (two vehicles were tested with different load settings and were therefore excluded from this evaluation). Table 4-21 presents composite emissions for both Rounds. Figures 4-20 through 4-27 present linear and logarithmic plots comparing composite gravimetric $PM_{2.5}$, HC, CO, and NO_x across the two Rounds of testing, with a 1:1 line provided for reference. Figures 4-28 through 4-31 present plots of each pollutant versus ambient temperature. Appendices G and H contains by-phase plots for all pollutants of interest.

Table 4-21. Round 1/ Round 2 Retest Composite Emissions

Round 1							Round 2						
Run #	Temp (F)	RH (%)	Grav PM (mg/mi)	HC (g/mi)	CO (g/mi)	NOx (g/mi)	Run #	Temp (F)	RH (%)	Grav PM (mg/mi)	HC (g/mi)	CO (g/mi)	NOx (g/mi)
84078	70.45	70.3	0.47	0.12	2.76	0.31	84399	32.70	43.4	2.82	0.25	6.72	0.29
84037	83.18	58.5	9.12	1.56	32.78	1.26	84413	18.40	47.0	140.91	1.88	34.24	1.42
84055	95.84	50.1	4.80	1.07	9.77	4.15	84422	37.40	38.5	18.68	1.50	16.91	5.27
84309	78.17	42.1	43.42	9.25	174.36	2.16	84470	38.00	42.9	332.68	16.18	212.79	2.14
84110	84.69	56.8	10.01	0.20	5.06	0.58	84463	34.70	62.5	101.18	0.25	7.56	0.77
84115	83.99	57.1	7.60	0.23	5.95	0.70	84463	34.70	62.5	101.18	0.25	7.56	0.77
84271	81.51	30.2	5.66	1.28	11.88	7.53	84482	39.00	70.1	14.10	1.11	12.85	6.99
84271	81.51	30.2	5.66	1.28	11.88	7.53	84484	40.70	56.8	8.66	1.05	12.37	7.08
84342	77.46	46.0	0.27	0.19	1.32	0.33	84437	60.10	47.0	2.08	0.30	2.59	0.34
84342	77.46	46.0	0.27	0.19	1.32	0.33	84442	40.70	59.6	2.53	0.30	2.63	0.35
84097	69.85	65.0	0.73	0.08	0.20	0.09	84408	15.90	45.3	16.91	0.38	0.86	0.23
84069	76.81	84.1	0.49	0.21	1.44	0.68	84404	14.50	43.0	19.94	0.58	5.84	0.83
84042	75.97	75.6	2.63	0.31	4.76	0.63	84412	17.80	44.8	3.09	0.56	9.62	0.47
84171	70.82	44.8	40.75	1.19	14.86	1.37	84474	35.90	67.1	63.87	1.08	10.66	1.23
84347	77.85	31.4	12.55	0.36	5.18	0.86	84406	20.90	36.0	62.64	0.79	9.47	0.99
84058	87.30	65.2	1.04	0.13	0.92	0.33	84393	37.90	70.6	2.48	0.34	3.19	0.30
84349	66.81	60.0	0.84	0.10	0.48	0.19	84444	25.00	32.6	18.07	0.31	1.20	0.20
84125	80.85	59.9	3.39	0.22	6.12	2.24	84424	41.30	41.5	13.91	0.24	4.04	2.39
84036	80.53	65.7	1.78	0.20	6.70	1.64	84396	39.10	65.5	10.49	0.30	8.74	1.39
84119	91.94	44.5	6.10	1.84	14.08	5.77	84425	43.90	39.3	28.28	2.23	16.13	5.50
84104	78.06	55.7	1.56	0.19	2.17	0.72	84401	30.10	41.3	4.75	0.34	4.57	0.96
84113	91.05	47.8	1.53	0.89	19.54	1.73	84456	55.40	44.1	37.30	1.46	25.72	1.54
84263	74.48	41.8	19.61	1.21	43.05	2.59	84477	39.40	59.8	74.32	1.50	58.74	1.81
84063	85.32	72.5	2.06	0.13	0.78	0.56	84411	18.40	43.9	83.29	0.53	5.42	0.84
84332	76.78	39.7	2.24	0.15	1.92	0.58	84418	31.40	33.5		0.24	3.92	0.90
84341	76.02	54.3	7.65	0.19	3.34	0.74	84418	31.40	33.5		0.24	3.92	0.90
84146	82.37	46.6	9.16	1.18	9.86	1.63	84467	37.20	55.0	23.32	1.62	17.69	1.82
84151	69.41	46.8	1.45	0.09	3.36	0.21	84420	30.40	39.4	17.05	0.25	5.16	0.36
84305	74.18	42.5	1.22	0.13	1.71	0.53	84409	17.90	43.5	4.54	0.50	8.38	1.15
84150	68.26	48.5	4.70	0.16	4.54	0.38	84394	39.20	69.1	21.09	0.31	5.25	0.30
84336	82.22	33.4	10.44	0.59	1.11	3.37	84489	34.90	63.0	15.40	0.67	3.14	3.12
84381	76.74	17.8	31.49	0.49	6.55	0.95	84528	31.40	24.0	133.10	0.61	8.85	1.59
84040	80.95	75.6	4.79	0.36	8.98	2.40	84430	46.70	56.0	23.64	0.63	16.22	1.75
84108	87.62	38.7	2.96	0.64	12.27	2.66	84402	29.40	39.2	20.31	1.02	17.42	2.62
84338	77.22	46.7	0.85	0.06	0.56	0.09	84445	24.10	33.4	3.24	0.24	2.18	0.24
84339	77.95	46.6	3.56	0.19	1.28	0.39	84448	24.70	38.9	22.75	0.44	6.22	0.41
84329	83.21	38.3	10.64	0.20	2.22	0.27	84433	48.30	57.4	27.54	0.28	3.62	0.32
84344	71.33	49.3	2.86	0.38	2.25	0.65	84446	23.60	35.8	30.30	0.76	5.18	0.63
84211	71.93	69.1	31.90	0.46	9.69	1.04	84475	36.80	65.2	43.59	1.61	31.43	0.85
84048	83.23	63.9	59.98	1.10	9.09	3.44	84469	37.60	43.0	138.65	1.39	15.30	2.59
84296	68.06	64.6	2.99	0.09	3.67	0.08	84416	28.20	36.0	3.84	0.19	6.60	0.08
84071	77.22	84.5	38.43	2.23	11.26	5.35	84407	23.90	32.5	151.32	2.90	24.18	4.59
84088	80.14	40.8	1.22	0.23	2.34	0.54	84419	34.10	30.8	4.29	0.45	6.90	0.52
84188	80.21	45.7	40.64	4.71	66.09	2.12	84472	40.00	40.9	91.37	4.28	59.49	2.04
84298	74.01	44.2	26.89	0.24	7.69	0.87	84415	28.40	33.7	27.03	0.33	8.13	1.63

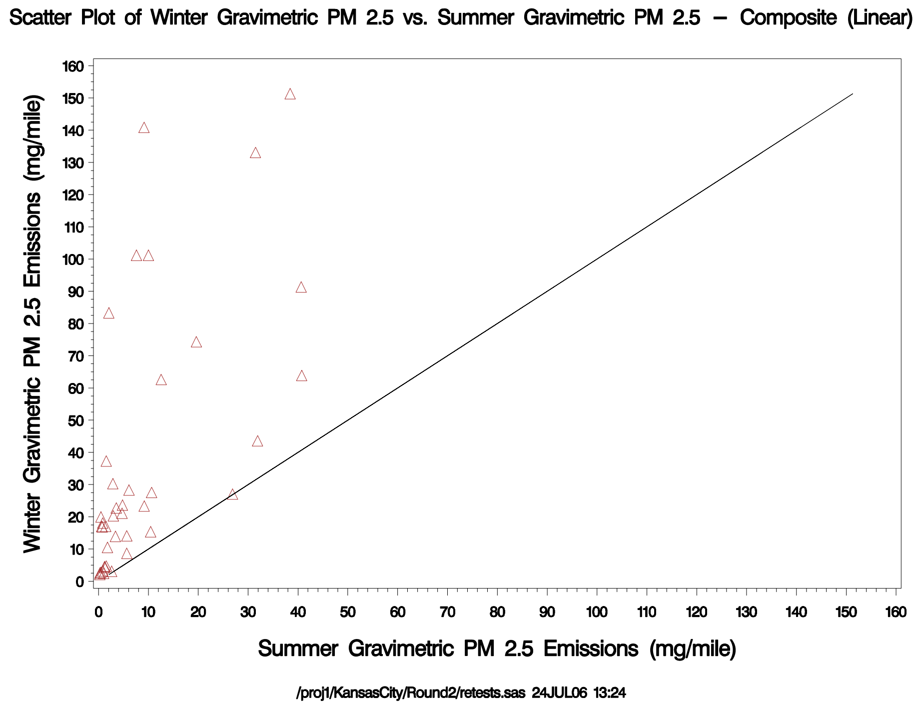


Figure 4-20. Winter vs. Summer Gravimetric PM 2.5 - Linear

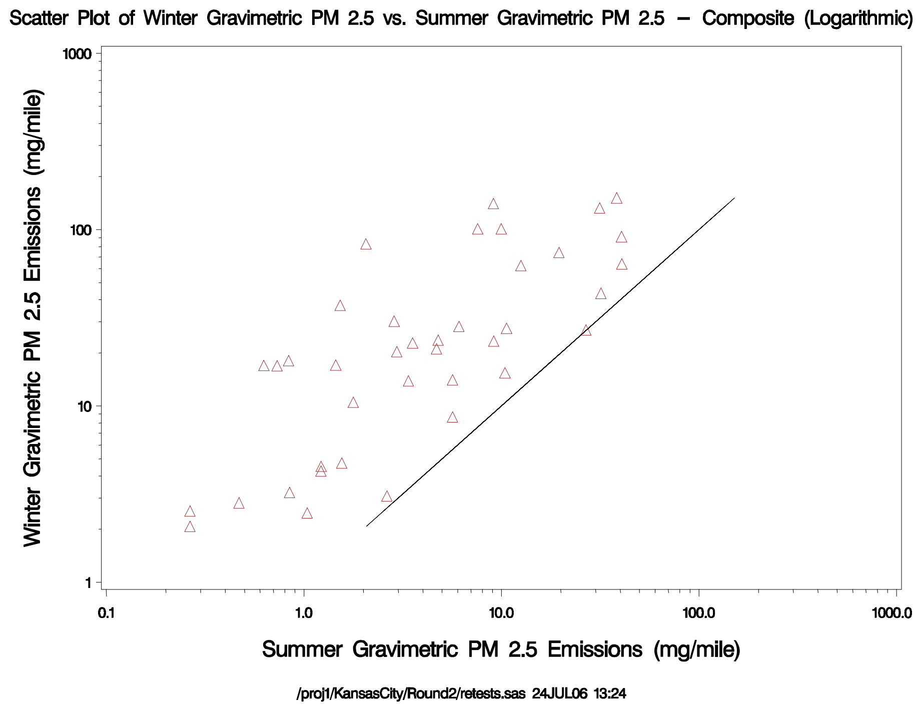


Figure 4-21. Winter vs. Summer Gravimetric PM 2.5 - Logarithmic

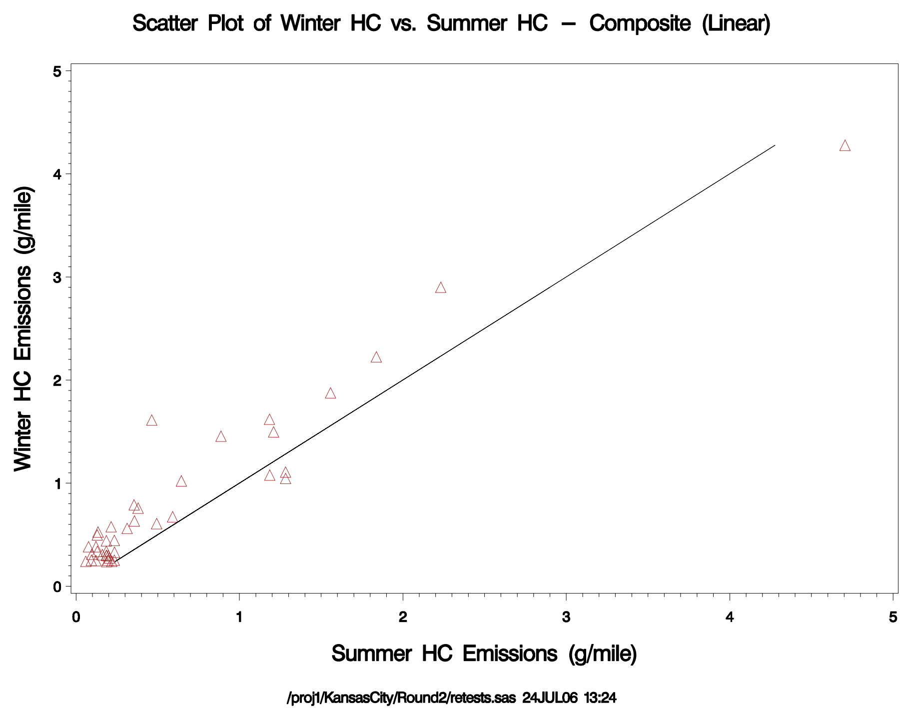


Figure 4-22. Winter vs. Summer HC – Linear

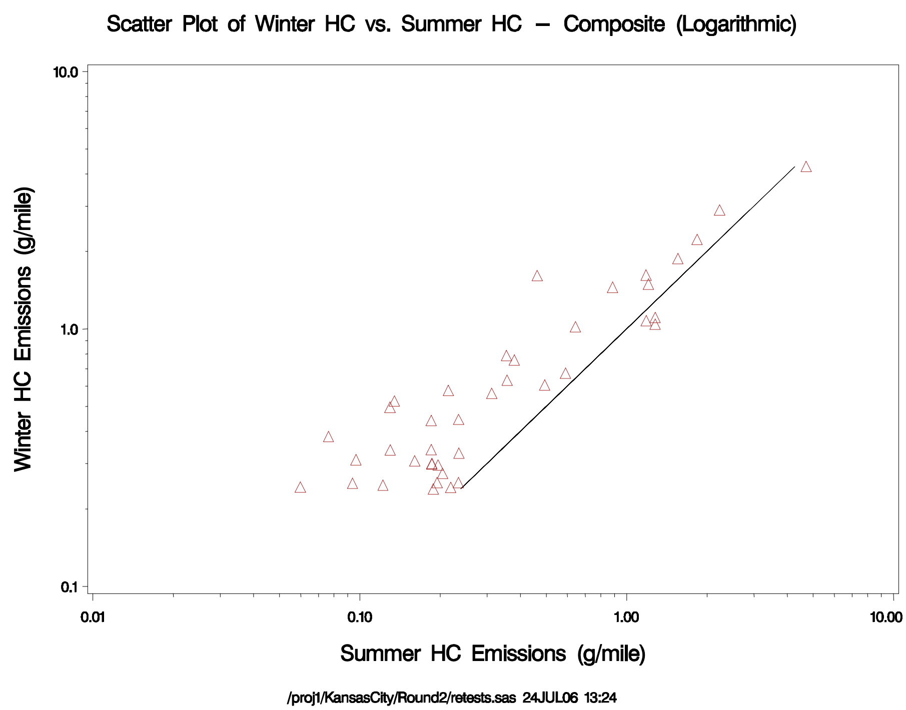


Figure 4-23. Winter vs. Summer HC - Logarithmic

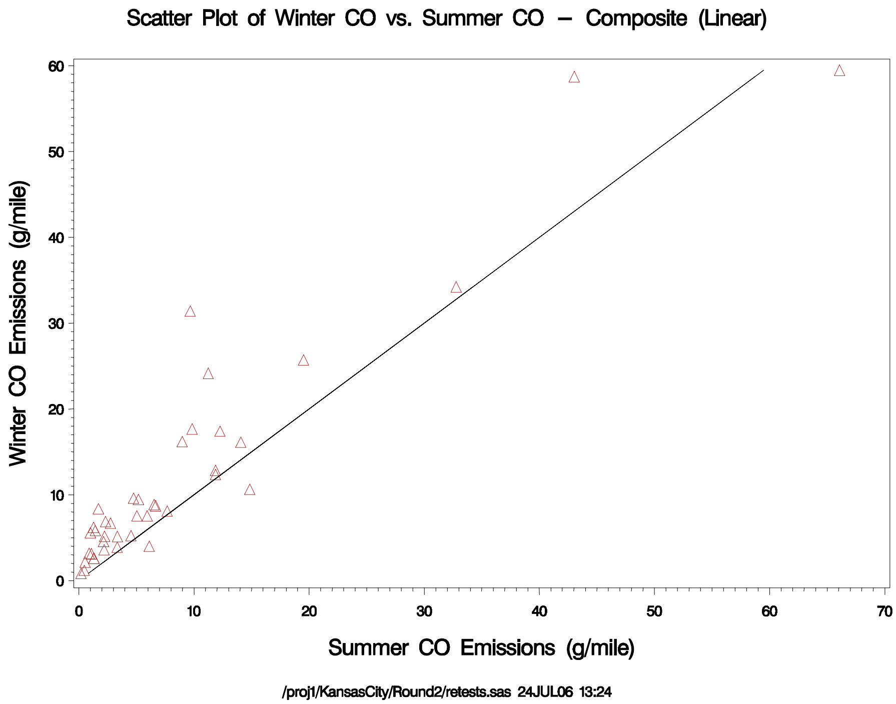


Figure 4-24. Winter vs. Summer CO – Linear

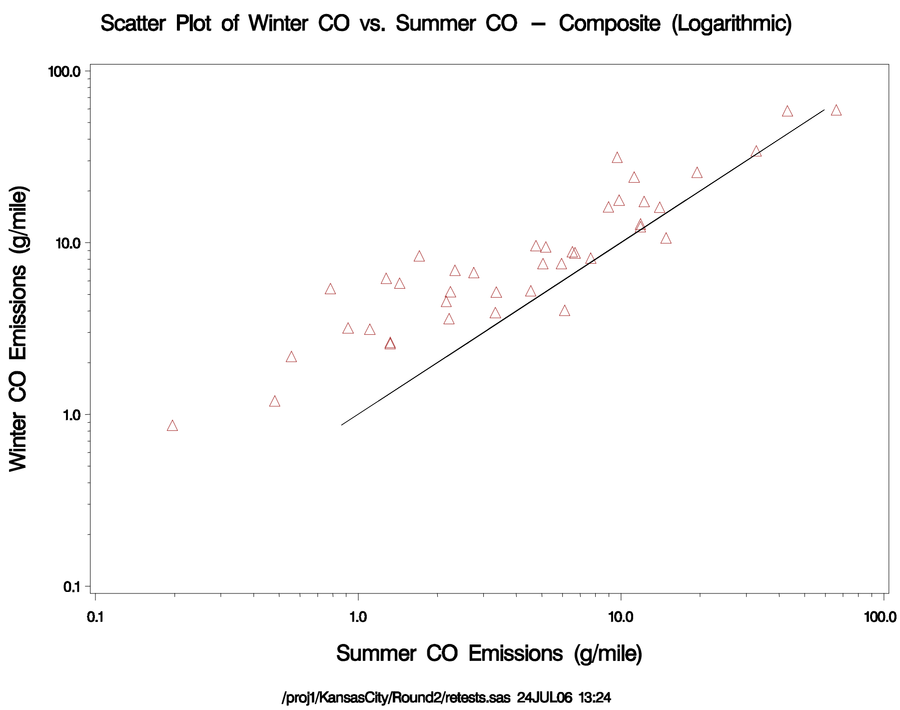


Figure 4-25. Winter vs. Summer CO - Logarithmic

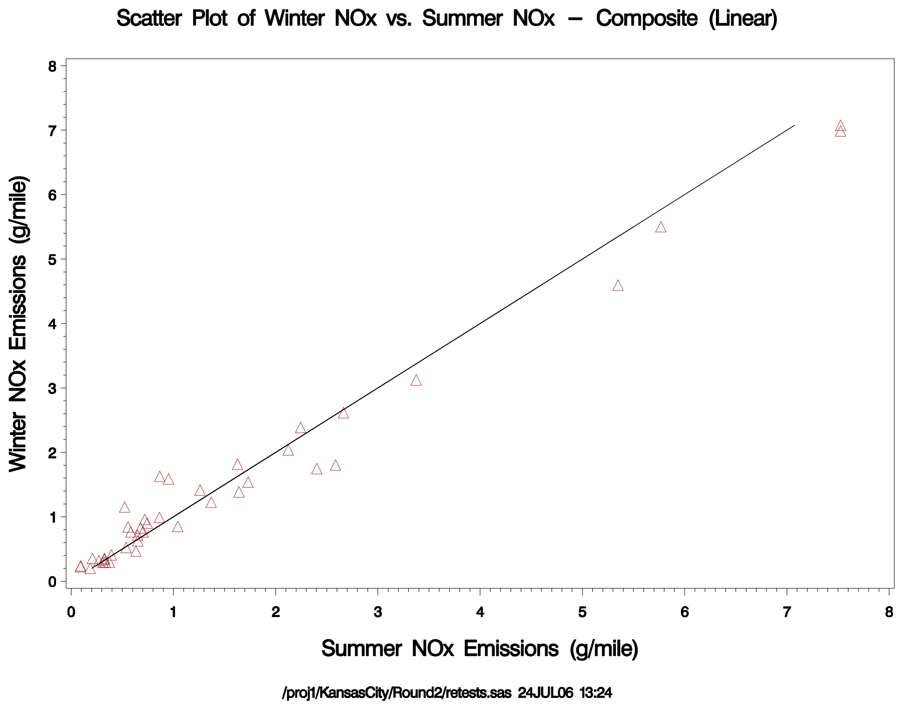


Figure 4-26. Winter vs. Summer NOx – Linear

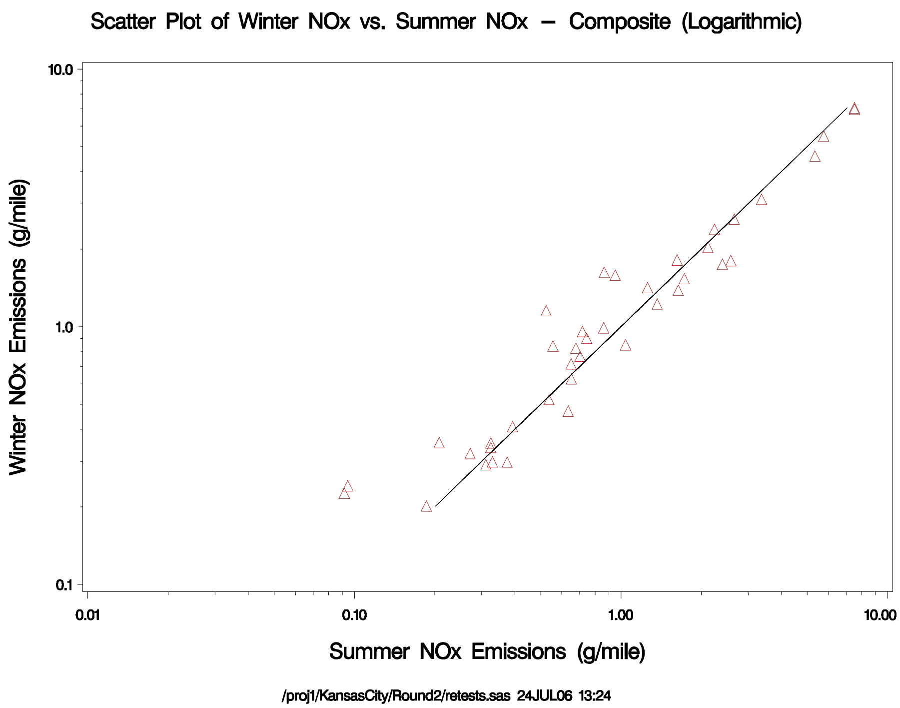


Figure 4-27. Winter vs. Summer NOx - Logarithmic

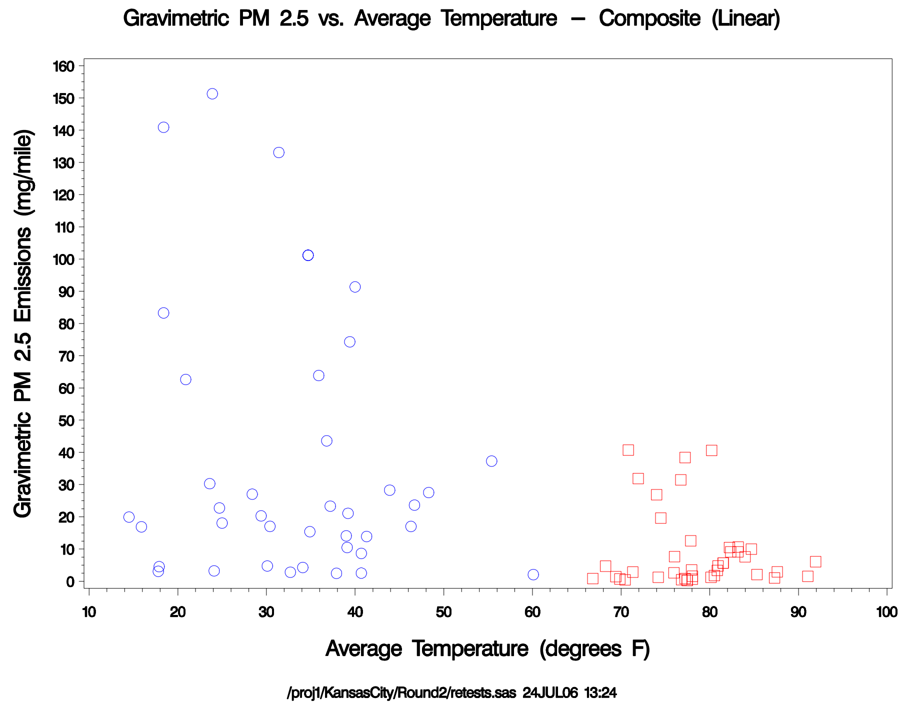


Figure 4-28. Gravimetric PM 2.5 vs. Average Temperature

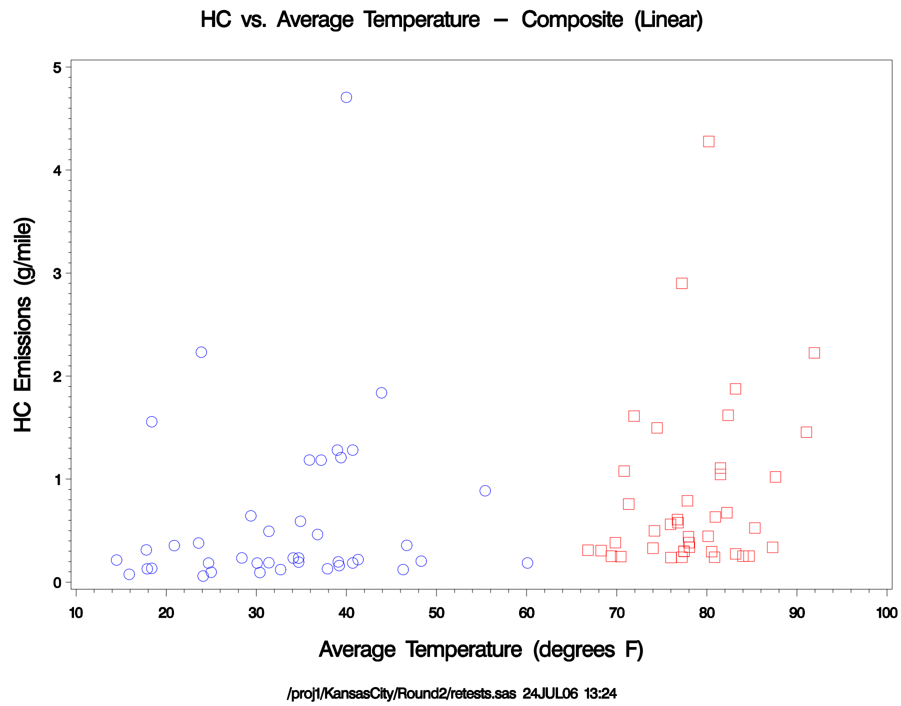


Figure 4-29. HC vs. Average Temperature

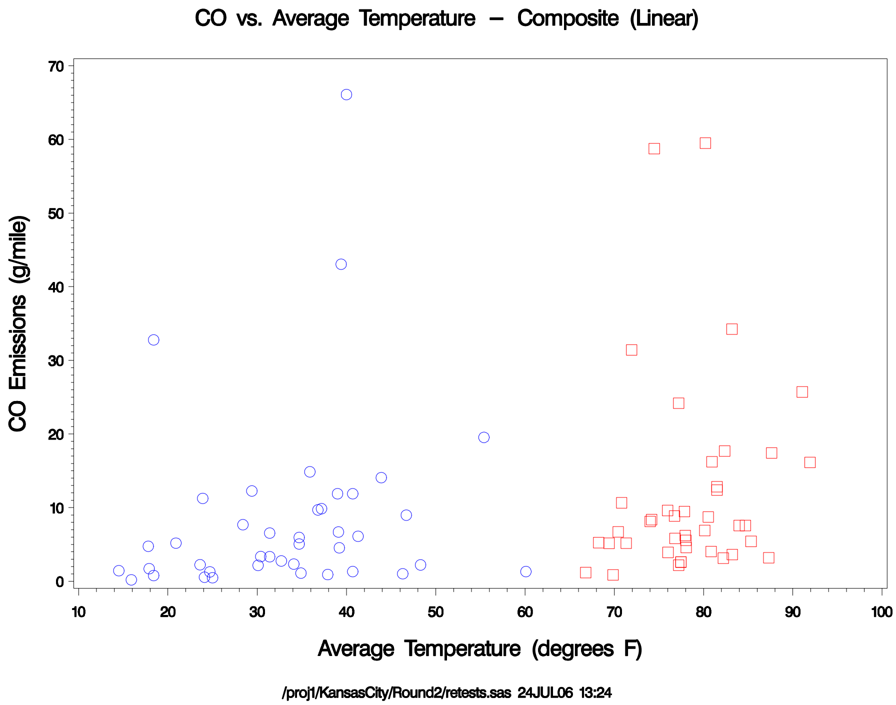


Figure 4-30. CO vs. Average Temperature

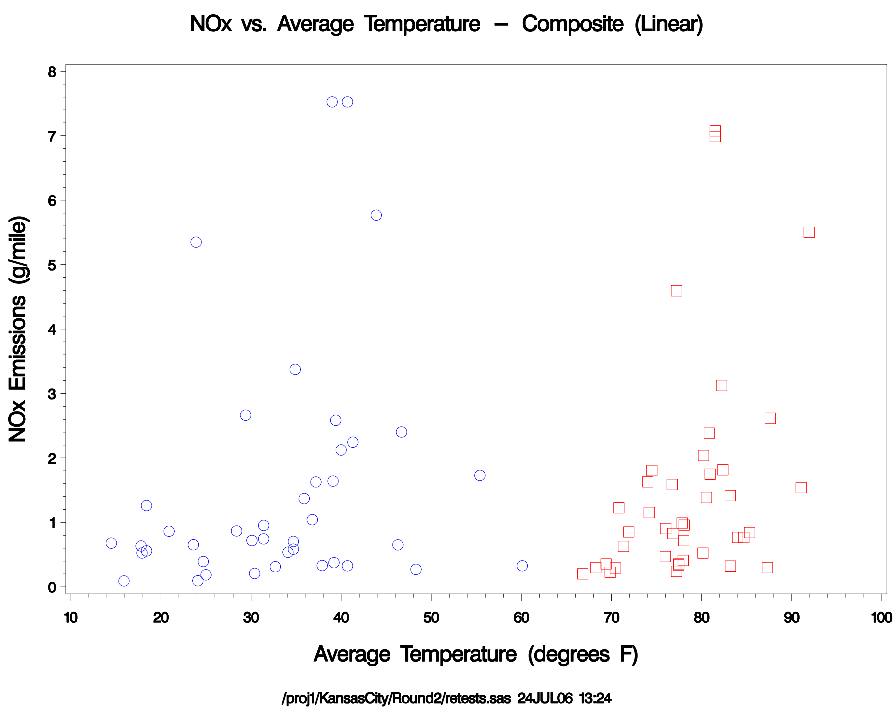


Figure 4-31. NOx vs. Average Temperature

4.4.5 Review of In-Round Duplicate Test Results

4.4.5.1 Round 1 Duplicate Testing

Sixteen vehicles were subject to duplicate testing in Round 1. One of these vehicles was tested three times, for a total of eighteen duplicate test pairs. Table 4-22 presents test run numbers, test conditions, and composite emissions for the Round 1 duplicate testing. Figures 4-32 through 4-39 present linear and logarithmic plots comparing composite gravimetric $PM_{2.5}$, HC, CO, and NOx across the first and second tests, with 1:1 lines for reference. Appendices G and H contains by-phase plots for all pollutants of interest.

Table 4-22. Round 1 Duplicate Testing Composite Emissions

		First Test							Second Test					
Duplicate #	Run #	Temp (F)	RH (%)	Grav PM (mg/mi)	HC (g/mi)	CO (g/mi)	NOx (g/mi)	Run #	Temp (F)	RH (%)	Grav PM (mg/mi)	HC (g/mi)	CO (g/mi)	NOx (g/mi)
1	84258	70.8	1.5	4.798	0.29	4.248	1.498	84262	71.8	50.2	3.321	0.437	8.355	1.576
2	84111	88.4	51.6	4.068	0.172	2.342	0.91	84116	87.6	49.5	1.787	0.201	2.435	0.916
3	84166	71.5	39.2	0.604	0.34	7.136	1.25	84169	70.7	44	0.043	0.269	4.825	1.288
4	84110	84.7	56.8	10.006	0.195	5.063	0.585	84115	84	57.1	7.597	0.234	5.948	0.704
5	84060	90.3	63.8	0.994	0.097	1.013	0.937	84062	83.9	80.3	1.236	0.066	0.638	0.93
6	84198	65.8	63.2	2.072	0.421	4.931	0.585	84200	65.2	68.8	3.687	0.481	6.285	0.663
7	84104	78.1	55.7	1.556	0.185	2.168	0.719	84109	83	59.1	1.069	0.173	1.965	0.751
8	84132	80.3	38.3	4.334	1.09	11.5	2.488	84137	76.9	34.9	4.413	1.049	10.222	2.394
9	84175	70.1	47.8	3.644	1.261	7.782	1.713	84180	74.6	44.4	9.257	1.338	9.151	2.017
10	84332	76.8	39.7	2.24	0.155	1.922	0.577	84341	76	54.3	7.647	0.189	3.335	0.744
11	84151	69.4	46.8	1.452	0.094	3.361	0.208	84156	65.4	59.4	2.022	0.107	4.69	0.223
12	84120	93.6	44.4	5.467	0.991	27.563	1.292	84123	85.1	56.2	3.428	0.918	26.13	1.047
13	84388	59.1	4.8		0.009	0.037	0.056	84389	60.2	5.4		0.001	0.01	0.001
14	84388	59.1	4.8		0.009	0.037	0.056	84390	60.9	6.8		0.001	0.003	
15	84388	59.1	4.8		0.009	0.037	0.056	84391	63.2	7.9		0.017	0.101	0
16	84321	80.5	33.3	1.366	0.197	0.972	0.482	84328	82	40.7	0.391	0.207	0.943	0.471
17	84345	74.1	42.5	0.327	0.183	1.954	0.654	84350	70.7	49.5	0.444	0.175	2.048	0.661
18	84308	77.4	42.3	3.914	0.266	8.071	2.044	84312	74.3	61.1	0.958	0.219	7.792	2.006

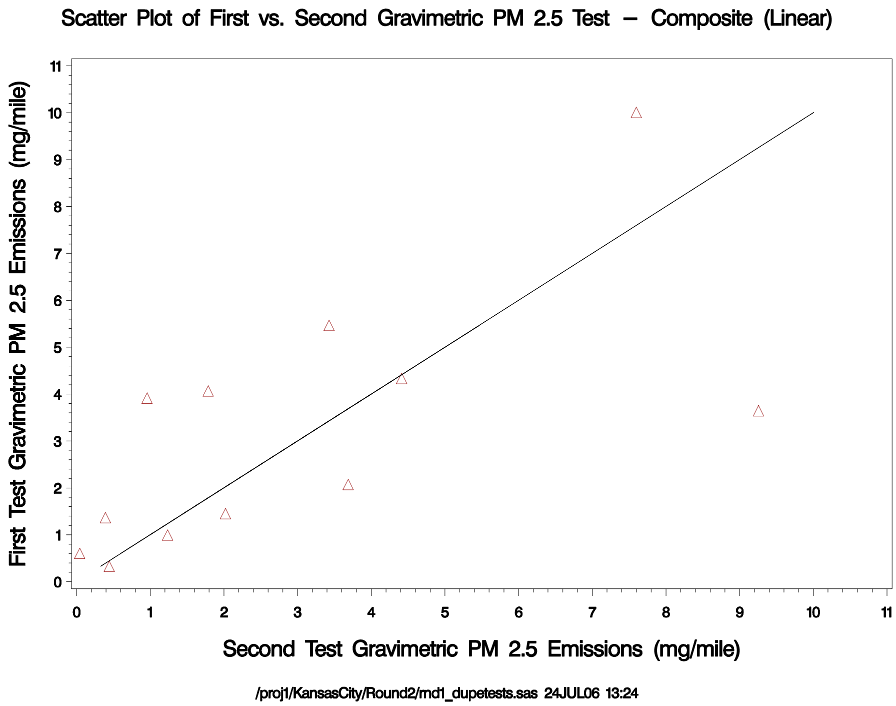


Figure 4-32. First vs. Second Round 1 Gravimetric PM 2.5 Tests - Linear

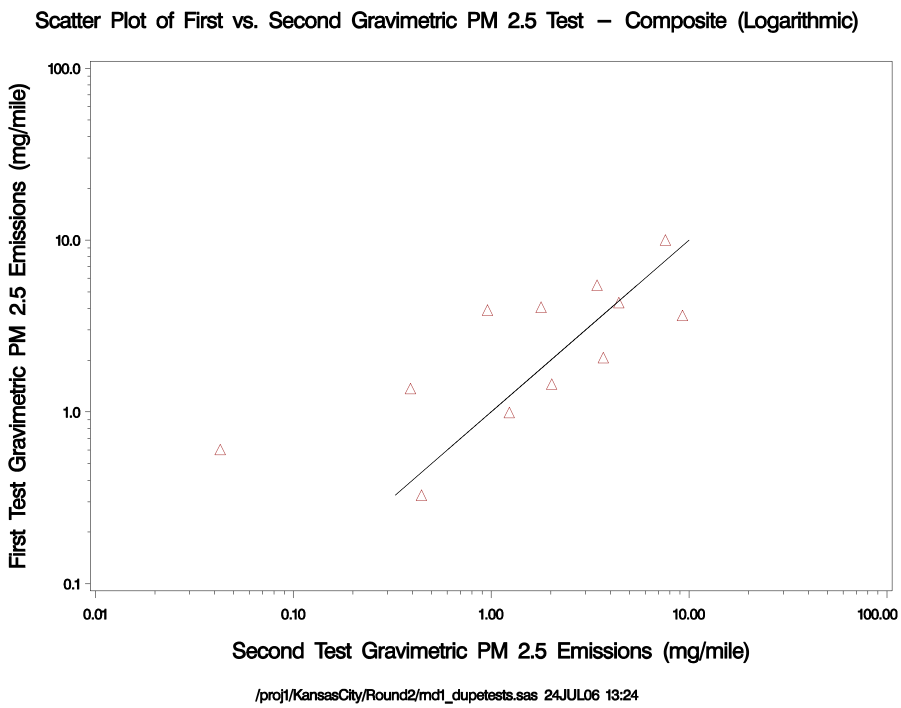


Figure 4-33. First vs. Second Round 1 Gravimetric PM 2.5 Tests - Logarithmic

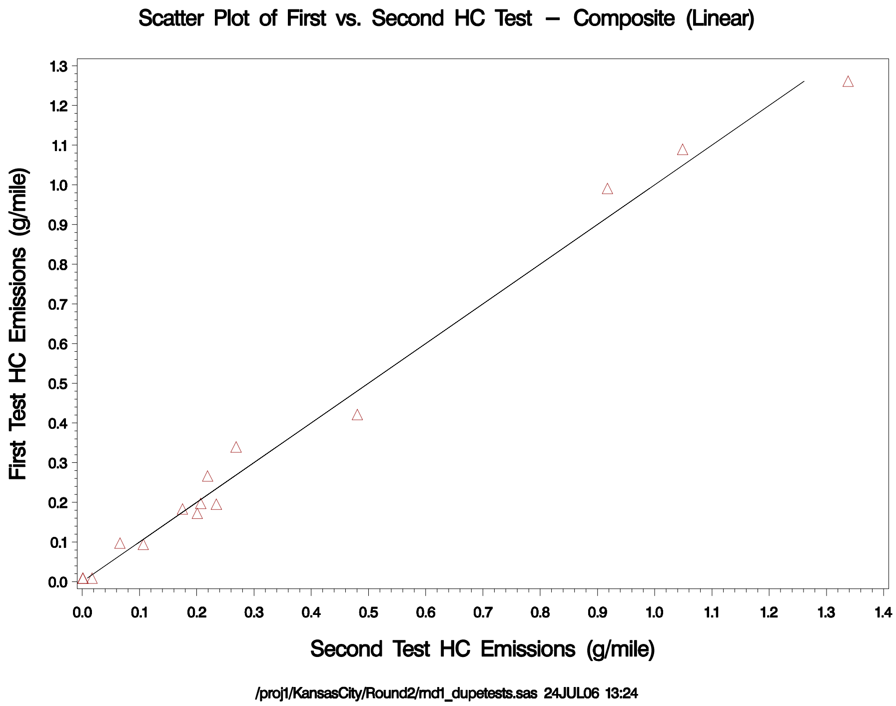


Figure 4-34. First vs. Second Round 1 HC Tests - Linear

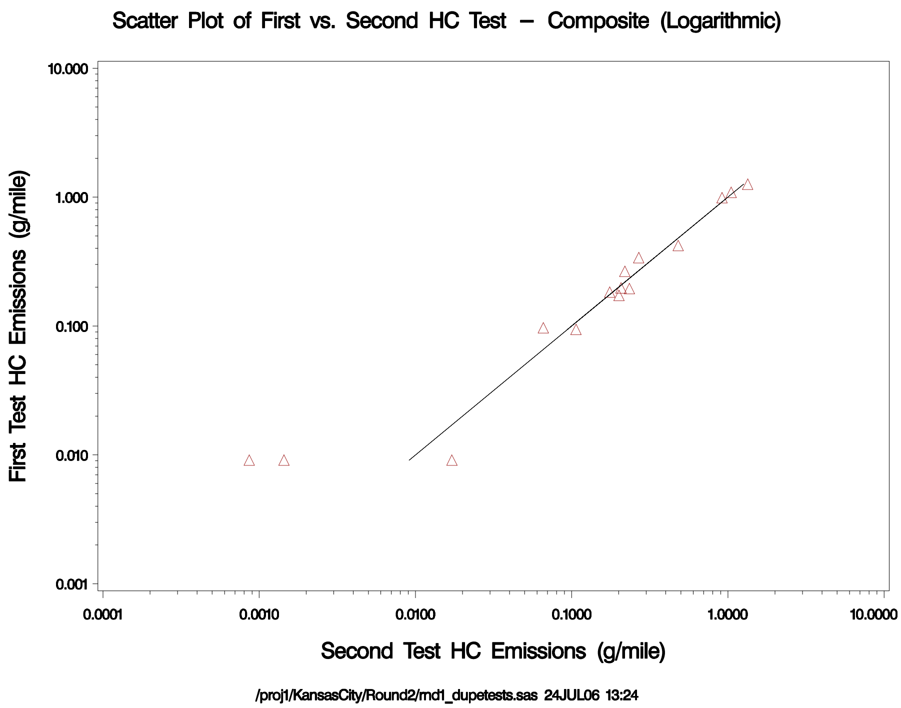


Figure 4-35. First vs. Second Round 1 HC Tests - Logarithmic

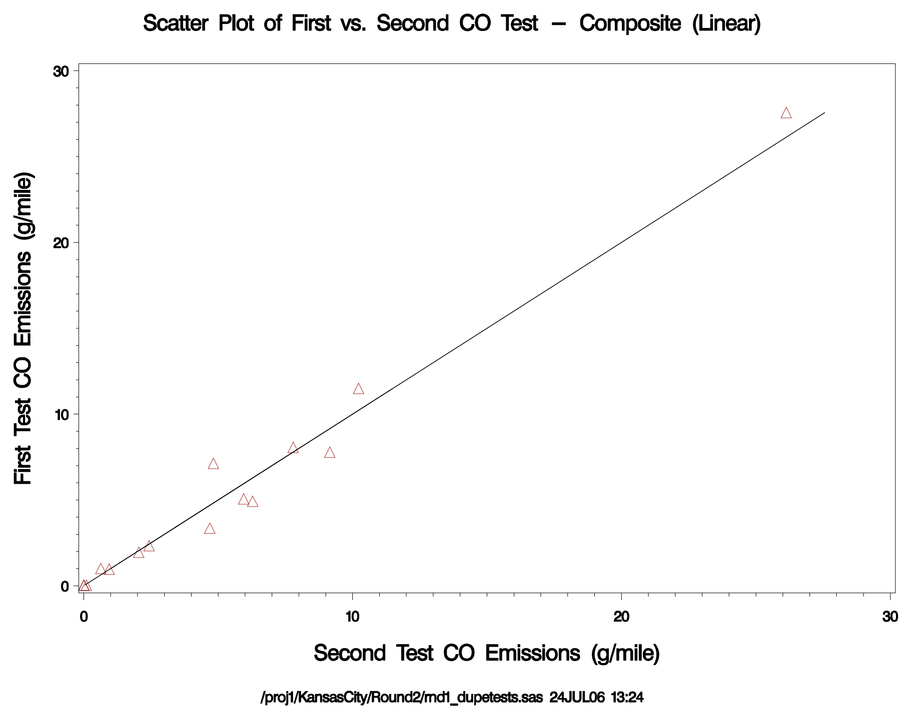


Figure 4-36. First vs. Second Round 1 CO Tests - Linear

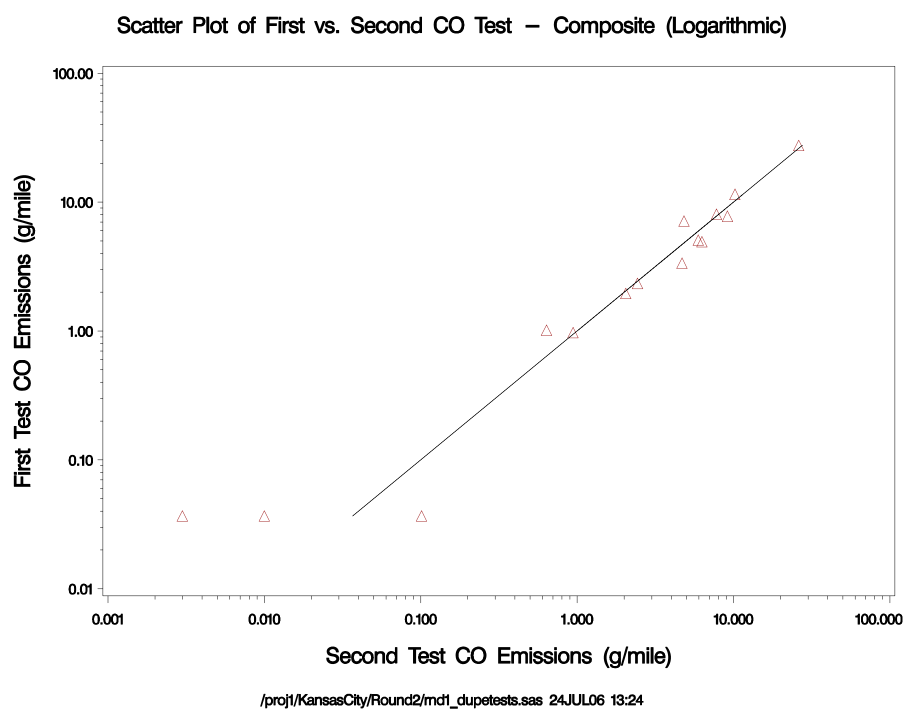


Figure 4-37. First vs. Second Round 1 CO Tests - Logarithmic

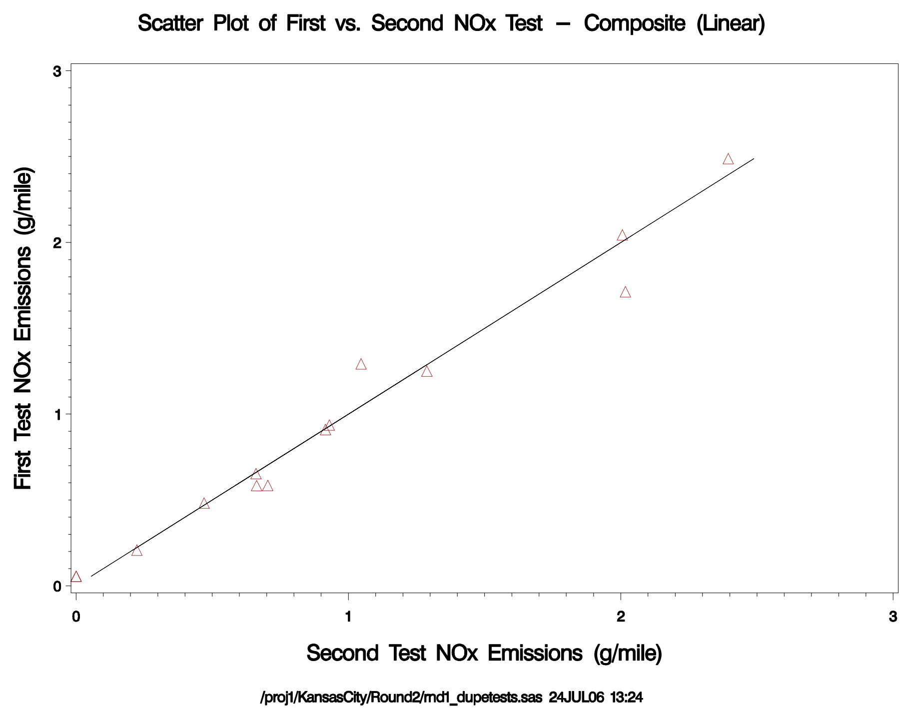


Figure 4-38. First vs. Second Round 1 NOx Tests - Linear

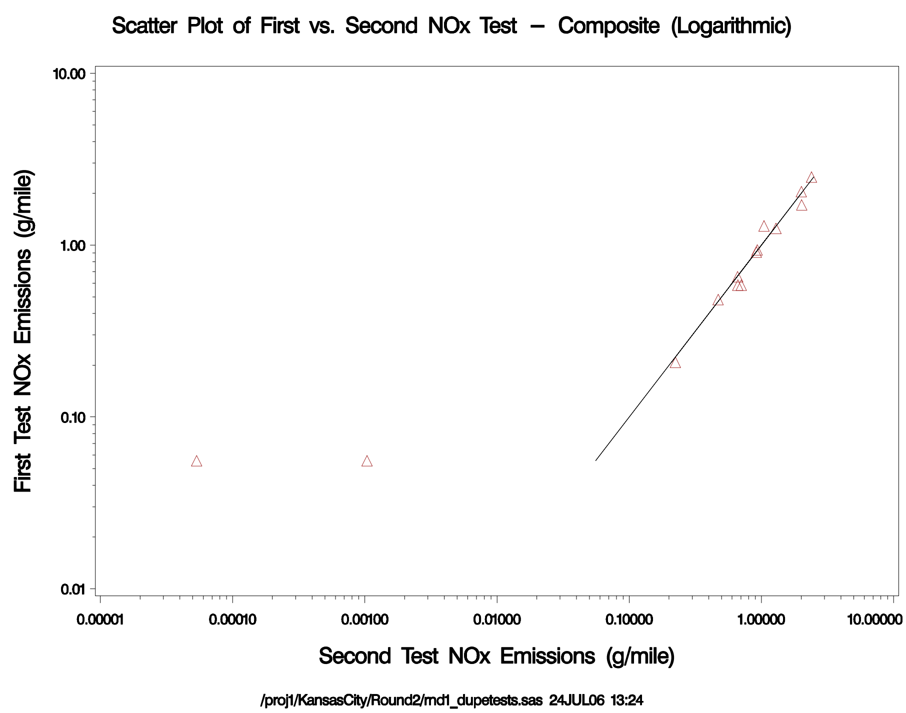


Figure 4-39. First vs. Second Round 1 NOx Tests - Logarithmic

4.4.5.2 Round 2 Duplicate Testing

Ten vehicles were subject to duplicate testing in Round 2. Table 4-23 presents test run numbers, test conditions, and composite emission results for the Round 2 duplicate testing. Figures 4-40 through 4-47 present linear and logarithmic plots comparing composite gravimetric $PM_{2.5}$, HC, CO, and NOx across the first and second tests, with 1:1 lines for reference. Appendices G and H contains by-phase plots for all pollutants of interest.

Table 4-23. Round 2 Duplicate Testing Composite Emissions

	First Test							Second Test						
Duplicate #	Run #	Temp (F)	RH (%)	Grav PM (mg/mi)	HC (g/mi)	CO (g/mi)	NOx (g/mi)	Run #	Temp (F)	RH (%)	Grav PM (mg/mi)	HC (g/mi)	CO (g/mi)	NOx (g/mi)
1	84537	40.900	63.8	3.178	0.304	4.495	0.740	84543	49.500	52.5	3.982	0.237	4.072	0.759
2	84482	39.000	70.1	14.104	1.109	12.847	6.988	84484	40.700	56.8	8.658	1.046	12.375	7.077
3	84437	60.100	47.0	2.078	0.299	2.587	0.340	84442	40.700	59.6	2.535	0.300	2.630	0.354
4	84690	55.200	38.3	2.005	0.684	9.336	1.268	84695	42.400	67.6	2.119	0.632	7.410	1.206
5	84465	37.900	56.0	188.706	0.227	3.337	0.920	84468	36.600	46.3	5.223	0.234	3.544	0.781
6	84627	47.000	34.9	232.116	14.917	69.159	3.776	84632	45.000	30.4	99.412	15.235	88.783	3.696
7	84675	52.900	28.9	4.114	0.342	4.899	2.001	84681	41.300	68.7		0.308	4.098	2.100
8	84541	49.800	68.3	6.332	0.705	13.630	1.059	84542	44.600	61.3	4.908	0.746	14.926	1.090
9	84449	25.800	39.0	10.153	0.441	7.926	1.136	84451	37.600	61.3	4.620	0.399	7.127	1.250
10	84485	38.900	59.2	20.047	1.099	25.170	1.027	84490	36.900	55.0	3.842	0.974	25.026	1.023

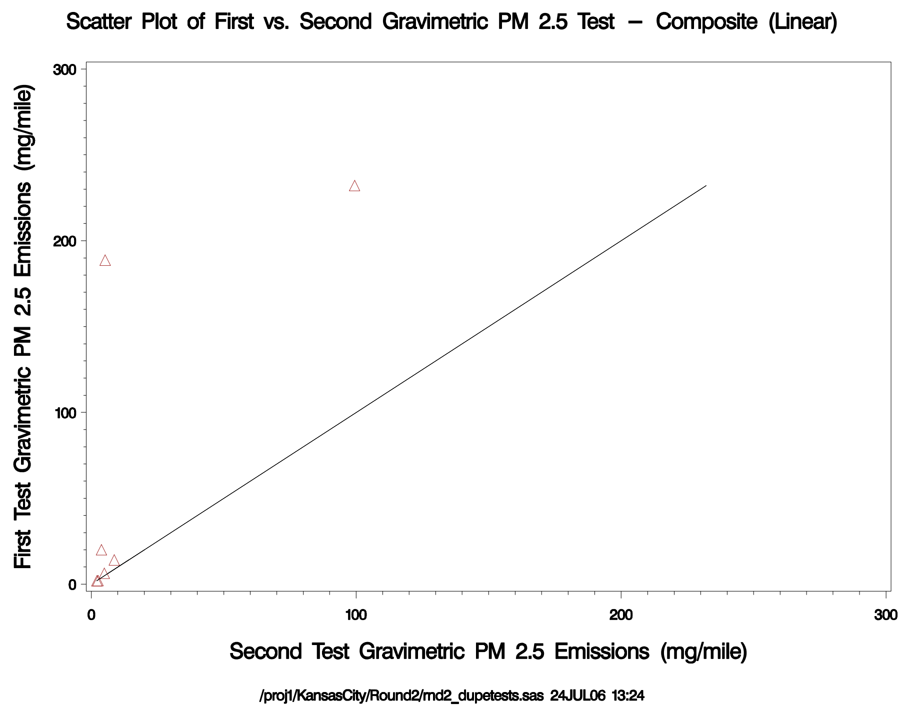


Figure 4-40. First vs. Second Round 2 Gravimetric PM 2.5 Tests - Linear

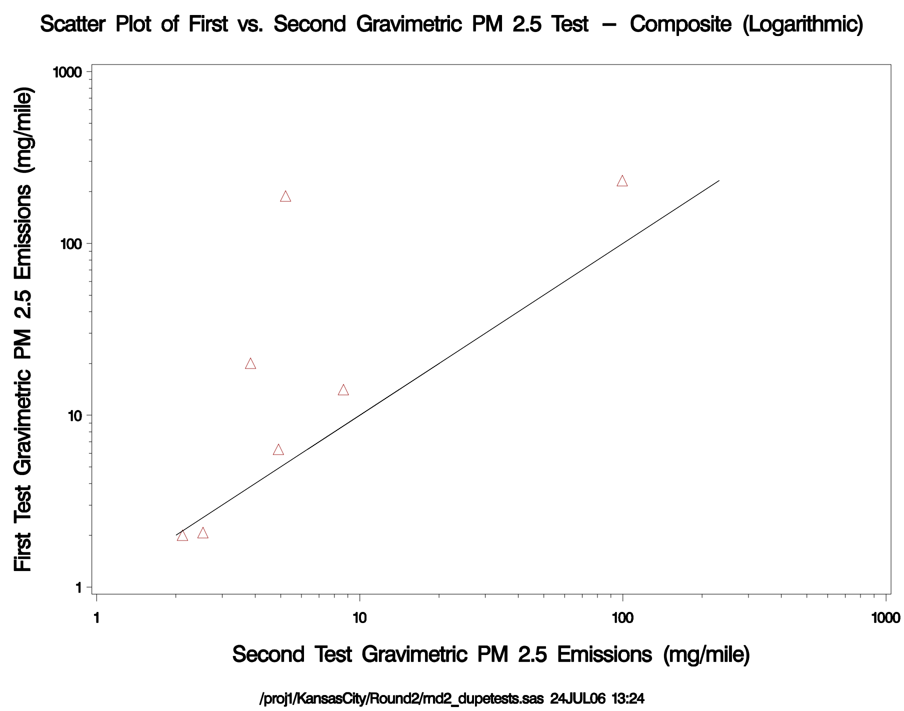


Figure 4-41. First vs. Second Round 2 Gravimetric PM 2.5 Tests - Logarithmic

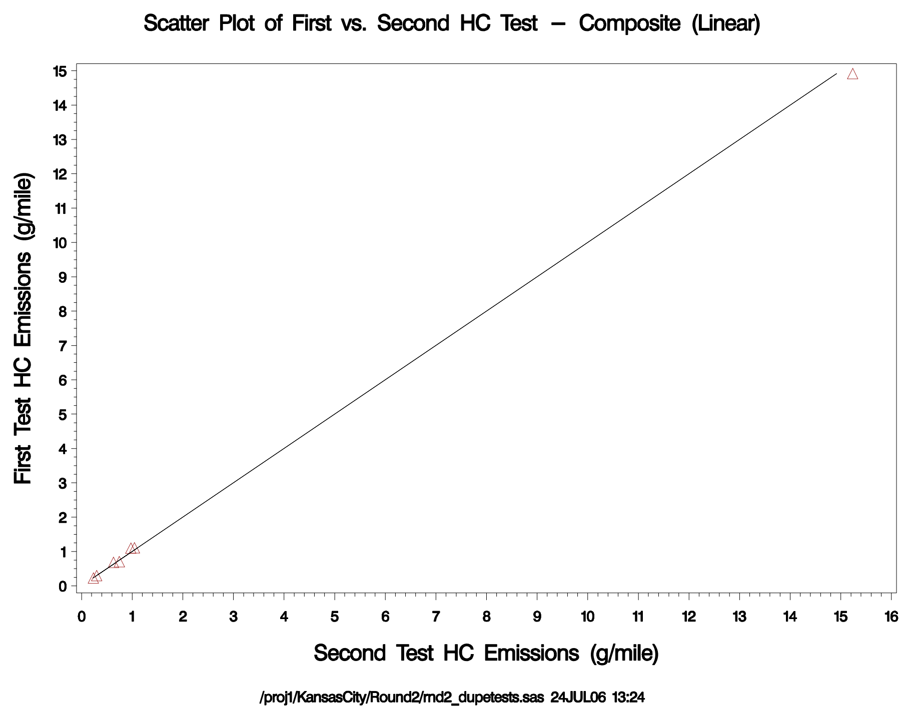


Figure 4-42. First vs. Second Round 2 HC Tests - Linear

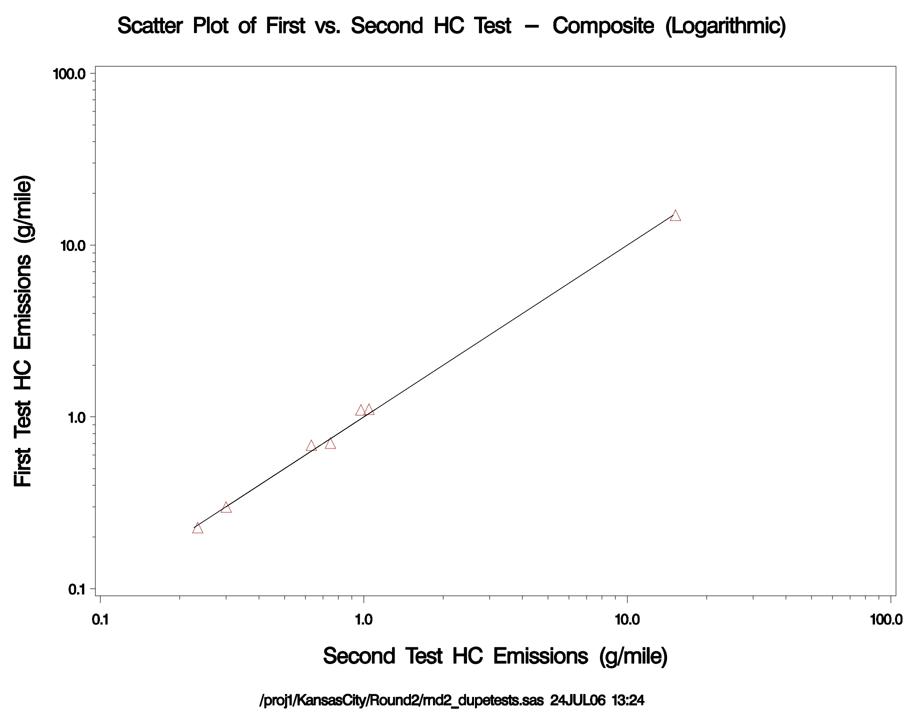


Figure 4-43. First vs. Second Round 2 HC Tests - Logarithmic

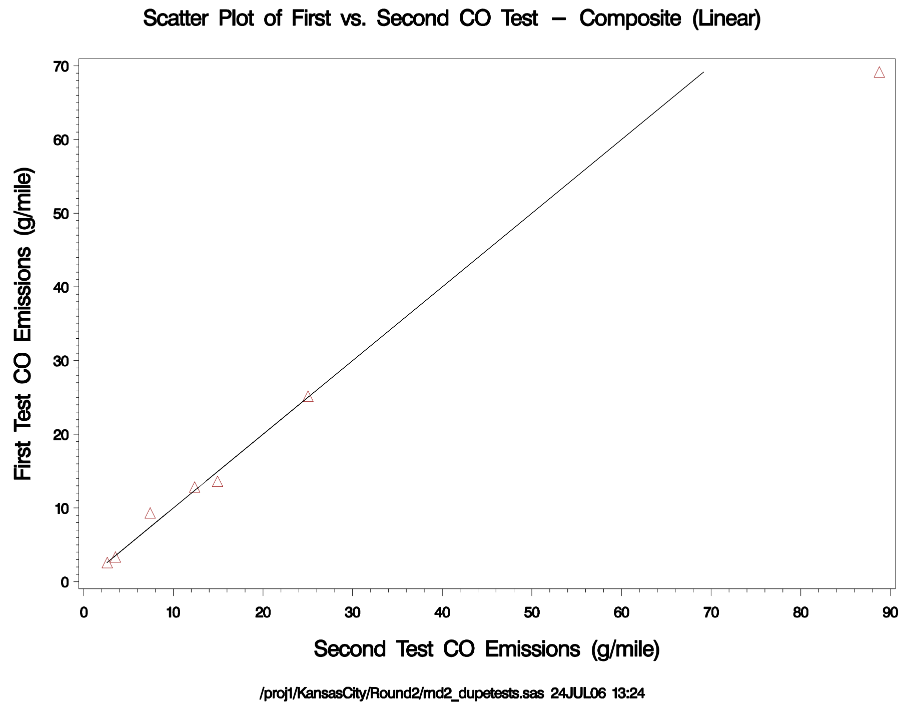


Figure 4-44. First vs. Second Round 2 CO Tests - Linear

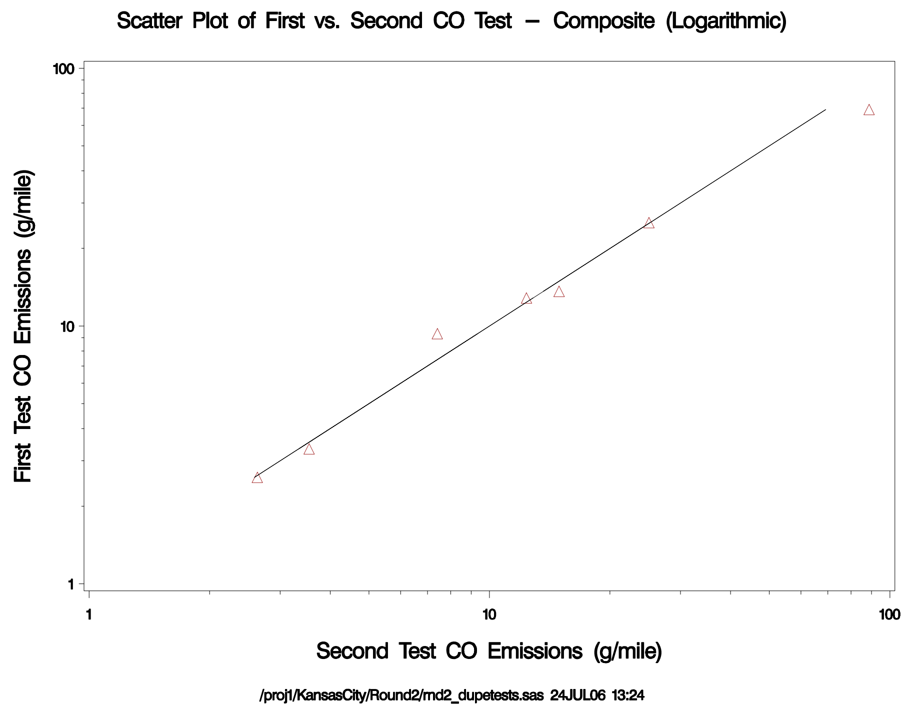


Figure 4-45. First vs. Second Round 2 CO Tests - Logarithmic

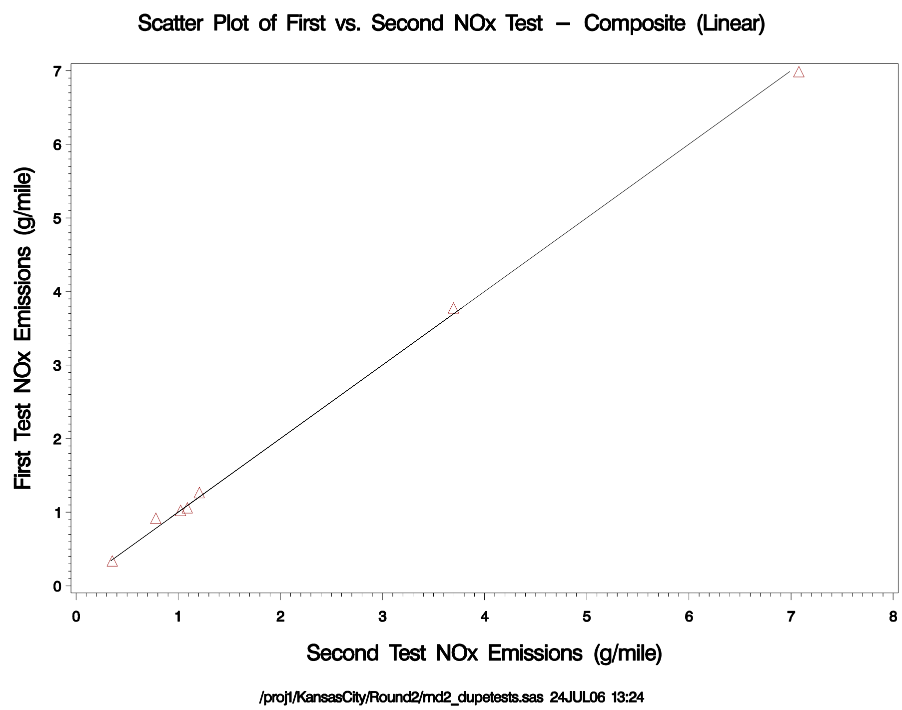


Figure 4-46. First vs. Second Round 2 NOx Tests - Linear

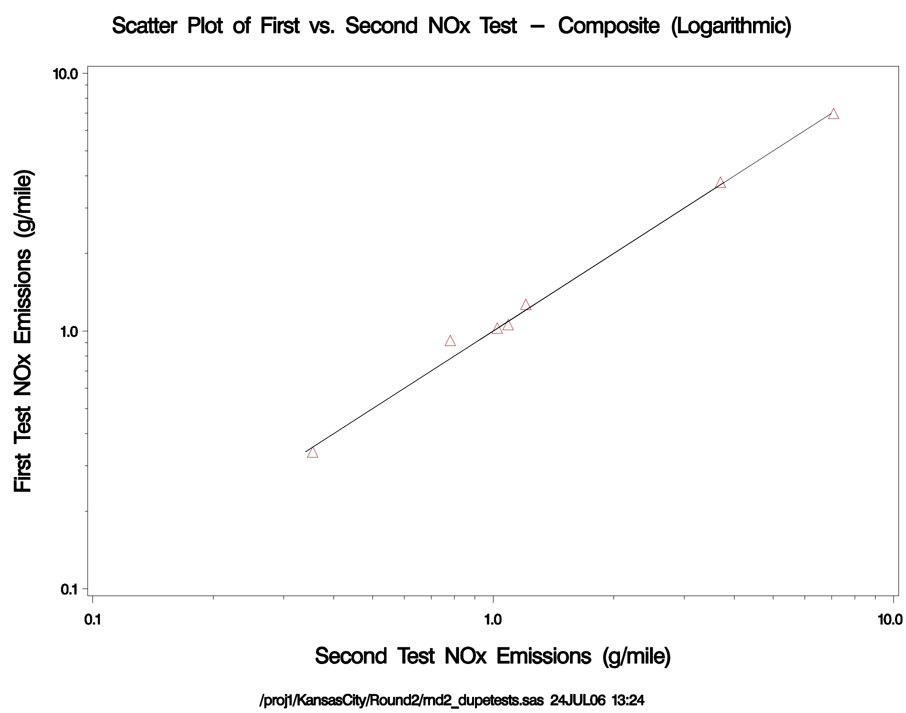


Figure 4-47. First vs. Second Round 2 NOx Tests – Logarithmic

Table 4-24 shows a statistical analysis on the duplicate measurements conducted during Round 1 and Round 2. A paired t-test is a sensitive test for evaluating repeat measurements. The table shows that random duplicate measurements were not significantly different. The relative humidity measurements were significantly different in Round 1 for the duplicates, but this does not appear to influence the NOx or other measurements in any meaningful way. We have also included the largest mean difference in the measurements in the far right column of the table. This column shows the threshold value for the mean difference beyond which the value would be called significant at the 95% confidence level for the number of paired measurements made. As shown, all the mean values for all the emissions and temperatures are well below this threshold. Even the relative humidity in Round 2 was below this value and hence not significantly different.

Table 4-24. Paired t-test Results for In-Round Duplicates

Round 1								
Variable	*Units*	*N*	*Mean*	*Std Error*	*t Value*	*Pr > |t|*	*t for 95% conf*	*Mean value needed for 95 % conf in diff*
PMdiff	mg/mi	15	0.03	0.66	0.05	0.96	2.15	1.41
HCdiff	g/mi	18	0.01	0.01	0.50	0.62	2.11	0.03
COdiff	g/mi	18	0.26	0.33	0.80	0.43	2.11	0.69
NXdiff	g/mi	17	0.02	0.03	0.70	0.49	2.12	0.06
tempdiff	deg. F	18	-0.76	0.85	-0.88	0.39	2.11	1.80
rhdiff	%	18	8.24	2.86	2.88	0.01	2.11	6.03
Round 2								
Variable	*Units*	*N*	*Mean*	*Std Error*	*t Value*	*Pr > |t|*	*t for 95% conf*	*Mean value needed for 95 % conf in diff*
PMdiff	mg/mi	9	-38.16	23.12	-1.65	0.14	2.31	53.32
HCdiff	g/mi	10	0.00	0.04	-0.04	0.97	2.26	0.09
COdiff	g/mi	10	1.66	2.01	0.82	0.43	2.26	4.55
NXdiff	g/mi	10	0.01	0.03	0.32	0.76	2.26	0.06
tempdiff	deg. F	10	-3.22	3.03	-1.06	0.31	2.26	6.84
rhdiff	%	10	5.40	6.05	0.89	0.40	2.26	13.68

4.4.6 Review of Miscellaneous Regulated Pollutant Emission Trends

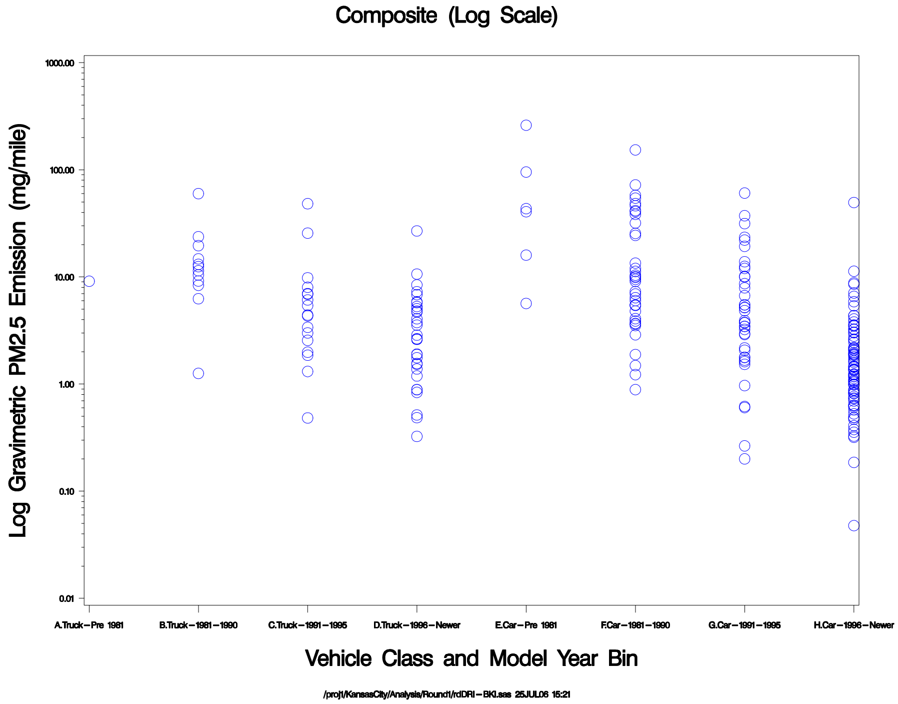
Figures 4-48 through 4-55 present composite $PM_{2.5}$, HC, CO, and NO_x measurements from the dynamometer classified by vehicle type and model year in both linear and log scale. All emissions show a negative relationship with model year, and vehicle type does not seem to have any influence on emission values. Plots of $PM_{2.5}$, HC, CO, and NO_x measurements from the dynamometer classified by vehicle type and model year for particular Phases are located in Appendices G and H (Note that the letters A through I present in the axis labels in the figures below are in place to sort the data appropriately for ease of reading; they serve no other purpose.)

Figures 4-56 through 4-59 present scatter plots of composite $PM_{2.5}$ vs. NO_x measurements from the dynamometer classified by vehicle type and model year in both linear and log scale. All plots show a positive relationship between $PM_{2.5}$ emissions and NO_x emissions, and the newest model year group shows the lowest amount of emissions. In these figures, Phase 1 emissions are depicted in red, phase 2 emissions in green, and phase 3 emissions in brown. Scatter plots of $PM_{2.5}$ against HC and CO measurements from the dynamometer can be found in Appendices G and H.

Figures 4-60 through 4-63 present plots of composite $PM_{2.5}$ emissions as a function of model year classified by vehicle type in both linear and log scale. All plots show lower emissions when the model year is newer. The dispersion within the model for each plot shows that newer model years have less variation than older ones. Plots of HC, CO and NO_x measurements from the dynamometer as a function of model year can be found in Appendices G and H.

Figures 4-64 through 4-71 present overlay plots of composite and Phase 1 $PM_{2.5}$, HC, CO, and NO_x emissions as a function of odometer in both linear and log scale. These plots reveal higher emissions under cold start conditions, as expected. Odometer readings do not seem to have a strong influence on emission levels. It should be noted that all odometer values shown in Figures 4-64 through 4-71 have not been corrected for odometer “turnover”. For example, the mileage for a vehicle with a 5-digit odometer and 103,000 miles would be shown in these plots as 3,000 miles. Figures 4-72 through 4-79 present overlay plots of the percent projected-fleet distribution of composite $PM_{2.5}$, HC, CO, and NO_x emissions. A solid line represents cumulative percent projected-fleet distribution, while a dashed line represents percent projected-fleet distribution. The $PM_{2.5}$ distribution shows that more then 95% of the fleet has $PM_{2.5}$ emission rates lower than 80 mg/mile. The reference point is the Tier 1 vehicle certification standard for PM emissions (approximately model years 1996 – 2003).

For Round 1, 267 LA92 tests were performed, excluding correlation vehicle tests. Using both the Kansas City fleet distribution for each stratum and the actual Round 1 stratum distribution, Kansas City fleet simulation can be achieved as shown in Table 4-25. This simulation is applied here for QA/QC purposes only and not for modeling purposes. It provides some insight to the effectiveness of the recruitment process to acquire vehicles that emit high PM emissions.



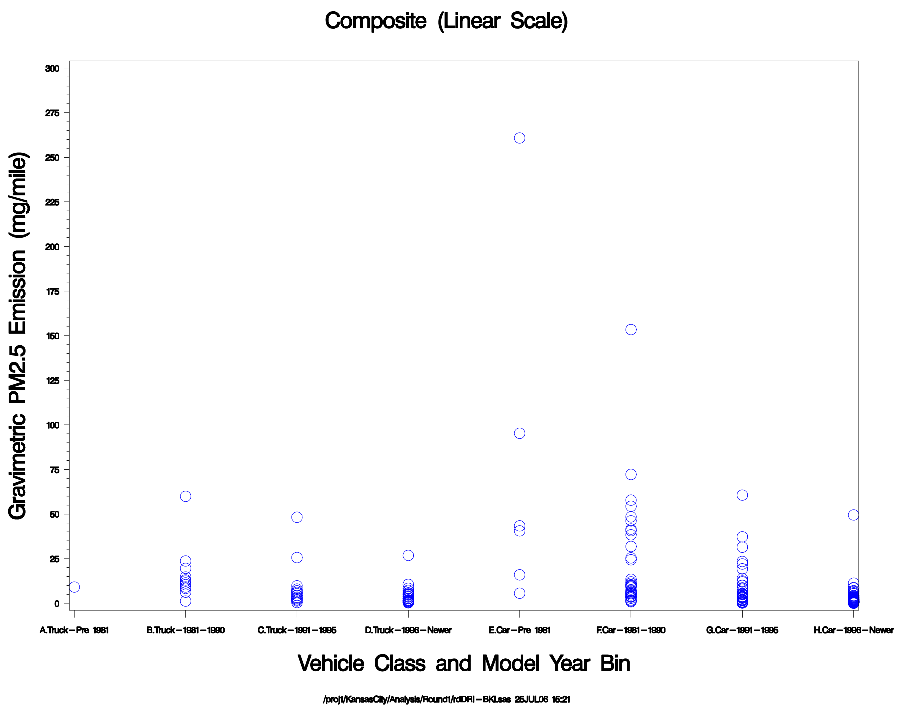
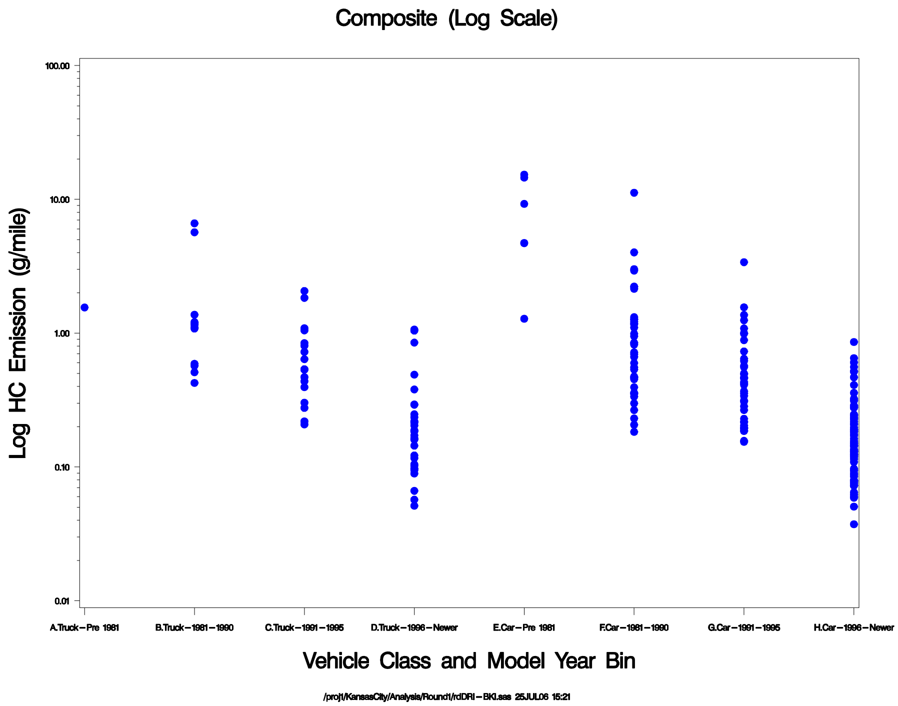


Figure 4-48. Round 1 Log/Linear Plots of $PM_{2.5}$ Emissions by Class-Year Bin



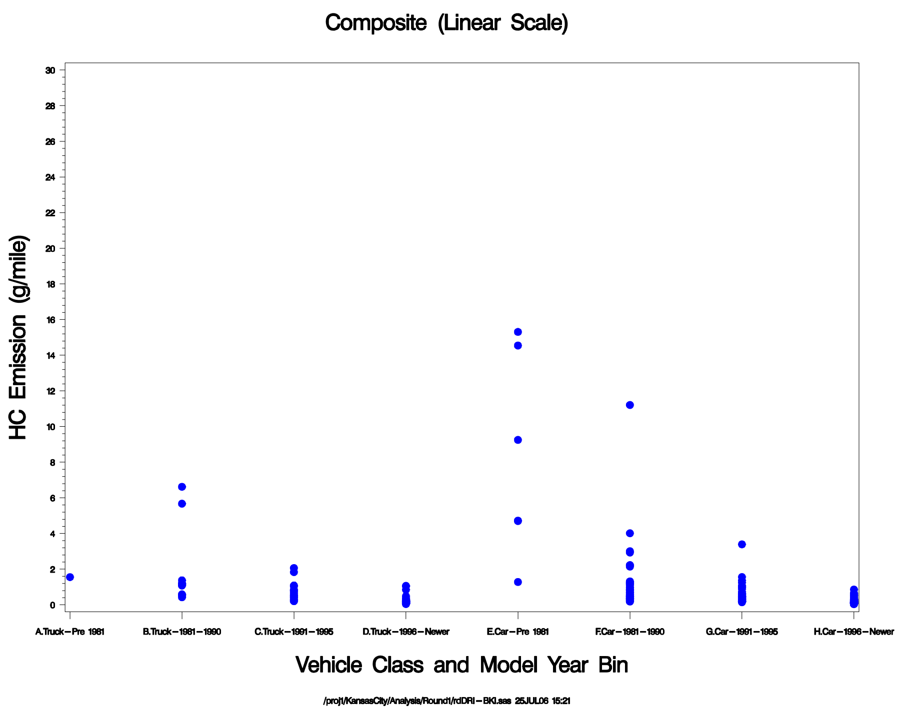
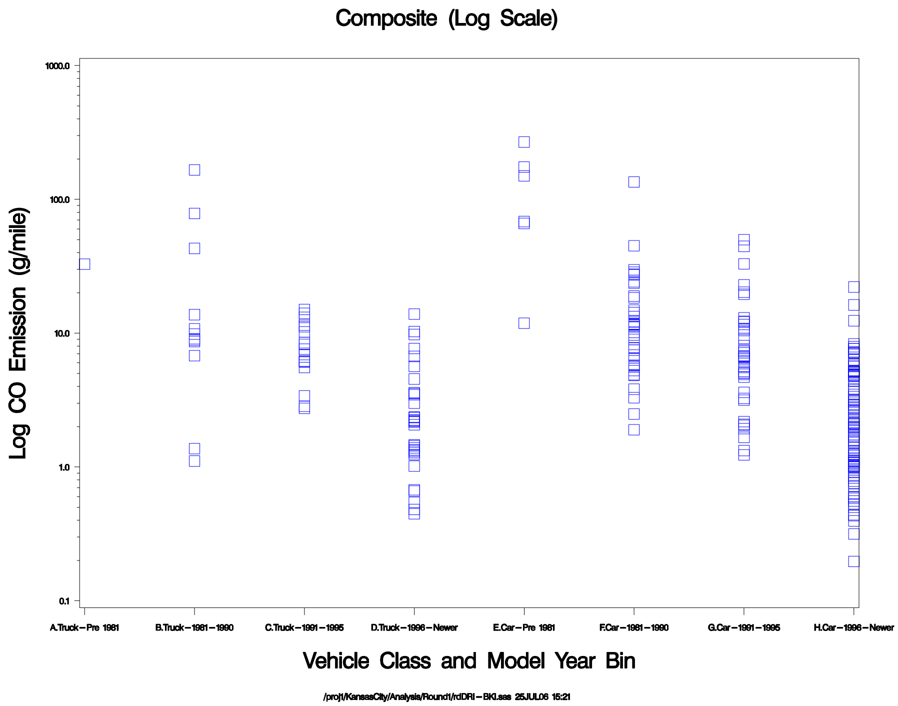


Figure 4-49. Round 1 Log/Linear Plots of HC Emissions by Class-Year Bin



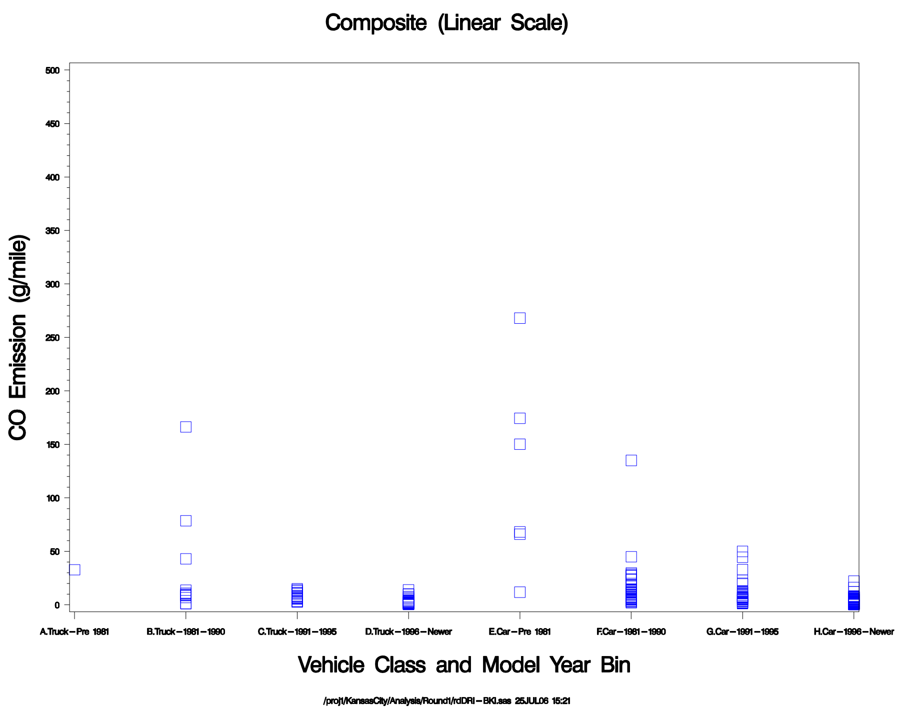


Figure 4-50. Round 1 Log/Linear Plots of CO Emissions by Class-Year Bin

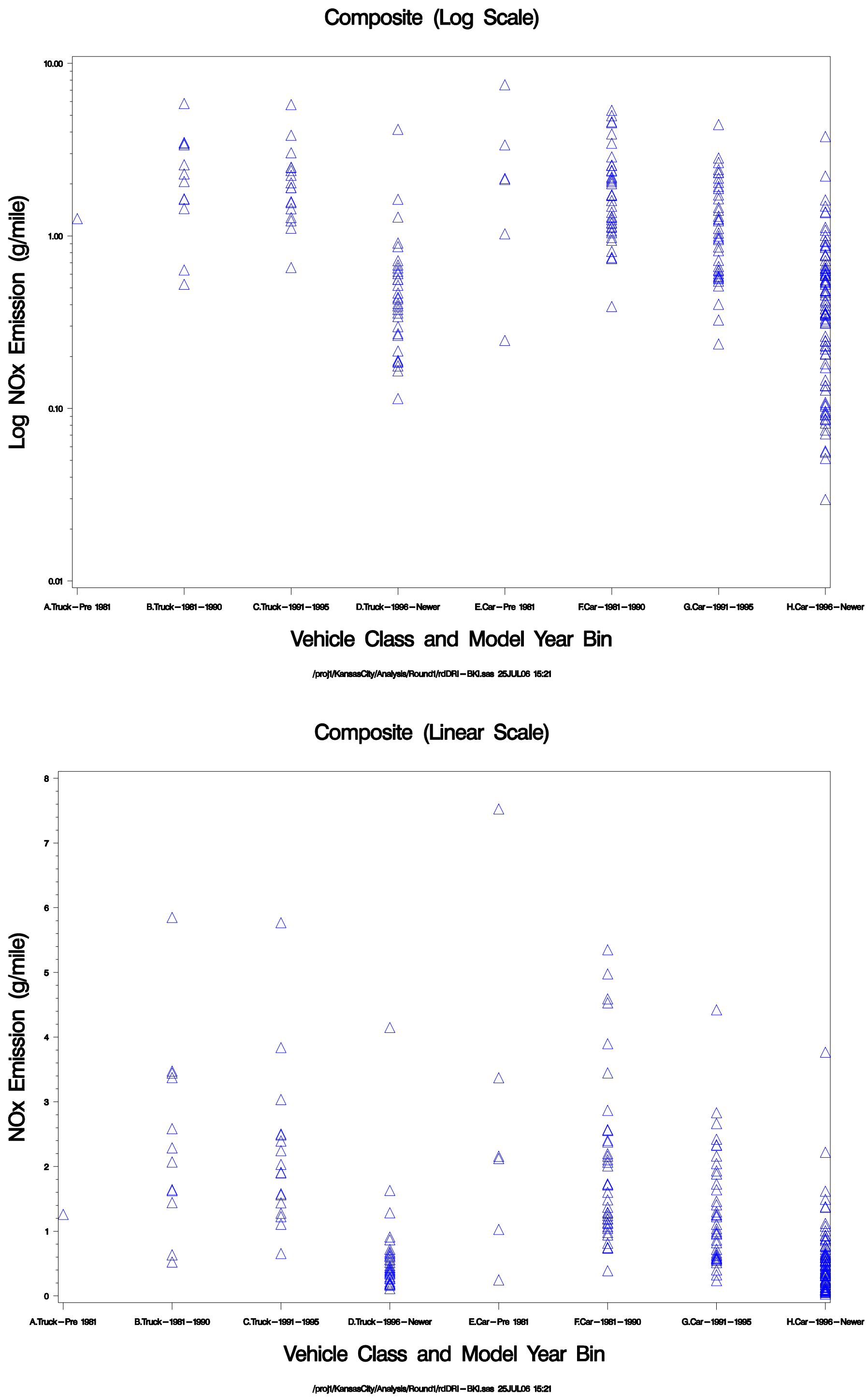
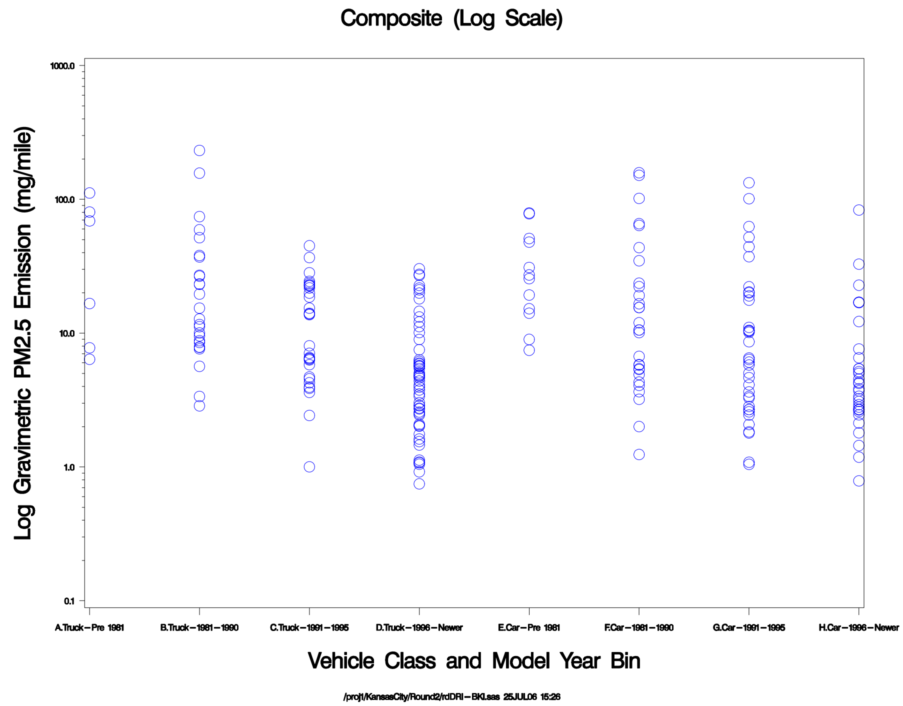


Figure 4-51. Round 1 Log/Linear Plots of NO_X Emissions by Class-Year Bin



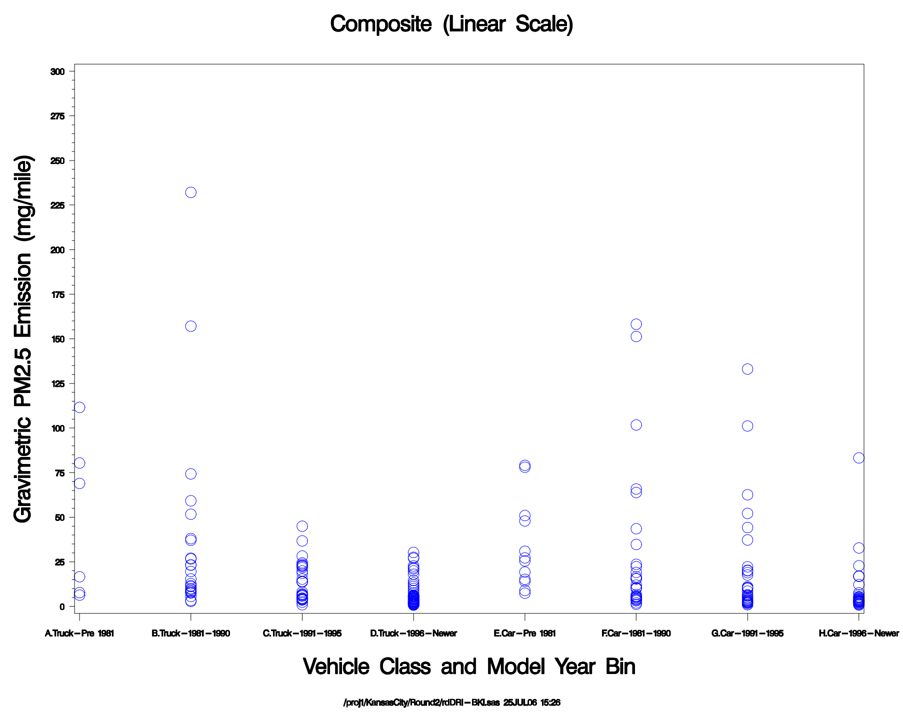


Figure 4-52. Round 2 Log/Linear Plots of $PM_{2.5}$ Emissions by Class-Year Bin

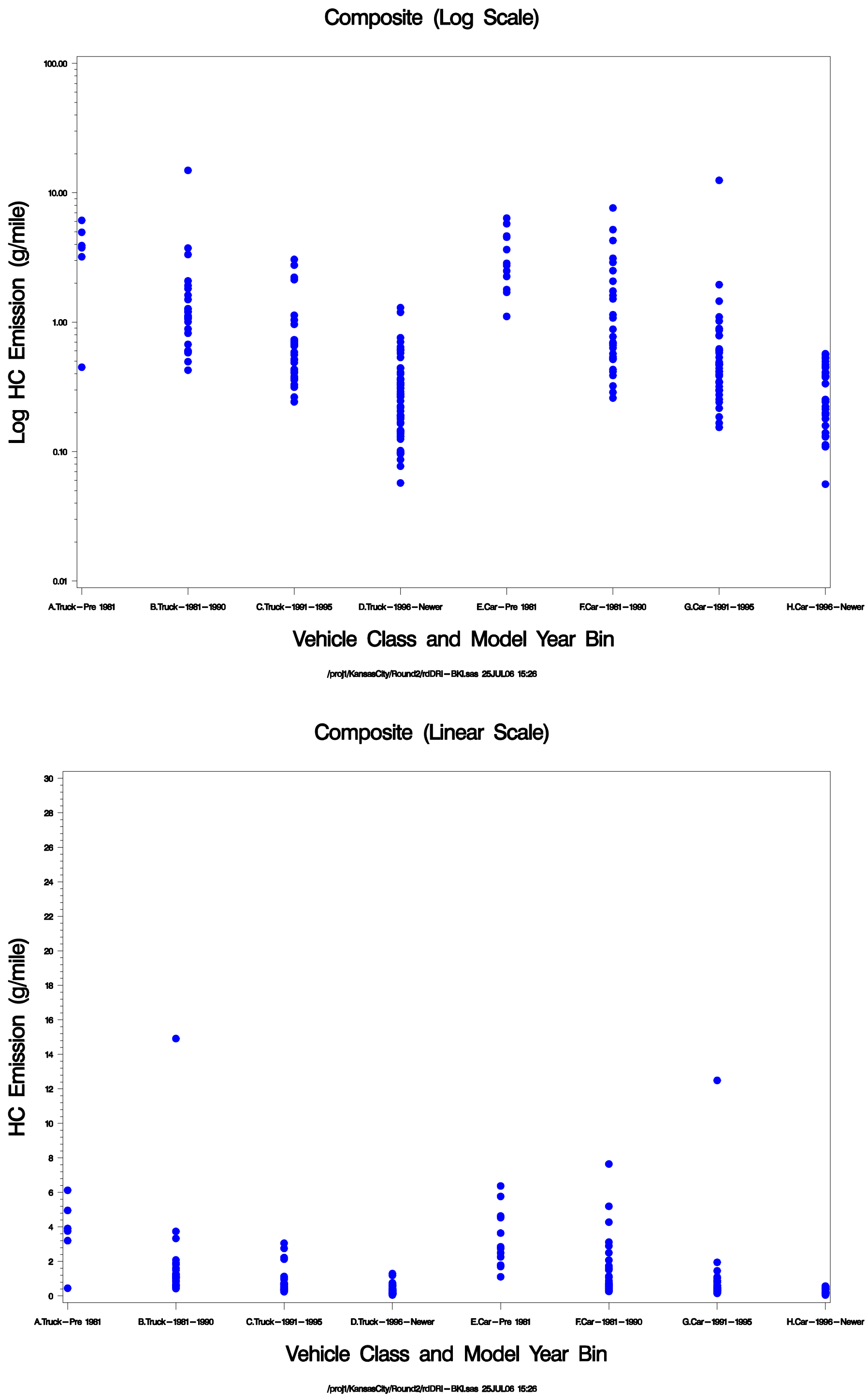
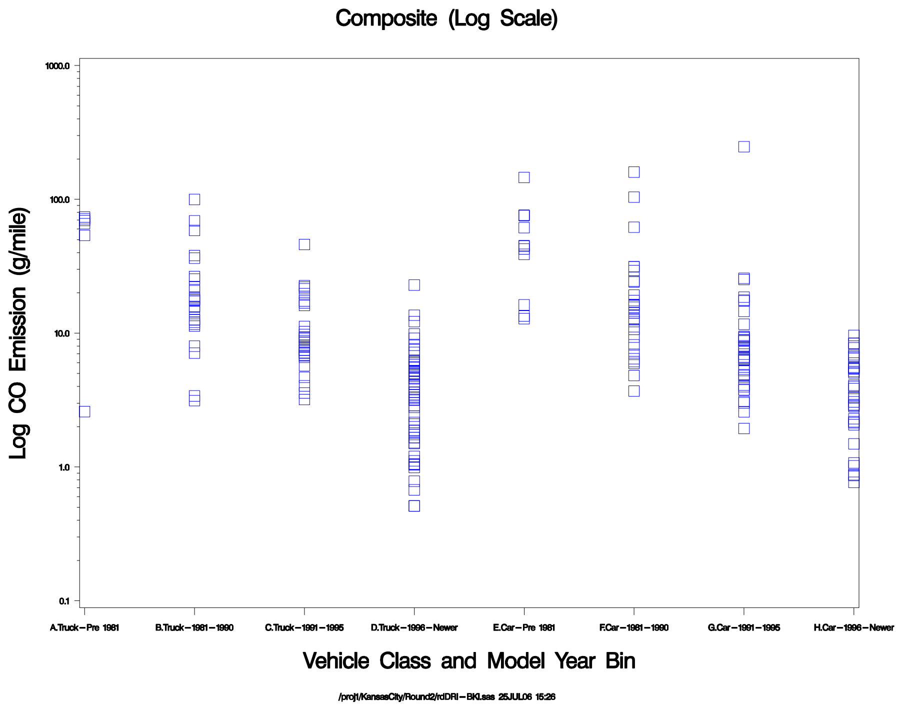


Figure 4-53. Round 2 Log/Linear Plots of HC Emissions by Class-Year Bin



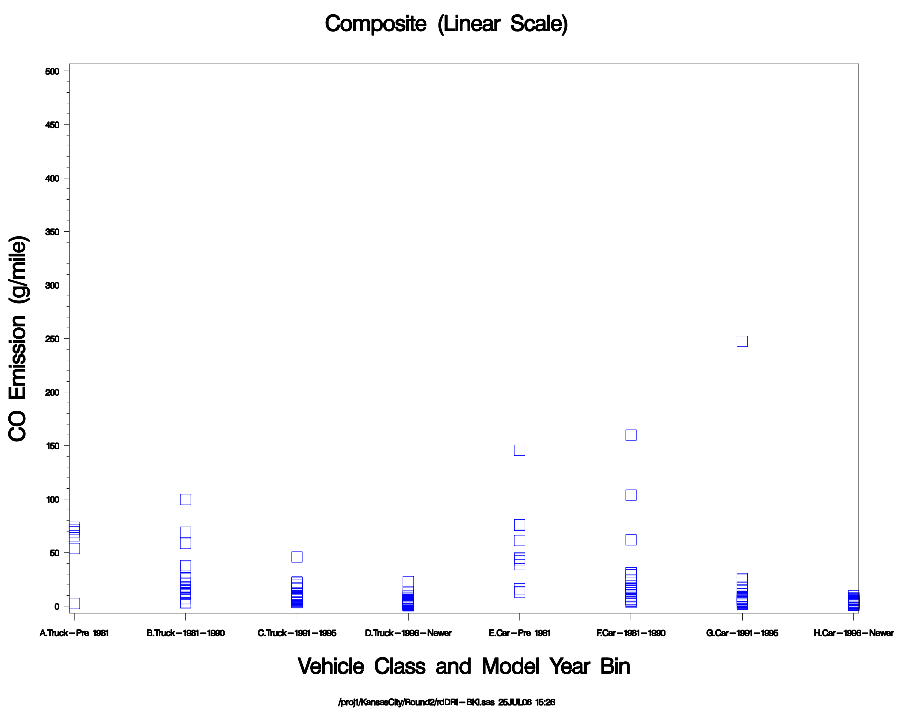


Figure 4-54. Round 2 Log/Linear Plots of CO Emissions by Class-Year Bin

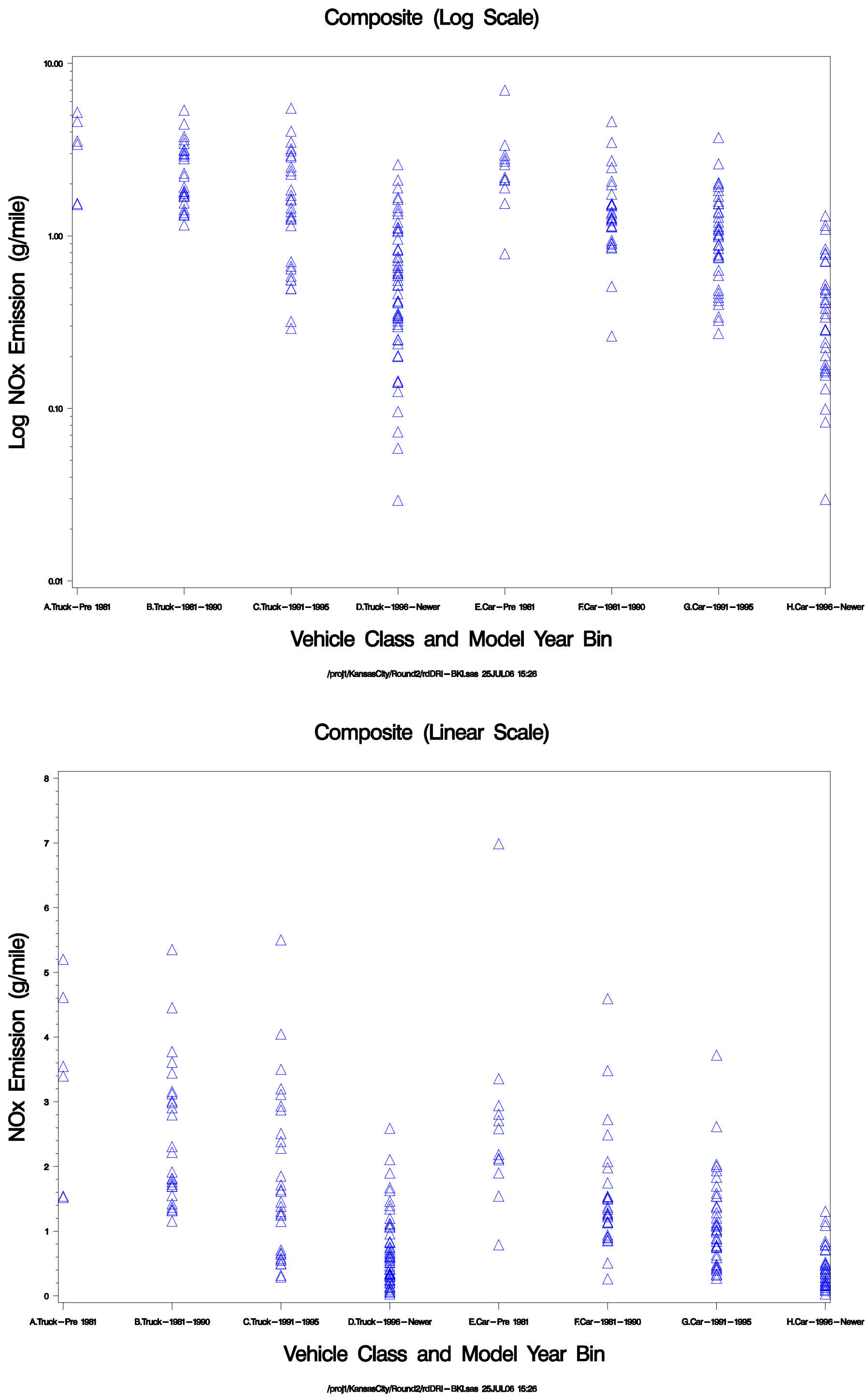
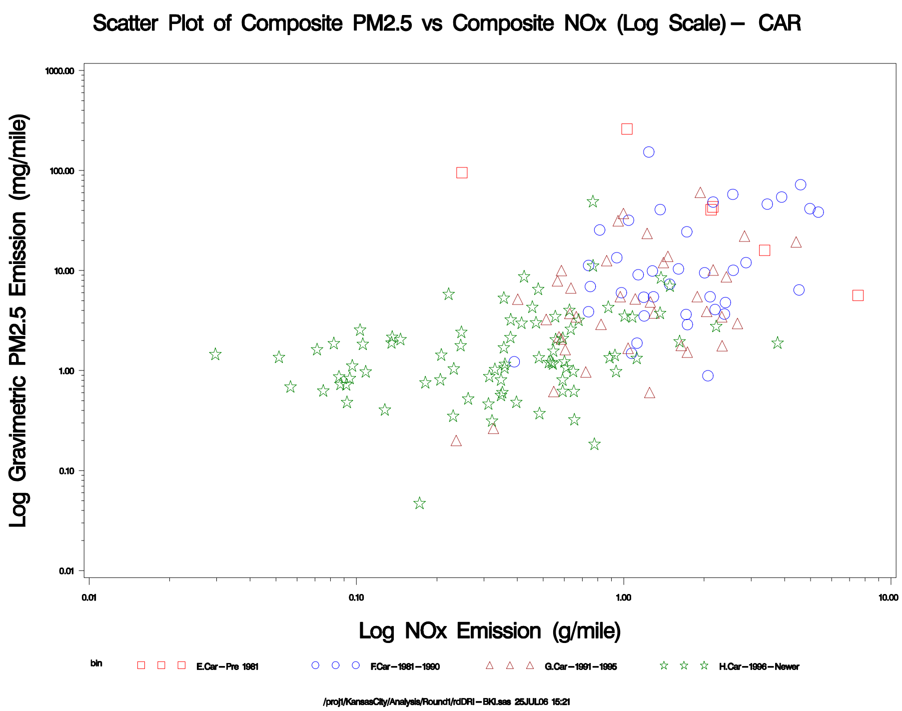


Figure 4-55. Round 2 Log/Linear Plots of NO_X Emissions by Class-Year Bin



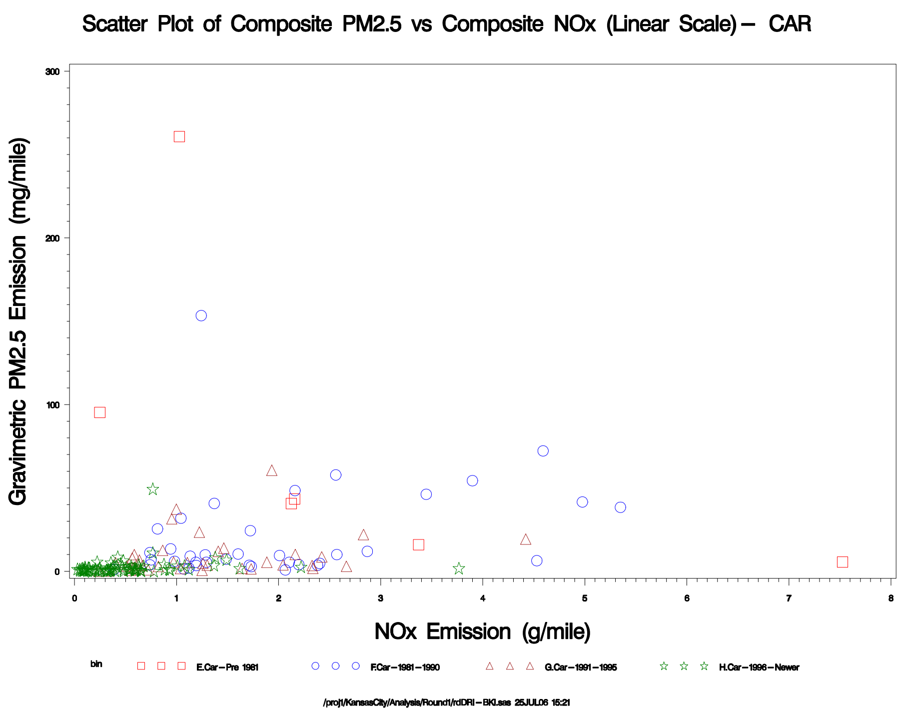
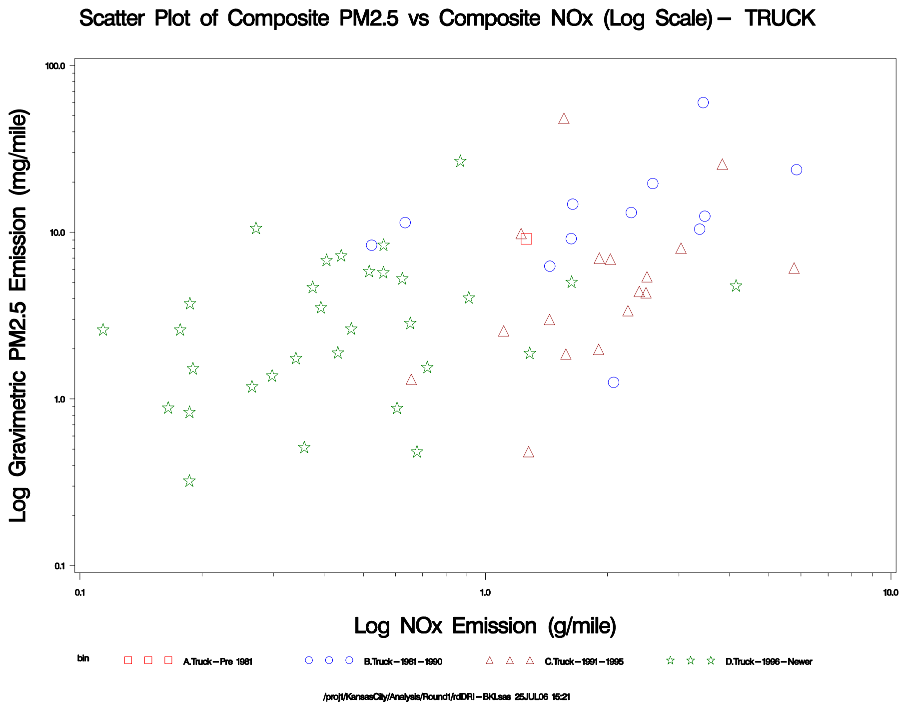


Figure 4-56. Round 1 Log/Linear Plots of $PM_{2.5}$ vs. NO_X by Vehicle Type-Year



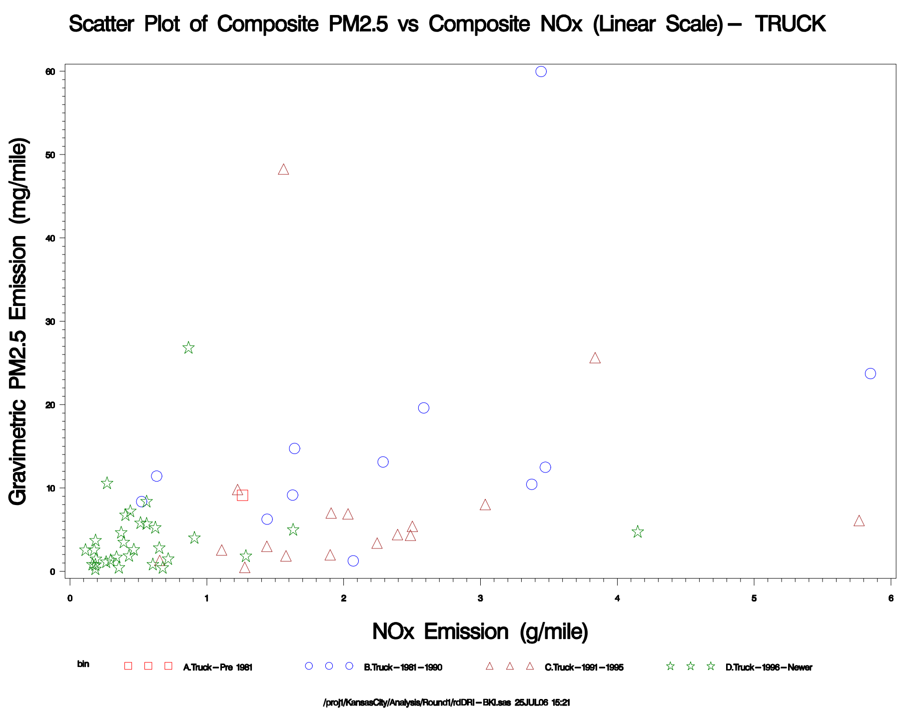
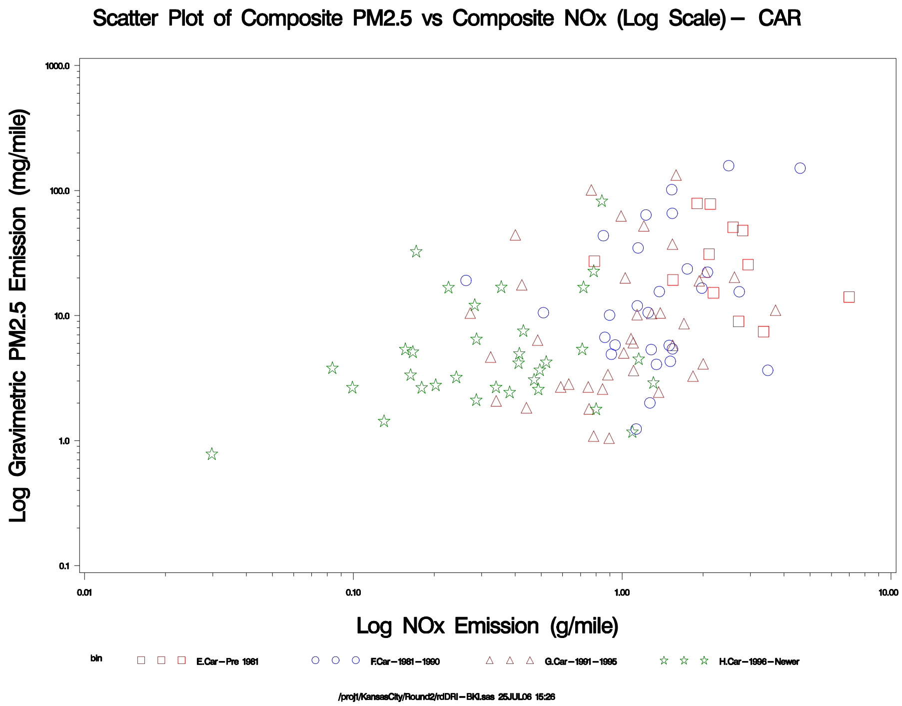


Figure 4-57. Round 1 Log/Linear Plots of $PM_{2.5}$ vs. NO_X by Vehicle Type-Year



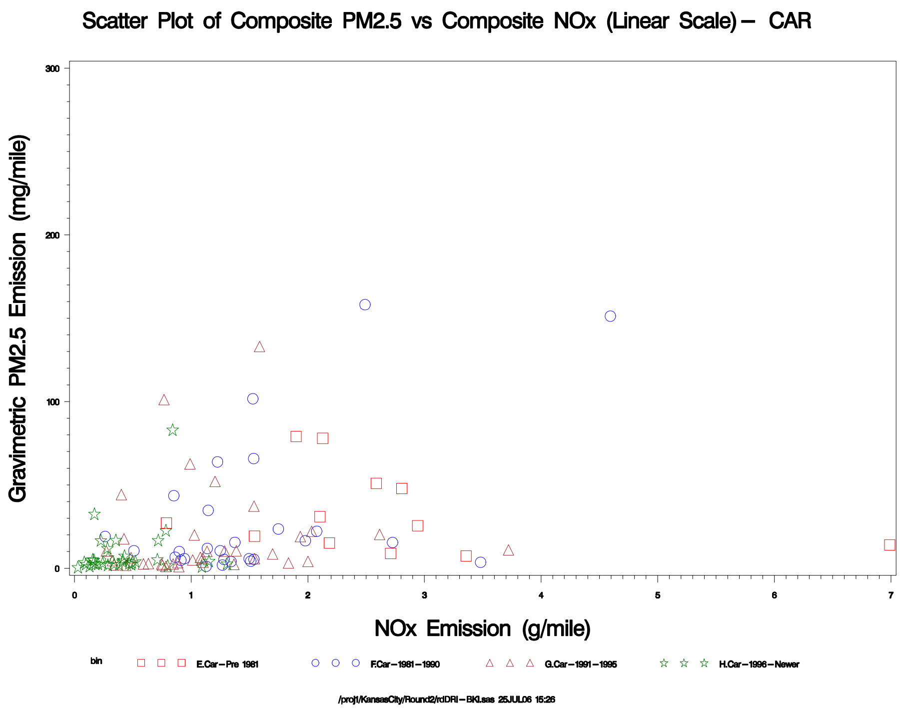
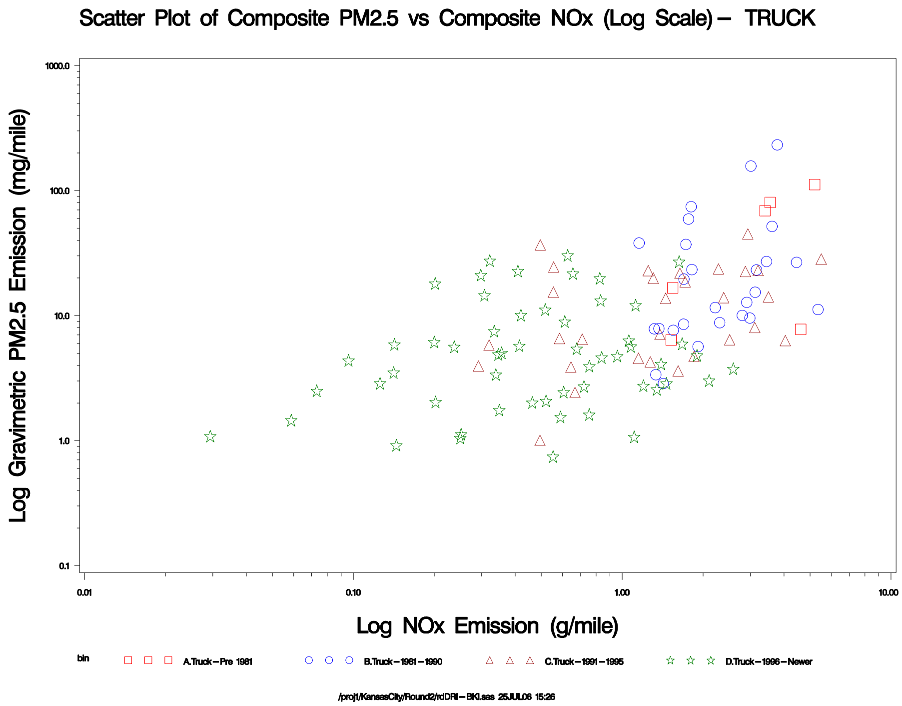


Figure 4-58. Round 2 Log/Linear Plots of $PM_{2.5}$ vs. NO_X by Vehicle Type-Year



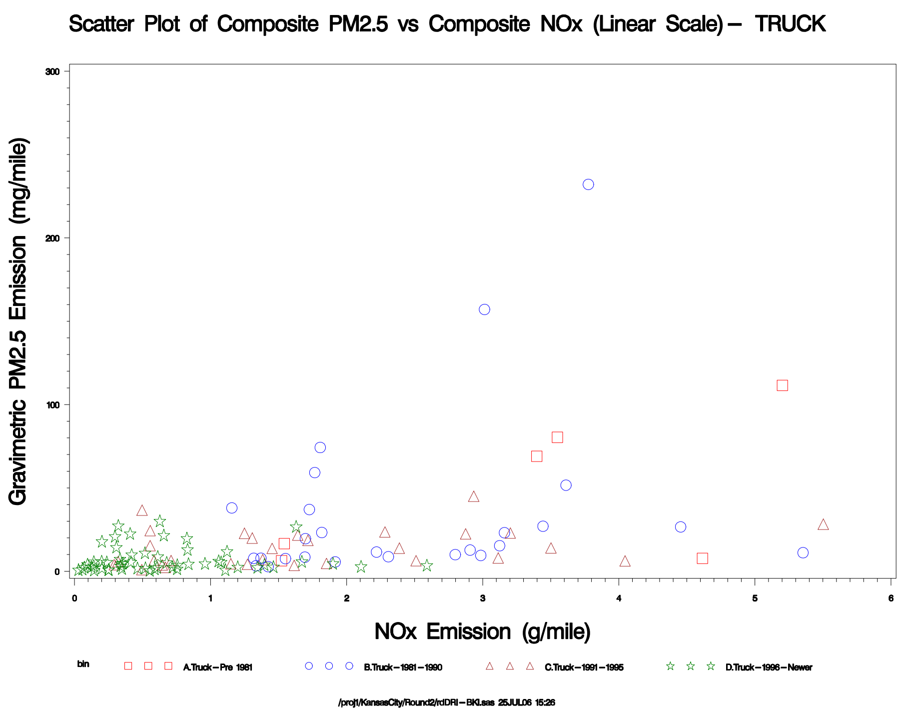
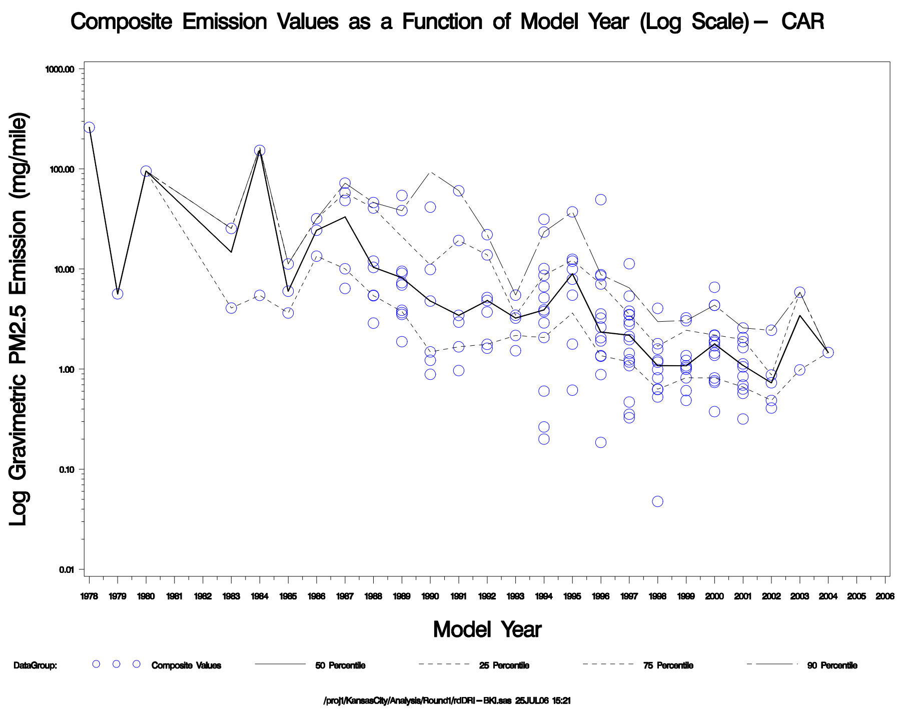


Figure 4-59. Round 2 Log/Linear Plots of $PM_{2.5}$ vs. NO_X by Vehicle Type-Year



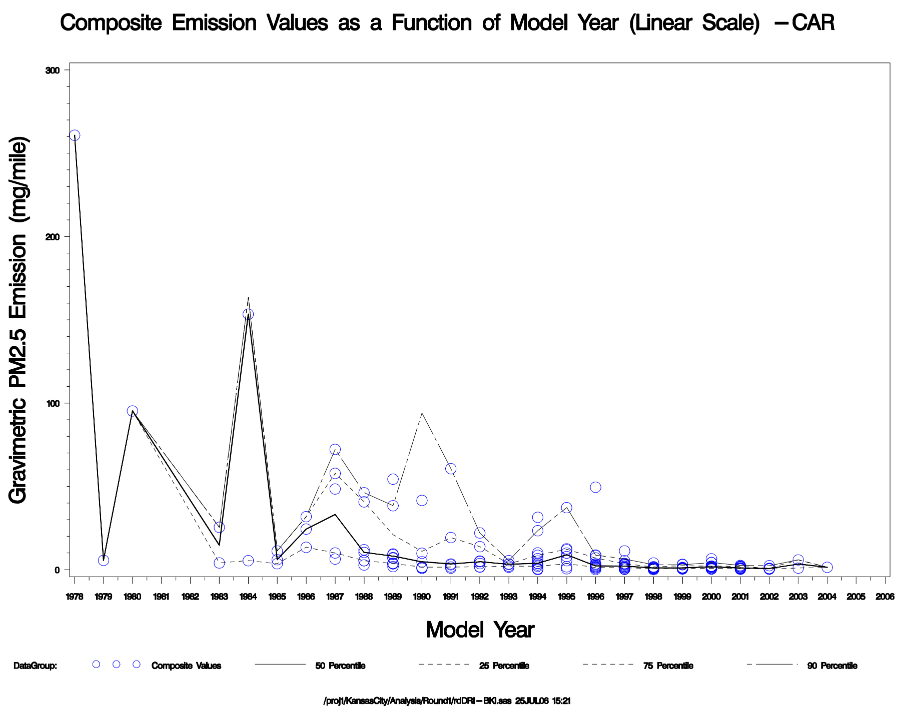
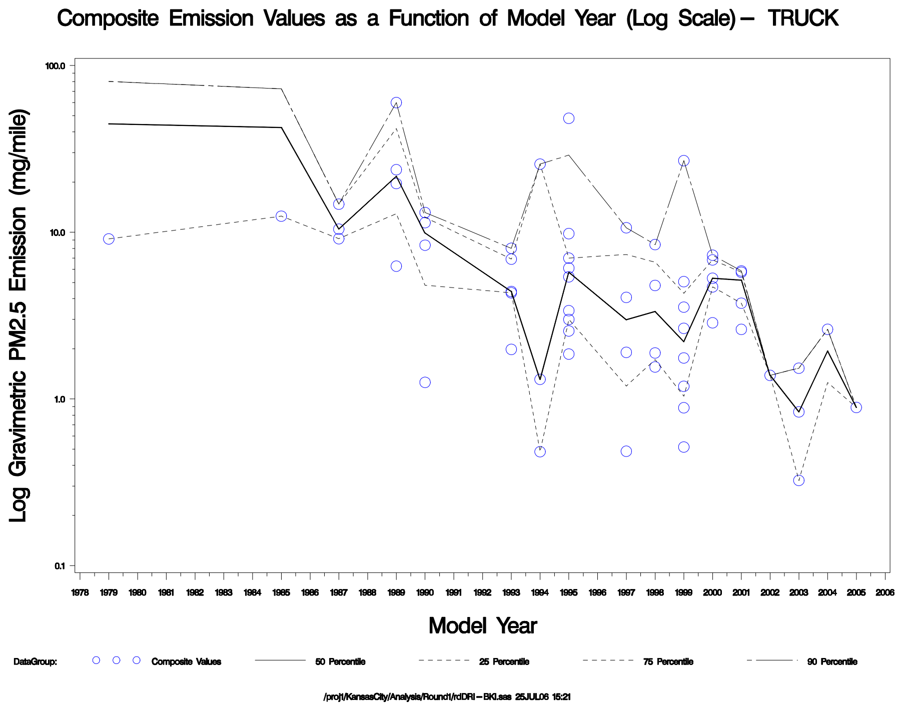


Figure 4-60. Round 1 Log/Linear Plots of $PM_{2.5}$ Emissions by Model Year



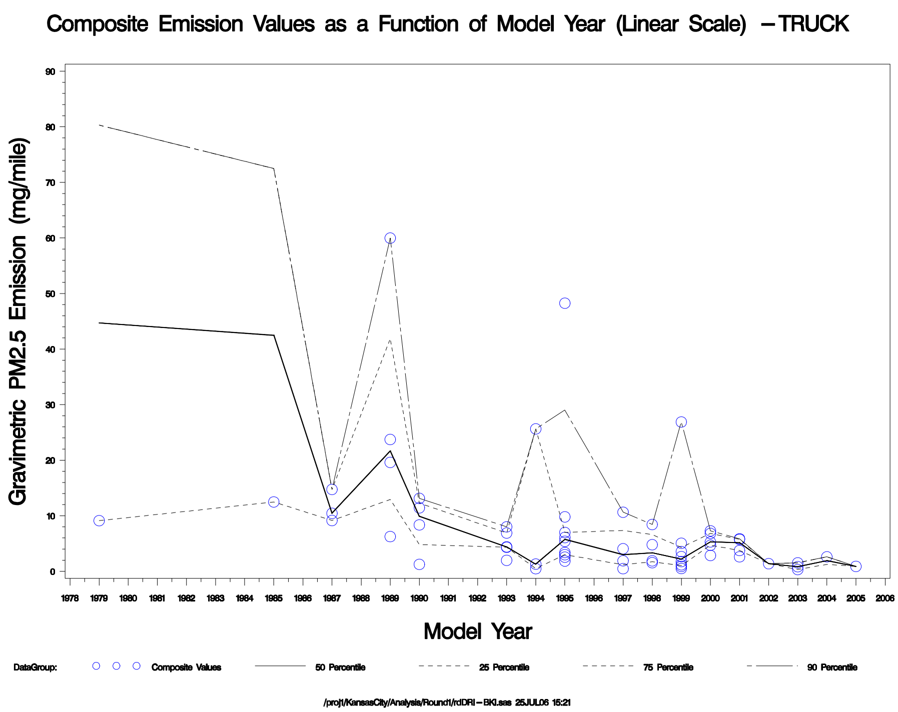
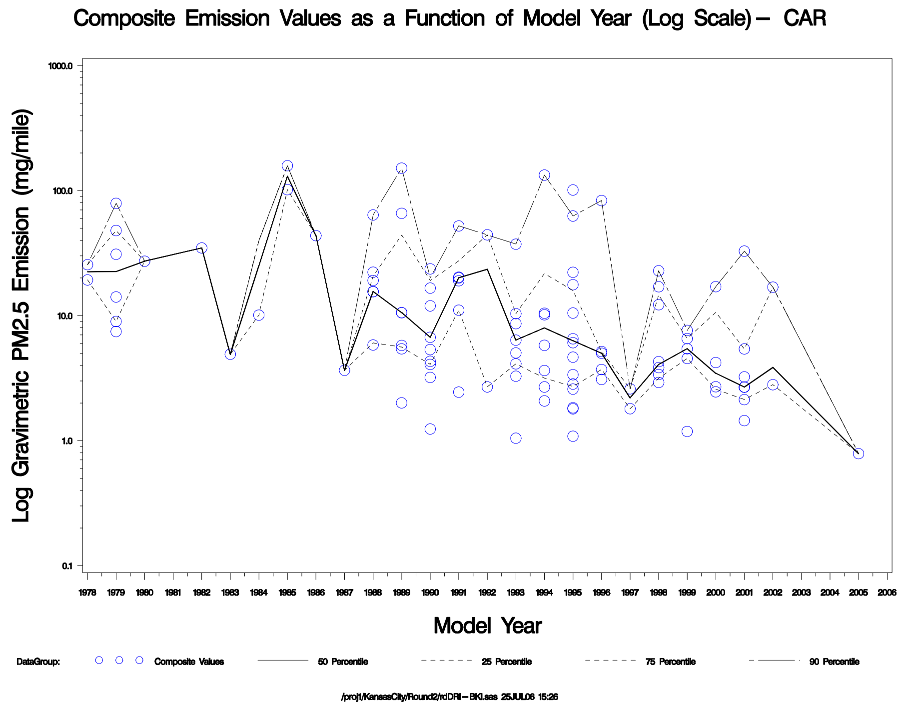


Figure 4-61. Round 1 Log/Linear Plots of $PM_{2.5}$ Emissions by Model Year



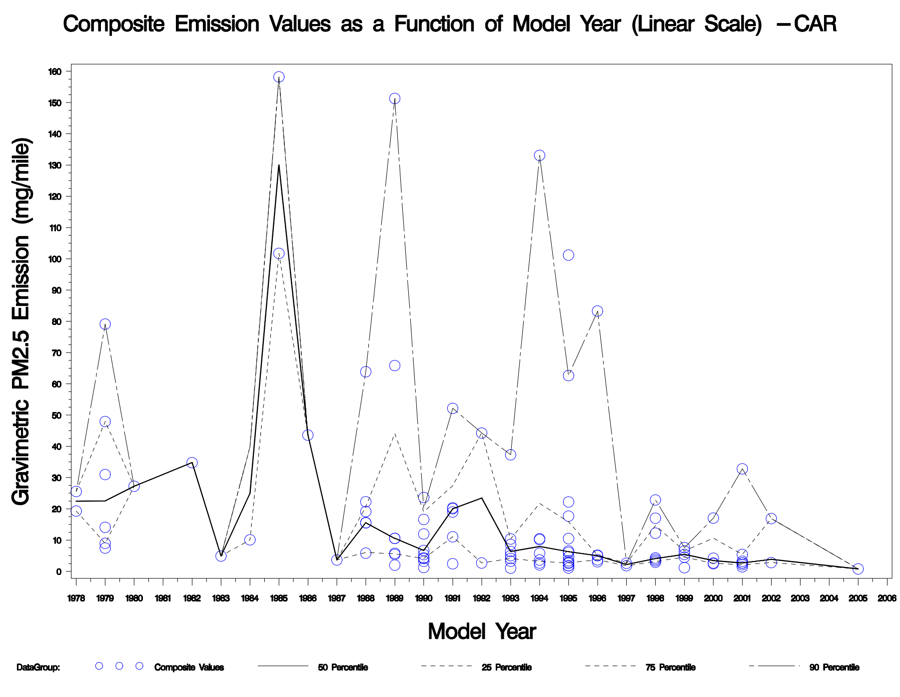


Figure 4-62. Round 2 Log/Linear Plots of $PM_{2.5}$ Emissions by Model Year

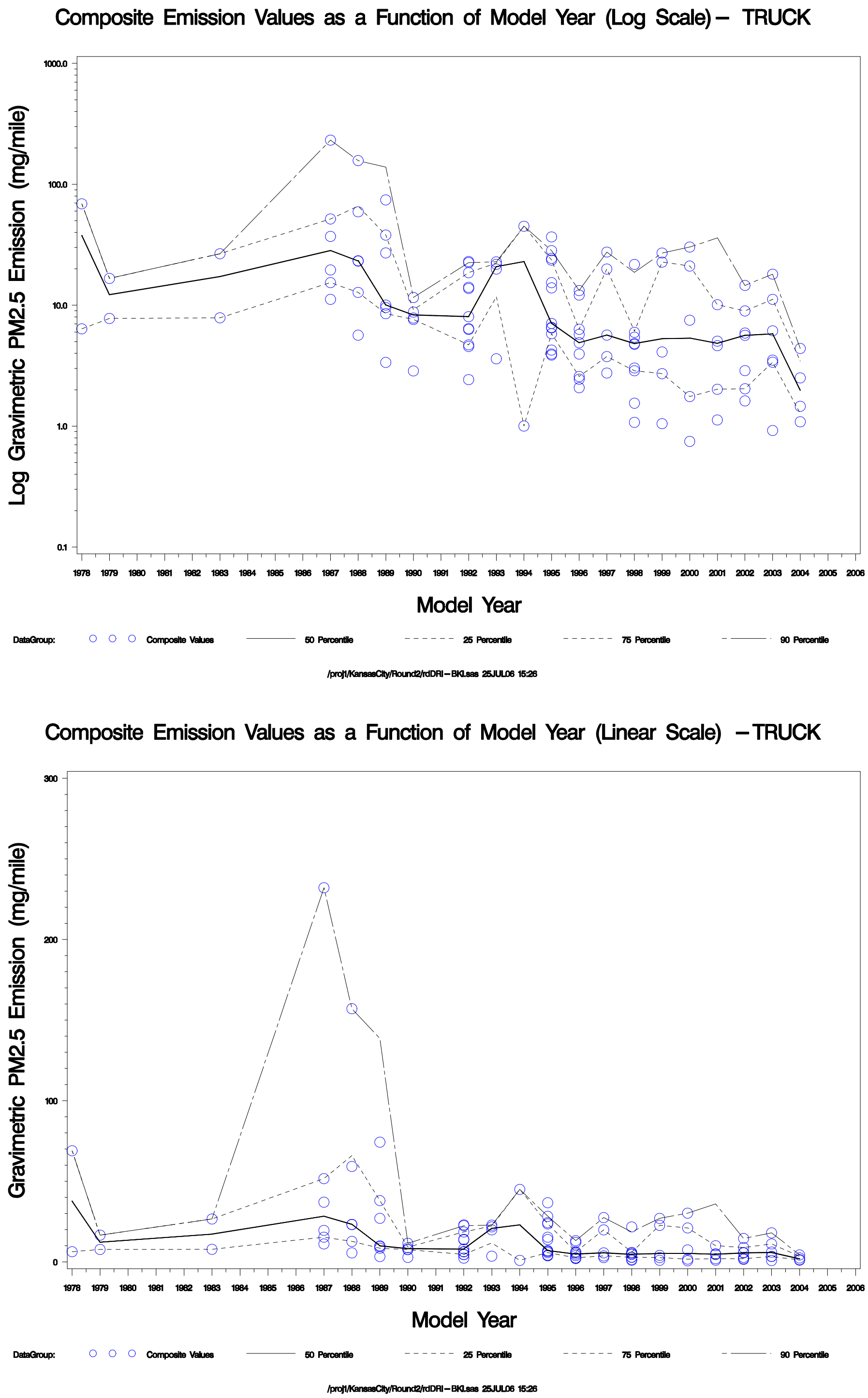
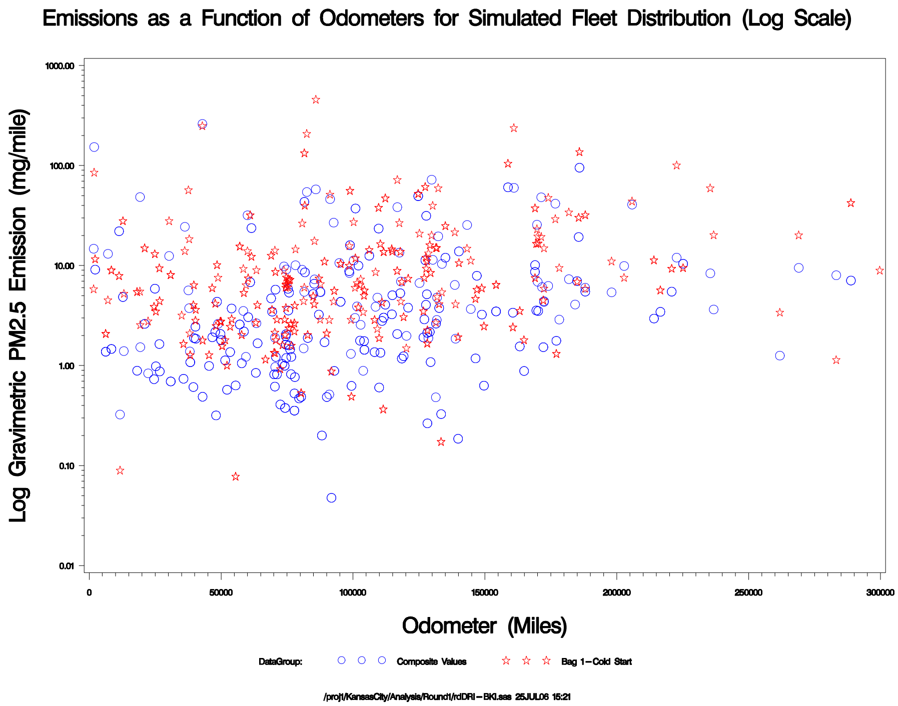


Figure 4-63. Round 2 Log/Linear Plots of $PM_{2.5}$ Emissions by Model Year



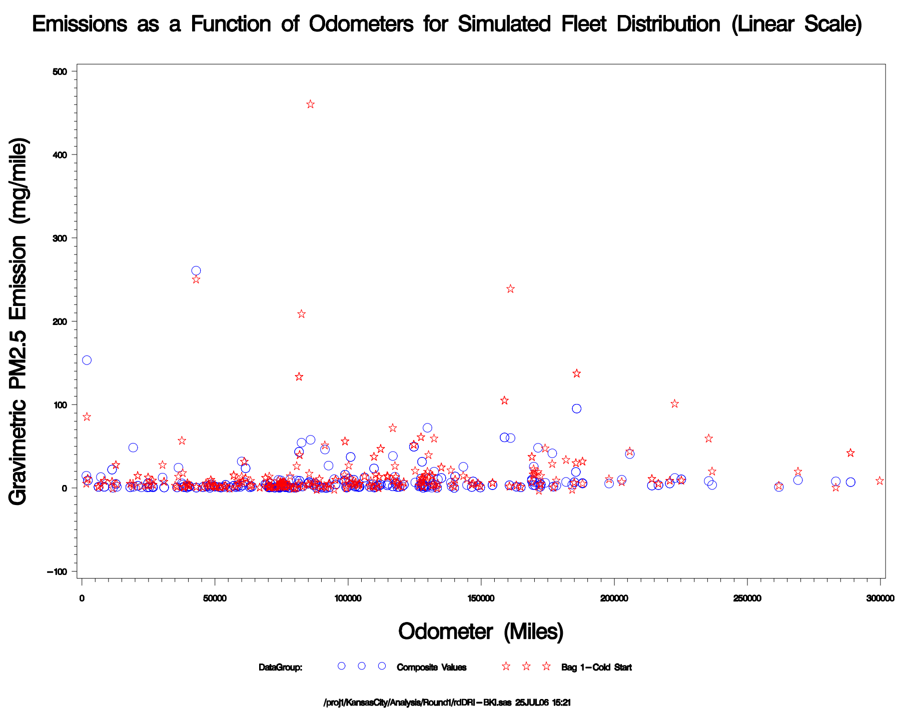
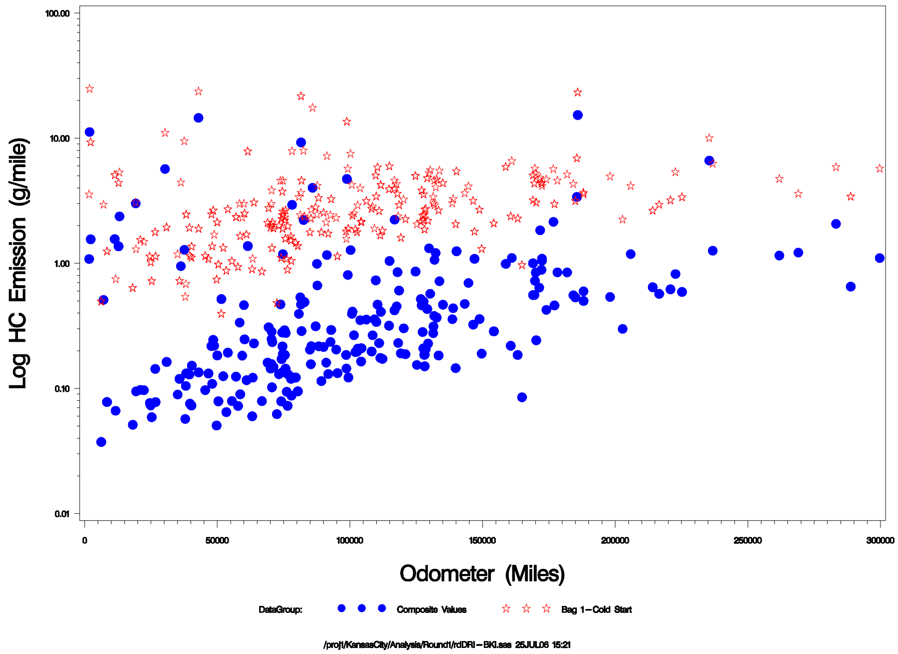


Figure 4-64. Round 1 Log/Linear Plots of $PM_{2.5}$ Emissions by Odometer Mileage

Emissions as a Function of Odometers for Simulated Fleet Distribution (Log Scale)



Emissions as a Function of Odometers for Simulated Fleet Distribution (Linear Scale)

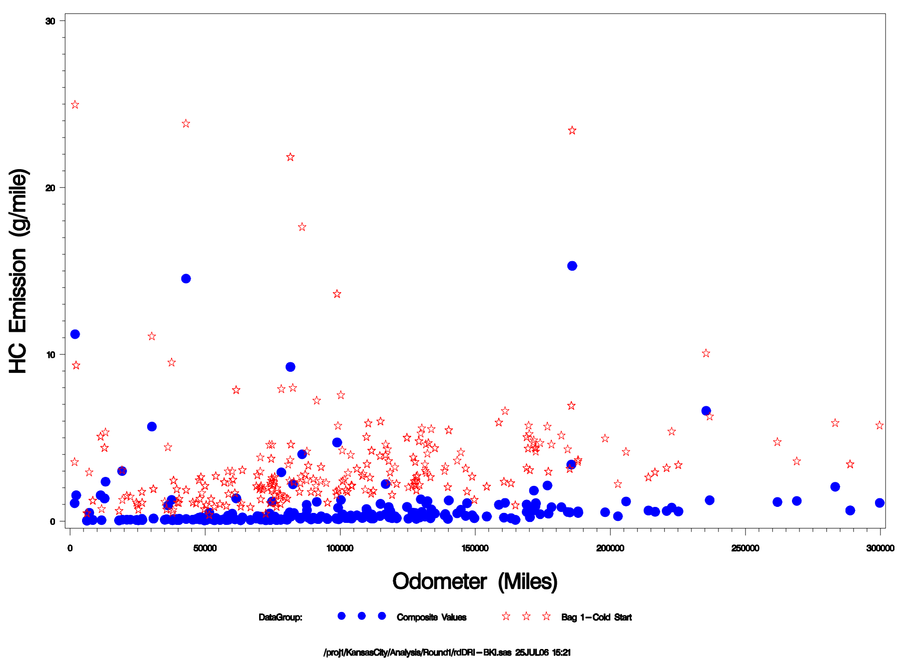
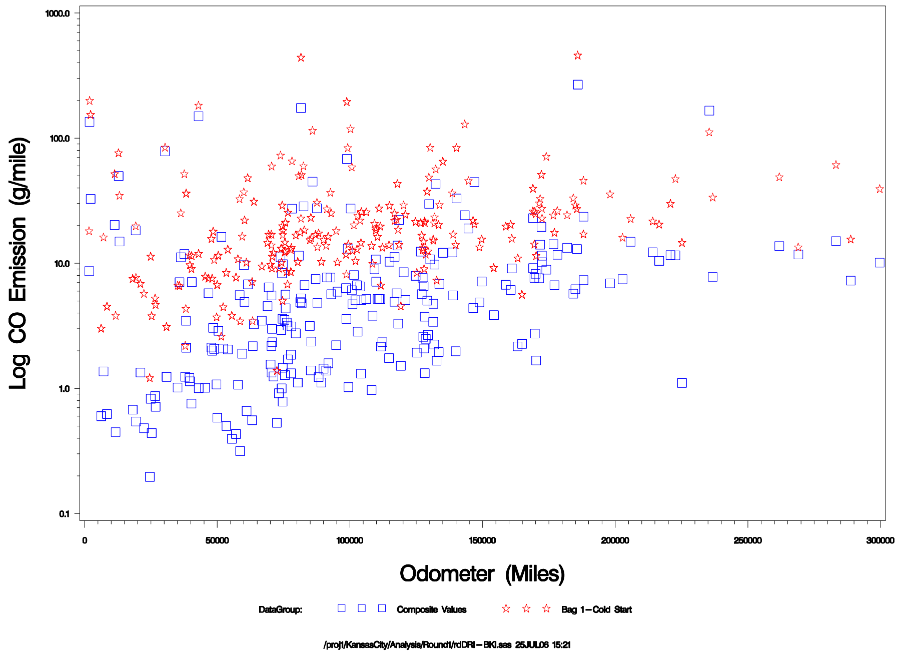


Figure 4-65. Round 1 Log/Linear Plots of HC Emissions by Odometer Mileage

Emissions as a Function of Odometers for Simulated Fleet Distribution (Log Scale)



Emissions as a Function of Odometers for Simulated Fleet Distribution (Linear Scale)

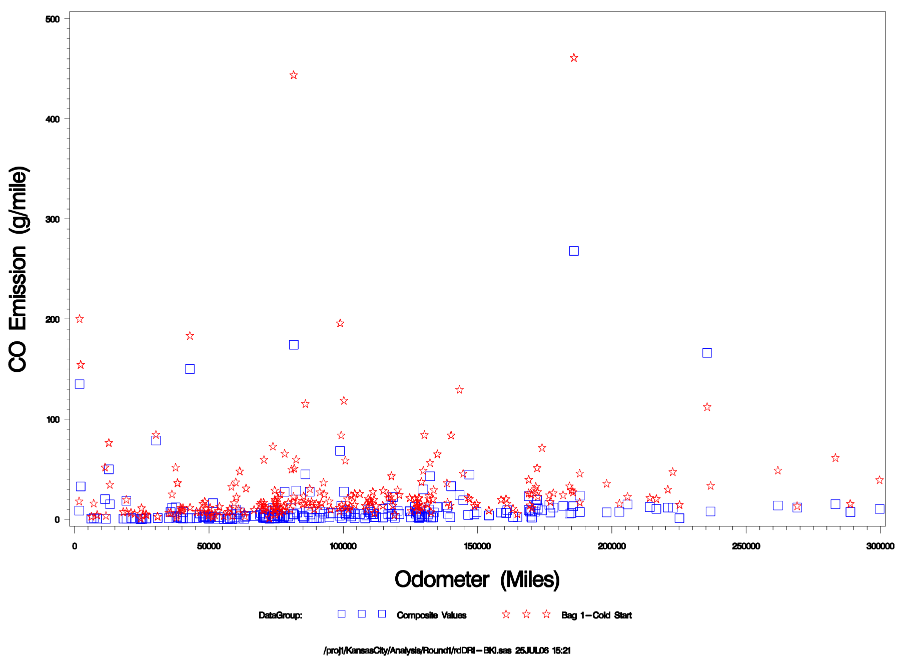
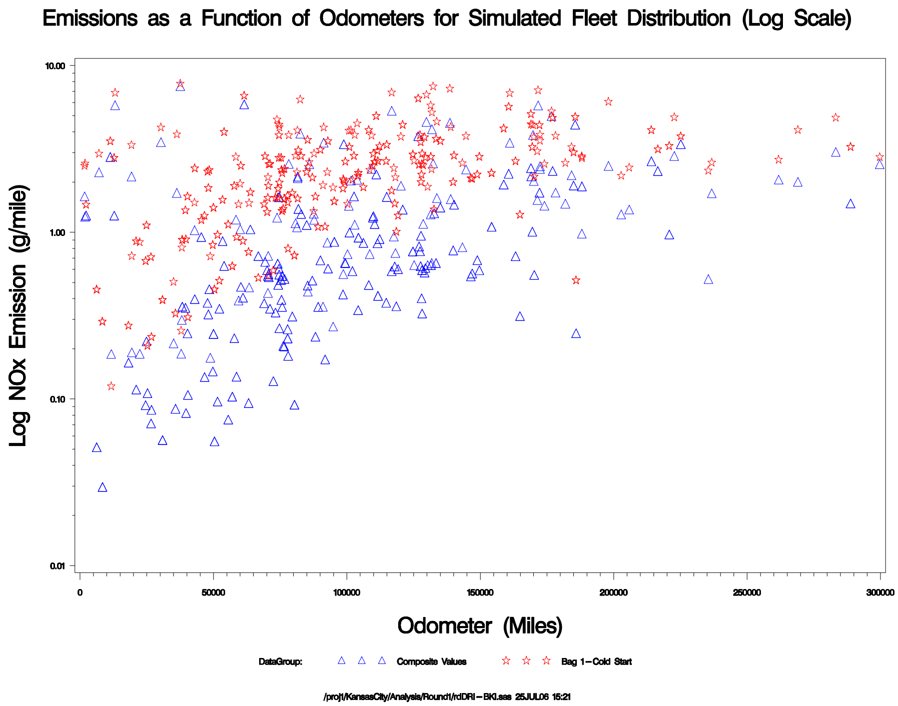


Figure 4-66. Round 1 Log/Linear Plots of CO Emissions by Odometer Mileage



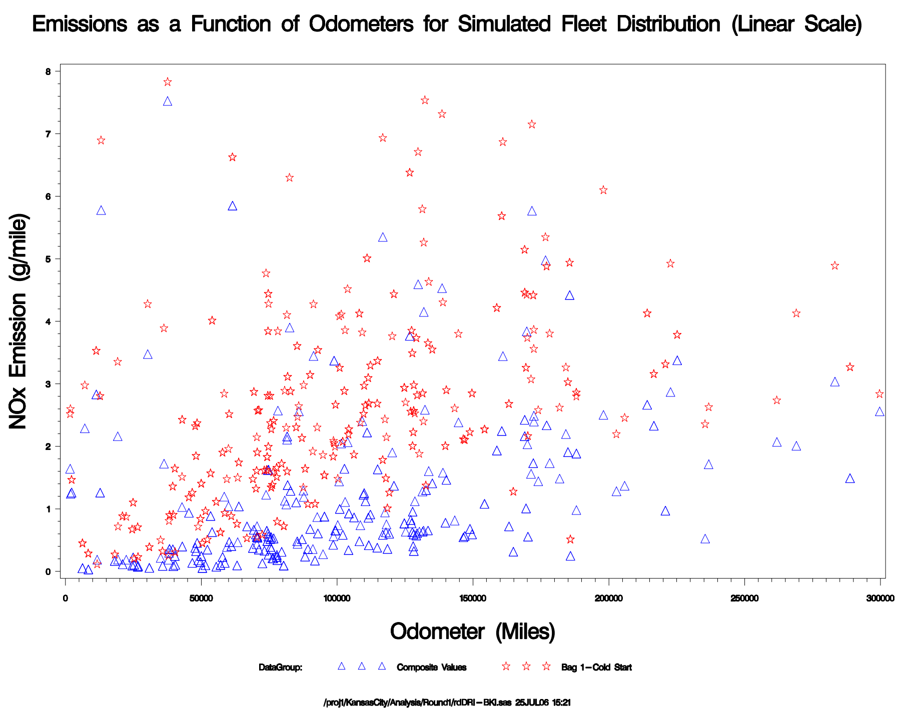


Figure 4-67. Round 1 Log/Linear Plots of NO_X Emissions by Odometer Mileage

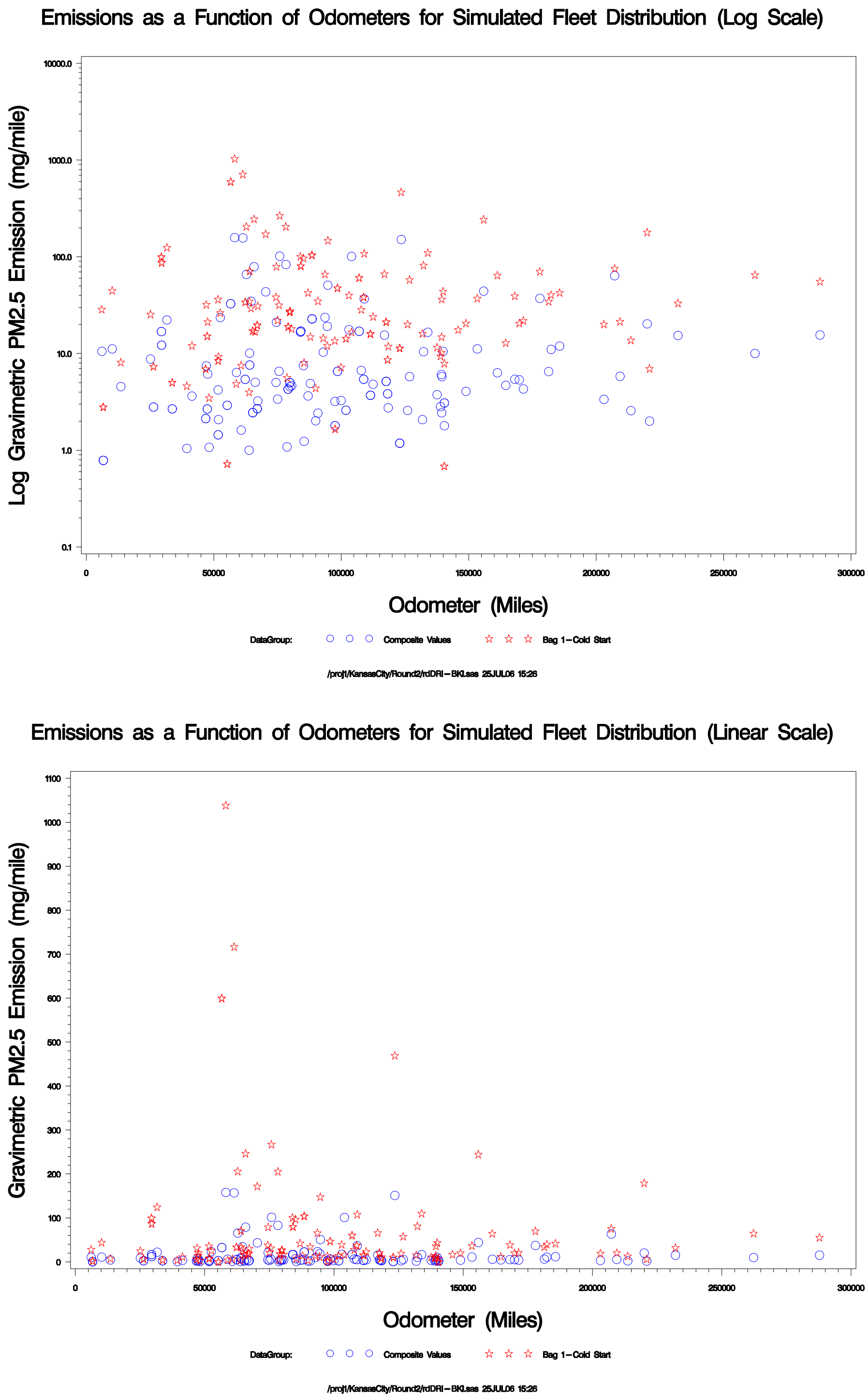
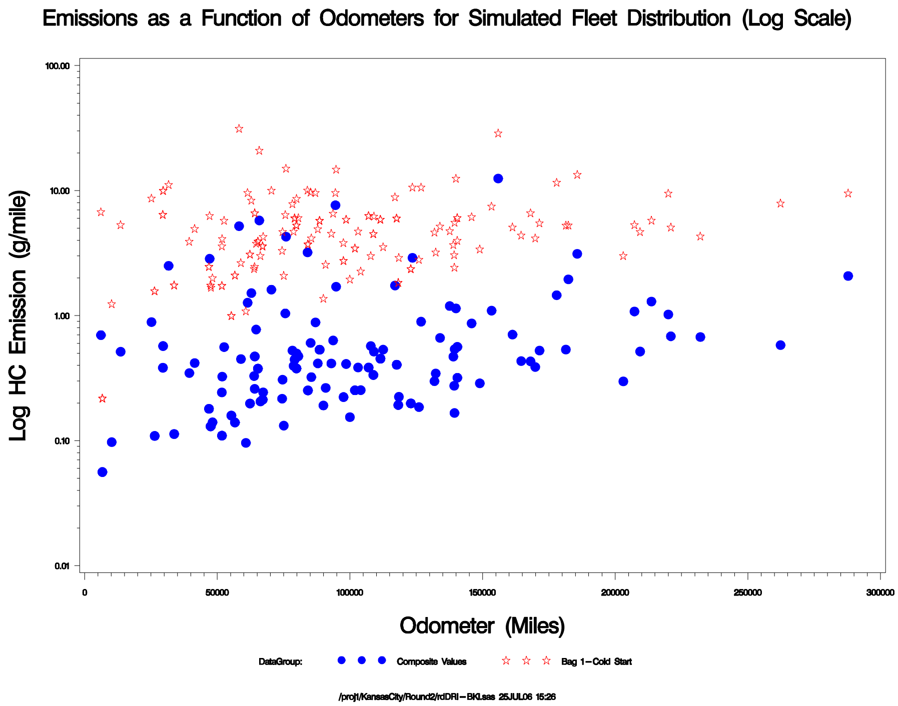


Figure 4-68. Round 2 Log/Linear Plots of $PM_{2.5}$ Emissions by Odometer Mileage



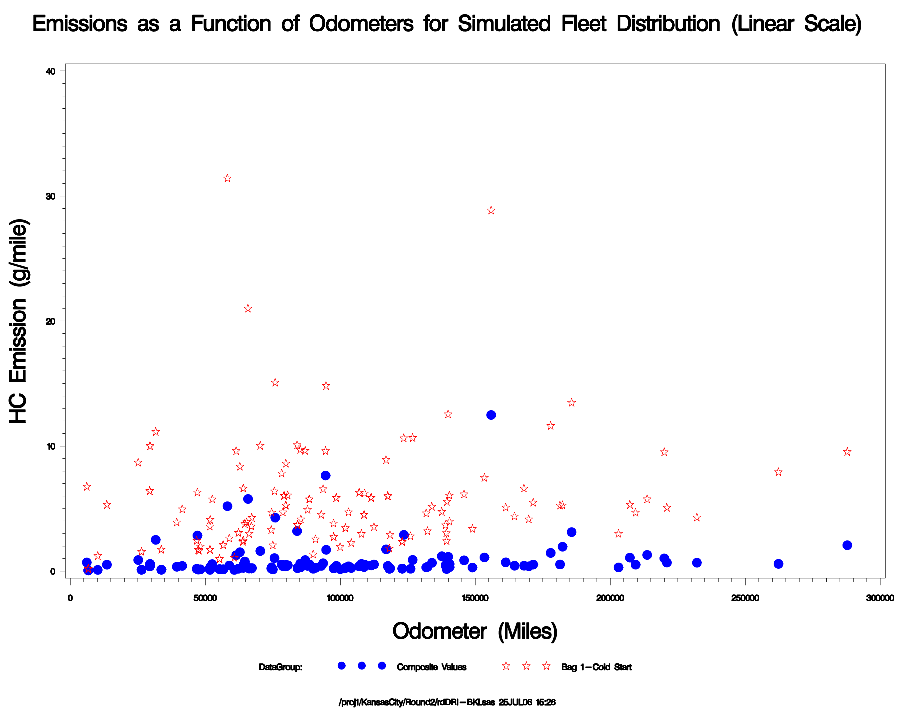
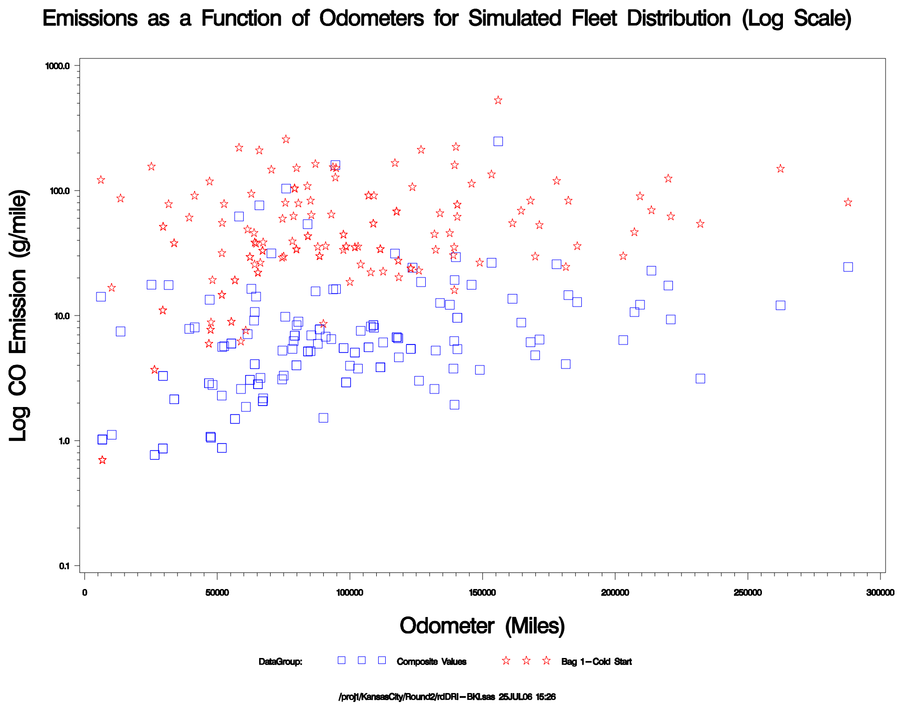


Figure 4-69. Round 2 Log/Linear Plots of HC Emissions by Odometer Mileage



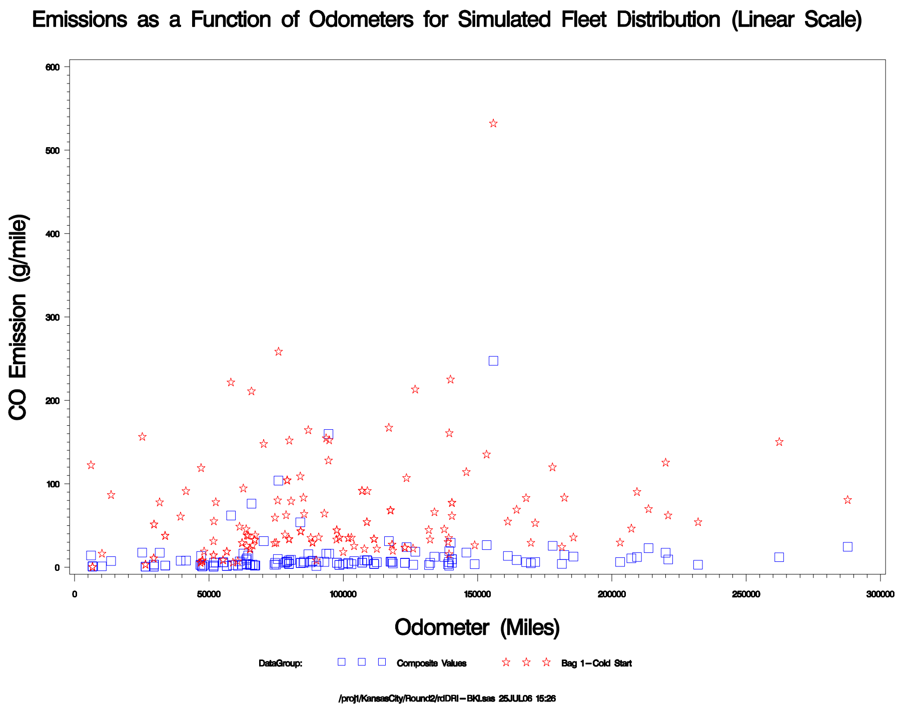
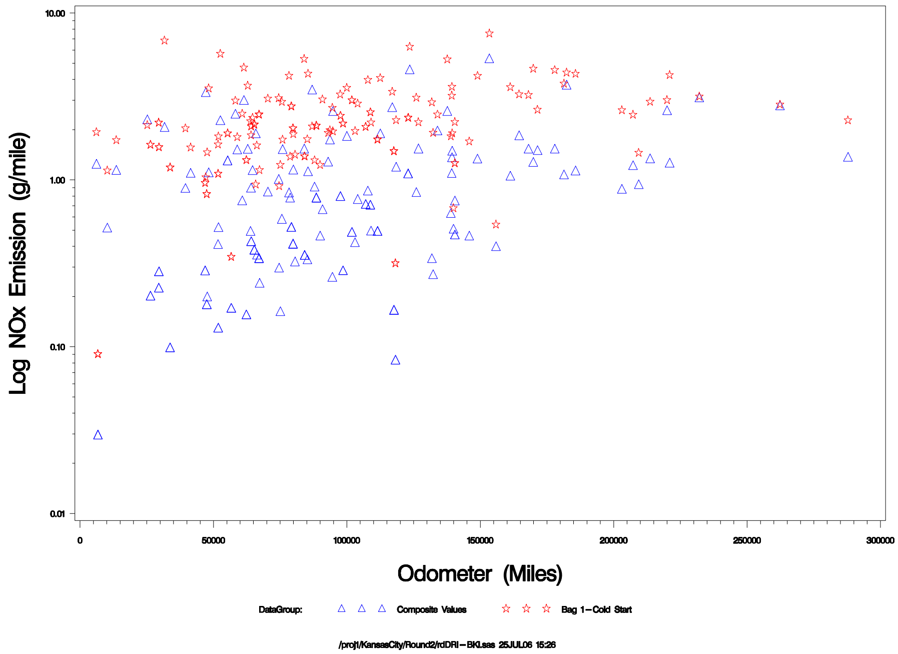


Figure 4-70. Round 2 Log/Linear Plots of CO Emissions by Odometer Mileage

Emissions as a Function of Odometers for Simulated Fleet Distribution (Log Scale)



Emissions as a Function of Odometers for Simulated Fleet Distribution (Linear Scale)

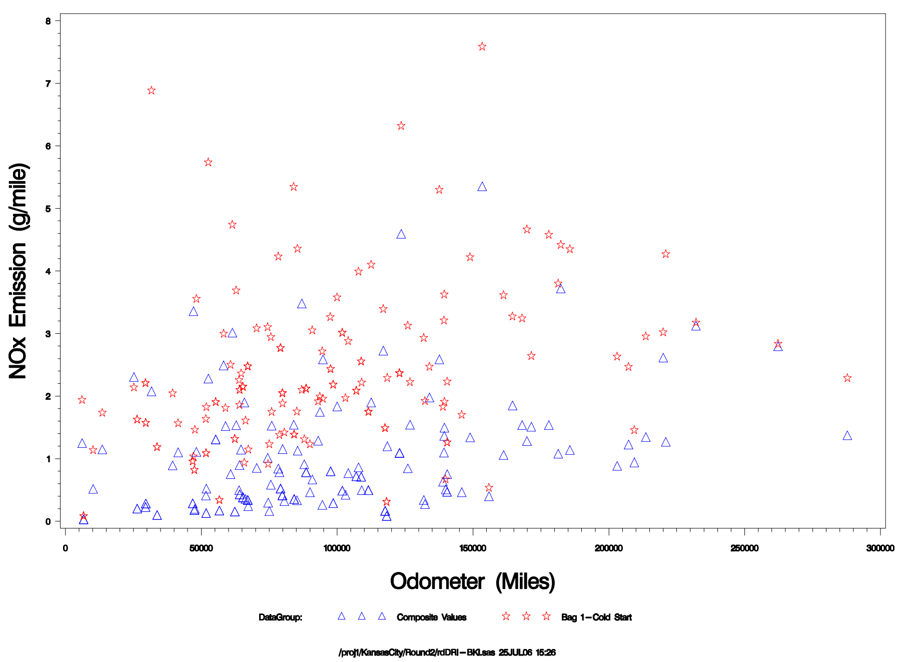
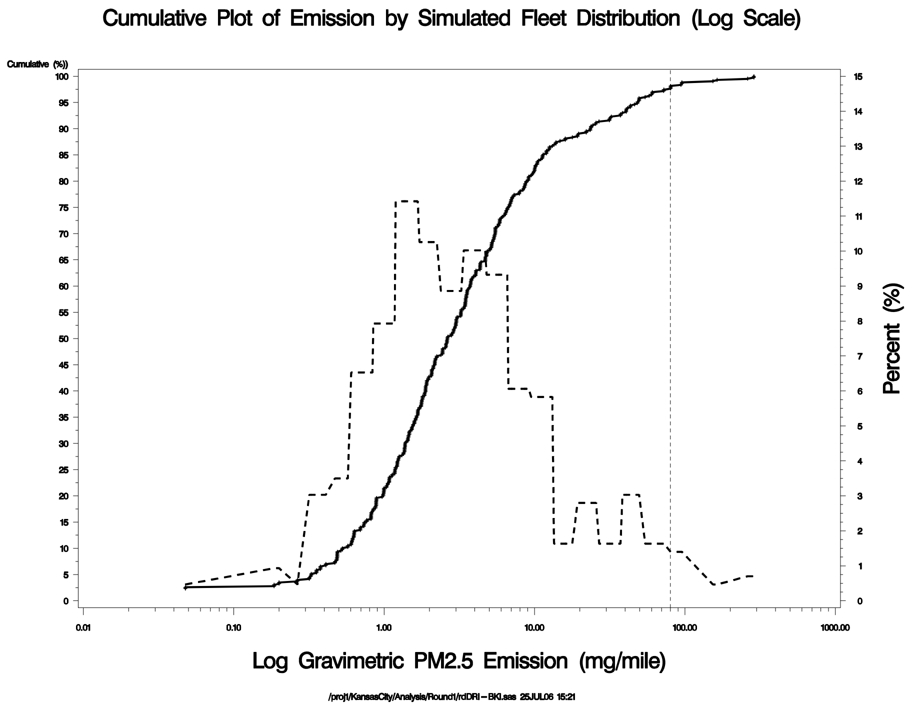


Figure 4-71. Round 2 Log/Linear Plots of NO_X Emissions by Odometer Mileage



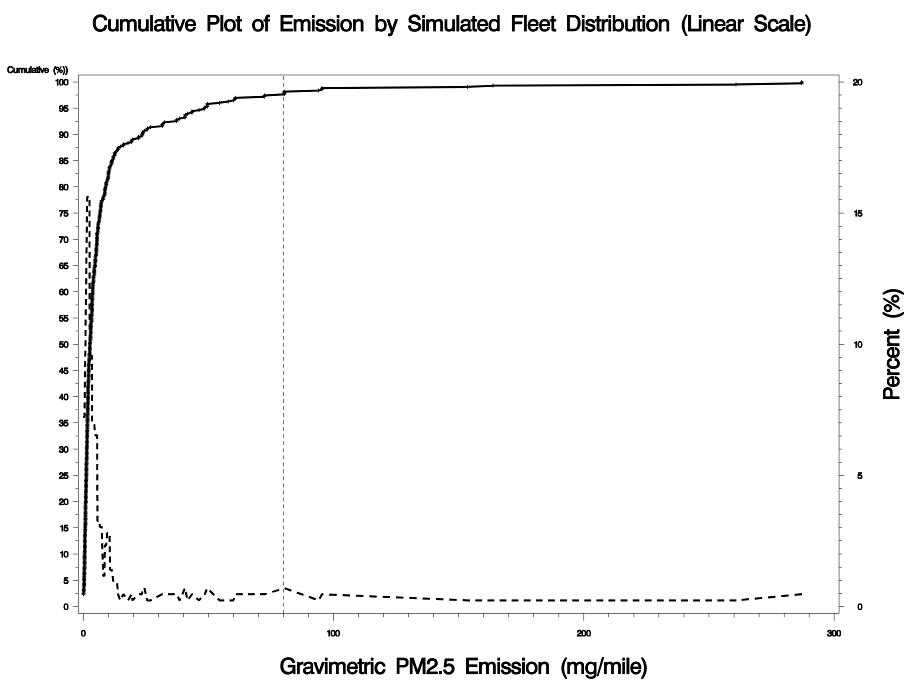
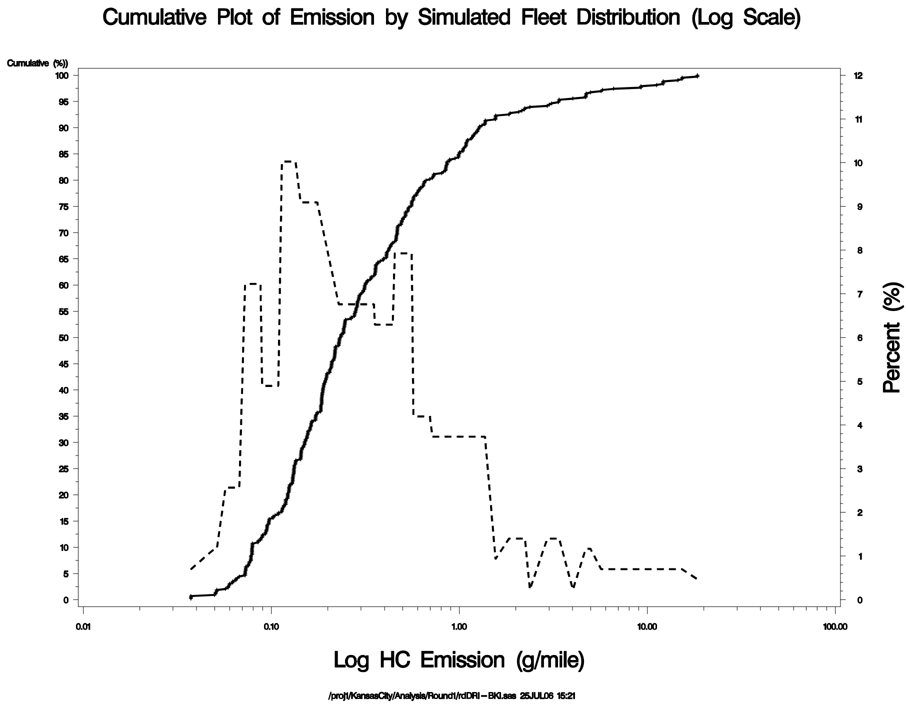


Figure 4-72. Round 1 Plots of % Projected-Fleet Distribution of Composite $PM_{2.5}$



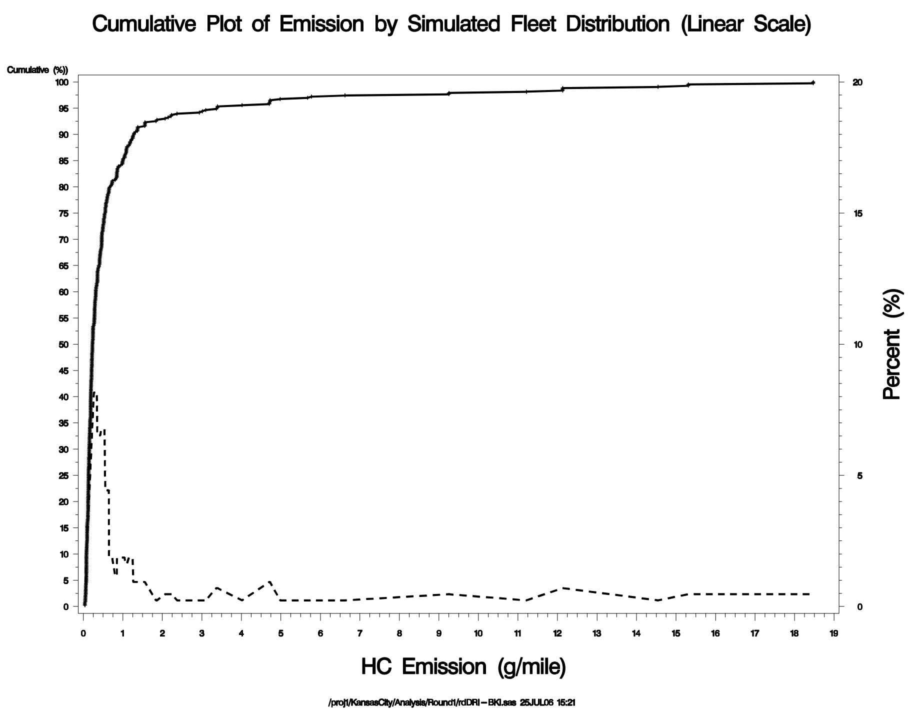
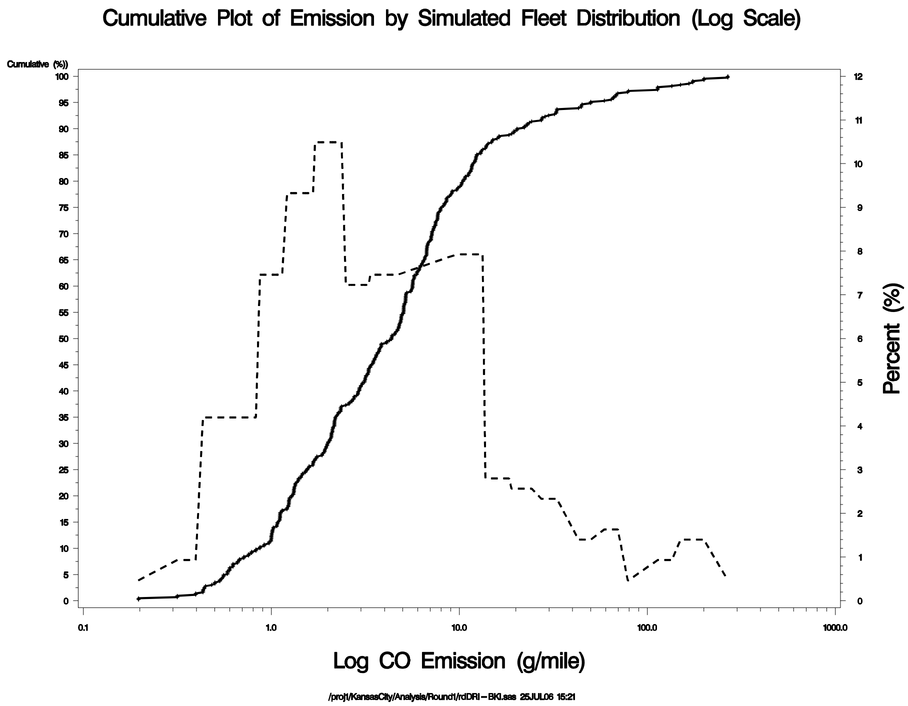


Figure 4-73. Round 1 Plots of % Projected-Fleet Distribution of Composite HC



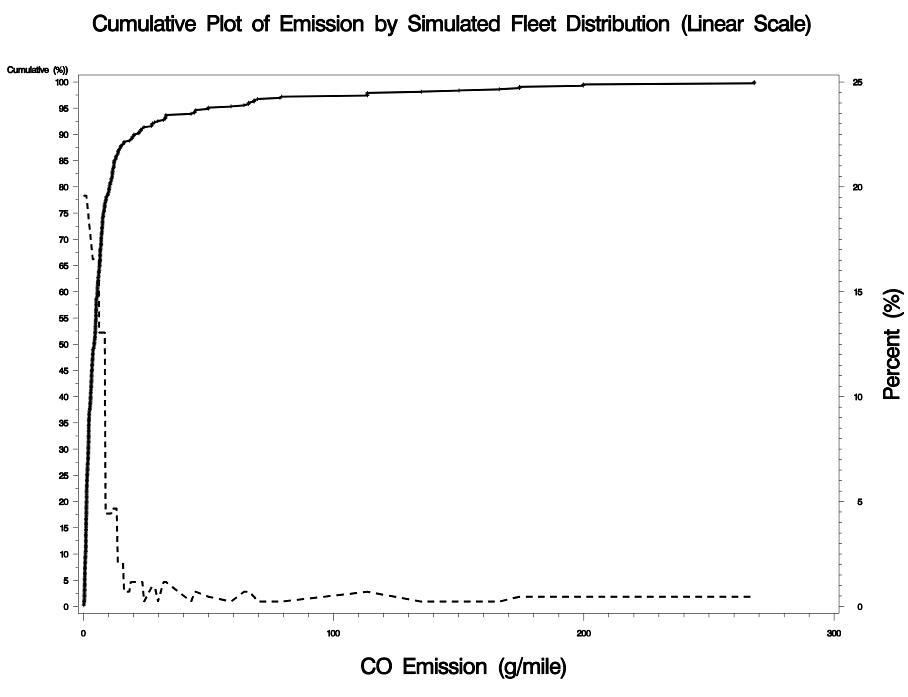
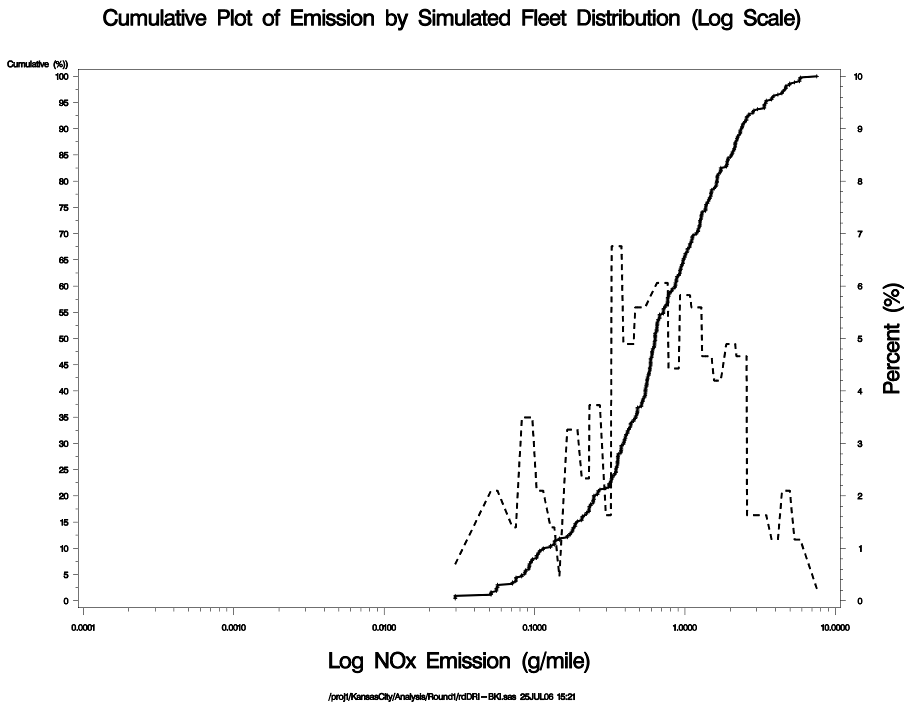


Figure 4-74. Round 1 Plots of % Projected-Fleet Distribution of Composite CO



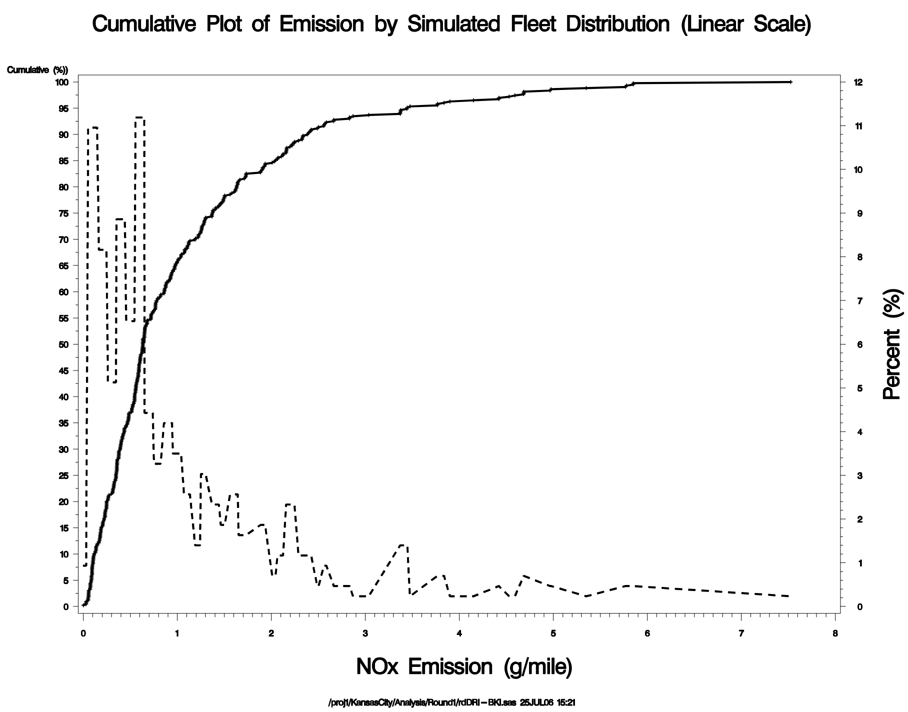
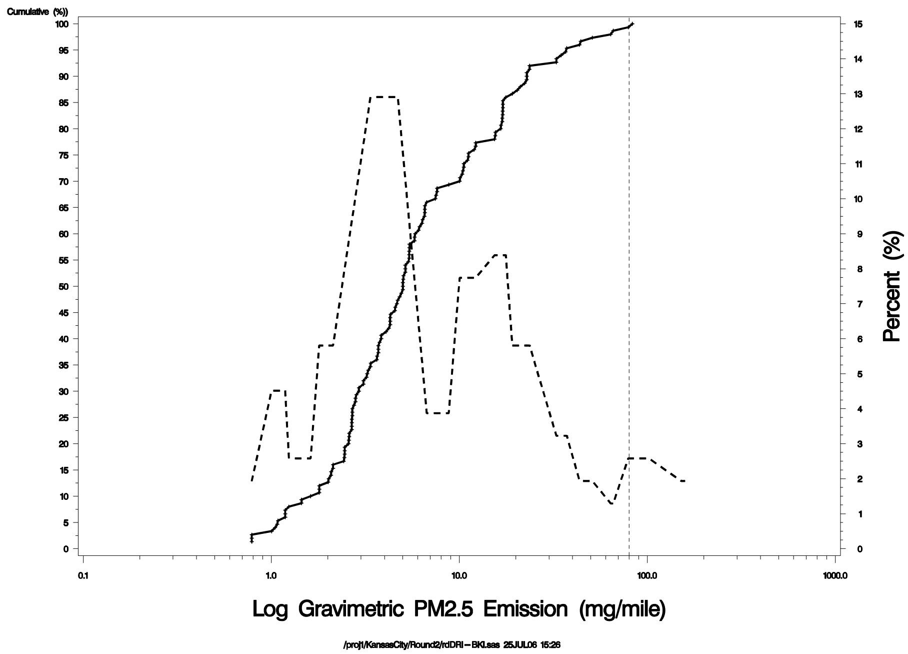


Figure 4-75. Round 1 Plots of % Projected-Fleet Distribution of Composite NO_x

Cumulative Plot of Emission by Simulated Fleet Distribution (Log Scale)



Cumulative Plot of Emission by Simulated Fleet Distribution (Linear Scale)

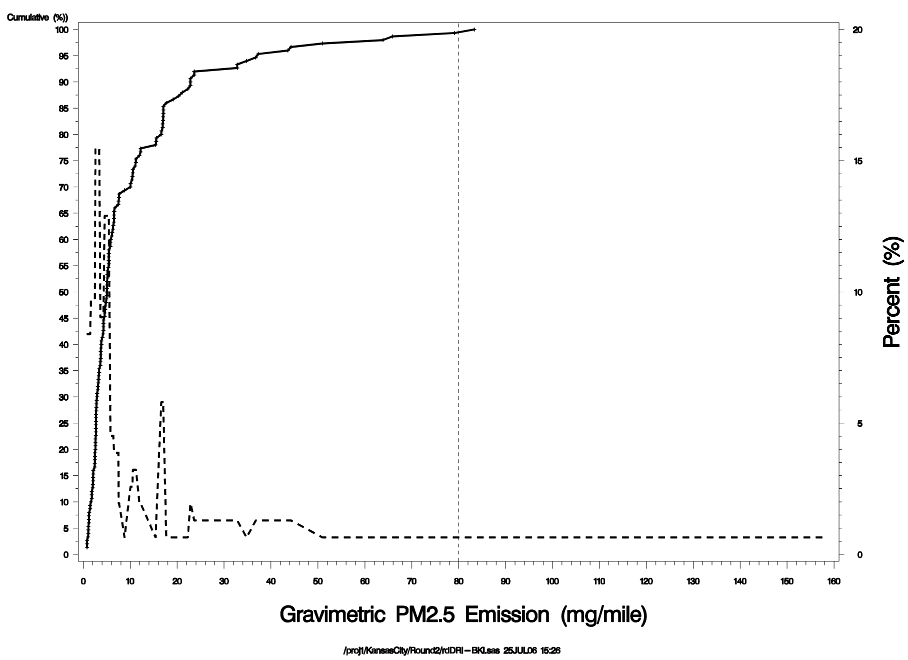
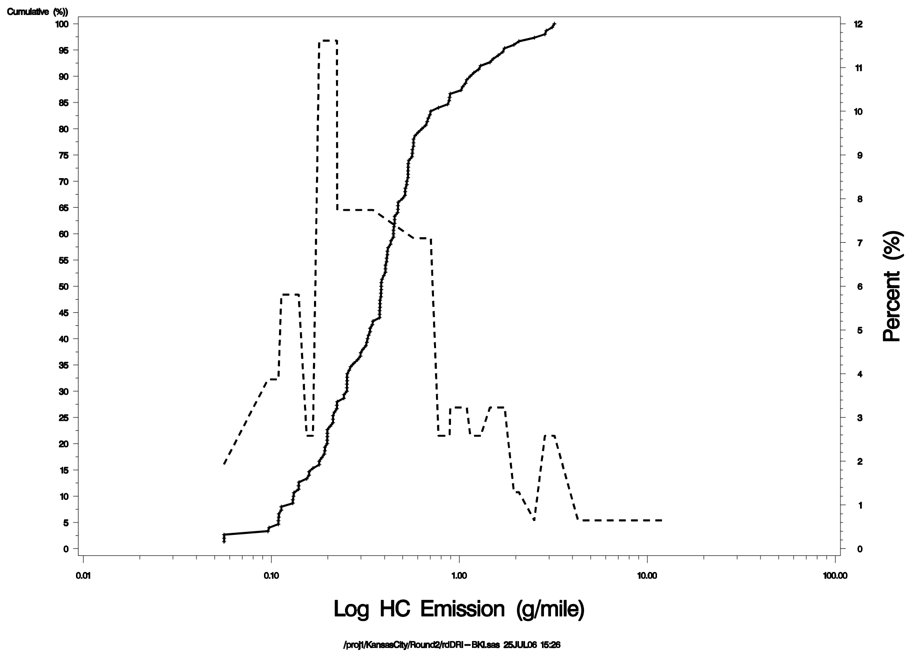


Figure 4-76. Round 2 Plots of % Projected-Fleet Distribution of Composite $PM_{2.5}$

Cumulative Plot of Emission by Simulated Fleet Distribution (Log Scale)



Cumulative Plot of Emission by Simulated Fleet Distribution (Linear Scale)

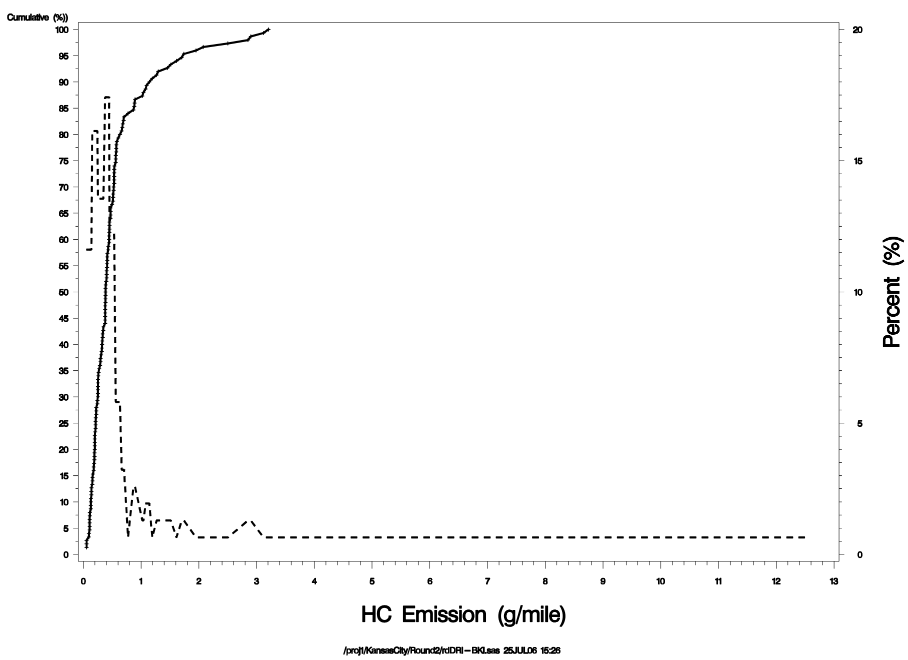


Figure 4-77. Round 2 Plots of % Projected-Fleet Distribution of Composite HC

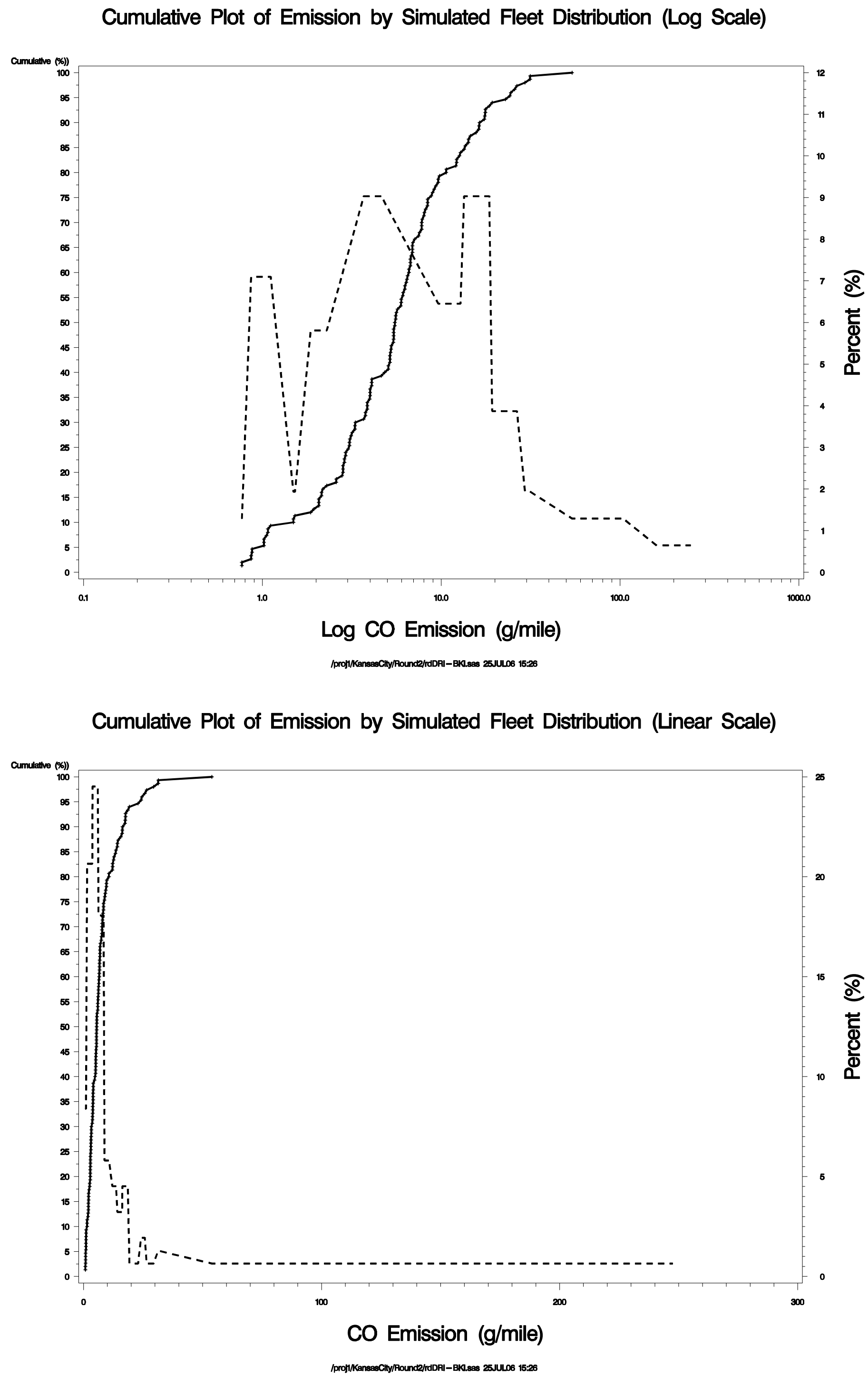
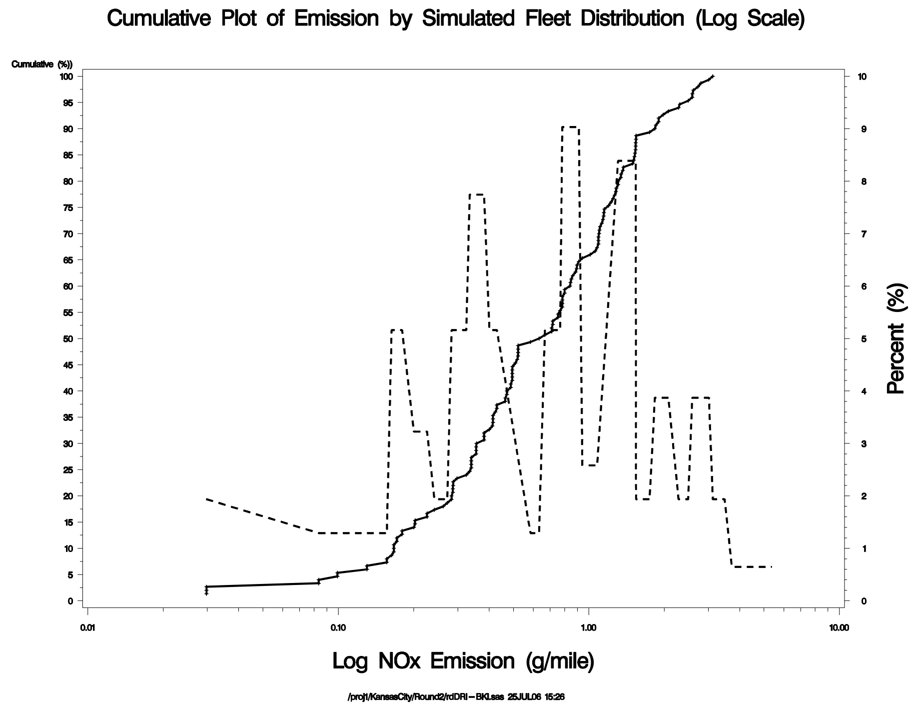


Figure 4-78. Round 2 Plots of % Projected-Fleet Distribution of Composite CO



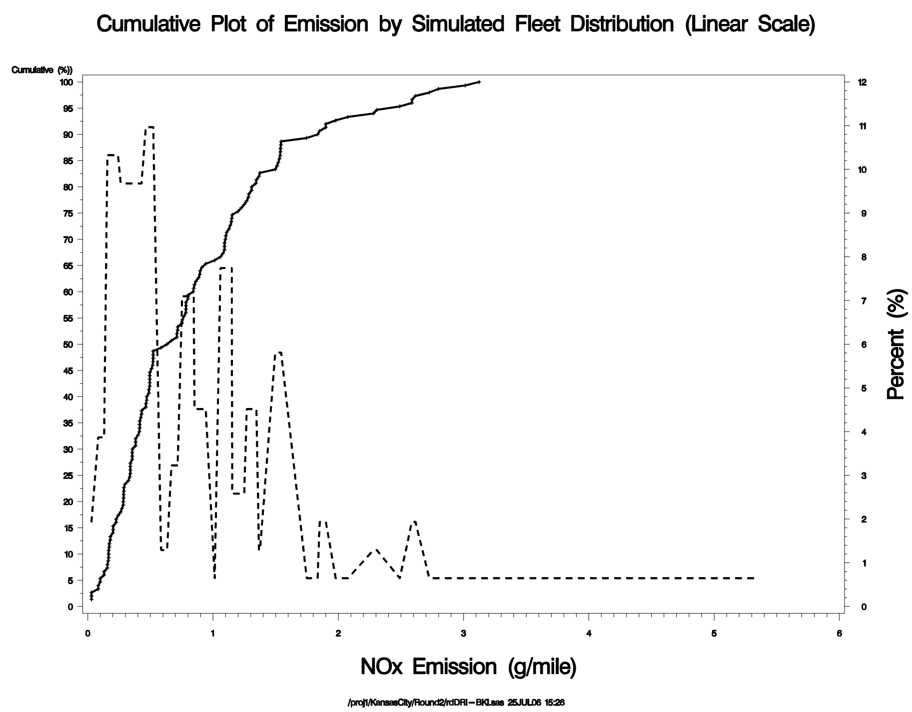


Figure 4-79. Round 2 Plots of % Projected-Fleet Distribution of Composite NO_x

Table 4-25. Round 1 Vehicle Distribution by Vehicle Type and Model Year Group

Stratum	Year of Make	VEHTYPE	KC DMV Vehicle %	Project Goals	Goal of Round 1	Round 1 Actual Tested	Round 1 and Its Duplication for Simulating of KC Fleet Distribution**
1	Pre-1981	TRUCK	1.20%	30	16	2	5(3)
2	1981-1990	TRUCK	3.70%	50	26	14	17(3)
3	1991-1995	TRUCK	4.40%	50	26	18	20(2)
4	1996 up	TRUCK	11.60%	75	39	36	52(16)
5	Pre-1981	CAR	2.20%	30	16	6	10(4)
6	1981-1990	CAR	10.70%	100	51	48	48(0)
7	1991-1995	CAR	18.00%	65	34	45	81(36)
8	1996 up	CAR	48.20%	80	42	98	216(118)
Total			100%	480	250	267	449(182)

** Number in parenthesis presents the duplicated records from that specific bin.

During Round 2, 291 LA92 tests were performed, excluding the 12 control vehicle tests. Using both the Kansas City fleet distribution for each stratum and the actual Round 2 stratum distribution, Kansas City fleet simulation can be achieved as shown in Table 4-26. Again, this simulation is applied here for QA/QC purposes only, not for modeling purposes.

Table 4-26. Round 2 Vehicle Distribution by Vehicle Type and Model Year Group

Stratum	Year of Make	VEHTYPE	KC DMV Vehicle %	Project Goals	Goal of Round 2	Round 2 Actual Tested	Round 2 and Its Duplication for Simulating of KC Fleet Distribution **
1	Pre-1981	TRUCK	1.20%	30	10	9	7(-2)
2	1981-1990	TRUCK	3.70%	50	37	29	21(-8)
3	1991-1995	TRUCK	4.40%	50	30	31	16(-15)
4	1996 up	TRUCK	11.60%	75	47	50	20(-30)
5	Pre-1981	CAR	2.20%	30	15	14	12(-2)
6	1981-1990	CAR	10.70%	100	34	36	36(0)
7	1991-1995	CAR	18.00%	65	36	37	36(-1)
8	1996 up	CAR	48.20%	80	27	29	72(43)
Total			100%	480	236	235	220(-15)

** Number in parenthesis presents the duplicated records from that specific bin.

4.5 Evaluation of Exhaust $PM_{2.5}$ Mass Measurements

DRI installed and operated a suite of instruments to provide continuous PM data during the Kansas City Light-Duty Gasoline Vehicle Emission Characterization Study. The instruments provided by EPA and operated by DRI included a Booker Systems Model RPM-101 Quartz Crystal Microbalance (QCM) manufactured by Sensor's, Inc. and a MIE, Inc. DataRAM4 nephelometer for PM mass. In addition, DRI operated a photoacoustic instrument for determination of BC mass concentrations (Arnott, Zielinska et al. 2004) and a TSI DustTrak. This section compares the continuous PM data to the corresponding time-integrated gravimetric mass data. Data from the real-time sensors were also used to examine PM emission rates under varying vehicle operating conditions and to monitor the blank levels in the dynamometer dilution tunnel during the purge cycle prior to each vehicle test.

4.5.1 Introduction

One objective of the study is to evaluate the performance of the Sensor's Inc. QCM as a component of a portable emission monitor. Although the QCM is a highly sensitive measure of cumulative mass, it has a limited dynamic range which requires adjustable dilution rates. In actual application, the dilution ratios would be continually adjusted as required. The dynamometer testing provided an opportunity to evaluate the QCM with other measurement methods under controlled conditions for a large range of emission rates.

Motor vehicle manufacturers have a long history of interest in measurement of BC emissions from vehicles with use of the photoacoustic method (Roessler 1984). A more recent study evaluated methods for continuous measurement of PM from light duty diesel vehicles tested on a dynamometer (Moosmüller, Arnott et al. 2001a; Moosmüller, Arnott et al. 2001b). The key findings of this work were that the time-averaged tapered-element oscillating microbalance (TEOM) data showed close correlation with $PM_{2.5}$ measurements using Teflon filters. The TEOM had considerably more noise than the DustTrak nephelometer also used for $PM_{2.5}$ measurement, though the DustTrak showed variable correlation with Teflon filter mass with the key dependence related to the amount of organic carbon in the exhaust and very likely, the change in particle size with vehicle model year. Photoacoustic (PA) measurements of BC were found to correlate well with elemental carbon measurements accomplished thermal optical reflectance analysis using the IMPROVE protocol (Chow, Watson et al. 1993) (TOR-IMPROVE) for the definitions of the various OC and EC stages as well as the correction for optical pyrolysis. An efficiency factor was obtained for converting aerosol light absorption measurements by the photoacoustic method to BC such that for light duty diesel vehicles, BC = EC. The instrument suite of TSI DustTrak and Thermo Electron Corporation DataRAM4 nephelometers for total PM, and DRI photoacoustic instrument for BC mass concentration were deployed during the study reported on here. DRI also was responsible for operation of the quartz crystal microbalance, though responsibility for final data analysis and reduction lies with the EPA.

4.5.2 Measurement Methods

DRI installed and operated a suite of instruments including the Photo-Acoustic BC Analyzer, QCM, TSI DustTrak, DataRAM4, and Filter Sample Holders to provide continuous

PM analysis and to collect batch samples of particle and gaseous exhaust components for later analysis in accordance with the methods and procedures specified in DRI's QAPP (June 23, 2004). These instruments collected sample air from the dynamometer dilution system via two isokinetic probes, provided by BKI and EPA, inserted within 5 cm of the center-line of the CVS dilution tunnel prior to a 90-degree bend in the dilution tunnel. Figure 2-4 illustrates the sample train as it was installed during the tests. Heated conductive lines carried air from the probes to the continuous instruments. Insulated copper tubing was used to carry sample air to the time-integrated samplers.

4.5.2.1 Gravimetric Mass Measurements

Unexposed and exposed Teflon-membrane filters were equilibrated at a temperature of 20 ± 5 °C and a relative humidity of 30 ± 5% for a minimum of 24 hours prior to weighing. Weighing was performed on a Sartorius SE2 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 mg, the balance is re-calibrated. If the difference exceeds ± 15 mg, the balance is recalibrated and the previous 10 samples are re-weighed. At least 30% of the weights are checked by an independent 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 PM_{10} Teflon filters were analyzed for mass and all weights entered by filter number into the DRI aerosol data base.

4.5.2.2 Continuous PM Measurements

The Quartz Crystal Monitor has had extensive use in monitoring atmospheric aerosol (Daley and Lundgren, 1975). More recently this monitoring concept has been adapted for use in measuring particulate emissions in real-time from vehicles (Dickens and Booker, 1998, Booker, 2001). For the Kansas City Project, a sampling system and QCM optimized for real-time vehicle particulate mass emissions were integrated in a cart at Sensors, Inc. A general description of the cart components and their use in the KC vehicle sampling system is found in Section 2.3.1.

Figure 4-80 provides a schematic of the QCM sensors used in the cart system. Sample air derived trough the FCS valve system is drawn through the QCM by a flow controlled sample pump at a nominal rate of 1 lpm. Sample air is passed through a high voltage corona where charge is deposited on the sample air particulates. These are then precipitated on a metal clad quartz piezoelectric crystal where they are collected. The crystal is excited to vibrate at its resonant frequency that is a function of collected mass. The greater the mass, the lower the resonant frequency. The frequency to mass relationship is:

$$d(-\Delta f)/d(\Delta m/A) = 2f^2/\delta_q c = S$$

where *f* is the crystal resonant frequency, Δf the change in frequency due to a change in mass per unit area on the crystal $\Delta m/A$, δ_q is the density of the quartz, *c* is the shear wave velocity perpendicular to the crystal surface and *S* is the sensitivity. The mass sensitivity for the QCM is typically 150 Hz/ug. Using the change in frequency, deposited mass can be determined in real-time and, with the measured sample flow, the measured mass concentration can be determined.

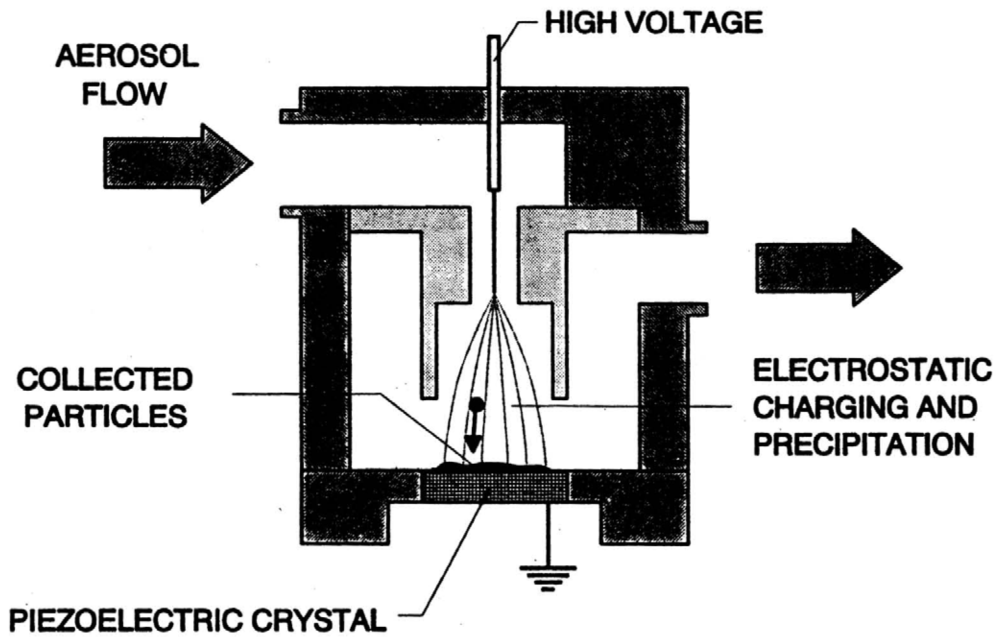


Figure 4-80. Schematic of the QCM.

The Kansas City Project consisted of two Rounds of measurements. For Round 1, 355 separate tests were conducted during which the QCM was used to measure vehicle particulate emissions. For Round 2, 384 separate tests were conducted. Figure 4-81 depicts an example trace of particulate mass collected by the QCM during one of these tests. The trace illustrates the three parts of each test: Phase 1, Phase 2, Hot Soak, and Phase 3. The procedures used in obtaining each part of this trace are indicated on the figure by letters and described below:

A. The quartz crystal is removed from the QCM and cleaned using ethanol. The crystal is then placed back in the QCM. The operator initiates a recording cycle and filtered air is supplied to the QCM through the FCS valve unit. During this period the excess moisture evaporates and the crystal temperature equilibrates. Usually a period of 15 min. is required for complete drying and equilibration.

B. Filtered sample air from the CVS is supplied to the QCM through the FCS valve unit. Quite often not enough time was permitted to remove moisture and permit the crystal to reach thermal equilibrium so the settling of the mass trace was not complete before the test was started. To correct for this, the following functional form is fitted to the trace of part B during data reduction and extrapolated values are used to correct QCM mass in part C, Phase 1 and Phase 2:

$$\text{Correction Mass} = a\,(\text{Time})^2 + b\,(\text{Time})$$

C. During Phase 1 and Phase 2 of the test, sample air from the CVA is supplied to the QCM through the FCS. Under computer control, the cart operator has the option of providing diluted or undiluted sample air to the QCM.

D. Part D of the trace is the Hot Soak. Here the same functional form is used to fit the mass trace. The result is then used to correct QCM mass trace in part E, Phase 3.

E. This is the mass trace for Phase 3. The same level of dilution is used here as that for Phase 1 and Phase 2.

F. Filtered sample air from the CVS is again supplied to the QCM through the FCS valve unit.

G. During this part of the test, the FCS unit switches filtered ambient air to the QCM in preparation for the next test.

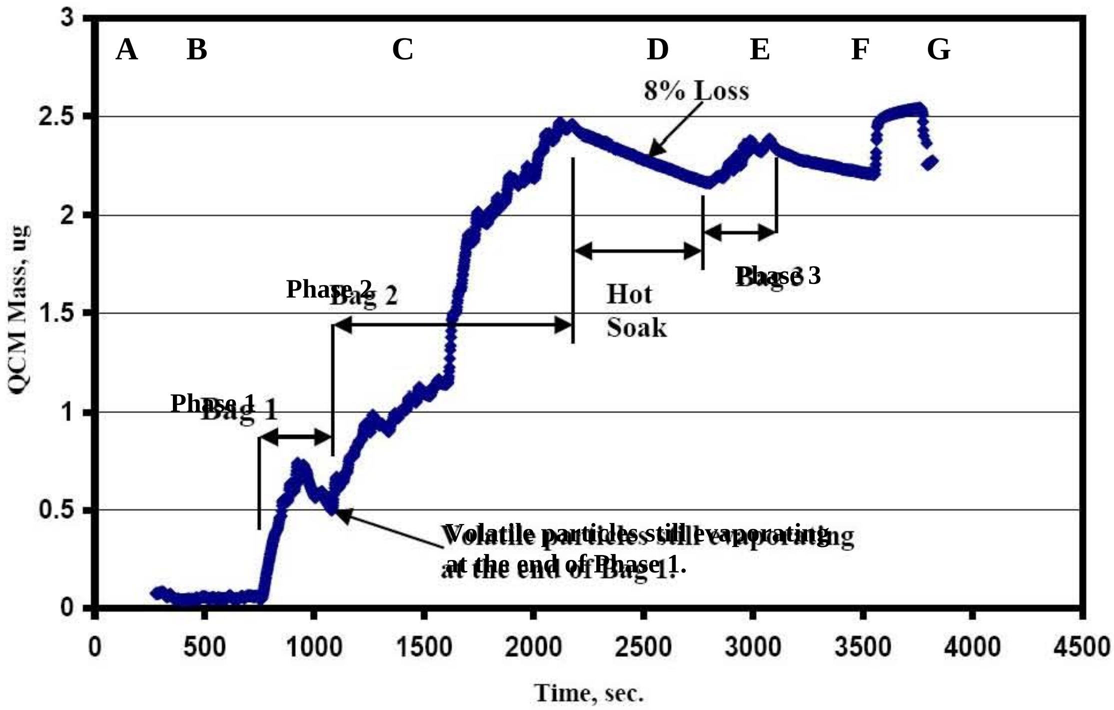


Figure 4-81. Example mass trace from the QCM analyzer.

Note that the trace shows definite loss of mass from the QCM due to loss of volatile particle constituents. This is as much as 8% from the particulate collected during Phases 1 and 2.

During each test, the Computer Control/Data Acquisition System records several parameters from the QCM Cart system. These are recorded in a data file and are listed for Round 1 in Table 4-27. During Round 1, dew point was recorded by the Viasala in a separate file.

Table 4-27. Parameters Recorded by the QCM System Computer Control/Data Acquisition System During Round 1 Tests.

Parameter	Unit	Parameter	Unit	Parameter	Unit
Date	mm/dd/yyyy	Inlet Temp.	°C	Diution Ratio	num.
Start Time	hr:min:sec	Block Temp.	°C	StDEV Dilution Ratio	num.
Time	sec.	Ref Crystal Temp.	°C	Heated Line 1 (opt.)	°C
Mass	μg	Baseline Logic (opt.)	num.	Heated Line 2 (opy.)	°C
QCM Flow	lpm	Tare Freq	Hz	Pressure Temp 1 (C)	°C
Corona Current	μA	Frequency	Hz	Pressure Temp 2 (C)	°C
StDEV Corona Current	μA	Pressure zone 4	psi	Inlet Temp (C)	°C
HV Volt	kV	Pressure zone 5	psi	QCM Pump Status	on (1), off(0)
StDev HV Volts	kV	Time	sec.	QCM Corona Status	on (1), off(0)
Raw Conc.	mg/m^3	MPS Major Flow	lpm	FCS Position	num.
Conc.	mg/m^3	MPS Minor Flow	lpm	TTL 1 (from BKI)	mv
Crystal Holder Temp.	°C	MPS Needle Flow	cc/sec.	TTL 2 (from BKI)	mv

Raw Conc. and Conc. are nominal concentrations using the QCM flow and mass results. The other parameters are used to monitor internal QCM operation and provide information during instrument trouble-shooting. During Round 2, additional parameters were recorded. These are summarized in Table 4-28. Added to the parameter list are the relative humidity (RH) and the RH temperature. For both Rounds 1 and 2 the QCM recorded data with a time resolution of 1.5 sec.

Table 4-28. Parameters Recorded by the QCM System Computer Control/Data Acquisition System During Round 2 Tests.

Parameter	Unit	Parameter	Unit	Parameter	Unit
Date	mm/dd/yyyy	Block Temp.	°C	FCS Position	num.
Start Time	hr:min:sec	Ref. Crystal Temp.	°C	Time	sec.
Time	sec.	Baseline Logic (opt.)	num.	MPS Major Flow	lpm
Mass	µg	Tare Freq	Hz	MPS Minor Flow	lpm
QCM Flow	lpm	Frequency	Hz	MPS Needle Flow	cc/sec.
Corona Current	µA	Pressure Zone 4	psi	Diution Ratio	num.
StDEV Corona Current	µA	Pressure Zone 5	psi	StDEV Dilution Ratio	num.
HV Volt	kV	RH	%	Heated Line 1(opt.)	°C
StDev HV Volts	kV	RH Temp	°C	Heated Line 2 (opt.)	°C
Raw Conc	mg/m^3	TTL 1	mv	Pressure Temp. 1	°C
Conc	mg/m^3	TTL 2	mv	Pressure Temp. 2	°C
Crystal Holder Temp.	°C	QCM PUMP Status	on (1), off(0)	Inlet Temp.	°C
Inlet Temp.	°C	QCM Corona	on (1), off(0)		

The Photo-Acoustic BC Analyzer, TSI DustTrak, DataRAM4, and Filter Sample Holder part of this instrument suite was previously evaluated in an earlier study of the emissions from light duty diesel trucks on a dynamometer (Moosmüller, Arnott et al. 2001a; Moosmüller, Arnott et al. 2001b). In brief, the findings of this previous work were derived from the comparison of traditional filter samples of PM and EC with time averages obtained from these real-time instruments. The DustTrak, being an optical measurement method, had sensitivity to both particle composition and size. Photoacoustic measurements of BC agreed quite favorably with EC measurements obtained from the Improve Protocol Thermal Optical Reflectance (TOR) measurement obtained from samples collected on quartz filters. TOR analysis is described in (Chow, Watson et al. 1993). With 1-second time constants the precision of the DustTrak and photoacoustic instrument are 1 µg m^{-3}.

Nephelometers like the DustTrak are designed to measure the light scattered by particles. While these instruments in general have performance issues associated with angular truncation and non-ideality in the detectors (Anderson and Ogren 1998), the angular response of the nephelometers used in this study has not been reported in the literature. Figure 4-82 indicates the mass-weighted scattering efficiency as a function of particle size for a wavelength of 760 nm, pertinent to the DustTrak nephelometer. Note that if the DustTrak were a perfect instrument for measuring particle mass the mass scattering efficiency curve would be a constant value and there would be no composition dependence. The DustTrak mass calibration factor is determined by the manufacturer using an ISO standard Arizona Road Dust having particle size distribution peak near 2 microns. However, typical combustion particles have mass weighted sizes near 0.3 microns, but because this size is about at the same value of mass scattering efficiency as the Arizona road dust value, and to the left of the peak of the curve shown in Figure 4-82, the DustTrak produces mass concentrations typically accurate to within a factor of 2. It should be noted that nephelometers are very sensitive to particles of sizes larger than about 0.1 to 0.3

microns, depending on composition, but that their calibration as a mass standard is dependent especially on particle size as well as composition to a lesser extent (Sioutas, Kim et al. 2000).

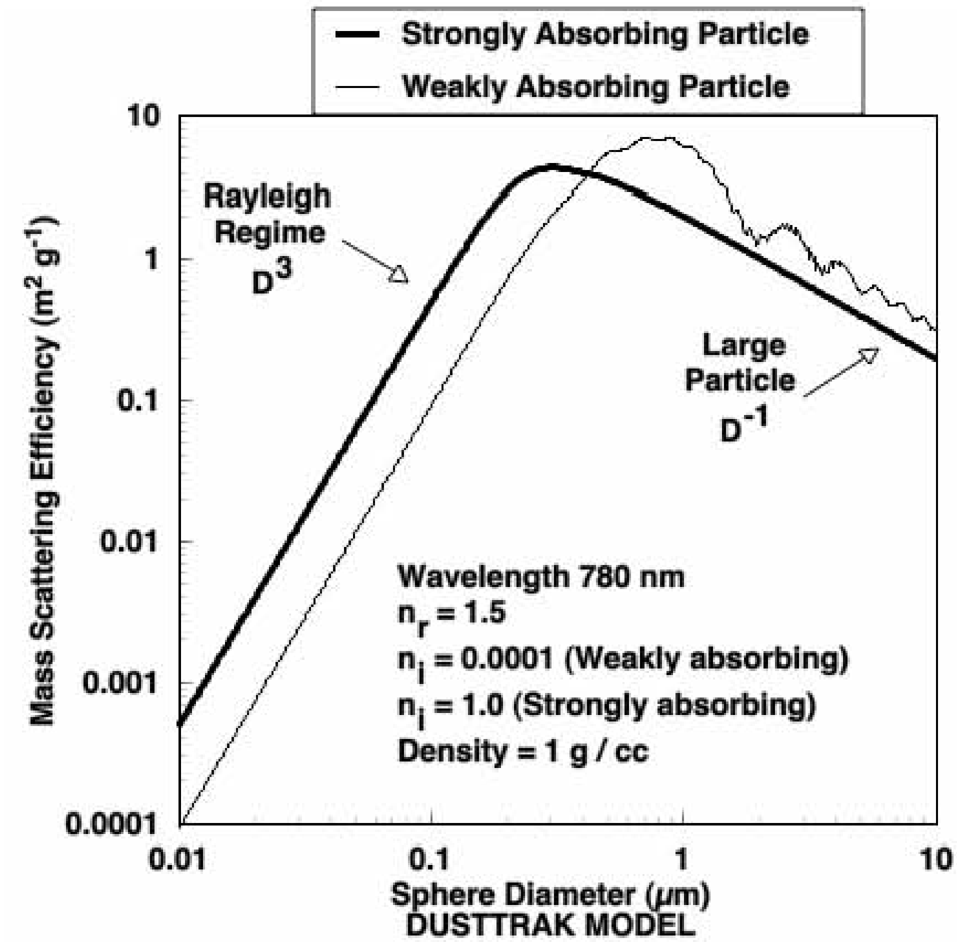


Figure 4-82. Theoretical mass scattering efficiency for a perfect nephelometer.

(Strongly absorbing particles such as BC are given by the thick curve and weakly absorbing particles such as organic carbon are given by the other curve.)

The Mie DataRAM4 (DR) manufactured by Thermo Electron Inc is a more sophisticated instrument than the TSI DustTrak (DT). The DR measures light scattering at two wavelengths, such as 880 nm and 760 nm. The use of two wavelengths allows for better knowledge of particle size as it relates to the mass scattering efficiency factor shown in Figure 4-82. The curves in Figure 4-82 were computed for a wavelength of 760 nm. If they were computed for a wavelength of 880 nm, the peak in the curves would be shifted to the right, so that for combustion size particles, the 880 nm scattering amount would be less than the 760 nm amount. The ratio of these two values would give a measure of particle size.

Photoacoustic instruments have been used in source sampling of BC aerosol. Sample air is pulled continuously through an acoustical resonator and is illuminated by laser light that is periodically modulated at the acoustical resonance frequency. Light absorption is manifested in particle heating and this heat transfers rapidly to the surrounding air, inducing pressure fluctuations that are picked up with a microphone on the resonator. Microphones have a very large dynamic range (at least 6 orders of magnitude), so BC measurements can be made over a large dynamic range with these instruments. The advancement that has been very important for the continued success of these instruments is the ability to measure very low levels of light absorption. Aerosol light absorption at visible and near IR wavelengths occurs throughout the entire particle volume for typically submicron combustion particles, so BC aerosol mass concentration is found to vary in direct proportion with light absorption. Vehicle manufactures pursued these methods in the 1970's and 1980's using bulky Argon Ion lasers and dye lasers (Terhune and Anderson 1977; Japar and Killinger 1979; Japar and Szkarlat 1981a; Japar and Szkarlat 1981; Japar, Szkarlat et al. 1984; Roessler 1984), and a resurgence of interest has emerged in research laboratories that coincides with technological developments in compact, efficient laser sources (Petzold and Niessner 1994; Petzold and Niessner 1995; Arnott, Moosmüller et al. 1999; Moosmüller, Arnott et al. 2000).

The photoacoustic instrument developed for this work operates at a convenient wavelength of 1047 nm where gaseous interference is not a problem and where a laser source is available that allows for direct electronic modulation of the power at the resonator frequency. The acoustical resonator, shown schematically in Figure 4-83, was designed for compactness, ease of reproducibility in manufacture, and robustness with respect to use of the instrument in very noisy, dirty sampling environments (Arnott, Moosmüller et al. 2003). The instrument comprises two identical coupling sections, and a third resonator section. These parts are manufactured out of aluminum. The coupling sections allow the laser beam to enter the instrument through windows well separated from the resonator section. The sample inlets and outlets are followed by cavities that are tuned to reduce the coupling of noise into the resonator section. The resonator section has a horizontal tube that is 1/2 of an acoustic wavelength long, and two vertical tubes that are 1/4 of an acoustic wavelength long. In previous designs (Arnott, Moosmüller et al. 1999), the vertical tubes were at an angle of 45 degrees to the horizontal instead of 90 degrees as they are now, and the tubes were formed from pipe rather than machined with precision. The 90 degree angles allow for symmetry when deciding where the holes in the resonator are placed to allow for laser beam and sample air passage. The piezoelectric transducer is used as a sound source to occasionally scan the resonator resonance frequency and quality factor for use in calibrating the instrument from an acoustical perspective. The microphone and piezoelectric transducer sit at pressure antinodes of the acoustic standing wave, and the holes in the resonator are at pressure nodes. The instrument is bolted together in three parts for easy disassembly in case it needs to be cleaned. The laser beam passes through the windows and the holes in the resonator section. The laser beam pumps the acoustic wave through light absorption, and the transfer of the associated heat to the surrounding air, in the resonator section.

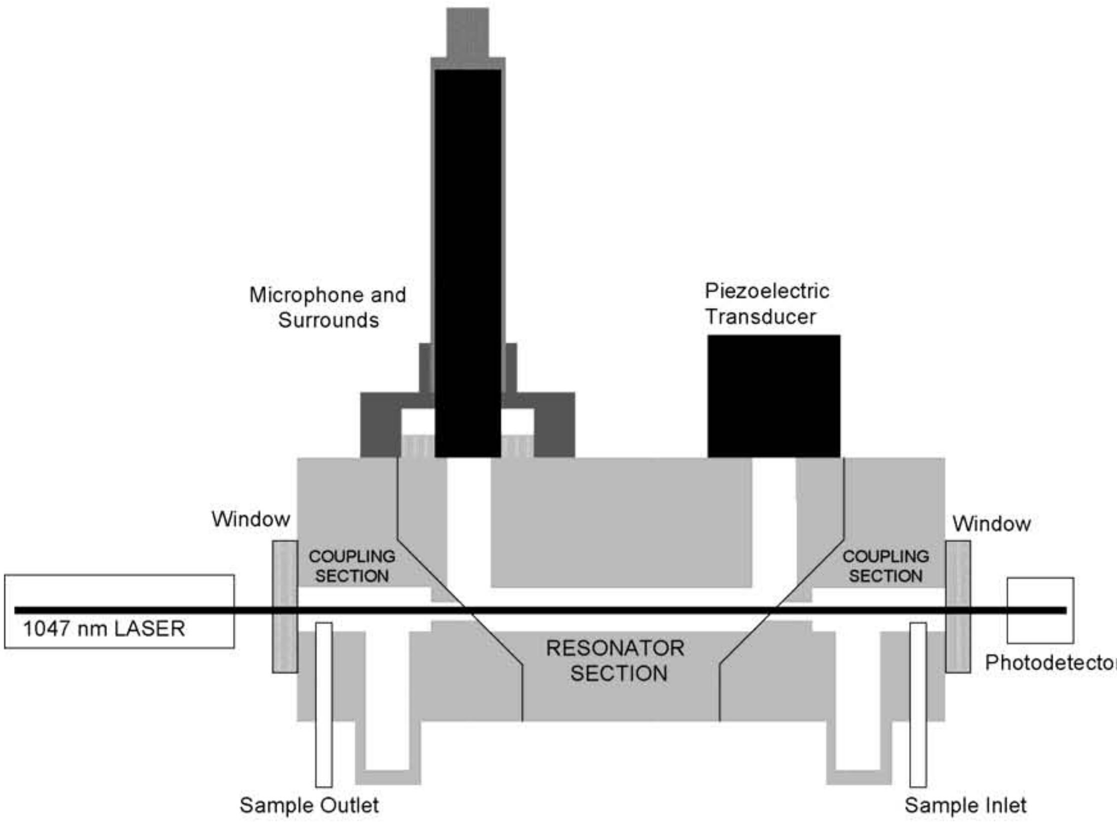


Figure 4-83. Schematic of the photoacoustic instrument.

The photoacoustic instrument measures the aerosol light absorption coefficient (Arnott, Moosmüller et al. 1999; Arnott, Moosmüller et al. 2000), and then a quantity defined as BC is computed from the absorption coefficient. The EC part of the exhaust absorbs light at 1047 nm much more strongly than any other common particulate aerosol in exhaust and in the atmosphere so that it is reasonable to associate elemental carbon with aerosol light absorption. Why is it reasonable to associate aerosol light absorption with a BC mass concentration (BC)? Because aerosol light absorption occurs throughout the entire particle volume for sufficiently small particles and large wavelengths of light, giving rise to a direct proportionality between the absorption measurement and the aerosol mass for typical combustion particle of typical size, and for the 1047 nm wavelength used in the instrument. It is perhaps inevitable to speculate that the aerosol complex refractive index could vary with combustion source (Dalzell and Sarofim 1969) (Fuller, Malm et al. 1999), so that the BC measured values could be different for particles actually having the same numbers of carbon atoms in them. It is also possible to postulate that aerosol coatings or adsorbents, or particle morphology, could also give rise to different absorption coefficients than one would observe for uncoated particles. Experiences to date have shown that for an emission source such as a late model diesel that is rich in EC, the IMPROVE protocol method of quantifying EC (Chow, Watson et al. 1993) correlates well with the aerosol light absorption measurement at 1047 nm.

The following relationship is used to obtain BC concentration from the aerosol light absorption measurement at 1047 nm:

$$BC\ (\mu g\ m^{-3}) = 5\ (m^2\ g^{-1})\ B_{abs}\ (Mm^{-1})\ \{\text{measured at 1047 nm}\}\ .\quad (1)$$

This relationship represents diesel emissions. EC from diesels provide a relatively unambiguous measurement from the various protocols and methods that have been developed though ambient and wood smoke samples have substantial differences (Watson, Chow et al. 1994; Chow, Watson et al. 2001). The relationship of these measurements to spark-ignition engines is discussed in Section 4.4.3.5, Evaluation of Continuous Optical Mass Measurements.

4.5.3 Results

4.5.3.1 Evaluation of Gravimetric Mass Measurements

The gravimetric mass data were corrected for transport field blanks only (i.e., dilution tunnel blanks have not been applied). The field blanks were collected weekly. In each case, the filters were installed in the sampler and immediately removed and placed back in their sealed storage bags. The field blanks are shown in Figure 4-84 in the sequence that they were collected during Round 1. They range from 1.1 to 9.9 μg/filter with an average of 5.4 and standard deviation of 3.4 μg/filter. This compares to the measurement uncertainty for these filters of 4.6 μg/filter, which is determined by replicate measurement by a second technician of 30% of the pre-weights and 100% of the post weights. The relatively large tare weight of the Teflon filter (~150 mg/filter) is a limiting factor in the measurement uncertainty. Since the average field blank is comparable to the measurement uncertainty, we subtracted the mean value of the transport field blanks to all samples rather than apply week-specific blanks. The loadings on the sampled Teflon filter prior to subtraction of the average transport field blank value are substantially higher than the field blanks with the exception of Strata 4 and 8 during Phase 3 of the test cycle.

EPA pointed out an apparent temporal pattern in the gravimetric mass results for the weekly field blanks collected during Round 1 (shown in Figure 4-84) which indicates that it may not be appropriate to use an average of all field blank masses to correct the test data. The vertical dashed lines divide the filters into three groups corresponding to how the filters were packaged for transport to and from the sampling site (a fourth group of three field blanks were collected but were damaged by flooding of the test facility). The third group exhibits consistently higher mass gain than the other two. Although this appears to suggest that some change in sampling conditions occurred during that 3 week period, the mass gains for the three filters are too uniform (9.3 ± 0.7 ug) to be explained by contamination of the media and there is no corresponding increase in any of the elements measured by XRF or in the carbon fractions on the corresponding quartz filters. Note that despite the noticeable increase in mass for the last three blanks, the differences from the rest of the blanks are not significant (bars indicate the 1 sigma uncertainty).

On further investigation we determined that the post-sampling weighing of that group of filters was performed 2 months after gravimetric analysis had been completed on all other samples from Round 1. This occurred due to a clerical error (the filters were mistakenly identified as void by the lab because they had originally been tagged for a vehicle test that was cancelled). The filter packs were packaged in sets of three pairs of Teflon and quartz filters for the three Phases of the test. The three pairs from this pack were used for the three successive field blanks at the end of Round 1. A change in weighing conditions is an alternative explanation that would need to be considered under this situation.

In order to monitor changes in weighing conditions, a media blank is selected from each group of 50 filters during pre-sampling analysis and is post-weighed along with the field samples using the same conditioning protocols. The resulting net gravimetric mass data for the media blanks during Round 1 are presented in Figure 4-85 both chronologically and sorted to show the distribution of values. The changes in mass on the media blanks are comparable in range to the field blanks.

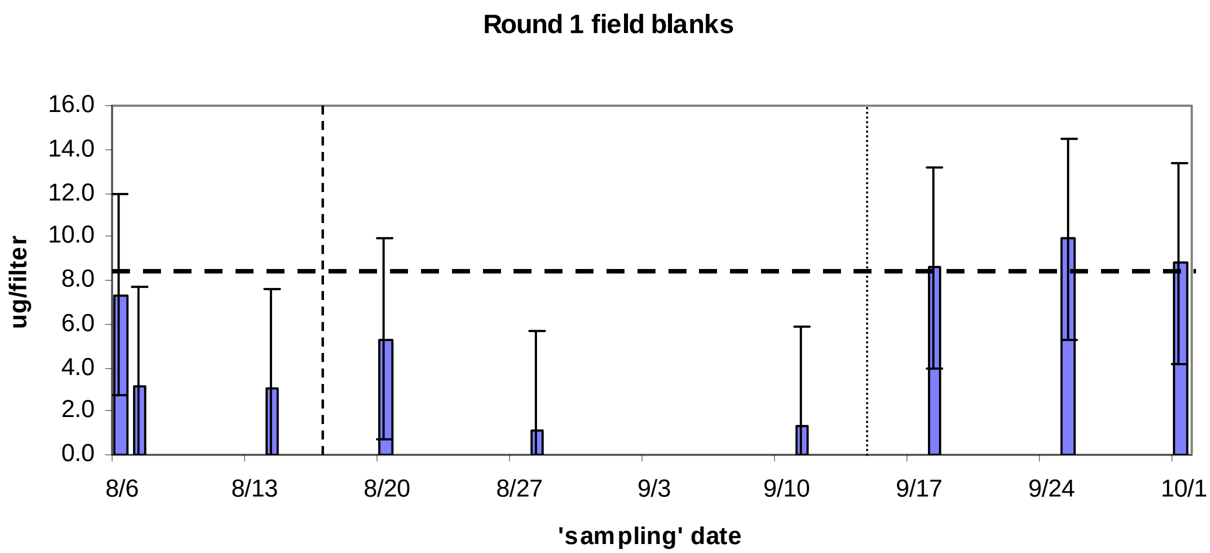


Figure 4-84. Field blanks for gravimetric mass during Round 1 of the Kansas City Study in µg/filter.

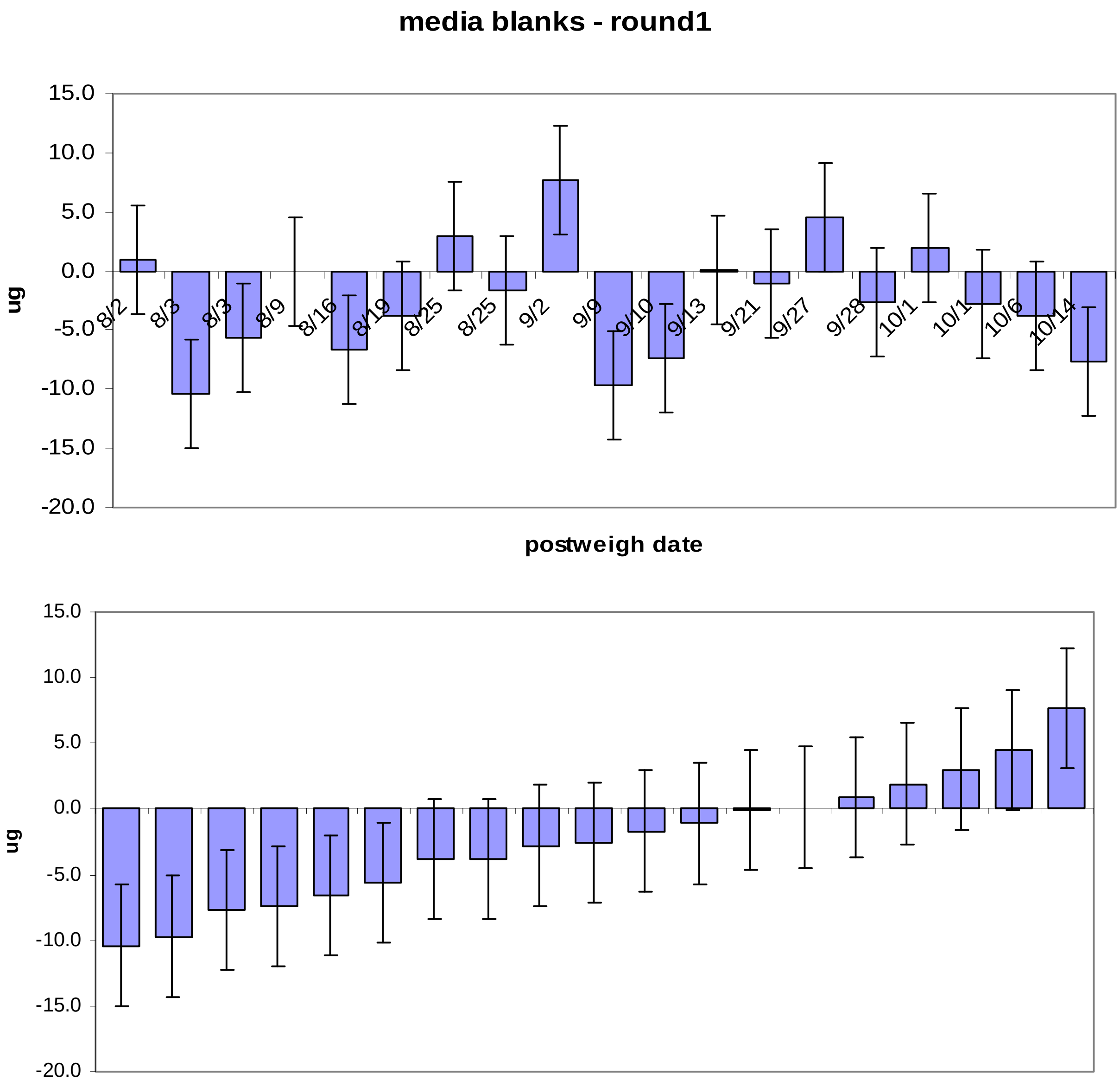


Figure 4-85. Round 1 Media Blanks.

(Net gravimetric mass data (µg/filter) for media blanks during Round 1 are shown chronologically in the top plot and sorted to show the distribution of values in the bottom plot. Note that the changes in mass on the media blanks are comparable in range to the field blanks.)

Unless we can discover some correctable discrepancy in the analysis procedures used for the three high field blanks (group 3) relative to that employed for the rest of the samples, the field blank data from group 3 should be considered invalid. Since there is no significant difference between the other two groups of field blanks, and all are below the “MDL” of the gravimetric analysis (twice the standard deviation of the control weights) indicated by the horizontal dashed line, we feel it is more appropriate to use the average mass of these six blanks to correct all of the test samples and dilution tunnel blanks. Eliminating the three suspect field blanks reduces the correction from 5.4 to 3.5 µg (equivalent to about 0.6 mg/mi for a Phase1 sample). This approach is consistent with the standard procedures used by DRI’s Environmental Analysis Facility for other projects. However, many of the samples have measured mass below this average field blank value as shown in the histogram in Figure 4-86 of the uncorrected gravimetric mass for all Phase 3 filter samples.

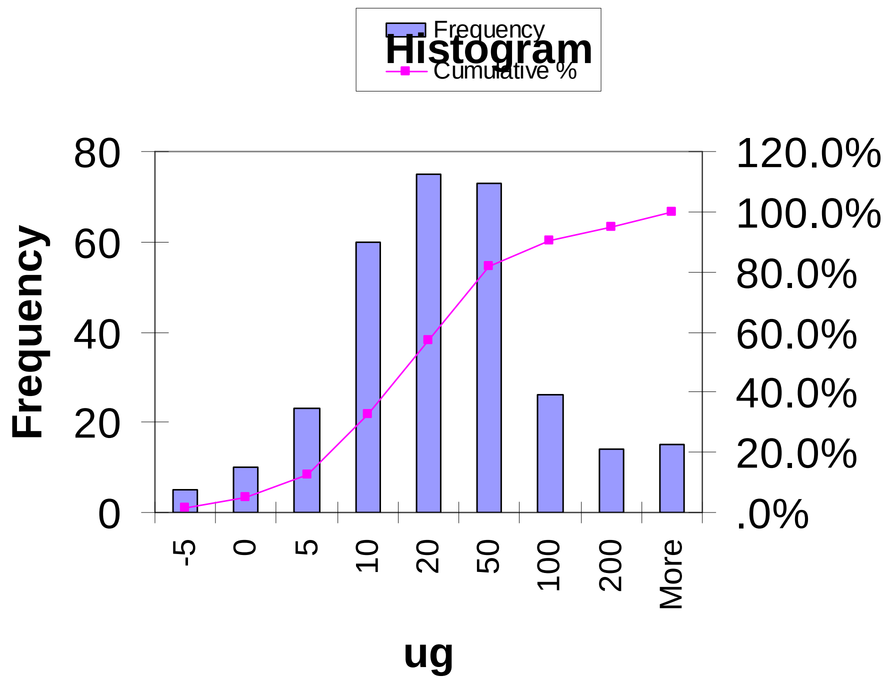
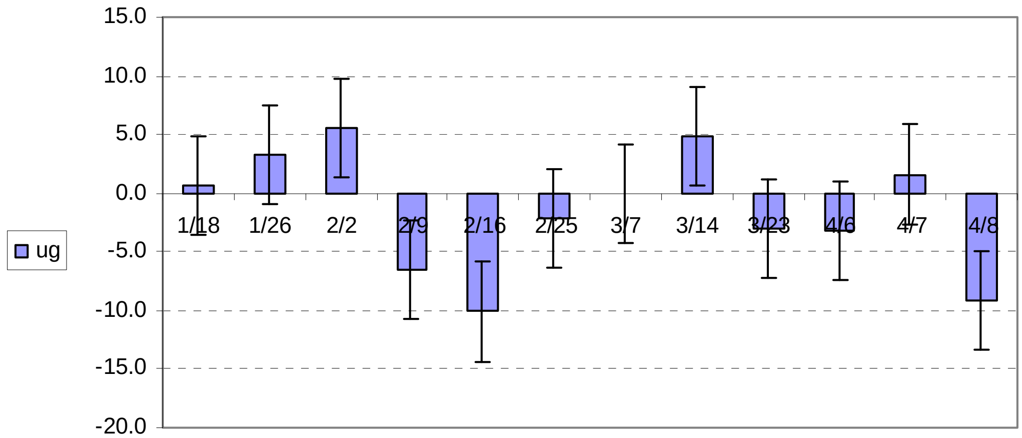


Figure 4-86. Histogram of uncorrected gravimetric mass for Phase 3 filter samples from Round 1.

Alternatively, we could have eliminated the field blank correction to gravimetric mass altogether, since the field blank masses are consistent with the range of mass measured for media blanks and therefore indistinguishable from the random measurement error. Field blanks for Round 2 are also very similar to the media blanks, with an average value of -1.5 ± 1.2 ug. They are shown in Figure 4-87 chronologically and sorted. Not correcting for field blanks would be consistent with what is done in the Speciation Trends Network (STN) and IMPROVE aerosol monitoring networks.



field blanks - round 2

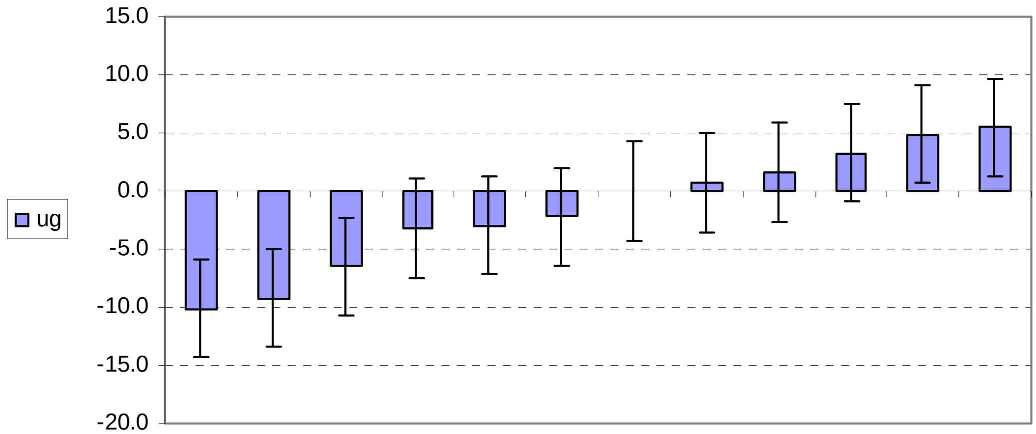


Figure 4-87. Round 2 Media Blanks.

(Net gravimetric mass data (ug/filter) for field blanks during Round 2 are shown chronologically in the top plot and sorted to show the distribution of values in the bottom plot. Note that the changes in mass on the field blanks are comparable in range to the media blanks shown in Fig. 4-13.)

DRI's gravimetric mass measurements were compared to those made by EPA's laboratory in Ann Arbor as part of quality assurance for the study. A batch of 21 Teflon filters were sent to EPA for pre-weights and returned to DRI for determination of the pre-weights. The filters were then sent to Kansas City and 15 of the filters were sampled during the week of 2/14. Five sets of three Teflon filters (one for each phase) were collected for this comparison study: twice for the correlation vehicle (Ford Taurus) and three other vehicles with varying particulate emission rates. Six samples were treated as field/transport blanks. From three of the blanks, DRI removed a tiny portion from each filter ring that is comparable to the magnitude of weight changes from actual sampling. Unlike an actual sample, this change in weight would not be subject to variations that might result from potential desorption of SVOCs. DRI determined post weights for the 21 comparison filters and sent the filters to EPA for post weights. Mass measurements were sent to an independent third party. Upon receipt of data from both groups, both data sets were sent to EPA and DRI simultaneously. The scatter plot of gravimetric mass measurements by EPA and DRI and absolute differences in Figure 4-88 again show that these differences are mostly below the limit of detection.

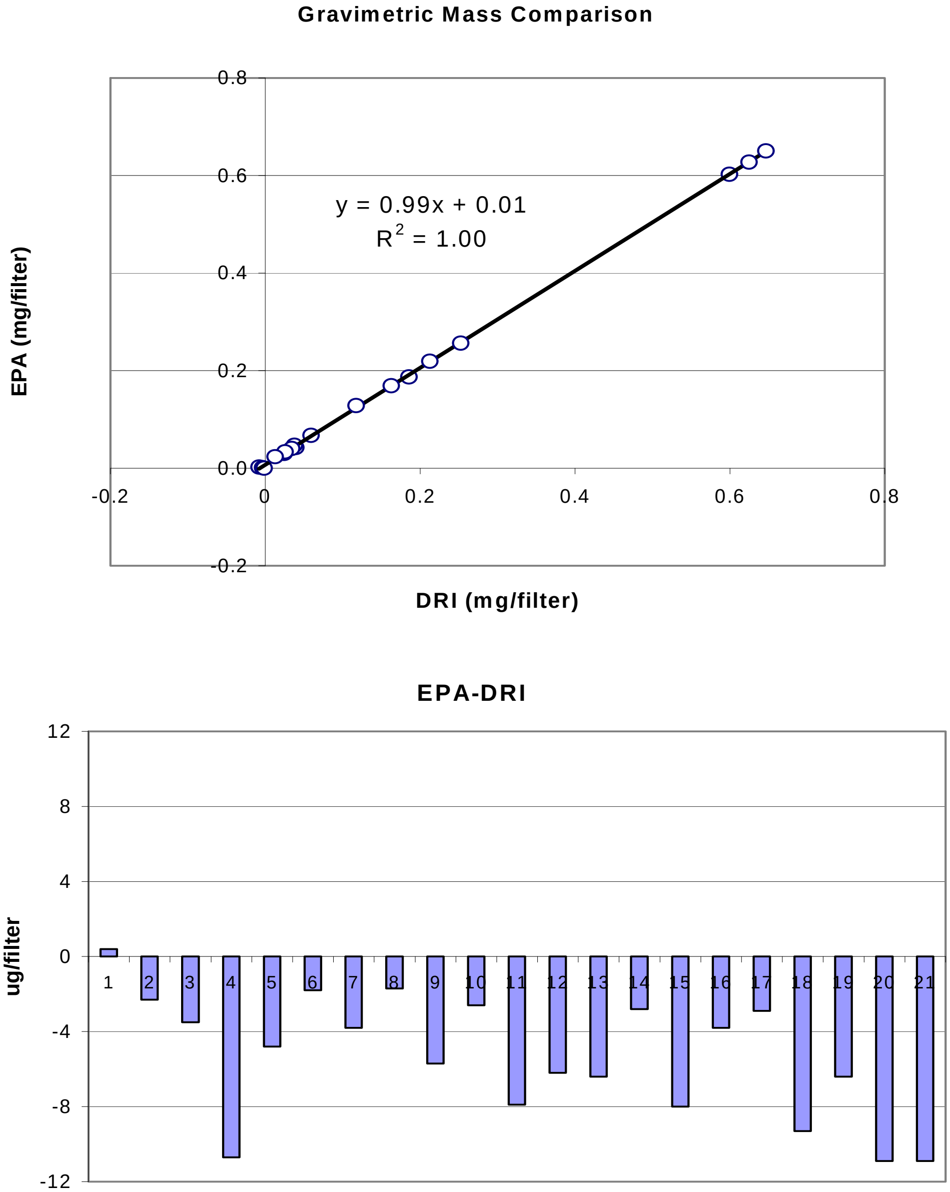


Figure 4-88. Gravimetric Mass Comparison.

(Scatterplot of gravimetric mass measurements by EPA and DRI (top panel) and absolute differences in ug/filter (lower panel). Differences are mostly below the limit of detection of 8 μg/filter)

A second round of interlaboratory gravimetric mass measurement comparisons was done during Round 2, due to an error in handling the data from the first comparison that invalidated the "double blind" nature of the experiment. In the second comparison; five unused Teflon filters were weighed by each lab, then a small punch was removed from the support ring of 3 of the filters and they were re-weighed by each lab. The results, shown in Table 4-29 and Figure 4-89, again indicate that there is no significant bias in the gravimetric mass measurements, and all differences in measured mass fall within the range of analytical uncertainty.

Table 4-29. Results of second gravimetric mass measurement interlaboratory comparison.

Pre DRI-EPA		Post DRI-EPA		Pre-Post			
Diff	RPD	Diff	RPD	DRI	EPA	DRI-EPA	RPD
0.0150	0.009%	0.0155	0.009%	-0.0002	0.0003	-0.0005	
0.0174	0.010%	0.0189	0.011%	-0.0013	0.0002	-0.0015	
0.0184	0.011%	0.0197	0.012%	0.7069	0.7082	-0.0013	-0.18%
0.0166	0.010%	0.0220	0.013%	0.9637	0.9691	-0.0054	-0.56%
0.0177	0.011%	0.0224	0.014%	0.7459	0.7506	-0.0047	-0.63%

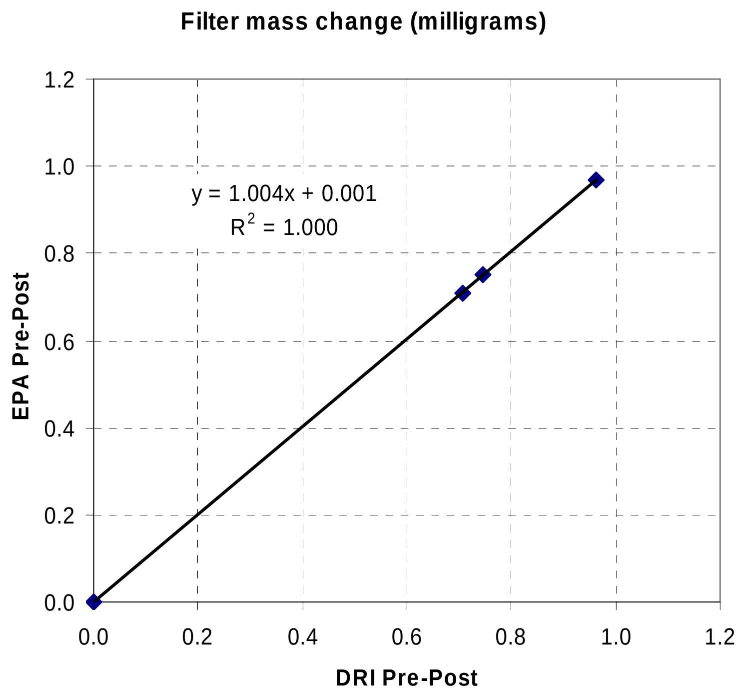


Figure 4-89. Results of second gravimetric mass measurement interlaboratory comparison.

4.5.3.2 Evaluation of QCM Mass Measurements

Analysis of the QCM data record for each test proceeded in steps. The first was correction of the QCM mass for volatile loss as mentioned in Section 4.4.2. The next was correction of the QCM mass for collection of water on the quartz crystal during the test. This was done using humidity measured in the QCM sample stream using the Vaisala, model M170 and applying a correction factor determined during the pre-test evaluation and calibration of the QCM.

After the QCM mass record is corrected, the measured particulate concentrations are calculated using moving a 10 second linear fit to the mass and sample flow data. This is a smoothing technique that is advanced in one second intervals. At this time continuous data recorded by the Photo-Acoustic instrument, DustTrak, DataRAM4, BKI Dynamometer (Dyno), and for the DRI integral filter measurements is imported by the QCM analysis program. Time alignment of these records is done using the TTL signals provided by BKI and recorded by the QCM and Photo-Acoustic systems and nominal time delays determined from sample flow through the CVS and the sample transport system for the continuous instruments.

Using the total dilute volume (Vmix) and distance traveled from BKI's integral Dyno summary record and vehicle speed and torque from the continuous Dyno record, both integral and continuous particulate mass emissions are determined. The results of this analysis for each test are recorded in two files. The first is a summary file containing the integral filter data and the reduced integral results from the continuous particulate instruments. The parameters reported in this file are summarized in Table 4-30. The second file, summarized in Table 4-31, contains the converted and time aligned data from all the continuous instruments. This includes both measured concentrations and vehicle emissions and is reported by test phase; ie. Phase 1, Phase 2, Hot Soak, and Phase 3. In addition, the FTP composite is reported for the instruments that measure particulate.

Table 4-30. Summary of Integral Parameters Reported for Each Test in both Round 1 and Round 2.

Parameter	Unit	Parameter	Unit	Parameter	Unit
File No		Dust Trak Bag 3 ave. conc.	Hg/m^3	model	
QCM Bag 1 ave. conc.	Hg/m^3	Data Ram Bag 1ave. conc.	Hg/m^3	Vehicle Type	car/truck
QCM Bag 2 ave. conc.	Hg/m^3	Data Ram Bag 2 ave. conc.	Hg/m^3	odometer	mi.
QCM Bag 3 ave. conc.	Hg/m^3	Data Ram Bag 3 ave. conc.	Hg/m^3	Bin No.	num.
QCM Bag 1 emissions	mg/mi	BC Bag 1 ave. conc.	Hg/m^3	replicate?	yes/no
QCM Bag 2 emissions	mg/mi	BC Bag 2 ave. conc.	Hg/m^3	Humidity Time Corr.	sec.
QCM Bag 3 emissions	mg/mi	BC Bag 3 ave. conc.	Hg/m^3	Humidity Correction	num.
QCM FTP Composite	mg/mi	Bag 1 DR	num.	QCM DELAY (No dilution)	num.
Volatile Fraction Bag1 and 2	num.	Bag 2 DR	num.	QCM Delay (With Dilution)	num.
Grav Bag1 emissions	mg/mi	Hot Soak DR	num.	PA Delay	sec.
Grav Bag2 emissions	mg/mi	Bag 3 DR	num.	Average Time (sec)	sec.
Grav Bag3 emissions	mg/mi	Grav Bag 1 ave. conc.	Hg/m^3	QC Code	*
Grav FTP Composite	mg/mi	Grav Bag 2 ave. conc.	Hg/m^3	Comment	*
Dust Trak Bag 1 ave. conc.	Hg/m^3	Grav Bag 3 ave. conc.	Hg/m^3		
Dust Trak Bag 2 ave. conc.	Hg/m^3	Model Year	yyyy		

Table 4-31. Summary of Reduced Data Reported for Each Test in Both Round1 and Round 2.

Parameter	Unit	Parameter	Unit	Parameter	Unit
Time All	sec.	Time Bag 1	sec.	Time PA	sec.
Mass All	µg	Conc. Bag 1	µg/m^3	Conc. PA	µg/m^3
Time Bag 1	sec.	Time Bag 2	sec.	Time Dust Trak	sec.
Mass Bag 1	µg	Conc. Bag 2	µg/m^3	Dust Trak Conc.	µg/m^3
Time Bag 2	sec.	Time HS	sec.	Time Data Ram	sec.
Mass Bag 2	µg	Conc. HS	µg/m^3	Data Ram Conc.	µg/m^3
Time HS	sec.	Time Bag 3	sec.	Time - Torque	sec.
Mass HS	µg	Conc. Bag 3	µg/m^3	Torque	Ft-Lbs/sec.
Time Bag 3	sec.	Time All	sec.	Time - Speed	sec.
Mass Bag 3	µg	Conc. All	µg/m^3	Speed	mph

In Table 4-30 a QC parameter is included as well as a comment field. The general intent is to indicate which files and parts of files should be voided, indicated by a prefix V, due to problems encountered during a test. A problem flag, indicated by a prefix F, was also used for the various instrument records. This is intended to signal that the data should be reviewed and analyzed to determine if it is valid before proceeding to use it. Table 4-32 summarizes the QC codes used in both Round 1 and Round 2 summary files

Tables 4-32. A Summary of QC Codes Used in the Integral Summary File.

Round 1

QC Codes	
FDP	DewPoint Problem Flag
VDP	Dewpoint Void
VD	Total Dyno Void
VD1,2,HS,3	Partial Dyno Void Phase(s)
FD1,2,HS,3	Dyno Problem Flag Phase(s)
VV	Vehicle Void
VQ1,2,HS,3	QCM Void Phase(s)
FQ1,2,HS,3	QCM Problem Flag Phase(s)
FPA	PA Problem Flag
FQPAD	QCM PA Dyno Flag
FTA	Time Alignment Flag
NAN	Not a Number
Cv	Control Vehicle (REFERENCE)

Round 2

QC Codes	
FDP	DewPoint Problem Flag
VDP	Dewpoint Void
VD	Total Dyno Void
VD1,2,HS,3	Partial Dyno Void Phase(s)
FD1,2,HS,3	Dyno Problem Flag Phase(s)
VV	Vehicle Void
VQ1,2,HS,3	QCM Void Phase(s)
FQ1,2,HS,3	QCM Problem Flag Phase(s)
VPA	PA Void
FPA	PA Problem Flag
FQPAD	QCM PA Dyno Flag
FTA	Time Alignment Flag
NAN	Not a Number
RDM	Raw Data Modified
VG	Gravimetric Void
FG	Gravimetric Problem Flag

The reduced data files containing all of the continuous PM instrument files can be used to provide displays of the results of the data reduction process for the QCM. Figures 4-90 and 4-91 provide an example of this for QCM and BC mass concentrations compared with Dyno Torque. The figures result from tests of the same vehicle in Round 1 and Round 2. They display the general differences noted between tests conducted in the summer (Round 1) and winter (Round 2).

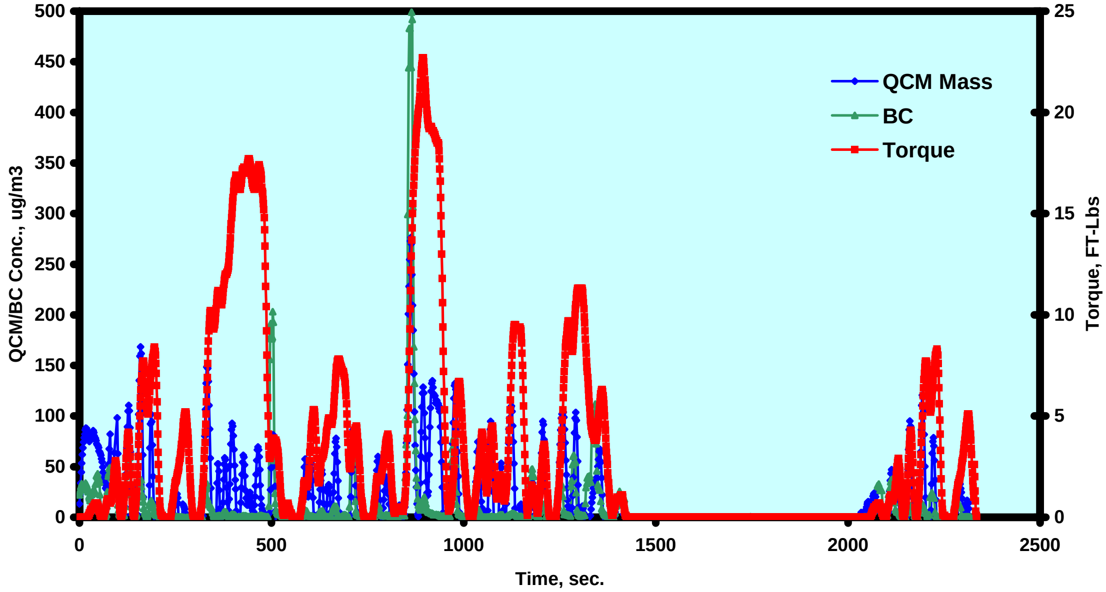


Figure 4-90. Example of Reduced Data for Round 1.

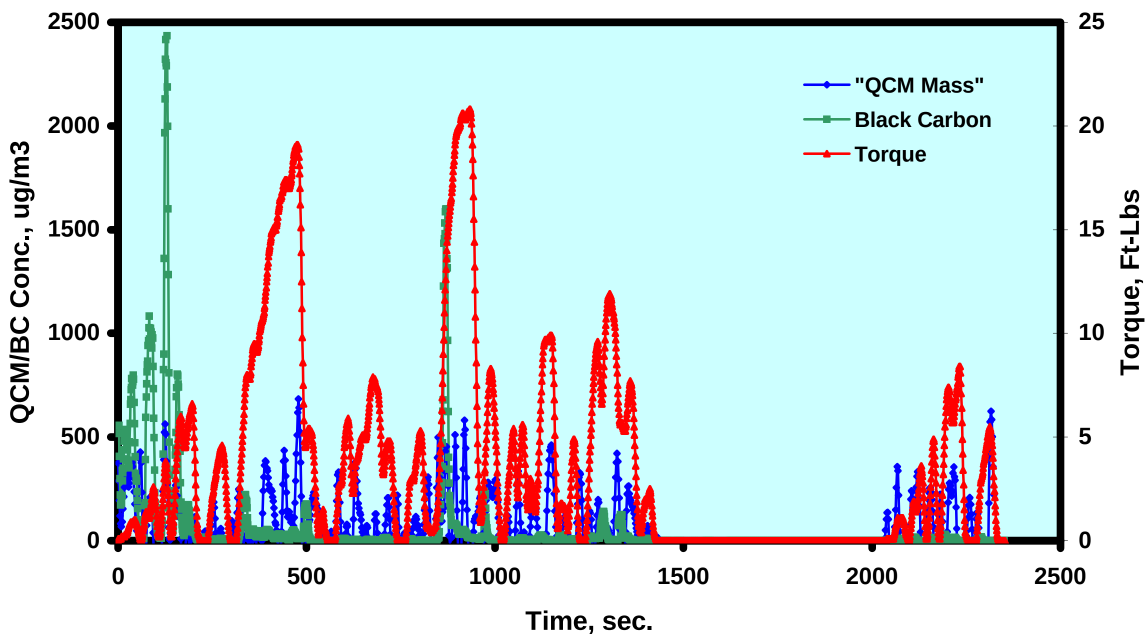


Figure 4-91. Example of Reduced Data for Round 2.

One of the principle differences that can be noted in these examples is the increase in particulate emissions during the winter months. This is particularly true for the cold start (Phase 1) portion of the tests.

4.5.3.3 Comparison of QCM Versus Time-Integrated Gravimetric Mass Measurements

4.5.3.3.1 Round 1 Comparison

Averages of the integral emission rate data from the summary file are presented in Table 4-33. These results reflect the systematic reduction of emissions for the newer categories of vehicles. The table provides a summary of emission rates for each phase of the Unified Test Cycle for both the QCM and the Gravimetric Filter results. The table also lists the composite emission rate from the same calculation as that used for the FTP Cycle. It should be noted that, with the exception of Pre-1981 Cars, the QCM reports a higher emission rate than the gravimetric filter. Also the emission rate for the Pre-1981 Trucks are also shown to be less than the Pre-1981 Cars.

Table 4-33. Average Emission Rates for Round 1 in mg/mile Derived from QCM and Gravimetric Filter Measurements for all Test Phases.

Vehicle	QCM Emission Rates (mg/mi)			Grav Emission Rates (mg/mi)		
Year	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3
TRUCKS						
1970-1980	62.03	50.65	22.58	87.80	45.05	9.14
1981-1990	44.23	16.74	17.20	93.80	37.65	51.05
1991-1995	18.92	8.09	11.89	14.48	11.13	14.41
1996-2005	13.20	4.53	3.44	9.58	4.01	2.33
CARS						
1970-1980	202.96	15.16	33.18	160.77	73.09	63.73
1981-1990	32.95	23.87	18.18	35.02	18.94	8.79
1991-1995	16.28	6.94	7.02	11.43	7.54	5.08
1996-2005	14.98	3.29	2.96	7.40	2.48	1.80

4.5.3.3.2 Round 2 Comparison

Averages of the integral emission rate data from the summary file for Round 2 are presented in Table 4-34. These results reflect the systematic reduction of emissions for the newer categories of vehicles. The table provides a summary of emission rates for each phase of the Unified Test Cycle for both the QCM and the Gravimetric Filter results. The table also lists the composite emission rate from the same calculation as that used for the FTP Cycle.

Table 4-34. Average Emission Rates for Round 2 in mg/mile Derived from QCM and Gravimetric Filter Measurements for all Test Phases.

Vehicle	QCM Emission Rates (mg/mi)			Grav Emission Rates (mg/mi)		
Year	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3
TRUCKS						
1970-1980	139.04	39.79	22.27	281.33	101.70	28.12
1981-1990	104.91	20.83	21.37	210.94	31.43	22.16
1991-1995	38.25	16.28	10.95	40.05	19.13	5.22
1996-2005	33.33	8.38	7.51	40.84	6.02	3.26
CARS						
1970-1980	74.95	9.71	9.52	361.73	42.34	14.31
1981-1990	71.68	16.01	14.07	114.81	23.86	13.68
1991-1995	42.20	16.00	7.67	55.06	16.25	6.70
1996-2005	29.67	9.31	3.92	46.88	6.20	4.21

4.5.3.4 Average QCM-measured concentrations relative to vehicle speed emissions

4.5.3.4.1 Round 1

Figures 4-92 through 4-97 display the average continuous Round 1 CVS concentrations measured using the QCM for four categories (BINS) each of trucks and cars tested for Phases 1, 3, and 2 of the test cycle. A nominal dynamometer speed trace is included in each figure for reference. Only vehicle tests for which no void or partial void was noted during reduction of the data were included in the averages. Consequently, these results should be considered as censured.

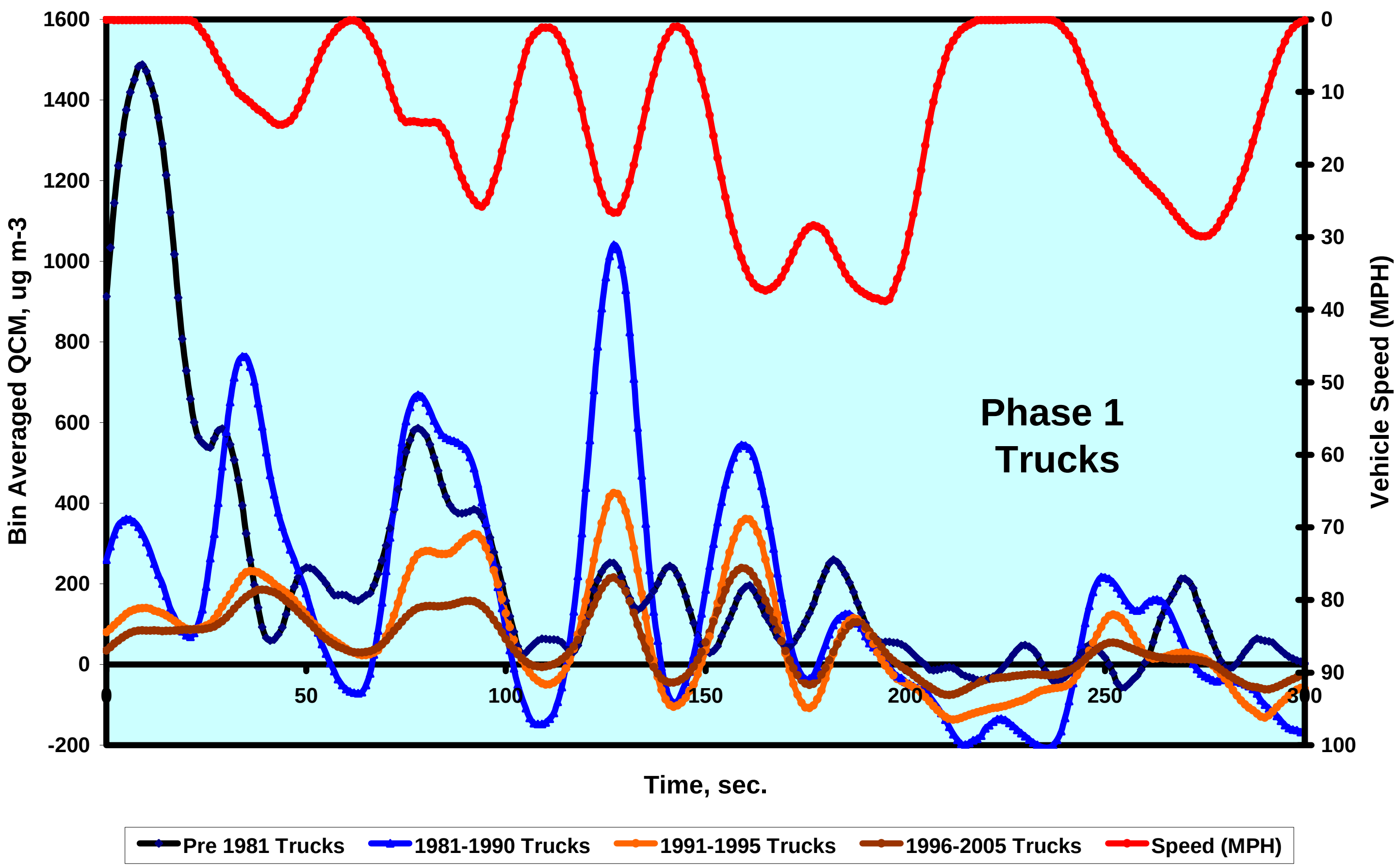


Figure 4-92 Round 1 Averaged CVS Particulate Mass Concentrations - QCM Phase 1 Trucks.

It will be noticed in this and subsequent figures that the QCM consistently reports negative concentrations during parts of the various test cycle components. This should not be considered a flaw in the instrument but rather an indication that volatile components of particulate collected during accelerations and high-speed portions of the test cycle are desorbing from the collected particulate. This is a phenomena that is common to collected vehicle emissions particulate but not accounted for in integral filter measurements.

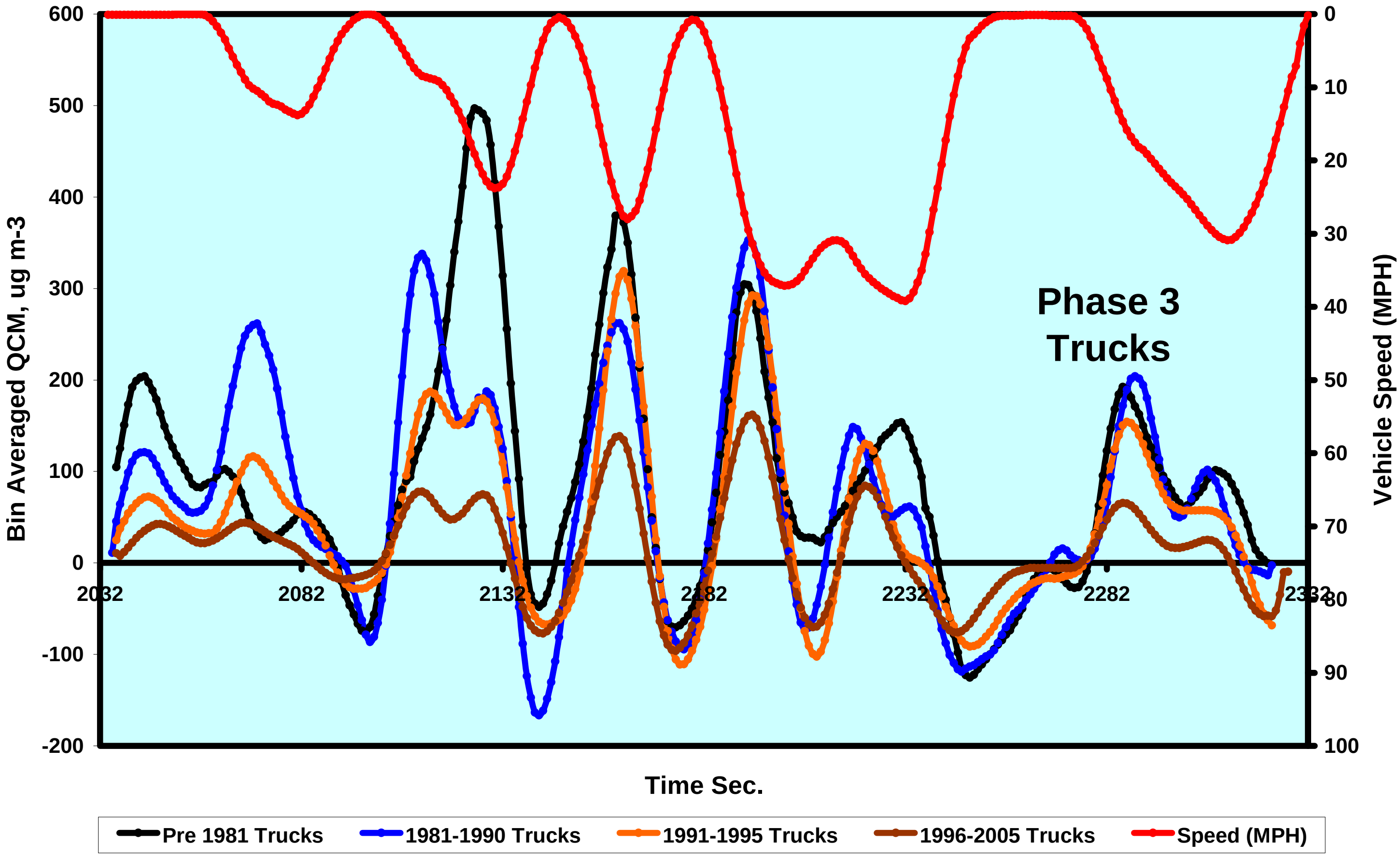


Figure 4-93 Round 1 Averaged CVS Particulate Mass Concentrations - QCM Phase 3 Trucks.

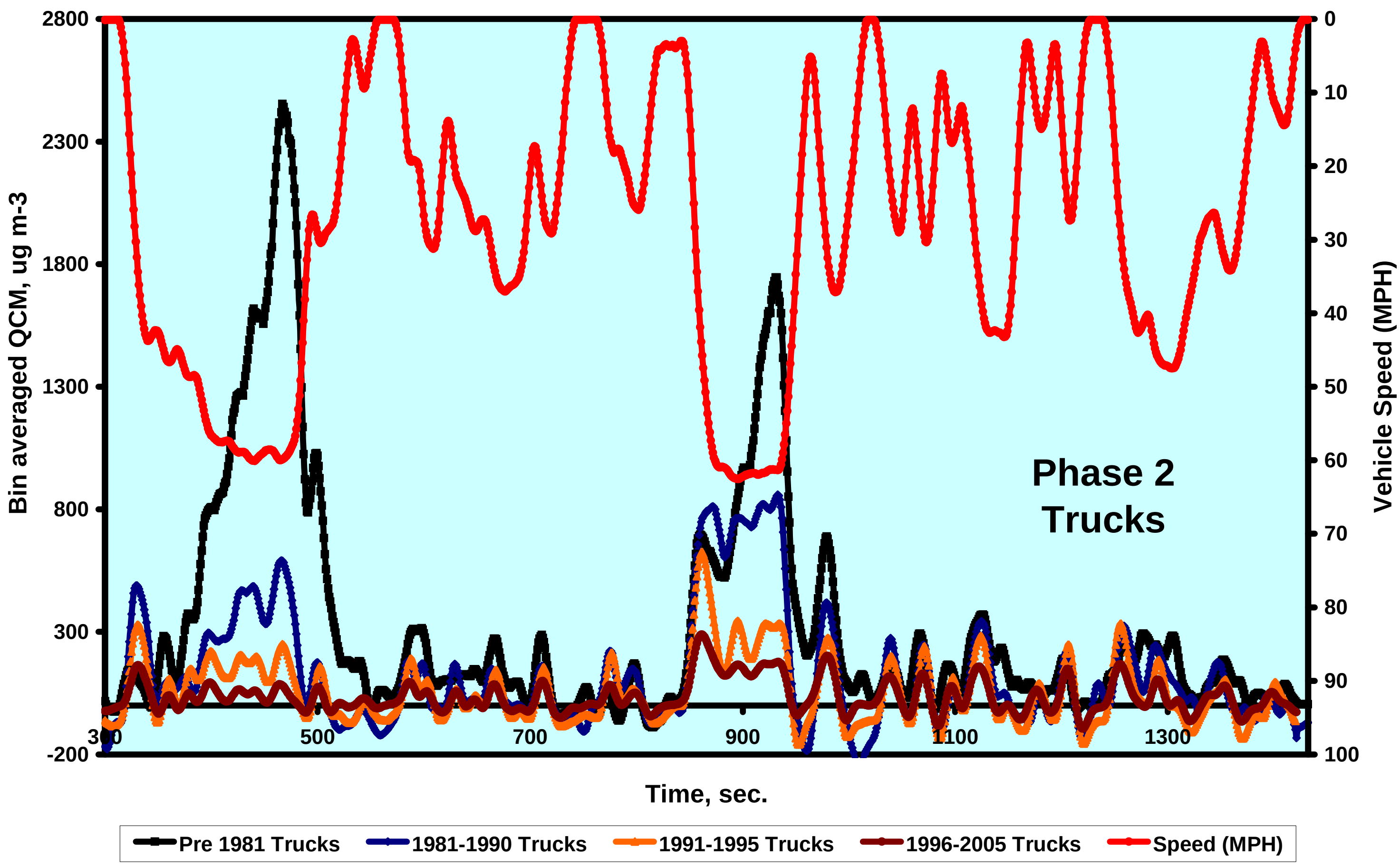


Figure 4-94 Round 1 Averaged CVS Particulate Mass Concentrations - QCM Phase 2 Trucks.

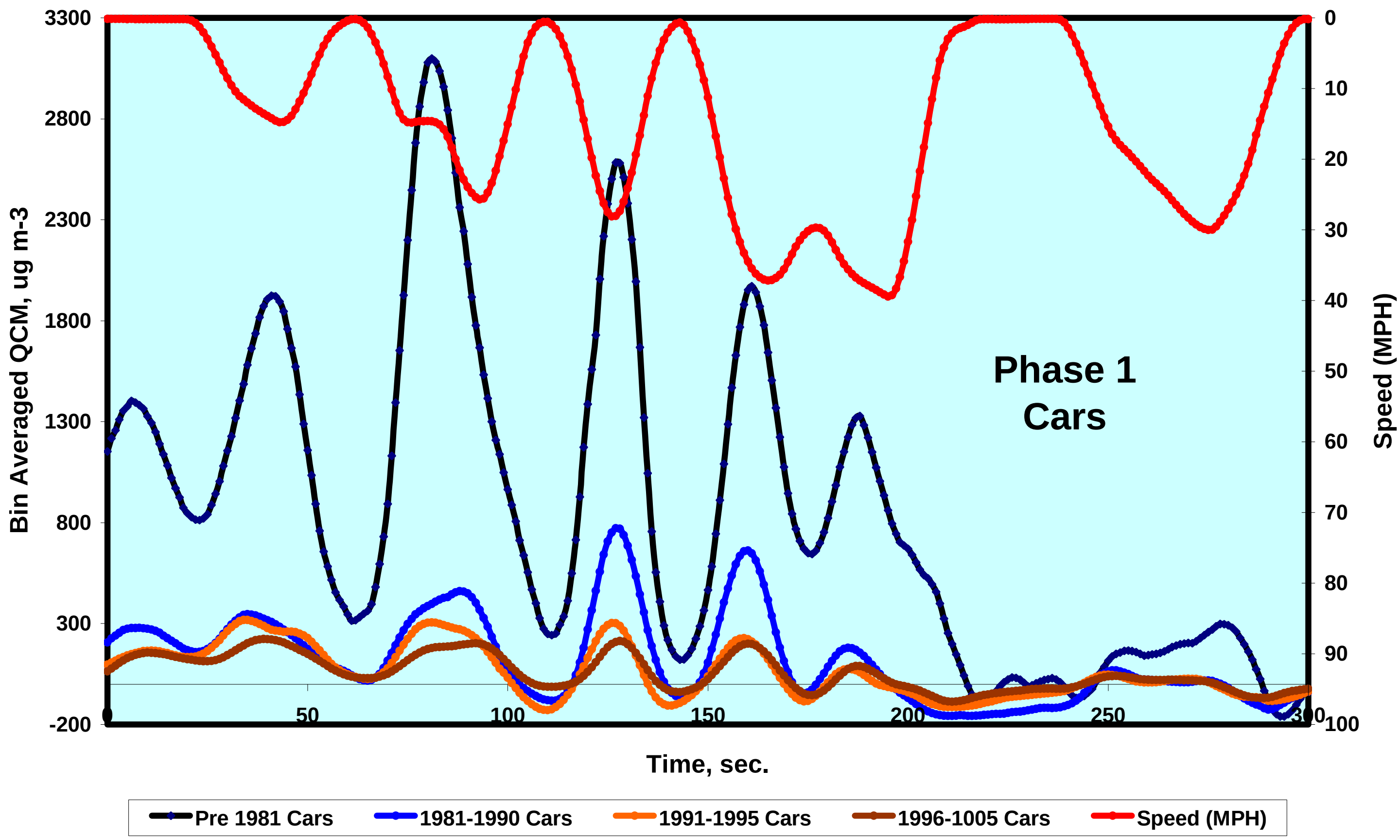


Figure 4-95 Round 1 Averaged CVS Particulate Mass Concentrations - QCM Phase 1 Cars.

It should be noted that the Pre-1981 Car concentrations are much higher than the comparable results for Pre-1981 Trucks. Even though only two trucks were tested in this category, it would seem that the older trucks are better taken care of than older cars.

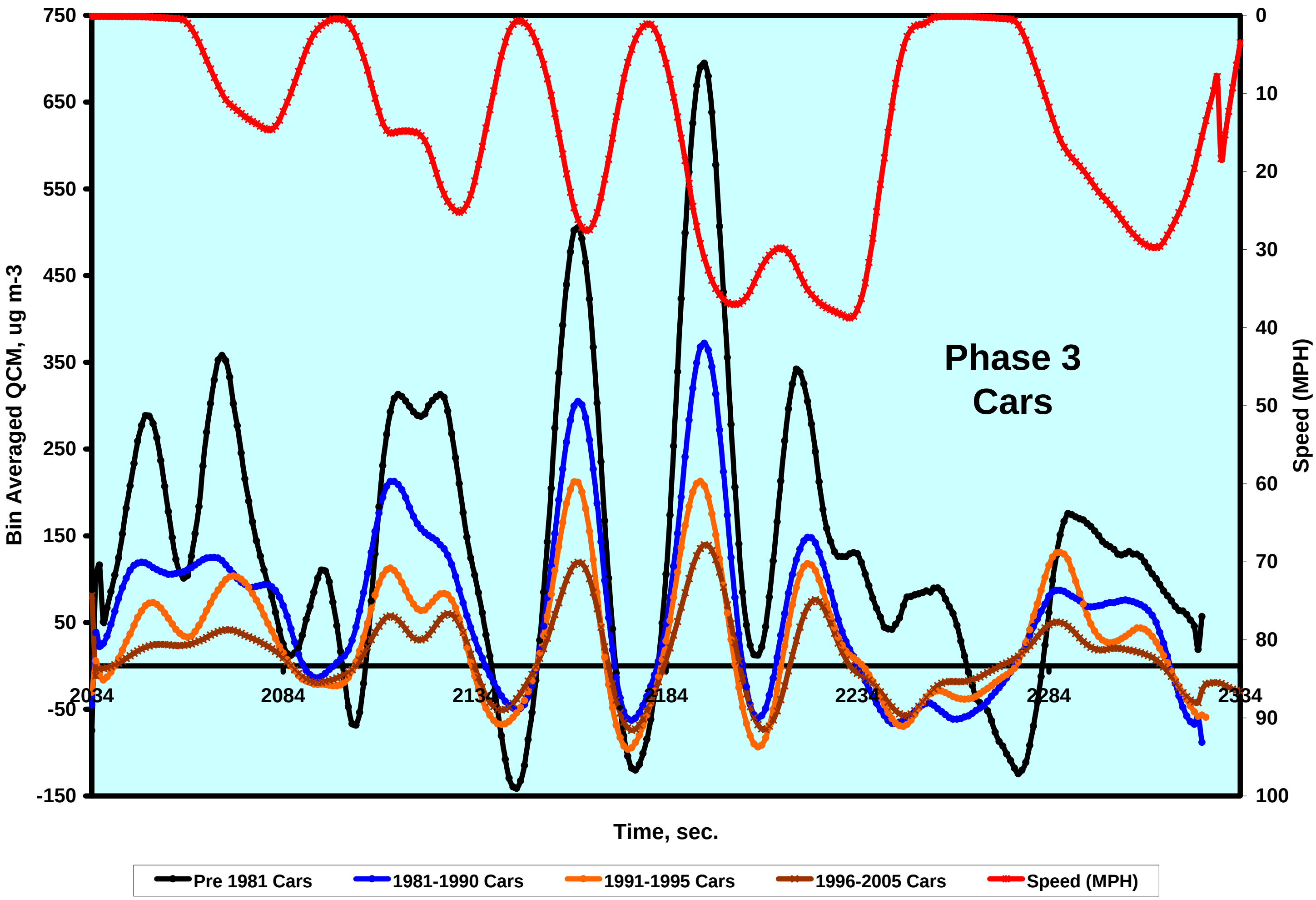


Figure 4-96 Round 1 Averaged CVS Particulate Mass Concentrations - QCM Phase 3 Cars.

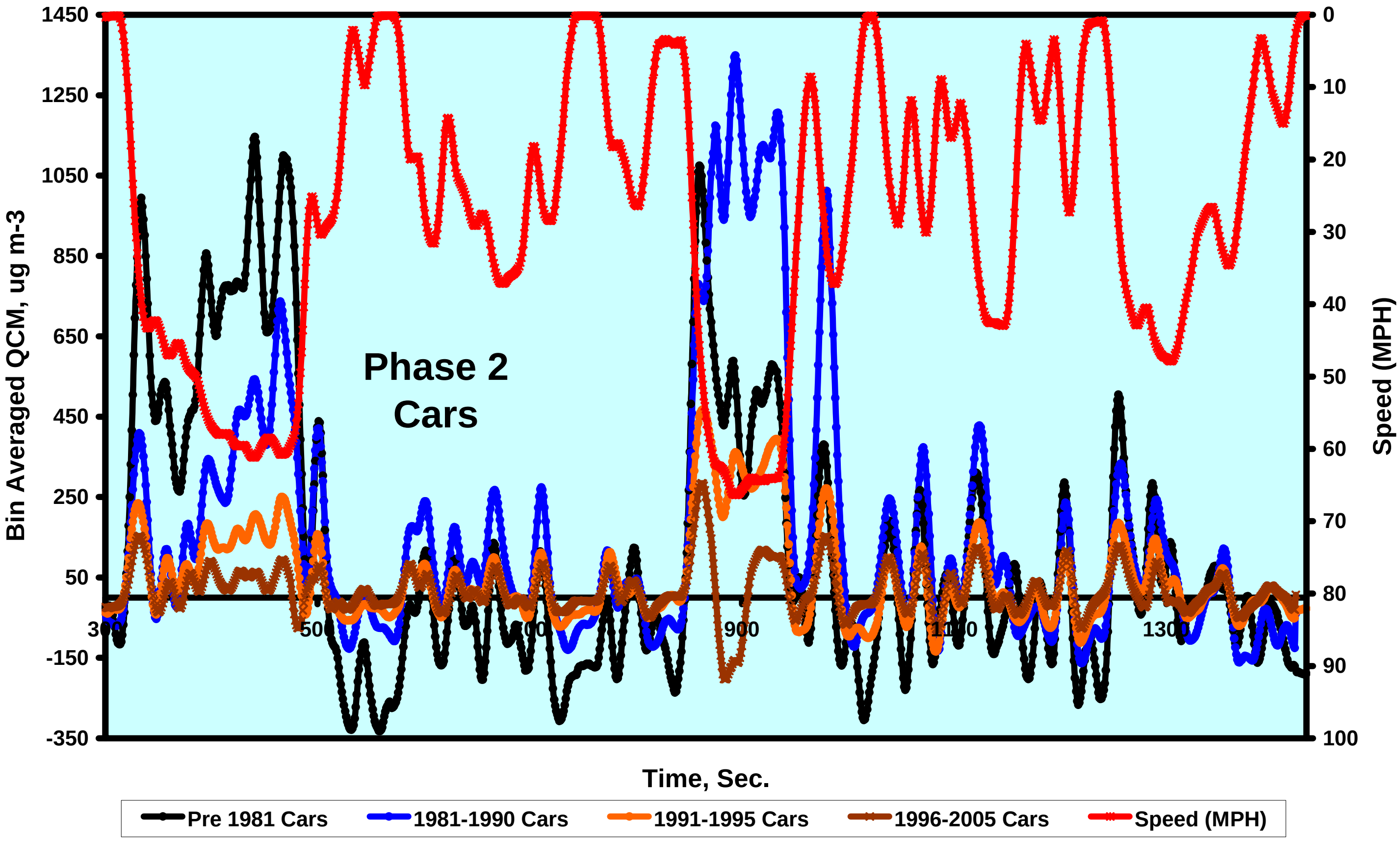


Figure 4-97. Round 1 Averaged CVS Particulate Mass Concentrations - QCM Phase 2 Cars.

In all the figures, a systematic reduction in measured concentrations can be noted for the newer categories of vehicles.

4.5.3.4.2 Round 2

Figures 4-98 through 4-103 display the average continuous Round 2 CVS concentrations measured using the QCM for four categories (BINS) each of Trucks and Cars tested for Phases 1, 3, and 2 of the test cycle. Only vehicle tests for which no void or partial void was noted during reduction of the data were included in the averages. Consequently, these results should be considered as censured.

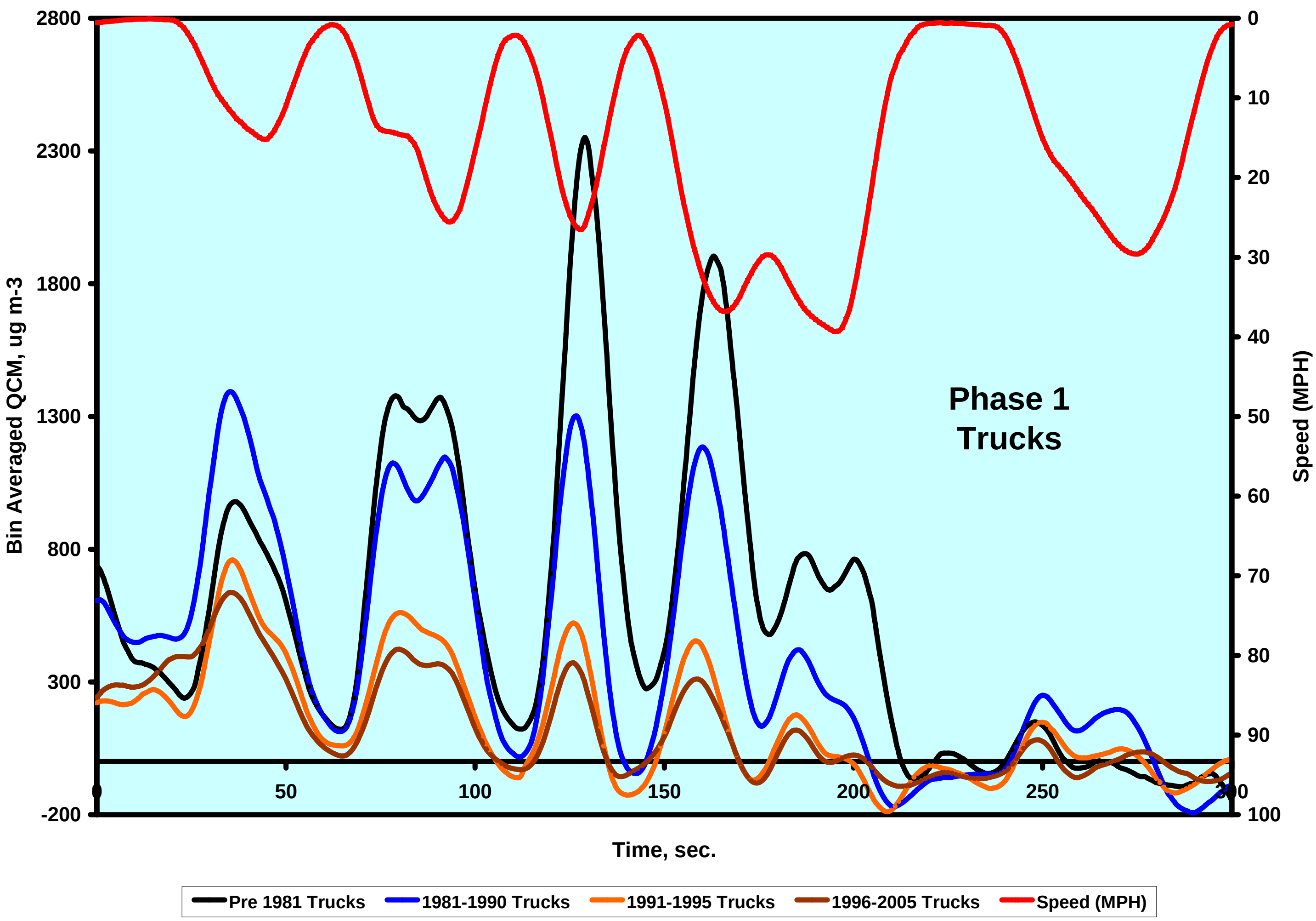


Figure 4-98 Round 2 Averaged CVS Particulate Mass Concentrations - QCM Phase 1 Trucks.

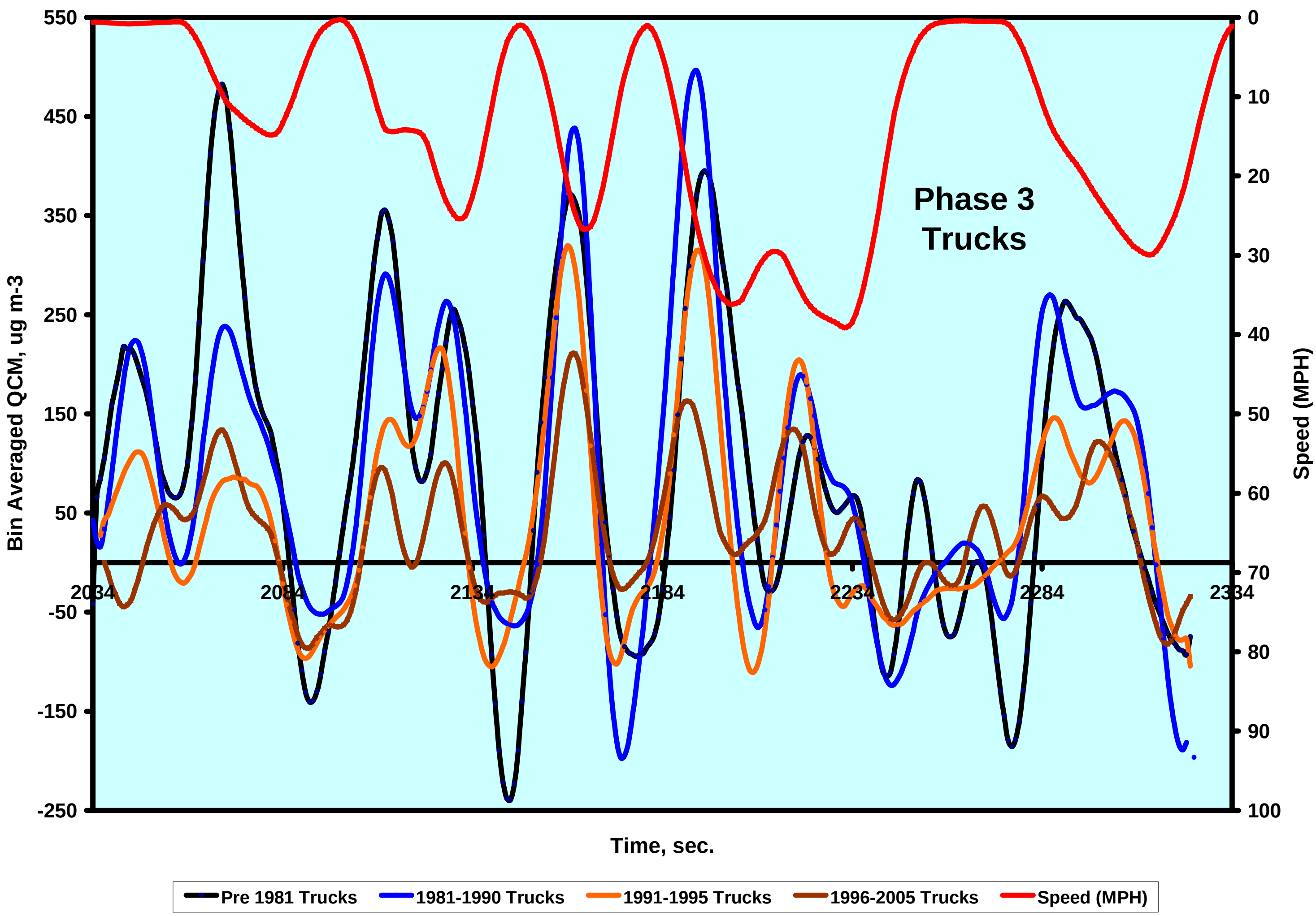


Figure 4-99 Round 2 Averaged CVS Particulate Mass Concentrations - QCM Phase 3 Trucks.

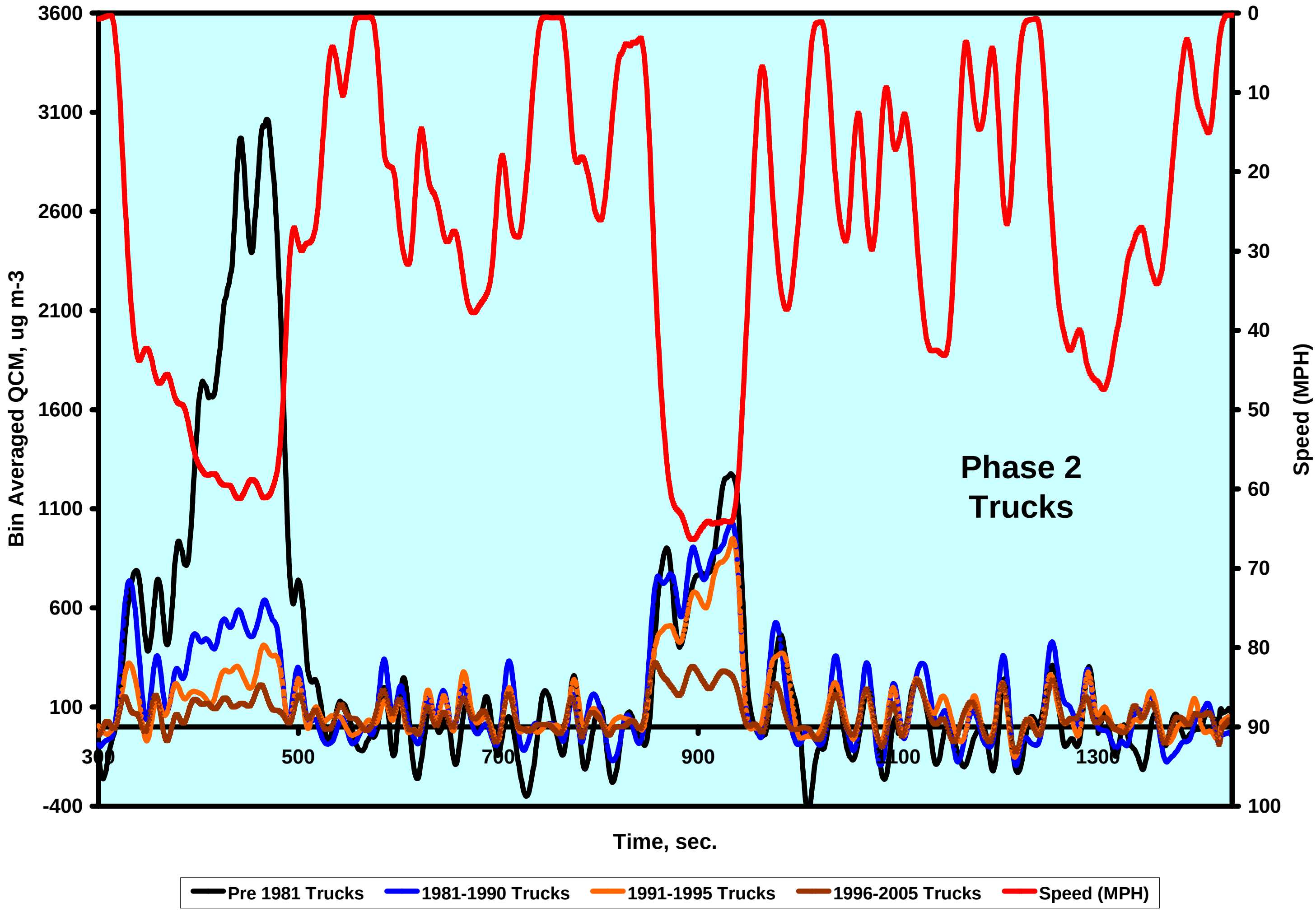


Figure 4-100 Round 2 Averaged CVS Particulate Mass Concentrations - QCM Phase 2 Trucks.

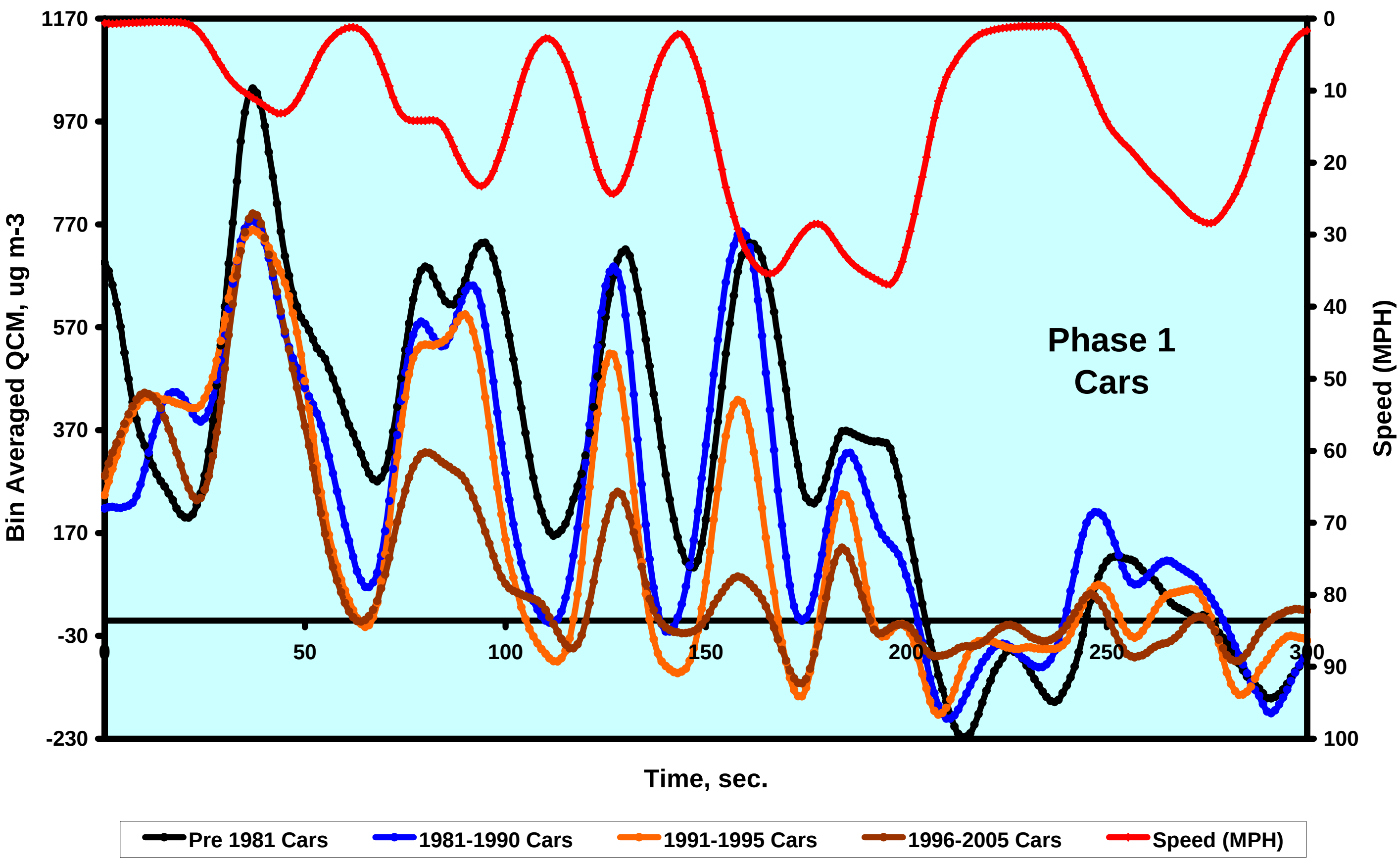


Figure 4-101 Round 2 Averaged CVS Particulate Mass Concentrations - QCM Phase 1 Cars.

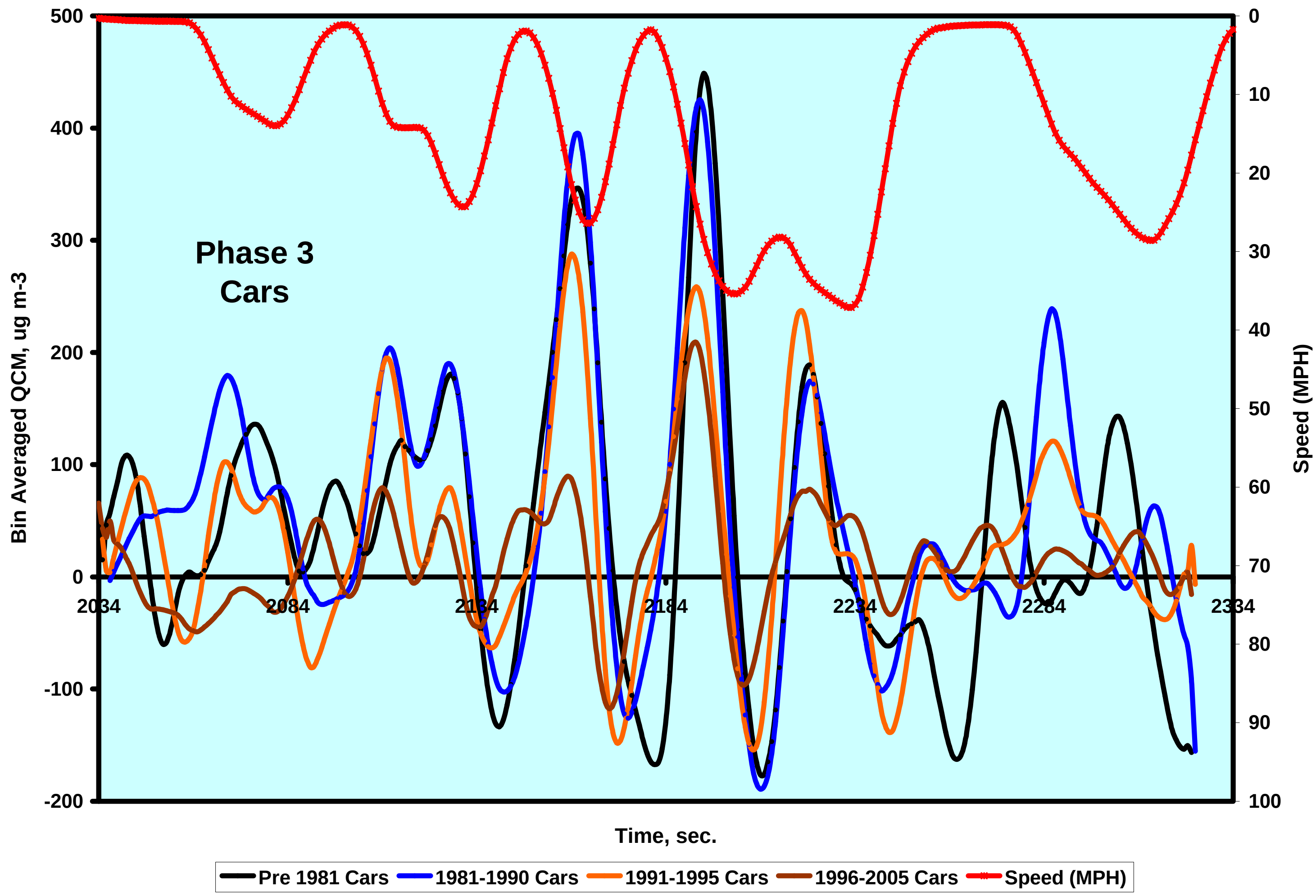


Figure 4-102 Round 2 Averaged CVS Particulate Mass Concentrations - QCM Phase 3 Cars.

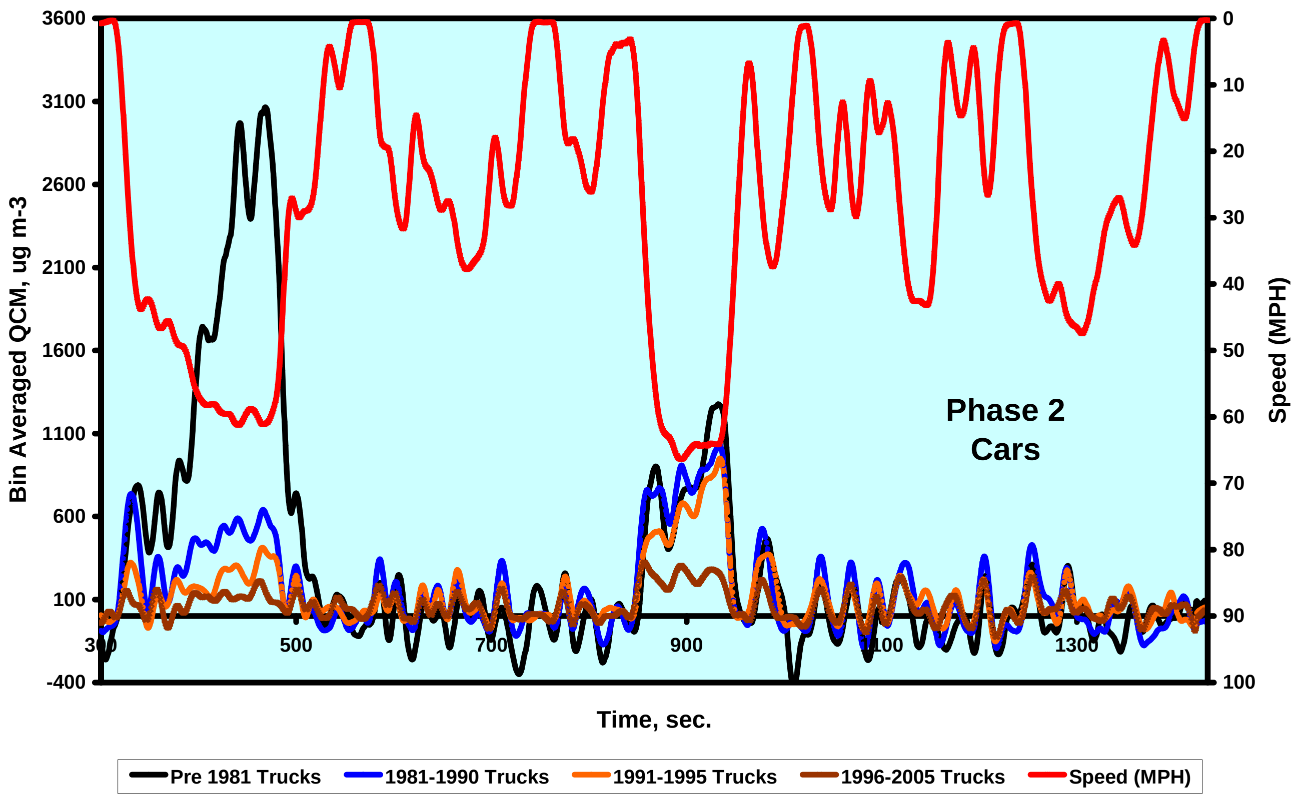


Figure 4-103 Round 2 Averaged CVS Particulate Mass Concentrations - QCM Phase 2 Cars.

4.5.3.5 Evaluation of Continuous Optical Mass Measurements

Figure 4-104 shows scatter plots of time averaged DustTrak and Mie DataRAM4 phase averaged data (i.e. each point represents a time average from phase 1, 2, or 3 of the unified cycle). Note that for mass concentrations below 250 µg m^{-3} relative agreement is found among these instruments as illustrated in Figure 4-104a. However, much more scatter occurs for high mass concentrations as shown in Figure 4-104b. Finally, Figure 4-104b shows that the DataRAM4 values are much in excess of those of the DustTrak. The DataRAM4 manufacturer states an upper range for the instrument of 400,000 µg m^{-3}, though a recent email correspondence with an expert (Wayne Harmon, 2004) on the instrument from the company that manufactures it is quoted here: "For vehicles with high emission, it may be necessary to dilute the air sample. The background will become slightly elevated due to contamination if high concentrations (above 20 mg m^{-3}) are sampled for an hour or more." Notice that 20 mg m^{-3} is 20,000 ug m^{-3}, well below the stated upper range of the instrument.

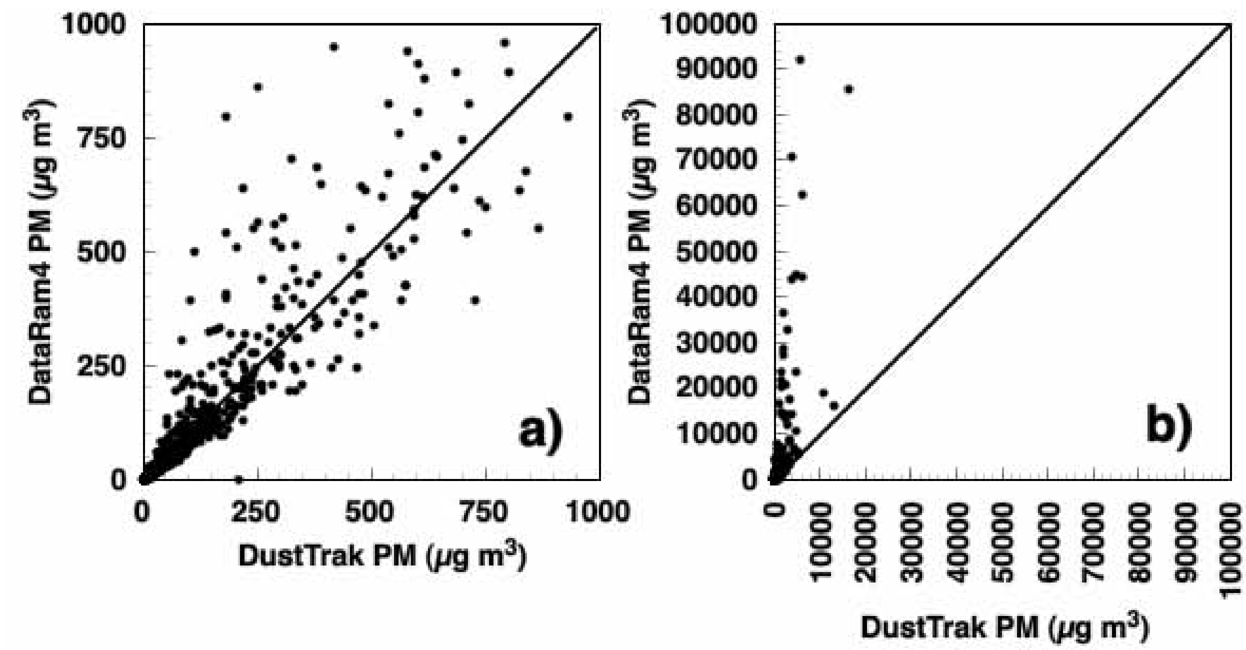


Figure 4-104. PM data from the DustTrak and DataRAM4 for a) low and b) high range.

Which nephelometer is closer to the "actual value" of aerosol-mass concentration? To answer this question one needs to keep in mind that aerosol mass concentration is a fleeting quantity. Change the air temperature or gaseous composition and the gas to particle phase partition is upset. When we capture particles on a filter and gases may also adsorb onto the particles and filter. Figure 4-105 shows the comparison of gravimetric mass with nephelometer mass for phase averaged data. Note in Figures 4-105a and 4-105b that both nephelometers produce values much larger than gravimetric mass for very high values of mass, though the DustTrak is closer to gravimetric mass than is the DataRAM4. Over the lower range shown in Figures 4-105c and Figure 4-105d much scatter is noted between nephelometer mass and gravimetric mass, and that the DT and DR have about the same amount of scatter. It is likely that variations in particle size and composition, and uncertainty in gravimetric mass give rise to the scattering seen in Figure 4-105.

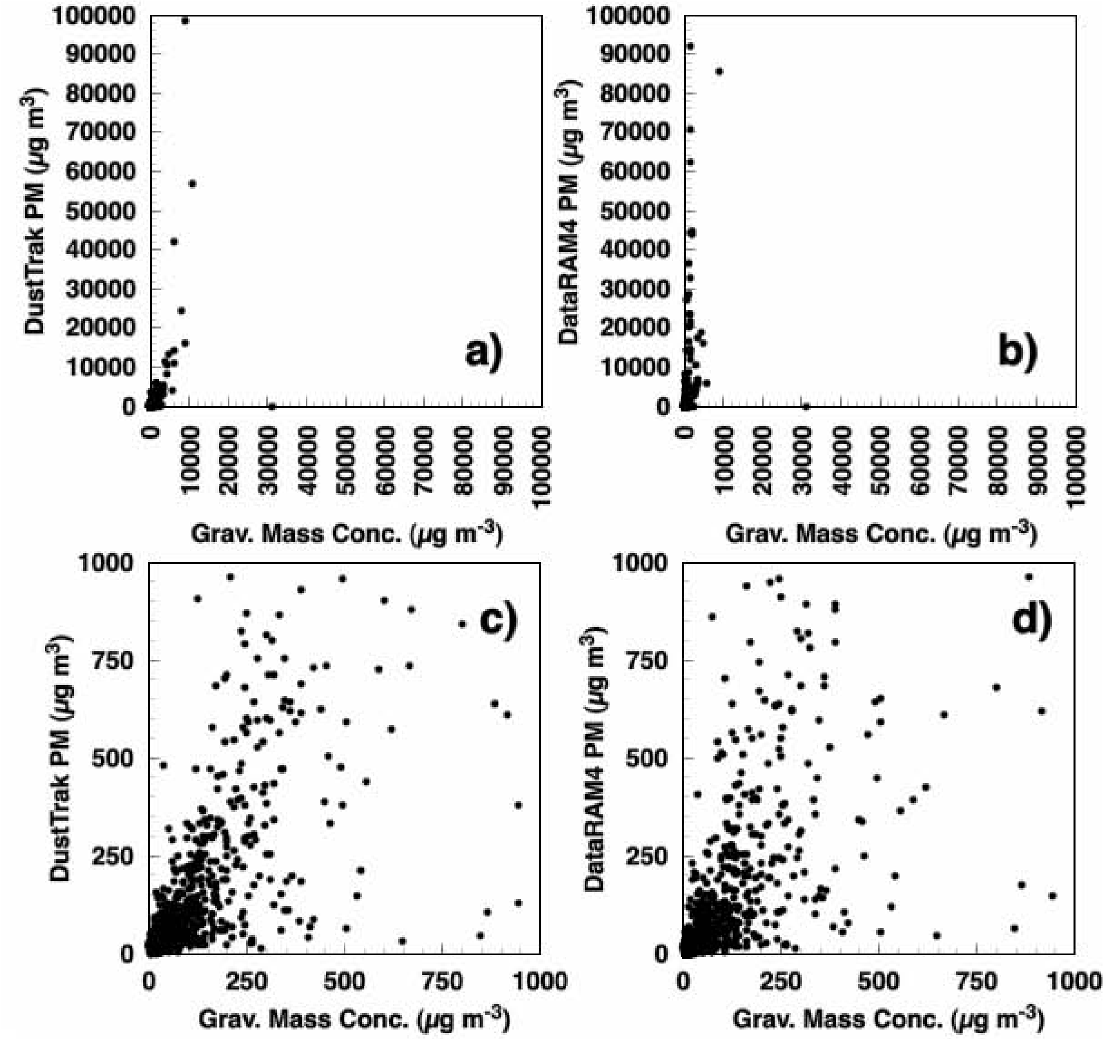


Figure 4-105. Scatter plots of gravimetric mass and nephelometer mass for the DustTrak and DataRAM4. Wide range in a) and b) and a lower narrower range in c) and d).

Figure 4-106 shows histograms of emission rates computed from DustTrak and DataRAM4 nephelometer measurements of PM averaged over Phases 1 through 3 of the unified cycle. It was necessary to use a logarithmic plot because the emission rates in the smallest bin, 0-20 mg/mile, dominate all other measurements. Note that the DataRAM4 indicates considerably more instances of very large emission rates than does the DustTrak. The gross shapes of the distributions are similar.

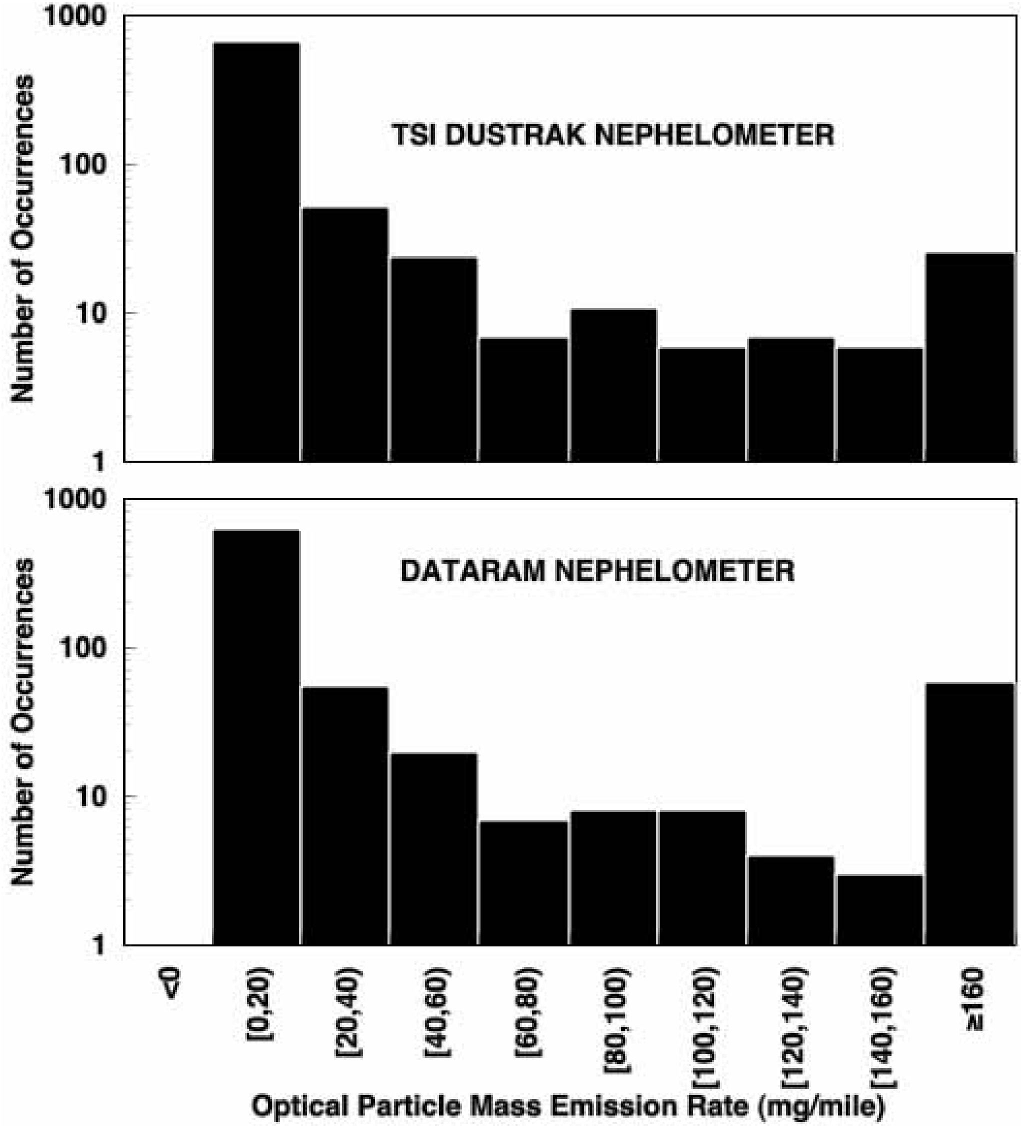


Figure 4-106. Histograms of optical PM obtained with the TSI DustTrak and DataRAM4 nephelometers.

(The DataRAM4 histogram has more cases of very high emitters than does the DustTrak or other samplers. Each car and each phase are counted as a single occurrence of data for a total of 250 cars times 3 Phases per car.)

Figure 4-107 shows a histogram of the number of occurrences of different BC emission rates. It has a form similar to the DT and DR emission rate histograms shown in Figure 4-106. The average BC emission rate was 4 mg/mile, and the average PM emission rate computed from the DustTrak data was 34 mg/mile. If all of the DustTrak PM is considered to be carbonaceous, then the ratio of BC to PM is around 1/9. The inset table shows average BC and PM emission rates from the phase 1 data set. Figure 4-108 shows histograms of the ratio of BC to PM, with PM obtained from the DT and DR nephelometers, and with gravimetric mass. Figure 4-108a is the most reasonable representation of this ratio. Most spark ignition PM is known to be OC and most PM is associated with total carbon (TC=OC + BC). The DataRAM4 produces too many large values of this ratio as shown in Figure 4-108c. The gravimetric mass in Figure 4-108c when used to compute the ratio BC to PM has a very broad unrealistic histogram, with many values greater than unity, and some less than zero. The uncertainty in the gravimetric mass is much greater than that of all the other PM measures. It should be noted that in general, continuous PM measurements (with the exception of the QCM) were primarily used to monitor the state of the dilution tunnel and provide an assessment of the reasonableness of QCM data. These systems were primarily used to assess system and test condition changes, rather than to provide a quantitative assessment of continuous emission rates (as was the intent of using the QCM).

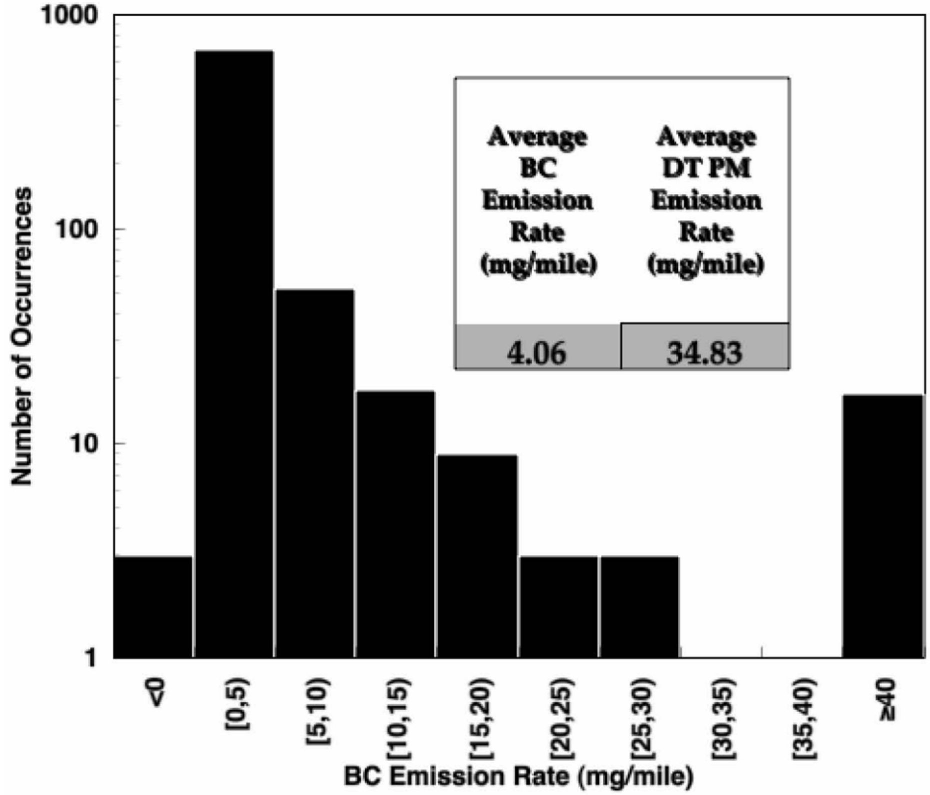


Figure 4-107. Histogram of BC mass emission rate obtained with the DRI photoacoustic instrument.

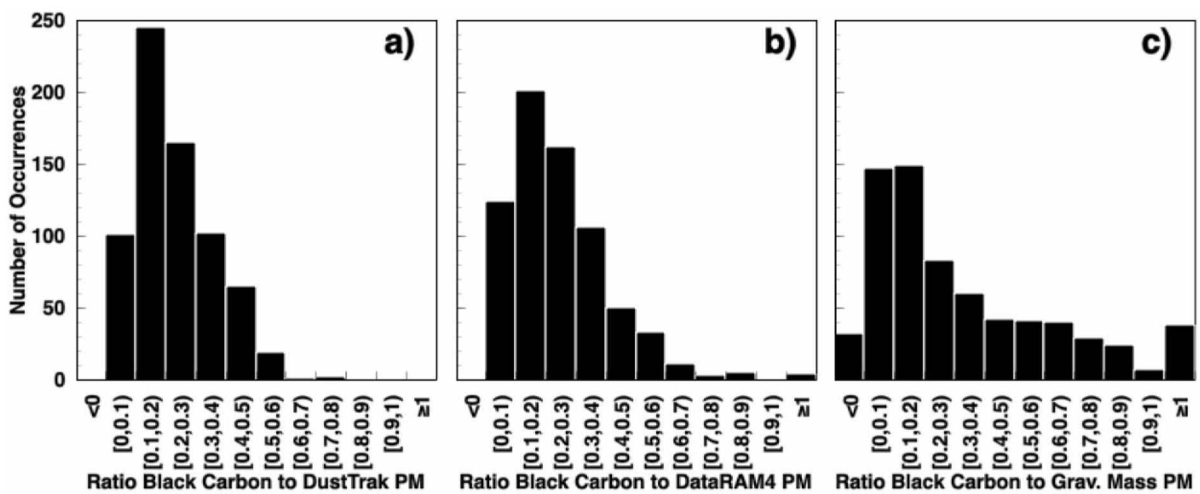


Figure 4-108. Histograms of the ratio BC to total PM

(Total PM from the DustTrak in a), from the DataRAM4 in b), and from the gravimetric mass in c). The vertical scale is the same in each plot. Histograms were developed from phase averaged data, excluding cases where the BC average is less than 2 μg m^{-3}.)

4.5.3.6 Average BC and PM concentrations in each stratum as related to vehicle speed

The utility of continuous measurements of BC and PM are most evident in evaluating the driving conditions that give rise to the bulk of the emissions. Figures 4-109 through 4-116 illustrate the emissions of BC as measured by the photoacoustic instrument, and PM as measured by the DustTrak nephelometer as a function of time. The data are from Round 1 and are averaged by model-year strata for cars and trucks. The vehicle speed profile is also overlain on these plots, and this trace is inverted so that the emissions can readily be seen. To produce the data shown in Figures 4-109 through 4-116, all data were aligned in time to the start of the unified cycle, and interpolated to 1-second steps. The captions document the data in detail, though some highlights are given here. Figure 4-109 is typical of the comparison of Phases 1 and 3 of the unified cycle. Phase 1 commences after a cold start of the vehicle, and phase 3 after a warm start. The vehicle speed profile is the same for these phases. Since Figures 4-109 through 4-116 are only intended to illustrate relative emission rate changes as measured by these different systems, they are only provided for Round 1. However, continuous emission rate measurement results as measured using the different instruments are provided in Tables 4-35 though 4-37 for both Rounds of the study.

Phase 1 emission rates are generally higher than those of phase 3 for all classes of vehicles, though the older vehicles have more emissions at all times. Phase 1 emissions from newer vehicles are associated with accelerations, decelerations, as well as higher speed driving, whereas phase 3 emissions from newer vehicles are mostly closely associated with accelerations. Phase 2 emissions from both cars (Figure 4-111) and trucks (Figure 4-112) are dominant during the high acceleration portion of the driving cycle before time 900 seconds.

Emission rates for each phase of the unified cycle, for each stratum of vehicles model year ranges, for BC and total particle mass (PM) are given in Tables 4-35 through 4-37. PM obtained from the DustTrak nephelometer are indicated by “DT” and those from the DataRAM4 are given by “DR”. Note that BC emission rates generally decrease from older to newer vehicles, though because the class of older trucks (pre 1980) was only represented by 2 vehicles the averages are highly uncertain. Note that BC and DT PM emission rates were highest (for cars) during phase 1, though phase 2 and 3 values were similar. Note that emission rates computed from the DataRAM4 (DR) are usually way in excess of those obtained with the DustTrak, except for those cases of low emission rates. The DataRAM4 seems to have a problem with high concentrations where it seems some optics get dirty, and this adds a scattering amount that gets interpreted erroneously as PM.

Note the interesting truck values for the 1970-1980 stratum. The BC emission rates were very high for this category in phase 1, though were much lower once the vehicles warmed up in Phases 2 and 3. Since this supplemental analysis was only performed as a cross-check, emission rates were computed based on nominal miles driven, on the average, during each phase, and from the nominal sample volume pulled through the constant volume sampler. The uncertainty introduced by using nominal values is likely around 20%. Phase 1, 2, and 3 miles driven were taken to be 1.18 miles, 8.6 miles, and 1.18 miles. The flow volume was 71.75 m^3 for Phases 1 and 3, and 267.8 m^3 for phase 2.

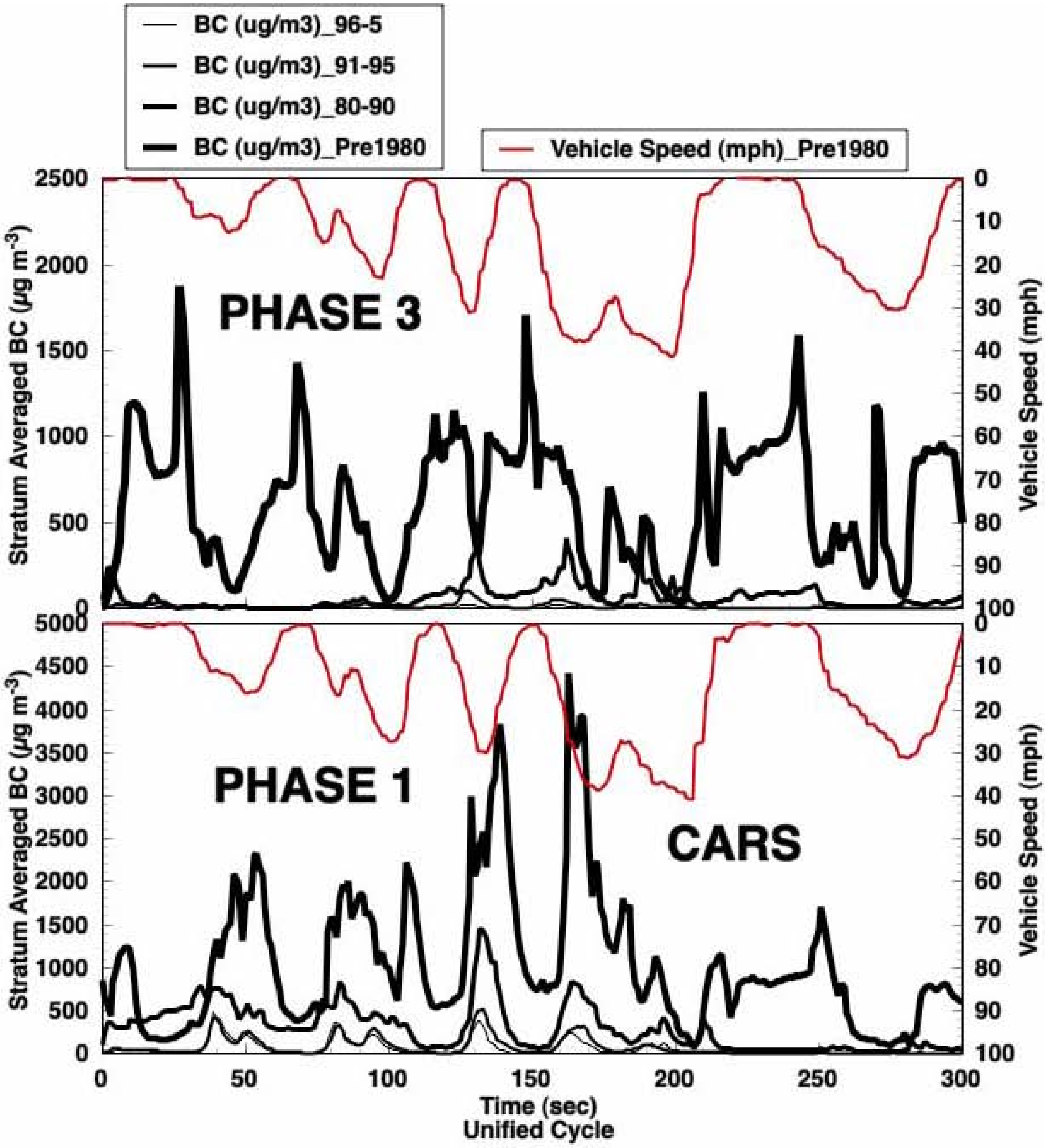


Figure 4-109. Stratum averaged BC emission for passenger cars as it relates to vehicle speed.

(Phase 1 is associated with a cold start of the vehicles, and Phase 3 is an identical driving cycle but one that follows a warm start after an 8 minute soak period. Note that newer cars have much less emission in Phase 3.)

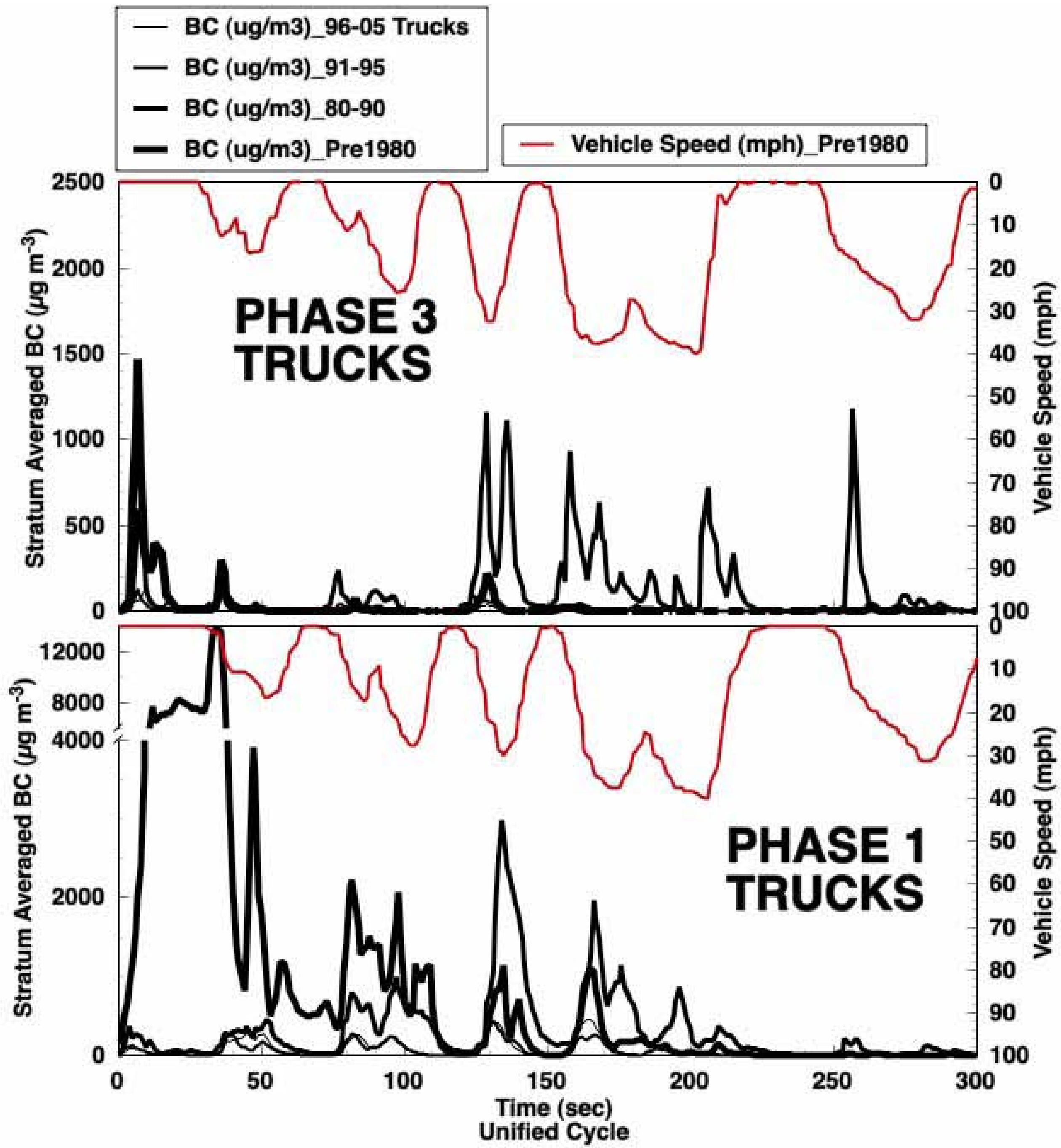


Figure 4-110. Stratum averaged BC emission for trucks as it relates to vehicle speed.

(Note the high emissions during Phase 1 of the oldest truck, and that it is much less in phase 3, illustrating that the warm vehicle emission rates are much lower. Note that there were only 2 trucks in that category. Cleaner trucks behave as cleaner cars.)

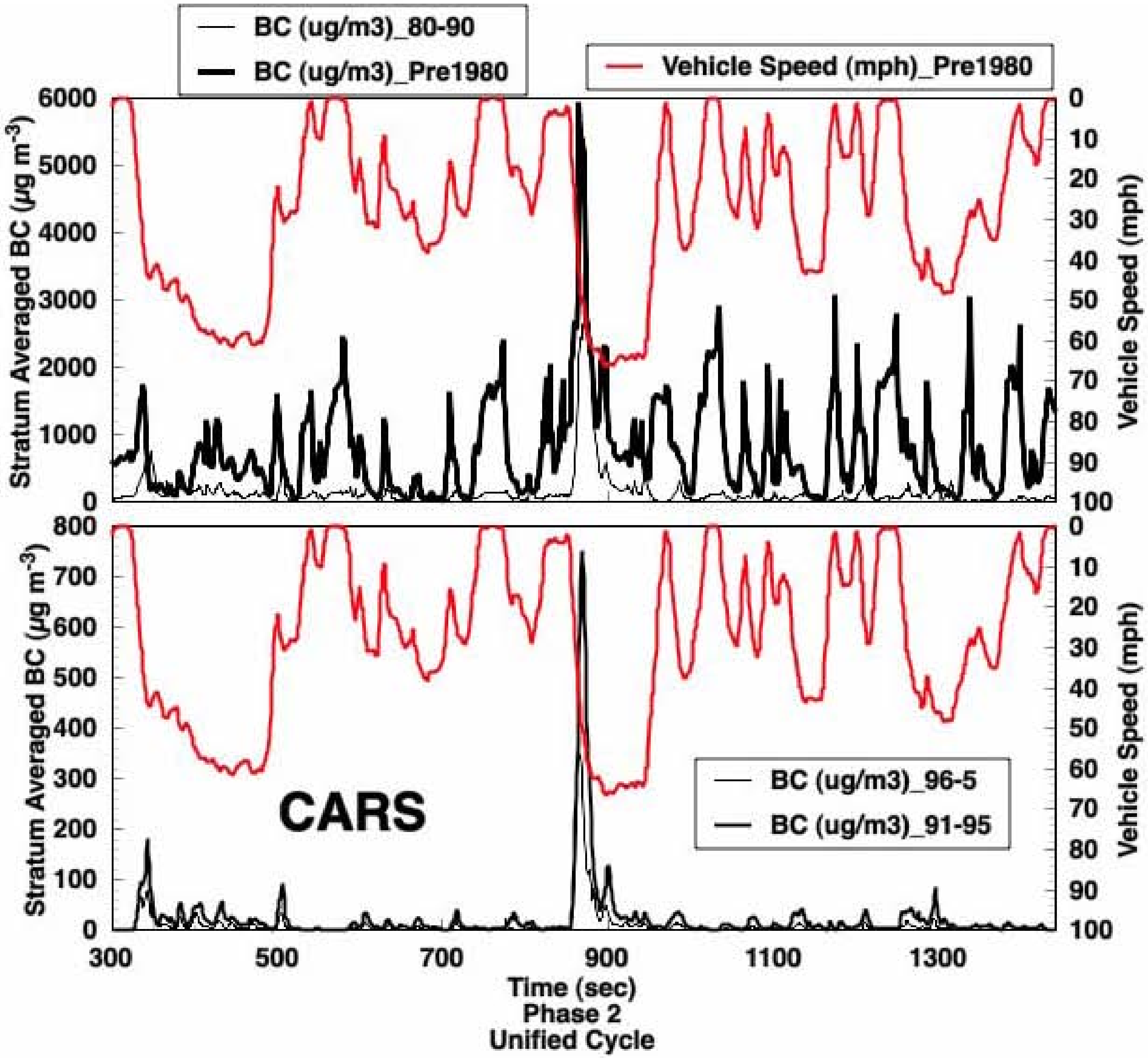


Figure 4-111. BC emissions during phase 2 of the unified cycle for passenger cars

(For newer (lower graph) and older (upper graph) vehicles. Note that BC emissions peak during the aggressive acceleration in about the middle portion of the cycle right before 900 seconds. Note in the upper graph that the oldest category of vehicles had high emission on both accelerations as well as decelerations.)

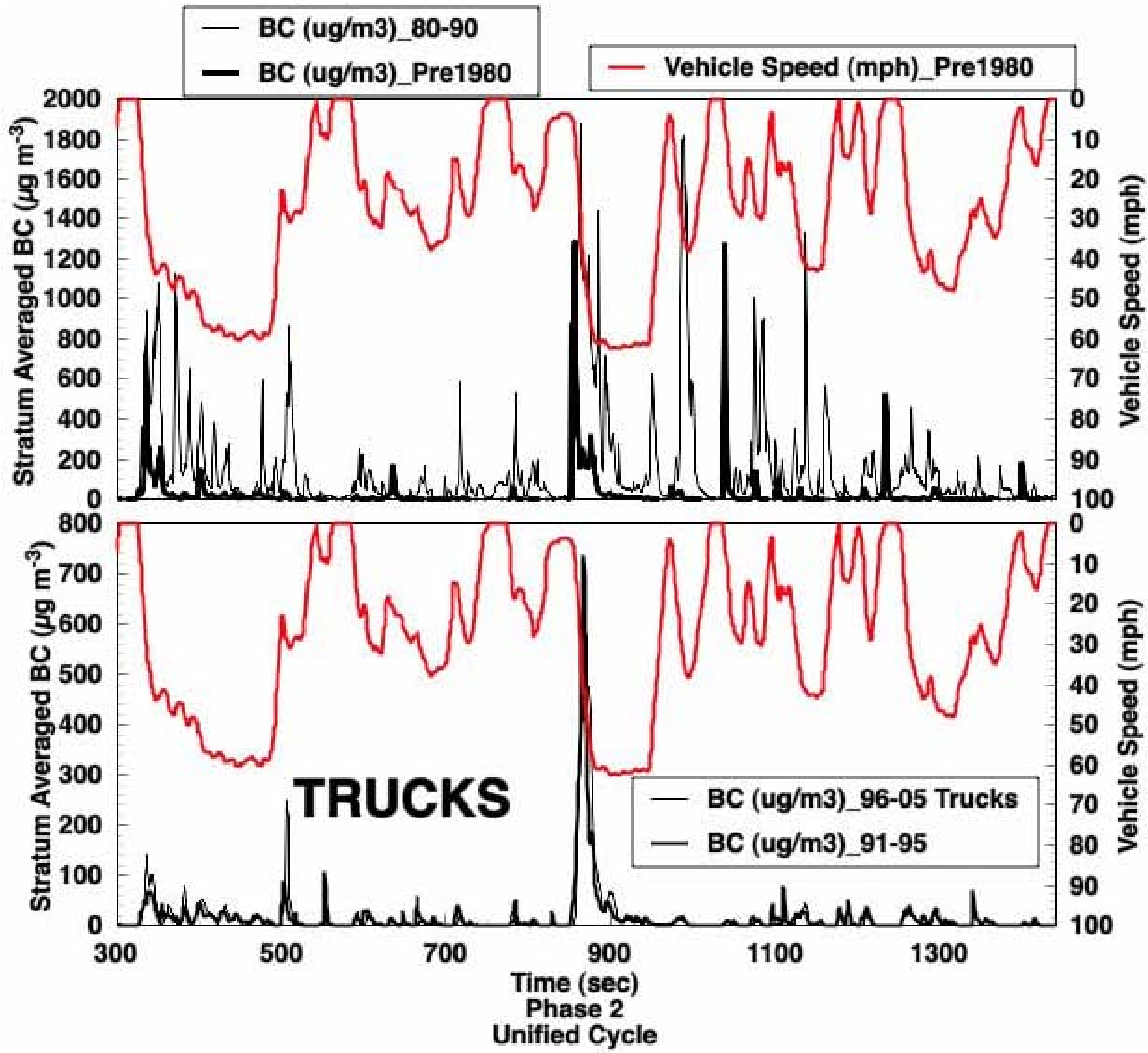


Figure 4-112. BC emissions during phase 2 of the unified cycle for trucks

(Note that in comparing the older cars and trucks that the older trucks had less emission during Phase 2 than did the cars. This could be an artifact of the sample size, though it does point out that older vehicles, when warmed up, can have modest emission rates.)

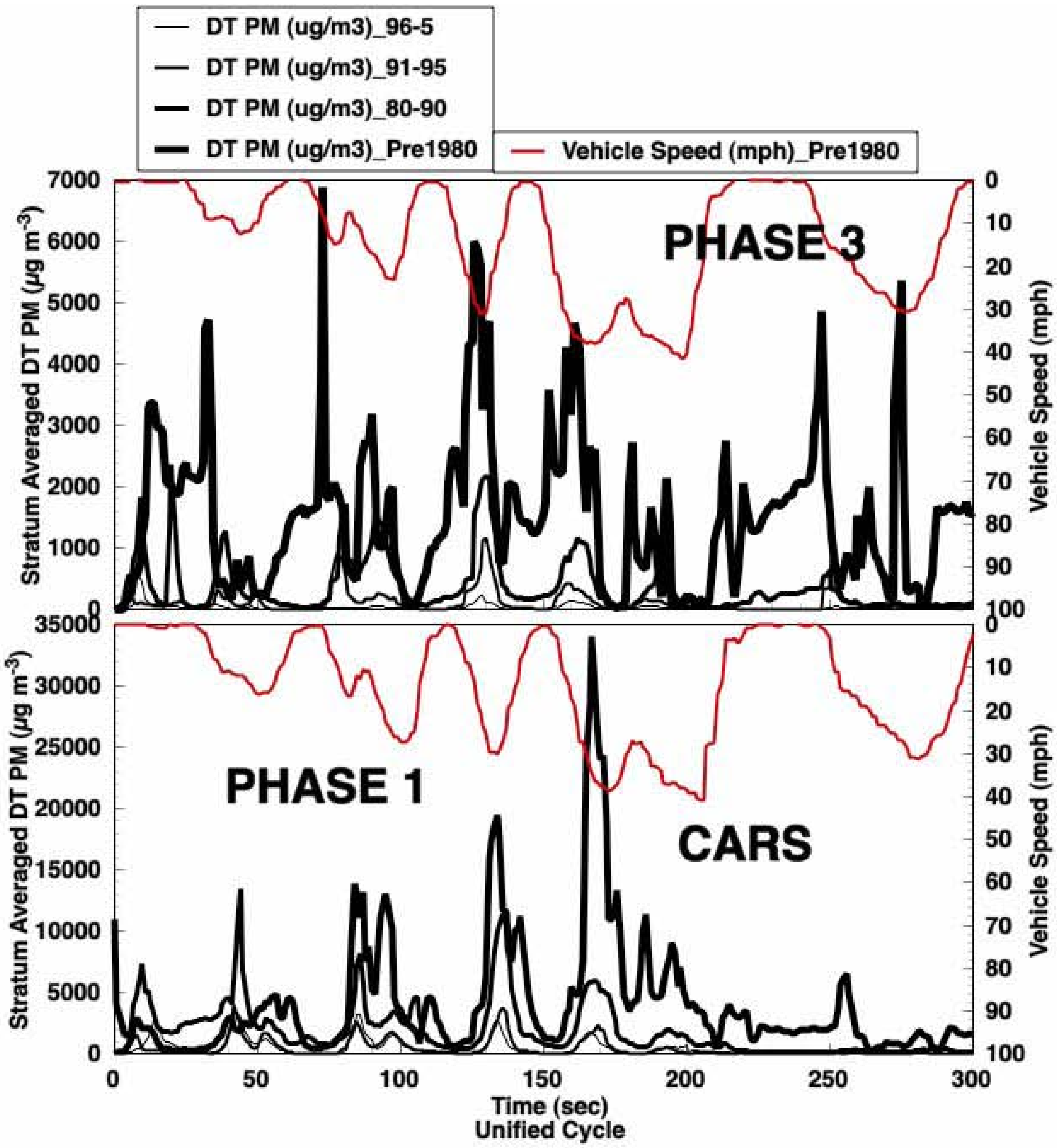


Figure 4-113. Stratum averaged DustTrak PM emission for passenger cars as it relates to vehicle speed.

(Phase 1 is associated with a cold start of the vehicles, and Phase 3 is an identical driving cycle but one that follows a warm start after an 8 minute soak period. Note that newer cars have much less emission in Phase 3.)

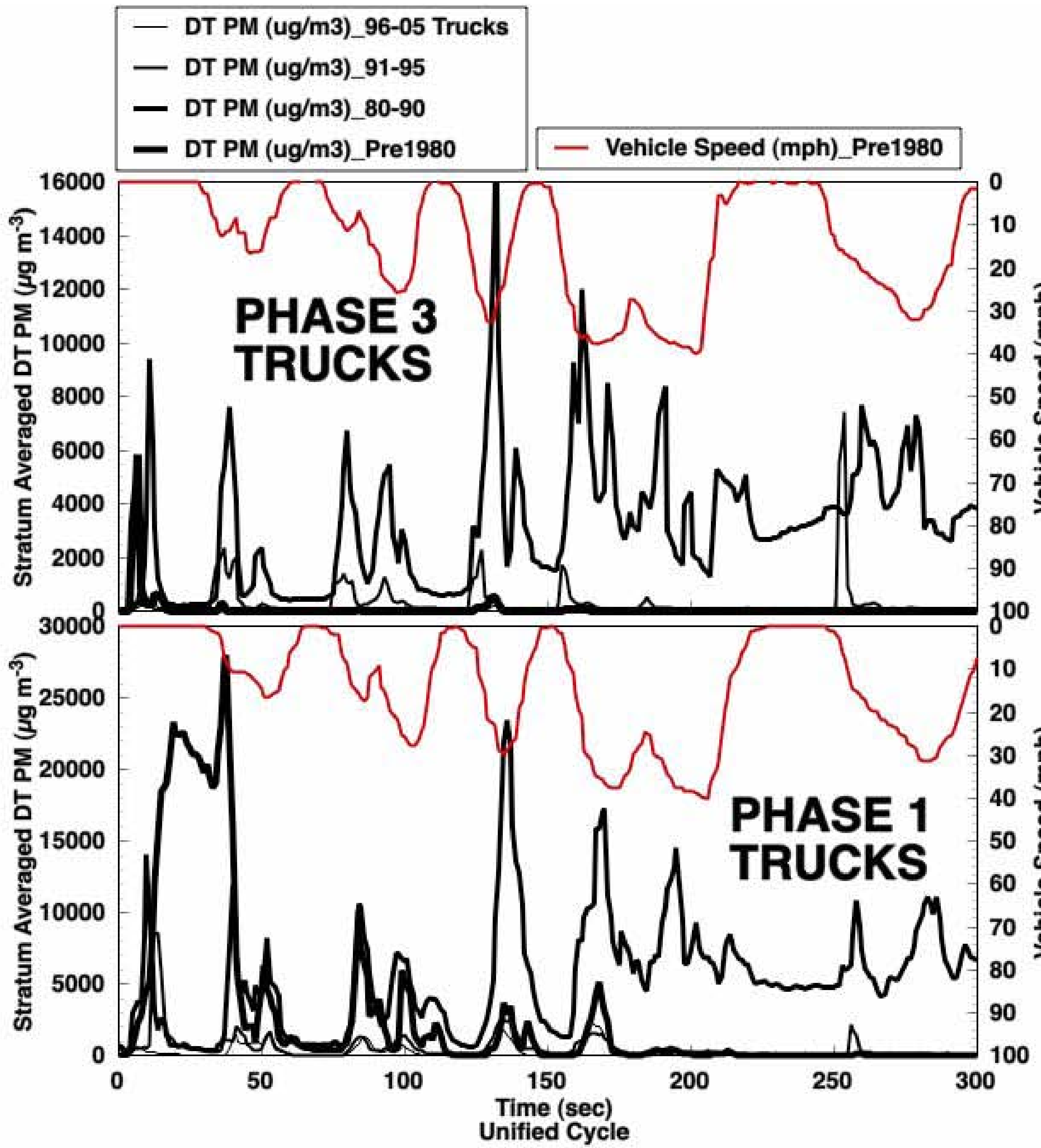


Figure 4-114. Stratum averaged DustTrak PM emission for trucks as it relates to vehicle speed.

(Note the high emissions during phase 1 of the oldest truck, and that it is much less in Phase 3, illustrating that the warm vehicle emission rates are much lower. Note that there were only 2 trucks in that category. Cleaner trucks behave as cleaner cars. Note that PM emission rates of the model year 80-90 vehicles during Phase 3 are high and seem to have little relation with the driving cycle.)

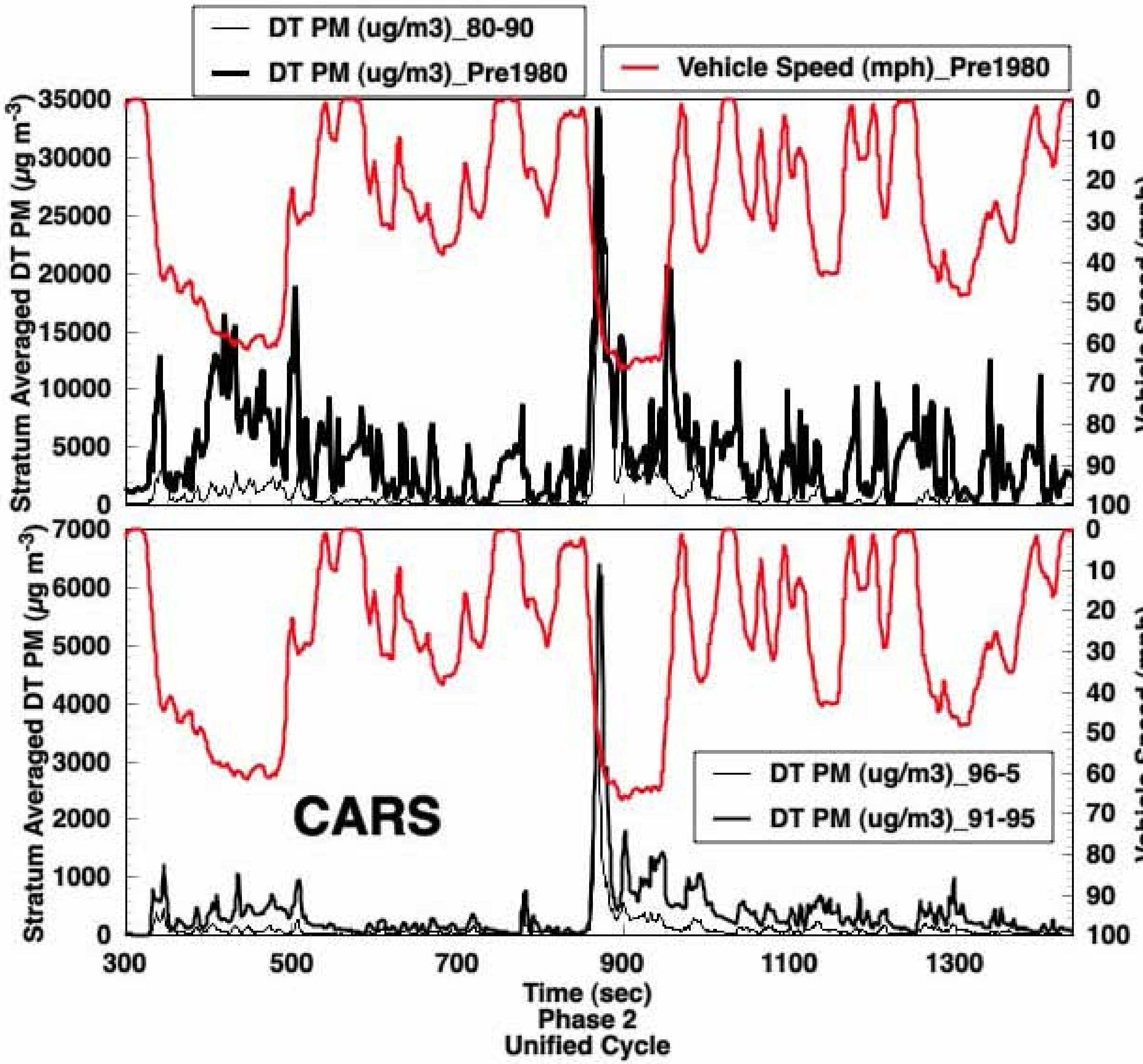


Figure 4-115. DustTrak PM emissions during phase 2 of the unified cycle for passenger cars

(For newer (lower graph) and older (upper graph) vehicles. Note that PM emissions peak during the aggressive acceleration in about the middle portion of the cycle right before 900 seconds. Note in the upper graph that the oldest category of vehicles had high emission on both accelerations as well as decelerations. Note that the older vehicles shown in the upper graph had about a factor of 5 more emission during the high acceleration portion of the cycle before 900 seconds.)

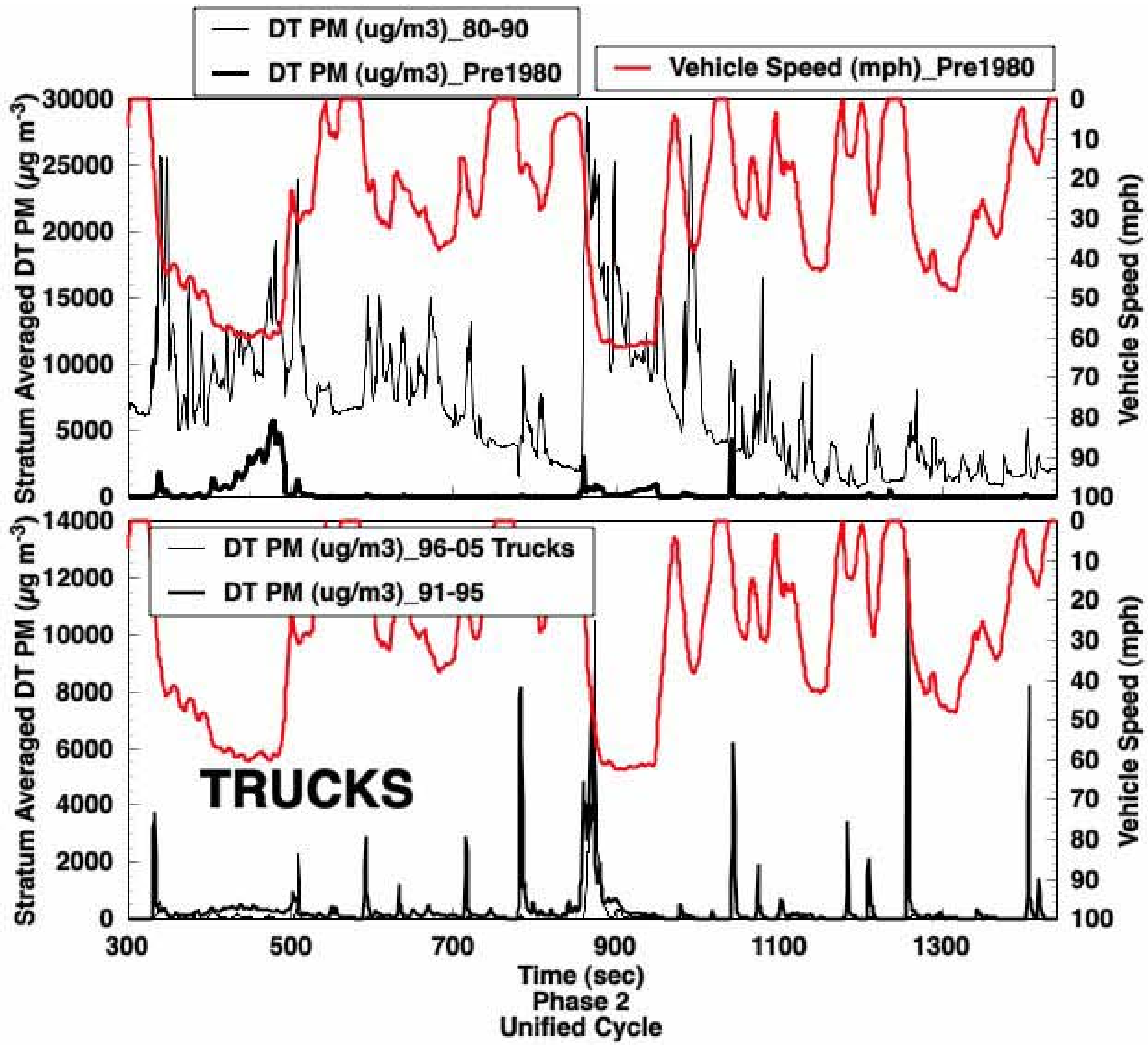


Figure 4-116. DustTrak PM emissions during phase 2 of the unified cycle for trucks

(Newer cars (see the lower graph in Fig. 4-28) have about 1/2 the emissions as newer trucks (lower graph above) and both have peaks during accelerations.)

Table 4-35. Emission rates in mg/mile for Phase 1 of the unified cycle for cars and trucks.

Phase 1		Car			Truck	
Model Year	BC	DustTrak	DataRam	BC	DustTrak	DataRam
Round 1						
1971-1980	63.9	249.2	396.7	72.5	171.5	194.2
1981-1990	18.1	112.7	781.8	19.7	324.8	4557.9
1991-2000	4.4	26.1	73.4	3.4	33.1	171.1
2001-2010	3.6	27.2	167.5	4.1	14.9	14.0
Round 2						
1971-1980	168.4	630.9	2285.7	57.3	422.0	2401.7
1981-1990	35.6	207.2	1026.5	68.1	364.3	1771.7
1991-2000	20.4	103.8	259.5	15.6	67.5	165.4
2001-2010	12.8	89.1	137.3	12.6	54.9	58.7

Table 4-36. Emission rates in mg/mile for Phase 2 of the unified cycle for cars and trucks.

Phase 2		Car			Truck	
Model Year	BC	DustTrak	DataRam	BC	DustTrak	DataRam
Round 1						
1971-1980	25.5	138.4	677.8	0.9	9.2	69.6
1981-1990	4.9	33.2	213.7	4.8	214.2	3800.6
1991-2000	0.7	11.8	70.6	0.5	10.9	78.4
2001-2010	0.3	3.8	32.0	0.5	3.2	2.8
Round 2						
1971-1980	20.0	50.8	82.4	3.2	41.8	129.8
1981-1990	3.1	31.3	186.0	10.4	39.4	91.3
1991-2000	1.2	20.8	111.3	0.6	15.2	32.8
2001-2010	0.4	2.5	2.9	0.3	1.5	2.0

Table 4-37. Emission rates in mg/mile for Phase 3 of the unified cycle for cars and trucks.

Phase 3		Car			Truck	
Model Year	BC	DustTrak	DataRam	BC	DustTrak	DataRam
Round 1						
1971-1980	37.5	92.1	105.6	1.9	4.8	4.7
1981-1990	3.8	22.2	142.7	7.3	192.0	2086.8
1991-2000	0.8	7.2	13.3	0.8	18.9	78.7
2001-2010	0.3	2.3	3.8	0.4	1.8	2.1
Round 2						
1971-1980	28.7	52.4	93.6	3.0	22.9	21.2
1981-1990	1.7	15.2	131.8	3.0	19.1	92.9
1991-2000	0.7	4.2	7.6	0.5	2.7	4.7
2001-2010	0.1	0.5	0.5	0.2	0.8	0.9

4.5.4 Conclusions

- Gravimetric mass measurements of field blanks ranged from 1.1 to 9.9 μg/filter with an average of 5.4 and standard deviation of 3.4 μg/filter for Round 1, and -1.5 ± 1.2 μg /filter for Round 2. This compares to the measurement uncertainty for these filters of 4.6 μg/filter, which is determined by replicate measurement.
- Interlaboratory comparisons of gravimetric mass measurements by DRI and EPA show agreement to within the analytical uncertainty of the method and no systematic bias.
- Continuous methods show large variations in PM emissions with vehicle speed. They can be useful for characterizing the effect of driving patterns on emissions and phase-specific emission rates.
- Photoacoustic BC is consistent with EC measured by TOR analysis of quartz filters. BC is a viable method for measuring inorganic carbon emissions with high time resolution, even when concentrations are low.
- Nephelometer based methods for continuous PM measurements agree well at lower concentrations, but show significant overestimation at higher concentrations. This problem is particularly severe for the DataRAM4and can result in over-emphasis of the emissions for high emitters.
- $PM_{2.5}$ concentrations for the 5-minute test cycle Phases are difficult to measure by gravimetric analysis of filter samples when the vehicle emission rates are low,

especially Phase 3. Continuous methods, if properly calibrated, may be more useful in those cases.

4.6 Speciated Emissions of Particulate Matter

4.6.1 Background

Receptor models have been widely used to estimate the contributions of various sources of measured ambient particulate matter concentrations (Hopke, 1997; Henry, 1997; Watson et al., 2001). This approach requires knowledge of the number of sources contributing to the observed airborne concentration of particle mass and chemical species, but also the composition of the particles emitted from each source. The emission rate and chemical composition of gaseous and particulate pollutants from motor vehicles depend upon many factors, which include vehicle age and mileage, fuel, lubricating oil, emission control technology, vehicle operating mode (cold start, hot stabilized), load, ambient temperature, and state of maintenance. Most gasoline vehicles are relatively clean, especially in hot-stabilized mode. Virtually all of the PM emissions from "normal emitters" come from the first few minutes during a cold start and from hard accelerations with relatively higher amounts of elemental carbon during both cold starts and hard accelerations (see Section 4.5). In contrast, high emitters have cumulative PM emissions that are more linear with time than normal emitters with higher OC/TC ratios. Because of the variability of OC/EC splits, gasoline and diesel vehicles are difficult to apportion by carbon analysis alone, and EC is not a unique tracer for diesel exhaust.

More recent applications of the chemical mass balance (CMB) receptor model utilized particulate organic markers (Schauer et al., 1996; Watson et al., 1998; Fujita et al., 1998) as well as combination of particulate and gaseous markers (Schauer et al., 2002). 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 benzo(a)pyrene, 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. Gasoline vehicles, whether low or high emitter, emit greater relative amounts of high molecular-weight particulate PAHs (e.g., benzo(b+j+k)fluoranthene, benzo(ghi)perylene, ideno(1,2,3-cd)pyrene, and coronene) (Zielinska and Sagebiel, 2001; Fujita et al., 2005) than diesel vehicles. These PAHs have been found in used gasoline motor oil but not in fresh oil nor in diesel engine oil. 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. Gasoline vehicles, even normal emitters, emit volatile PAH's (e.g., naphthalene and methylnaphthalenes) in amounts per unit of fuel that equals or exceeds that of diesel vehicles. These semi-volatile PAH and other organic compounds (e.g., alkanes) in motor vehicle emissions contribute to the formation of secondary organic aerosols.

Hopanes and steranes have also been identified as potential molecular markers for PM emission from motor vehicles. These organic compounds are present in lubricating oil with similar composition for both gasoline and diesel vehicles and are not present in gasoline or diesel fuels. Emission rates of hopanes and steranes are the highest for both gasoline and diesel "high emitting" vehicles. While hopanes and steranes are useful markers for internal combustion engines, the composition of various individual hopanes and steranes are similar in the exhaust from both gasoline and diesel engines. However, the relative abundances of hopanes and steranes to emissions of elemental carbon differ substantially for the diesel and gasoline vehicles. The differences in the ratios of hopanes plus steranes to elemental carbon could be used to quantify the contribution of gasoline-powered and diesel-powered vehicles (Schauer, 2002).

A major goal of the vehicle test program in Kansas City is to obtain up-to-date gasoline-powered vehicle exhaust composition profiles for application in developing speciated emissions inventories and ambient source apportionment studies. An important issue in the general applicability of these profiles is whether gas-particle partitioning of certain organic compounds with the high-volume source sampling used in Kansas City differs substantially from the low-flow, ambient sampling techniques used in some source apportionment studies. To address this issue, organic samples were also collected during Round 2 with ambient, low-flow samplers to compare with source, high-volume organic samples collected in the Kansas City Light Duty Vehicle Emissions Study.

4.6.2 Experimental Methods

BKI conducted the vehicle emissions tests on their transportable Clayton Model CTE-50-0 chassis dynamometer over the LA92 Unified Driving Cycle. The test site and dynamometer setup are described in Chapter 2. The vehicle emissions tests were conducted in Kansas City during July to September 2004 (summer/Round 1) and January to March 2005 (winter/Round 2). The cycle consists of a cold start Phase 1 (first 310 seconds), a stabilized Phase 2 (311-1427 second), a 600-second engine off soak, and a warm start Phase 3 (repeat of Phase 1 of the LA92). Cars and light-duty trucks were recruited for testing in four model year groups (Pre-1981, 1981-90, 1991-95 and 1996 and newer). The vehicle groupings for trucks and cars are designated strata 1-4 and 5-8, respectively. The strata are ordered from to older to newer model years. Details of the vehicle recruitment aspects of the study are given in Chapter 2. Tables 4-38 and 4-39 summarize the numbers of samples collected and subsequently selected for chemical analysis in Rounds 1 and 2, respectively. Pairs of Teflon and quartz filters were collected for each of the three phases of the cold start LA92 driving cycle, and integrated samples were collected over the entire cycle for organic speciation samples. Full sets of sampling media were also collected for daily 60-minute tunnel blanks and weekly (approximate) field/transport blanks. Teflon and quartz filters were collected during weekly tests of the calibration vehicle and for 15 replicate tests in Round 1 and 10 in Round 2.

Table 4-38. Summary of sample selection for chemical analysis during Round 1.

Week	Week Ending	STRATUM 1	2	3	4	5	6	7	8	Weekly Total	Dilution Blanks	Transit Blanks	Corr. Vehicle	Replicate Tests
Vehicles Tested														
1	17-Jul	1	0	0	3	0	0	3	2	9	4	0	0	0
2	24-Jul	0	1	5	4	1	3	1	8	23	6	0	0	1
3	31-Jul	0	0	1	4	0	2	3	15	25	6	0	1	0
4	7-Aug	0	0	4	4	0	2	5	7	22	6	2	2	4
5	14-Aug	1	1	2	4	0	5	5	6	24	6	1	1	1
6	21-Aug	0	2	1	3	1	0	3	6	16	6	1	1	2
7	28-Aug	0	0	2	2	0	6	7	5	22	6	1	1	0
8	4-Sep	0	2	0	1	0	5	5	4	17	4	0	0	0
9	11-Sep	0	1	2	0	2	5	2	2	14	4	1	1	1
10	18-Sep	0	1	3	1	1	7	4	13	30	6	1	1	1
11	25-Sep	0	2	0	6	0	1	5	13	27	6	1	1	4
12	2-Oct	0	0	1	2	1	1	8	12	25	5	1	3	0
	Actual	2	10	21	34	6	37	51	93	254	65	9	12	14
	Planned	16	26	26	39	16	51	34	42	250	60	12	12	15
Samples Selected for Chemical Analysis														
1	17-Jul	1	0	0	1	0	0	0	1	3	2	0		
2	24-Jul	0	1	3	2	1	1	0	3	11	4	0		
3	31-Jul	0	0	0	0	0	1	2	1	4	1	0		
4	7-Aug	0	0	0	0	0	0	0	0	0	0	2		
5	14-Aug	1	0	0	0	0	1	3	0	5	5	1		
6	21-Aug	0	1	0	0	1	0	0	5	7	4	1		
7	28-Aug	0	0	0	0	0	0	0	0	0	0	1		
8	4-Sep	0	0	0	0	0	0	0	0	0	1	0		
9	11-Sep	0	1	1	0	2	1	1	0	6	2	1		
10	18-Sep	0	1	2	0	0	0	1	5	9	5	1		
11	25-Sep	0	0	0	5	0	0	0	0	5	0	1		
12	2-Oct	0	0	0	0	1	0	0	0	1	0	1		
	Actual	2	4	6	8	5	4	7	15	51	24	9		
	Planned	4	4	6	10	5	4	9	10	52	30	12		
	% of Total (a)	100%	40%	29%	24%	83%	11%	14%	16%	20%				
Individual/Composites Samples Analyzed														
1	17-Jul	0	0	0	0	0	0	0	0	0				
2	24-Jul	1	1	1	1	1	2	0	1	8				
3	31-Jul	0	0	0	0	0	1	1	0	2				
4	7-Aug	0	0	0	0	0	0	0	0	0				
5	14-Aug	1	0	0	0	0	0	1	0	2				
6	21-Aug	0	1	0	0	1	0	0	1	3				
7	28-Aug	0	0	0	0	0	0	0	0	0				
8	4-Sep	0	0	0	0	0	0	0	0	0				
9	11-Sep	0	1	0	0	2	1	1	0	5				
10	18-Sep	0	1	1	0	0	0	1	1	4				
11	25-Sep	0	0	0	1	0	0	0	0	1				
12	2-Oct	0	0	0	0	1	0	0	0	1				
	ACTUAL	2	4	2	2	5	4	4	3	26	6	3		
	PLANNED	4	4	2	2	5	4	3	2	26	6	3		
	No./Comp (b)	1	1	3	4	1	1	1.75	5		4	3		

a. The percentage of total vehicles tested in each stratum that is reflected in the chemical analysis.
b. The average number of vehicles included in each chemical composite by strata. The targets were no compositing for Strata 1, 2, 5, and 6, three vehicles for Strata 3 and 7, and five vehicles in Strata 4 and 8.

Table 4-39. Summary of sample selection for chemical analysis during Round 2.

		STRATUM								Weekly	Dilution	Transit	Corr.	Replicate
Week	Week Ending	1	2	3	4	5	6	7	8	Total	Blanks	Blanks	Vehicle	Tests
Vehicles Tested														
1	15-Jan	2	0	0	4	0	1	3	7	17	4	1	0	0
2	22-Jan	0	0	3	6	0	1	6	12	28	6	1	1	1
3	29-Jan	0	4	3	1	2	2	7	0	19	5	1	1	2
4	5-Feb	0	2	2	6	1	0	4	4	19	6	1	2	2
5	12-Feb	0	0	6	8	0	1	6	4	25	6	1	1	0
6	19-Feb	0	0	3	10	0	1	5	1	20	6	1	1	2
7	26-Feb	0	0	2	3	2	1	5	2	15	6	1	1	0
8	5-Mar	0	0	1	2	5	3	1	2	14	6	1	1	0
9	12-Mar	0	5	4	5	1	6	2	2	25	6	1	1	1
10	19-Mar	3	13	1	0	1	11	2	0	31	6	1	1	1
11	26-Mar	1	9	1	2	4	5	2	0	24	6	1	1	1
12	2-Apr	1	1	2	2	1	6	1	4	18	6	1	1	0
13	9-Apr	2	0	5	13	0	2	0	2	24	5	1	0	0
	Actual	9	34	33	62	17	40	44	40	279	74	13	12	10
	Planned	11	42	32	56	18	39	43	38	279	68	12	12	10
Samples Selected for Chemical Analysis														
1	15-Jan	0	0	0	0	0	0	0	0	0	0			
2	22-Jan	0	0	0	0	0	0	0	0	0	0			
3	29-Jan	0	1	0	0	0	1	2	0	4	1			
4	5-Feb	0	1	2	5	2	0	3	4	17	4			
5	12-Feb	0	0	1	0	0	0	0	0	1	0			
6	19-Feb	0	0	0	0	0	0	0	0	0	0			
7	26-Feb	0	0	2	3	0	1	1	2	9	5			
8	5-Mar	0	0	1	1	2	2	1	2	9	5			
9	12-Mar	0	1	1	2	0	1	2	1	8	6			
10	19-Mar	2	0	0	0	0	0	0	0	2	2			
11	26-Mar	1	0	0	0	0	0	0	0	1	0			
12	9-Apr	0	0	0	0	0	0	0	0	0	0			
	Actual	3	3	7	11	4	5	9	9	51	23	14		
	Planned	3	3	9	15	3	4	12	15	64	30	12		
	% of Total (a)	33%	9%	21%	18%	24%	13%	20%	23%	18%				
Individual/Composites Samples Analyzed														
1	15-Jan	0	0	0	0	0	0	0	0	0	0			
2	22-Jan	0	0	0	0	0	0	0	0	0	0			
3	29-Jan	0	1	0	0	0	1	1	0	3	0			
4	5-Feb	0	1	1	1	1	0	1	1	6	1			
5	12-Feb	0	0	0	0	0	0	0	0	0	0			
6	19-Feb	0	0	0	0	0	0	0	0	0	0			
7	26-Feb	0	0	1	0	0	1	1	1	4	1			
8	5-Mar	0	0	0	2	2	1	0	1	6	2			
9	12-Mar	1	1	1	0	0	1	1	0	5	2			
10	19-Mar	1	0	0	0	0	0	0	0	1	0			
11	26-Mar	1	0	0	0	0	0	0	0	1	0			
12	9-Apr	0	0	0	0	0	0	0	0	0	0			
	Actual	3	3	3	3	3	4	4	3	26	6		58	
	Planned	3	3	3	3	3	4	4	3	26	6	3	61	
	No./Comp (b)	1	1	2.33	3.67	1.33	1.25	2.25	3	4				
	EPA Add-on (c)		1	1		1	1			4				

a. The percentage of total vehicles tested in each stratum that is reflected in the chemical analysis.
b. The average number of vehicles included in each chemical composite by strata. The targets were no compositing for Strata 1, 2, 5, and 6, three vehicles for Strata 3 and 7, and five vehicles in Strata 4 and 8.
c. Additional composites developed for low-flow sampling experiment.

4.6.2.1 Sampling Methods

DRI installed and operated a suite of instruments and samplers to provide continuous PM analysis and to collect batch samples of particle and gaseous exhaust components for later analysis in accordance with the methods and procedures specified in the project QAPP. Samples were collected from the dynamometer dilution system via two isokinetic probes, provided by BKI, inserted prior to a 90-degree bend in the dilution tunnel. Figure 4-117 illustrates the sample train as it was installed during the study. Heated conductive lines carried air from the probes to the continuous instruments. Sample air was drawn from the CVS via ½" insulated copper tubing to a small heated stainless steel chamber. The sample air exited via a $PM_{2.5}$ cyclone contained in the chamber to a heated diffusing chamber approximately 50 cm tall, containing a temperature and RH probe. From this chamber, the sample air exited through two filter cartridges. Up to eight cartridges could be installed in the base of the diffusing chamber, allowing four successive pairs of filters to sample without changing cartridges. Airflow thru the cartridges was switched by means of microprocessor controlled relays and solenoid valves, that responded to TTL line signals from the dynamometer control. Flow rates for each filter were set to 56 lpm by adjustable valves to give a combined flow of approximately 113 lpm as required by the inlet cyclone, and monitored by TSI 4000 flowmeters with serial data outputs. A single oil-less pump was used to draw air through the sampler.

Filter samples were collected during each phase of the unified cycle tests. Pre-weighed Gelman polymethylpentane ringed, 2.0 mm pore size, 47 mm diameter PTFE Teflon-membrane Teflo filters (No. RPJ047) collected particles for measurement of gravimetric mass and elements. Pallflex 47 mm diameter pre-fired quartz-fiber filters (No. 2500 QAT-UP) were used for water-soluble chloride, nitrate and sulfate and for organic and elemental carbon measurements. Samples were collected by a separate sampler for determination of particulate and semi-volatile organic compounds on Pallflex TX40HI20-WW 102 mm diameter Teflon-impregnated glass fiber (TIGF) filters followed by glass cartridges containing Aldrich Chemical Company, Inc. 20-60 mesh Amberlite XAD-4 (polystyrene-divinylbenzene) adsorbent resins at a flow rate of 112 lpm. A single filter and adsorbent pair were collected for each unified cycle, combining Phases 1, 2 and 3. Sampling was suspended during the 10-minute soak period by turning off the pump.

Prior to the start of Round1 and Round 2, all samplers were checked for leaks and the in-line flow meters were cross-calibrated using reference flow measurement devices. Leak testing was performed by capping the inlet lines leading to each sampler and turning on the pumps. If the flow meter readings decreased to less than 10% of the nominal sampling flow rate in a reasonably short time, the system was passed. If not, the leak was fixed and the test repeated. With the exception of the Teflon/Quartz filter sampler, all units achieved near-zero flow rates during the leak test. Due to the friable nature of the pre-fired quartz filters, it is not possible to obtain a perfect seal in the filter holders without damaging the media, but the <10% criteria was still met for each filter individually and for the system as a whole. In addition to the vacuum test, the sum of flows through each of the two filter cartridges was compared to the total flow entering the inlet and found to agree within 5%.

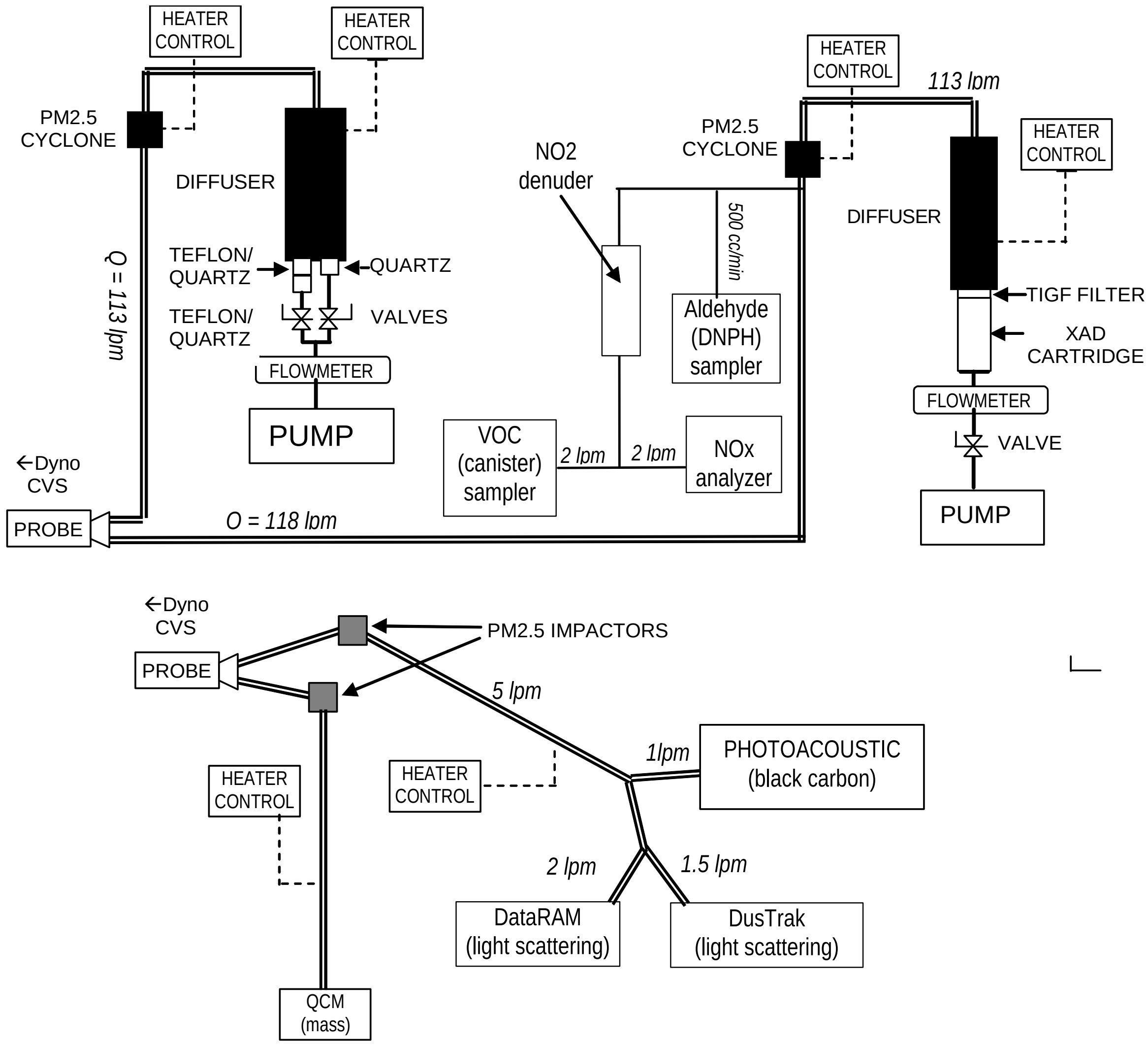


Figure 4-117. Schematic of sampling train with flow rates. (Heated tubing is shown as double lines.)

All flowmeters were calibrated using either a Gillibrator electronic bubble meter or a rotameter that had been cross-calibrated with a Roots meter at DRI. Calibration flows were measured at the inlet point of each sampler (or outlet for the canister sampler) with appropriate sampling media installed. The resulting calibrations were used to determine the desired nominal flow rates, and these were marked on a label on each flowmeter so that the operator could observe any deviations during testing. Variations in nominal flow rate due to sampler problems were recorded in a logbook. For each integrated sample, the run number, start and stop time, elapsed time, initial and final flow rate, and any exceptional occurrences were recorded on log sheets which were kept with the media at all times. Bar coded stickers with unique media IDs were attached to all media and their corresponding log sheets for tracking. Immediately after the conclusion of each test cycle, the media were repacked with the log sheets and stored in a refrigerator, except for the canisters, which were packed and shipped via 2-day express to DRI each day. All media were packed into coolers with ice packs and shipped overnight back to DRI where they were logged in and placed in cold storage until analysis. Media were shipped near weekly basis. Run number, date, time, and vehicle license plate number were attached to all files to identify the data.

The low-volume samples were collected in parallel with the higher-volume TIGF/XAD samples collected for the main study. The high-volume flow was split into two channels, one at 103 lpm and the other at 10 lpm. Seventy-two (72) low-volume (10 lpm) samples were collected during a contiguous three-week period at the mid-point of the main Kansas City Study from 2/15 to 3/8. These samples were collected on Teflon filters (Gelman 37 mm Teflo) using a dual stage 37 mm Teflon filter pack (EPA custom design with ¼" FNPT with quick release) using filter holders supplied by EPA. Eight field/transport blanks were included using the same media loading/unloading and transport procedure and tunnel blanks were collected daily.

4.6.2.2 Sample Selection for Chemical Analyses

Based upon previous studies (e.g., Gasoline/Diesel PM Split Study), PM loadings were expected to be sufficient for chemical analysis for most vehicles in the two older model year strata. In contrast, the need for compositing was anticipated for the two new model year categories in order to obtain adequate analytical sensitivity for organic analysis. Because the study design called for testing the vehicles in random order, no media composites were possible (i.e., sampling multiple vehicles on the same media). Rather an appropriate number of samples were extracted and analyzed together for analytical methods that allow compositing prior to the chemical analysis (e.g., elements by ICP-MS, ions by IC, organic speciation by GC/MS, carbonyl compounds by HPLC-UV, and volatile organics by GC-FID).

Sufficient numbers of samples were collected weekly to create composites in all categories except for the 1996 and newer categories. Timely decisions were required to either analyze the sample set, hold them for subsequent compositing with other samples, or remove the sample from further consideration by either archiving the sample or, in the case of canisters, to discard the sample and recycle the clean evacuated canister back to the field. DRI made these decisions on a weekly basis. The target mass loading for each composite was a minimum of 1 mg of organic carbon, which was estimated by the differences of the continuous mass measurements (average of the QCM and DustTrak) minus the continuous BC measurements by PA. Composites consisted of samples with similar OC to PM ratios. Some composites containing high BC to PM ratios (i.e., black smokers) were also selected for analysis. The remaining samples not selected for analysis were sent to EPA in Research Triangle Park to be archived.

All field and tunnel blanks and samples for replicate and calibration vehicle test were analyzed for gravimetric mass and OC and EC. Complete speciation was obtained for dilution tunnel blanks, field/transport blanks and for subsets of vehicle test samples from each round. The test samples were selected for chemical analysis and grouped into composites according to the protocol developed in consultation with EPA. A total of 26 individual/composite chemical profiles were obtained from 51 of 254 vehicles tested in Round 1 and another 26 composites from 51 of 230 vehicles tested in Round 2 (excludes repeat vehicles from Round 1). Tables 4-40 and 4-41 lists the samples selected for chemical analysis in Rounds 1 and 2, respectively. Dilution tunnel blanks were also combined into several composites as shown in Table 4-42. The composites are identified according to the following convention: Xa-b, where X= season/round

(S for summer/Round 1 and W for winter /Round 2); a is the stratum (1 through 8) and 0 for tunnel blank composites; and b is the composite number within each stratum. The test samples for the later model-year strata (3, 4, 7 and 8) were analyzed as composites of multiple samples. The samples within each composite were extracted together or otherwise combined prior to the chemical analysis (e.g., elements by ICP-MS, ions by IC, organic speciation by GC/MS, carbonyl compounds by HPLC-UV, and volatile organics by GC-FID). Samples for the older vehicle strata (1, 2, 5, and 6) were analyzed without compositing. The odometer readings shown in Tables 4-40 and 4-41 are uncorrected for odometer malfunctions or turnovers.

4.6.2.3 Analytical Methods

The relevant analytical methods and procedures are described in the project QAPP and references cited therein. Selected Teflon filters were analyzed by a combination of XRF (40 elements) using DRI protocol A (Watson et al., 1999) and ICP-MS (Pb, Hg, As, Cr, Cu, Zn and Mn). Following gravimetric mass and XRF analysis of the Teflon filters for the separate phases of the LA92 test cycle, the three filters were extracted together and the composite sample analyzed by ICP-MS. Selected quartz filter were analyzed for OC/EC by thermal optical reflectance (TOR) method using the IMPROVE (Interagency Monitoring of Protected Visual Environment) temperature/oxygen cycle (IMPROVE-TOR) (Chow et al., 1993; Chow et al., 2001). It should be noted that because EC and OC are operationally defined, the specific instrument used and details of its operation and choice of thermal evolution protocol can influence the split between EC and OC (Watson et al. 2005). Each half of the quartz filter for the three phases of the LA92 test cycle was extracted together and analyzed for chloride, nitrate, and sulfate by ion chromatography. No cations analysis was budgeted for this project.

The TIGF/XAD samples were extracted and analyzed together for the two older model year groups (pre-1980 and 1980–1990). TIGF and XAD extracts were analyzed separately for the two newer model year groups (1991-1995 and 1996 and newer) and for the tunnel and field/transport blanks. Samples selected for analysis were extracted and the extracts combined according to the composite decisions. The extracts were analyzed on a Varian 1200 triple quadruple gas chromatograph/mass spectrometer (GC/MS/MS) system or a Varian coupled to a Saturn 2000 ion trap mass spectrometer system with MS/MS and chemical ionization capabilities. Species identification and quantitation include 95 semi-volatile and particulate PAH, 19 hopanes, 18 steranes, 49 alkanes, 99 polar organic compounds, and 25 nitro-PAH. Method detection limits are 0.01-0.03 ng/μl for PAH, hopanes and steranes, and alkane compounds, and 0.03-0.04 ng/μl for polar compounds.

Table 4-40. Vehicle test samples selected for chemical analysis in Round 1 and composite identification.

Sample Composite	Run #	Sample Date	Time	Model Year	Make	Model	Vehicle Type	Odometer	Stratum
S1-1	84037	7/15	10:50	1979	Ford	F250	Truck	102264	1
S1-2	84154	8/10	15:21	1979	Ford	F150	Truck	53493	1
S2-1	84048	7/19	11:00	1989	Dodge	Caravan	Truck	161017	2
S2-2	84201	8/21	9:42	1985	Chevrolet	S10	Truck	30295	2
S2-3	84263	9/9	10:57	1989	Dodge	Ram	Truck	132325	2
S2-4	84283	9/13	13:48	1985	Dodge	Ram	Truck	47582	2
S3-1	84066	7/22	14:08	1995	Jeep	Wrangler	Truck	74158	3
S3-1	84067	7/22	15:44	1995	Dodge	Caravan	Truck	113890	3
S3-1	84073	7/24	10:09	1995	Chevrolet	S10 Blazer	Truck	100758	3
S3-2	84278	9/11	15:22	1990	GMC	Jimmy	Truck	130254	2
S3-2	84281	9/13	11:15	1995	Chevy	Suburban	Truck	73848	3
S3-2	84287	9/14	11:02	1995	GMC	Sierra	Truck	171370	3
S4-1	84034	7/14	14:16	1999	Isuzu	Trooper	Truck	63375	4
S4-1	84055	7/20	15:36	1998	Jeep	Cherokee	Truck	131875	4
S4-1	84072	7/24	8:34	2003	Chevrolet	S10 Pickup	Truck	19366	4
S4-2	84337	9/23	8:08	2003	Ford	Ranger	Truck	11678	4
S4-2	84339	9/23	10:34	1999	Plymouth	Voyager	Truck	75489	4
S4-2	84343	9/24	8:23	2004	KIA	Sedona	Truck	na	4
S4-2	84344	9/24	9:43	2000	Toyota	Sienna	Truck	na	4
S4-2	84349	9/25	8:11	2003	Chevy	Tracker	Truck	na	4
S5-1	84076	7/24	14:28	1968	Ford	Mustang	Car	98852	5
S5-2	84188	8/18	9:40	1977	Chevrolet	Monte Carlo	Car	135545	5
S5-3	84271	9/10	14:41	1979	Buick	LeSabre	Car	37608	5
S5-4	84277	9/11	13:45	1978	MG	MGB	Car	42926	5
S5-5	84367	9/28	16:11	1980	Mercedes	450SEL	Car	na	5
S6-1	84071	7/23	12:42	1989	Pontiac	Grand Am	Car	116806	6
S6-2	84079	7/26	11:08	1989	Honda	Accord	Car	209972	6
S6-3	84180	8/16	10:39	1985	Pontiac	Bonneville	Car	236759	6
S6-4	84270	9/10	13:21	1986	Mercury	Grand Marquis	Car	36277	6
S7-1	84101	7/30	13:22	1994	Toyota	Camry	Car	169034	7
S7-1	84108	7/31	14:59	1991	Honda	Civic	Car	214131	7
S7-2	84157	8/11	10:54	1994	Nissan	Sentra	Car	127045	7
S7-2	84165	8/12	15:05	1991	Mazda	Protégé	Car	185565	7
S7-2	84174	8/14	9:37	1994	Mercury	Topaz	Car	32686	7
S7-3	84308	9/17	14:36	1994	Pontiac	GrandAM	Car	101526	7
S7-4	84258	9/8	8:46	1991	Olds	Delta	Car	226269	7
S8-1	84042	7/17	9:20	1996	Honda	Civic	Car	131483	8
S8-1	84060	7/21	14:06	1998	Buick	LeSabre	Car	45444	8
S8-1	84062	7/22	8:19	1998	Buick	LeSabre	Car	45444	8
S8-1	84063	7/22	9:47	1996	Saturn	0	Car	74620	8
S8-1	84078	7/26	9:34	1997	Honda	Accord LX	Car	79584	8
S8-2	84178	8/16	8:12	1997	Toyota	Camry	Car	129415	8
S8-2	84183	8/17	8:12	2000	Toyota	Corolla	Car	70118	8
S8-2	84184	8/17	9:37	2000	Honda	Civic	Car	40402	8
S8-2	84185	8/17	10:56	1996	Toyota	Corolla	Car	148857	8
S8-2	84191	8/19	8:13	2000	Toyota	Camry	Car	47771	8
S8-3	84279	9/13	8:39	2001	Toyota	Camry	Car	61415	8
S8-3	84297	9/16	9:45	1996	Dodge	Stratus	Car	146579	8
S8-3	84303	9/17	8:05	2002	Olds	Silhouette	Car	40271	8
S8-3	84304	9/17	9:24	2001	Honda	Civic	Car	49751	8
S8-3	84310	9/18	8:02	2003	Chevy	Venture	Car	24915	8

Table 4-41. Vehicle test samples selected for chemical analysis in Round 2 and composite identification.

Analysis Code	Run #	Sample Date	Time	Model Year	Model	Vehicle Type	Odometer	Stratum
W1-1	84653	3/14	13:21	1977	C-20 Pu	truck	37697	1
W1-2	84687	3/19	15:16	1976	El Camino	truck	61809	1
W1-3	84700	3/22	14:06	1978	Pu	truck	73447	1
W2-1	84462	1/26	14:26	1989	Voyager	truck	145307	2
W2-2	84489	2/2	9:33	1987	Pu	truck	232098	2
W2-3	84634	3/10	9:27	1988	Voyager	truck	162874	2
W2-E	84632	3/9	13:33	1987	F150 Pu	truck	428	2
W3-1	84487	2/1	13:40	1992	B2200	truck	101090	3
W3-1	84497	2/3	13:44	1995	4 Runner	truck	85898	3
W3-1	84510	2/7	10:55	1994	Suburban	truck	187410	3
W3-2	84584	2/24	8:18	1995	Pu	truck	86705	3
W3-2	84591	2/26	8:13	1993	4Runner	truck	178462	3
W3-2	84600	3/1	9:27	1993	Explorer	truck	47980	3
W3-3	84618	3/7	10:39	1992	Voyager	truck	154297	3
W3-E	84621	3/7	14:11	1992	Ranger	truck	13586	3
W4-1	84479	1/31	9:22	1996	Caravan	truck	118369	4
W4-1	84493	2/3	8:38	2004	Freestar Minivan	truck	14714	4
W4-1	84495	2/3	11:13	1996	Sonoma Pu	truck	51863	4
W4-1	84498	2/4	8:24	2001	Sienna Minivan	truck	59734	4
W4-1	84500	2/4	10:58	1998	Frontier Pu	truck	112521	4
W4-2	84577	2/22	8:20	1998	Aerostar	truck	0	4
W4-2	84580	2/23	8:21	2002	Town & Country	truck	84580	4
W4-2	84616	3/7	8:07	1999	Voyager	truck	113389	4
W4-3	84587	2/25	8:56	1996	Villager	truck	166799	4
W4-3	84608	3/4	8:10	1996	Quest	truck	125651	4
W4-3	84617	3/7	9:25	1997	Suburban	truck	145147	4
W5-1	84482	1/31	13:32	1979	Lasabre	car	40364	5
W5-1	84484	2/1	9:25	1979	Lesabre	car	40385	5
W5-2	84601	3/1	10:41	1979	Regal	car	5864	5
W5-3	84605	3/3	10:15	1977	280Z	car	94782	5
W5-E	84637	3/10	13:07	1980	Cutlass Supreme	car	79420	5
W6-1	84474	1/29	9:35	1988	Civic	car	207265	6
W6-2	84582	2/23	11:14	1988	528E	car	287806	6
W6-3	84611	3/4	11:49	1989	Camry	car	168091	6
W6-3	84613	3/5	9:24	1990	Delta 88	car	185694	6
W6-4	84635	3/10	10:36	1989	Crown Vic	car	62847	6
W6-E	84630	3/9	10:38	1989	Accord	car	139963	6
W7-1	84453	1/25	10:59	1995	Maxima	car	181395	7
W7-1	84455	1/25	13:15	1995	Mustang	car	146289	7
W7-2	84485	2/1	11:03	1991	Fleetwood	car	97124	7
W7-2	84499	2/4	9:43	1995	Integra	car	80579	7
W7-2	84505	2/5	10:53	1993	Intrepid	car	210298	7
W7-3	84581	2/23	9:44	1995	Corsica	car	78767	7
W7-3	84597	2/28	11:10	1994	Sunbird	car	145869	7
W7-4	84639	3/11	9:19	1995	Cavalier	car	140500	7
W7-4	84645	3/12	9:15	1993	960	car	197094	7
W8-1	84483	2/1	8:11	1996	Neon	car	79848	8
W8-1	84502	2/4	13:41	1996	Concorde	car	111502	8
W8-1	84503	2/5	8:19	2002	Taurus	car	26406	8
W8-1	84504	2/5	9:37	2000	Concorde	car	65330	8
W8-2	84596	2/28	9:50	1997	Taurus	car	97601	8
W8-2	84599	3/1	8:11	1998	Avalon	car	29575	8
W8-3	84589	2/25	11:28	2001	Sedan	car	56662	8
W8-3	84593	2/26	10:45	1998	Accord	car	75067	8
W8-3	84622	3/8	8:00	1999	Camry	car	64134	8

Note: Identifications ending in “E” are additional composites samples analyzed for the low-flow sampler comparisons.

Table 4-42. Chemical speciation composites of dilution blanks.

Summer/Round1				Winter/Round2			
Composite ID	Run #	Date	Time	Composite ID	Run #	Date	Time
S0-1	84038	7/15	12:32	W0-1	84454	1/25	11:36
S0-1	84044	7/17	12:02	W0-1	84481	1/31	11:51
S0-1	84059	7/21	12:12	W0-1	84486	2/1	12:09
S0-1	84065	7/22	12:23	W0-1	84501	2/4	12:05
S0-1	84075	7/24	12:52	W0-1	84506	2/5	12:01
S0-2	84049	7/19	11:34	W0-2	84579	2/22	10:42
S0-2	84080	7/26	12:20	W0-2	84607	3/3	12:42
S0-3	84147	8/9	11:54	W0-3	84586	2/24	10:41
S0-3	84152	8/10	12:11	W0-3	84590	2/25	12:42
S0-3	84158	8/11	12:04	W0-3	84594	2/26	11:52
S0-3	84170	8/13	12:03	W0-3	84604	3/2	9:42
S0-3	84176	8/14	11:58	W0-4	84583	2/23	12:21
S0-4	84181	8/16	11:55	W0-4	84602	3/1	11:50
S0-4	84186	8/17	12:19	W0-4	84610	3/4	10:31
S0-4	84194	8/19	12:11	W0-4	84615	3/5	11:51
S0-4	84199	8/20	11:12	W0-5	84619	3/7	11:45
S0-5	84255	9/2	11:58	W0-5	84625	3/8	11:47
S0-5	84260	9/8	11:12	W0-5	84631	3/9	11:54
S0-5	84275	9/11	0:00	W0-5	84636	3/10	11:42
S0-6	84282	9/13	12:22	W0-6	84641	3/11	11:36
S0-6	84288	9/14	12:08	W0-6	84647	3/12	11:36
S0-6	84294	9/15	11:56	W0-6	84652	3/14	11:49
S0-6	84306	9/17	11:48	W0-6	84657	3/15	11:31
S0-6	84313	9/18	11:47				

Each sample is reported initially in terms of mass per sample (µg/sample). Ambient concentrations in terms of mass per volume (i.e., ng/m^3 or other units if requested) are reported based upon the sample volume adjusted for ambient temperature and pressure, or reported as "standard" volume. The measurement uncertainties associated with each individual compound are reported as the combined root mean square of the replicate precision for analytical uncertainty, which is defined by the following equation:

$$\sqrt{(\text{replicate precision} * \text{analyte concentration})^2 + (\text{analyte detection limit})^2}$$

This equation incorporates the analyte detection limit for each compound so when concentrations approach zero, the error is reported as the analyte detection limit.

4.6.2.4 Field Blank Subtraction

Analytical results for composite field blanks were divided by the number of media combined for each analysis and the results in µg/sample were compared to each other for consistency. Any obvious outliers were compared to dilution tunnel blanks and exhaust samples for indications of contamination. If outliers appear to be contaminated or substantially different in composition relative to the other field blanks, they were removed from the field blank set. All remaining field blank results are summed and divided by the total number of media represented.

$$\overline{M}_{fb} = \frac{\sum_1^j N_j M_j}{n}$$

where n is the total number of field blank media used in average, N_j is the number of field blank media combined in analysis j, and M_j is the measured mass in µg for analysis j.

For each composite exhaust sample or dilution tunnel blank, the average field blank mass is multiplied by the number of media combined in the exhaust or dilution sample composite and subtracted from the composite sample mass, M_c.

$$M_s = M_c - N_j \overline{M}_{fb}$$

If the result is negative for a species, the composite mass M_s is set to zero for that species. In cases where backup media were sampled and analyzed separately from the primary filter, as for some of the TIGF filters and XAD adsorbent cartridges, blank subtraction is performed before combining the primary and backup media analysis results, using the field blanks of corresponding type.

The uncertainty of the field blank subtracted mass is calculated as:

$$U = \sqrt{U_m^2 + S_{fb}^2}$$

where $U_m \equiv$ the analytical uncertainty of the composite sample mass, in μg and S_{fb} is the standard deviation of the field blanks, weighted by number of media combined in each field blank analysis.

$$S_{fb} = \sqrt{\frac{n\sum_1^j N_j M_j^{\;2} - \left(\sum_1^j N_j M_j\right)^2}{n(n-1)}}$$

4.6.2.5 Calculation of Composite Speciated Profiles

For a composite profile consisting of *i* sample analyses (each analysis may represent 1 to 5 vehicle tests or dilution tunnel blanks), the <u>mean concentration</u> in μg /m³ of species *x* for composite *s* is calculated as:

$$\frac{\sum_1^i M_i^x}{\sum_1^i V_i} = C_s^x$$

where $M_i^x \equiv$ mass of species *x* on filter *i*, corrected for the mean field blank value, in μg, and $V_i \equiv$ sample volume for filter *i*, in m³.

The uncertainty of the composite concentration is:

$$c_s^x = C_s^x \sqrt{\left(\frac{\sum_1^i m_i^x}{\sum_1^i M_i^x}\right)^2 + \left(\frac{\sum_1^i v_i^x}{\sum_1^i V_i^x}\right)^2}$$

where $m_i^x \equiv$ uncertainty of the mass of species *x* on filter *i*, corrected for the mean field blank value, in μg and $v_i \equiv$ uncertainty of the sample volume for filter *i*, in m³. Uncertainties for DRI sample volumes were estimated as 5% of measured value, based on the results of periodic flow audits. No uncertainties for the CVS volume or mileage were reported, but these are assumed to be small relative to the analytical errors. This method was used in order to be consistent with the sample compositing for speciated organic analysis, in which filter extracts for each composite group were combined before analysis. Analytical and volumetric uncertainties are propagated throughout the calculation to provide an overall uncertainty for each concentration and emission rate.

The composite emission rate in mg/mi of species *x* for composite *s* is calculated as:

$$\left(0.001\frac{mg}{\mu g}\right)\frac{\sum_1^i D_i}{\sum_1^i d_i} C_s^x = E_s^x$$

where D_i = CVS total diluted volume (V_{mix}) for sample *i*, in m^3 and d_i = total mileage driven during sample *i*, in miles. Analytical and volumetric uncertainties* are propagated throughout the calculation to provide an overall uncertainty for each emission rate.

4.6.3 Results and Conclusions

Full chemical speciation was determined for 26 individual/composite samples and 6 composite dilution tunnel blanks samples in each test round. Tables 4-40 and 4-41 list the vehicle exhaust samples that were combined together for chemical analysis in Rounds 1 and 2, respectively, and Table 4-42 lists the dilution tunnel blanks that were combined into composites. All data are field-blank corrected. Appendix A shows the range (minimum, maximum, and the 10th, 50th, and 90th percentile) of concentrations for each chemical species normalized to either the mean field blank or minimum detection limit, whichever is larger. This table shows that the chemical data that were obtained in Round 1 are well above the analytical sensitivities for most species. The chemical composition data for dilution tunnel blanks and exhaust samples are presented in Appendix B. The summaries of the PM data for composite exhaust and dilution blank samples in Tables 4-43 and 4-44 for Rounds 1 and 2, respectively, show that emissions levels are well above the ranges of values for dilution tunnel blanks with the exception of hopanes and steranes emissions for the newer model-year strata. Summary data include gravimetric mass, OC, and EC are in mg/mile and PAH, hopanes, and steranes are in ug/mile. The three PAHs that are potential markers for gasoline exhaust are indeno[123-cd]pyrene, benzo(ghi)perylene and coronene.

Comparisons of co-pollutants can provide validation checks for assessing the overall accuracy and validity of the measurements. Species emitted from the same source type should correlate and exhibit average ratios of species that reflect the nature of the source. Figure 4-118 shows gravimetric mass versus total carbon by IMPROVE-TOR in ug/m^3 of diluted exhaust for Round 1 dynamometer test filters by test phase. PM mass and TC are strongly correlated for the phase 1 samples and poorly correlated for the lightly loaded phase 3 samples. Similar results are shown in Figure 4-119 for the correlation of elemental carbon by TOR versus average BC by the photoacoustic instrument. As we have seen in prior studies (e.g., Gasoline/Diesel PM Split Study) for highly loaded samples, PM mass is typically well correlated with TC and EC obtained by IMPROVE-TOR or STN-TOT agree with photoacoustic BC. That is not the case at lower sample loading where sampling artifacts associated with adsorbed organic compounds on the quartz filter may be relatively more important. The correlations of the sum of elements by XRF analysis (Figure 4-120) show the similar correlations to PM mass as TC, which again reflects the lower mass loadings for the phase 3 samples. Figure 4-121 shows that sulfur by XRF analysis is strongly correlated to sulfate by ion chromatography. Figure 4-122 shows that benzo(ghi)perylene, indeno[123-cd]pyrene and coronene all correlate well with TC emissions and Figure 4-123 shows that the sum of hopanes and steranes also correlated well with TC.

Figures 4-124 through 4-143 show the abundances of various chemical species in the dilution blank and composite exhaust samples during each round of testing. OC and EC are the most abundant species in motor vehicle exhaust, accounting for over 95% of the total PM mass. For SI vehicles, BC and PM emission rates can be several times larger during the cold start phase than during hot stabilized operation. Relatively clean SI vehicles produce BC emissions during the more aggressive portions of the driving cycle and during cold starts. Therefore, the emission profiles for clean SI vehicles from dynamometer tests may contain higher fractions of EC than would be produced in congested urban driving conditions. PM emissions from SI high-emitter contain predominantly OC. Variability of emissions from a vehicle may be as great as the difference between vehicles, particularly for the high emitters. The abundances of individual organic species relative to total mass or carbon are consistent from profile to profile for organic and elemental carbon, PAH, Hopanes, steranes, and nitroPAH. Alkanes and polars appear too variable to be useful for receptor modeling. Gasoline vehicles, whether low or high emitters, emit higher proportions of high molecular-weight particulate PAHs (e.g., benzo(b+j+k)fluoranthene, benzo(ghi)perylene, indeno(1,2,3-cd)pyrene, and coronene). Hopanes and steranes are markers for lubricating oil from internal combustion engines and their emission rates were highest for high emitting vehicles.

Table 4-43. Summary of PM data for Round 1 composite exhaust samples[1].

Composites	PM Mass	OC	EC	EC/TC	PAH gas markers	Sum of Hopanes	Sum of Steranes
Dilution Tunnel Blanks							
S0-1	0.39	0.256	0.154	0.38	0.00	0.73	0.45
S0-2	0.53	0.129	0.020	0.13	0.16	0.73	0.48
S0-3	0.19	0.268	0.031	0.10	0.04	1.17	0.48
S0-4	0.24	0.293	0.030	0.09	0.00	0.73	0.35
S0-5	0.95	0.940	0.235	0.20	0.19	2.16	1.09
S0-6	0.70	0.588	0.142	0.19	0.18	2.42	1.90
Trucks							
S1-1	9.13	2.204	1.516	0.41	12.07	1.56	0.03
S1-2	81.73	26.070	17.884	0.41	373.42	31.36	5.79
S2-1	73.07	59.132	4.510	0.07	13.09	164.02	44.50
S2-2	20.11	11.332	6.588	0.37	113.03	8.32	3.52
S2-3	22.02	16.212	4.030	0.20	30.93	59.78	48.31
S2-4	76.16	28.193	25.780	0.48	254.90	36.02	14.42
S3-1	3.76	1.097	0.933	0.46	1.43	0.91	0.76
S3-2	22.36	8.186	5.641	0.41	39.02	22.74	6.07
S4-1	3.31	1.438	0.582	0.29	1.15	1.30	0.48
S4-2	2.12	1.801	1.178	0.40	2.28	2.82	1.73
Cars							
S5-1	18.14	9.029	9.929	0.52	128.83	120.60	0.00
S5-2	60.91	46.521	9.412	0.17	263.07	292.58	63.74
S5-3	9.46	7.177	2.549	0.26	4.62	29.35	5.18
S5-4	207.43	101.649	77.566	0.43	1031.44	405.41	63.62
S5-5	99.63	33.934	50.871	0.60	480.44	175.76	46.40
S6-1	41.62	35.609	0.639	0.02	4.01	52.49	12.35
S6-2	49.04	9.079	36.603	0.80	345.07	16.52	6.04
S6-3	10.10	3.738	4.739	0.56	19.03	5.24	0.67
S6-4	22.84	13.998	2.682	0.16	24.25	26.04	8.70
S7-1	7.66	3.856	2.316	0.38	8.04	10.84	7.25
S7-2	8.81	5.258	1.808	0.26	13.08	25.45	8.62
S7-3	4.12	1.666	0.994	0.37	11.97	11.46	0.45
S7-4	4.78	1.155	1.537	0.57	7.54	7.80	0.36
S8-1	1.81	0.983	0.544	0.36	0.34	1.01	0.57
S8-2	2.08	1.488	0.906	0.38	2.22	3.52	1.19
S8-3	3.48	2.346	1.339	0.36	2.27	3.45	1.29

[1] Gravimetric mass, OC, and EC are in mg/mile and PAH, hopanes, and steranes are in ug/mile. The three PAHs that are potential markers for gasoline exhaust are indeno[123-cd]pyrene, benzo(ghi)perylene, and coronene.

Table 4-44. Summary of PM data for Round 2 composite exhaust samples[1].

Composites	PM2.5 Mass	Organic Carbon	Elemental Carbon	EC/TC ratio	PAH gas markers	Sum of Hopanes	Sum of Steranes
Dilution Tunnel Blanks							
W0-1	0.85	0.68	0.14	0.17	0.31	0.97	0.31
W0-2	0.27	0.66	0.03	0.05	0.00	0.29	0.20
W0-3	0.50	0.65	0.16	0.20	0.09	0.44	0.13
W0-4	0.39	0.71	0.08	0.10	0.13	0.49	0.18
W0-5	0.90	0.90	0.17	0.16	0.07	0.65	0.13
W0-6	0.45	0.70	0.10	0.13	0.09	0.48	0.25
Trucks							
W1-1	113.12	74.96	14.09	0.16	364.44	290.43	80.48
W1-2	43.21	31.26	10.01	0.24	87.72	93.86	5.61
W1-3	59.60	34.09	11.59	0.25	251.27	66.64	8.49
W2-1	52.30	25.69	22.84	0.47	319.34	173.27	15.77
W2-2	15.30	4.79	3.58	0.43	7.14	15.00	2.74
W3-1	5.98	2.50	2.66	0.52	128.18	23.96	1.63
W3-2	29.38	10.21	16.25	0.61	71.84	12.80	2.54
W3-3	23.57	7.94	9.00	0.53	21.35	12.01	1.29
W4-1	15.21	5.11	4.23	0.45	16.23	3.01	0.13
W2-3	6.89	2.09	3.35	0.62	9.79	1.98	0.71
W4-2	6.02	2.56	3.07	0.55	19.08	1.90	0.92
W4-3	11.65	5.30	5.24	0.50	26.19	7.96	0.87
Cars							
W5-1	16.82	8.54	7.39	0.46	14.78	6.85	0.57
W5-2	47.47	16.45	28.13	0.63	170.79	12.92	1.84
W5-3	45.26	15.57	15.66	0.50	252.19	18.94	11.78
W6-1	56.31	32.13	20.39	0.39	206.65	170.82	50.03
W6-2	17.14	7.33	9.59	0.57	24.79	5.72	3.35
W6-3	9.97	5.00	3.22	0.39	18.07	7.69	4.02
W6-4	73.13	49.20	4.27	0.08	51.57	216.55	98.98
W7-1	5.08	2.70	2.82	0.51	10.43	1.17	0.34
W7-2	12.44	6.68	3.84	0.36	34.37	6.43	2.23
W7-3	3.45	2.69	1.29	0.32	8.52	3.05	1.75
W7-4	4.65	2.58	1.49	0.37	11.31	0.75	0.46
W8-1	4.21	2.60	1.50	0.37	9.40	2.06	1.08
W8-2	8.46	2.95	4.53	0.61	14.39	2.13	1.47
W8-3	27.78	2.52	3.34	0.57	18.11	2.06	0.52

[1] Gravimetric mass, OC, and EC are in mg/mile and PAH, hopanes, and steranes are in ug/mile. The three PAHs that are potential markers for gasoline exhaust are indeno[123-cd]pyrene, benzo(ghi)perylene, and coronene.

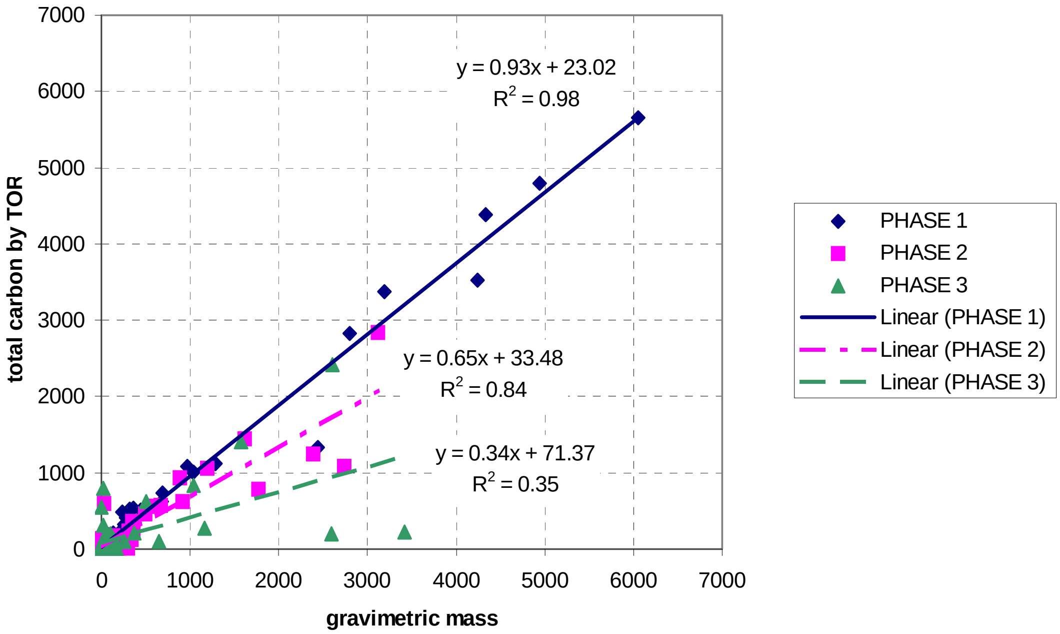


Figure 4-118. Gravimetric mass versus total carbon by TOR

For all dynamometer test filters, separated by test phase. Concentrations are in ug/m3 of diluted exhaust.

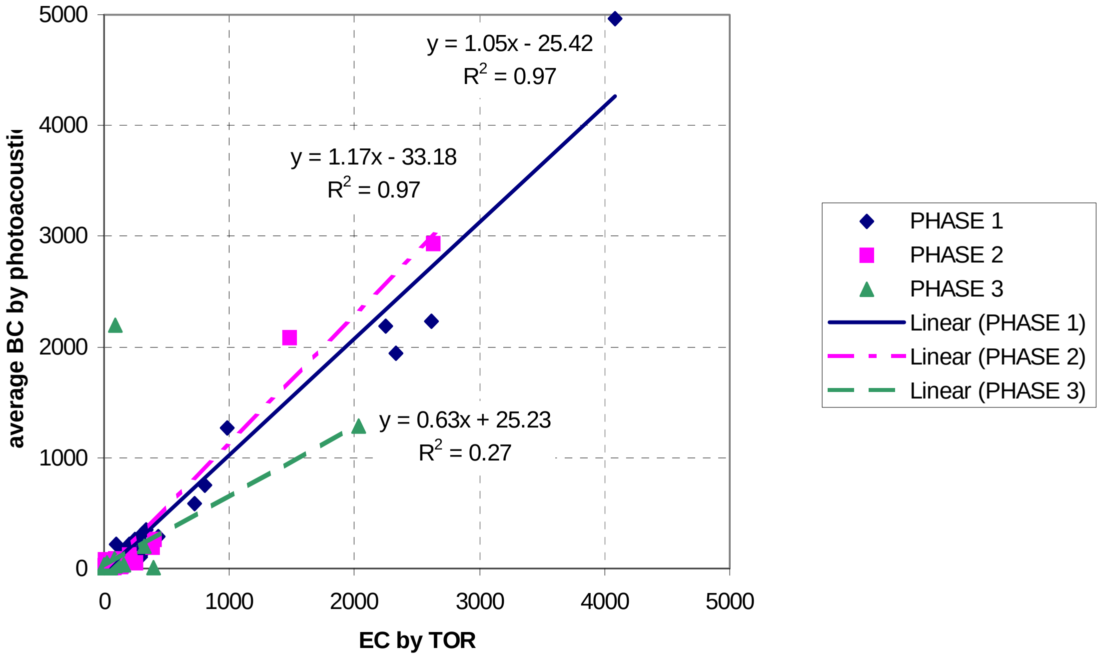


Figure 4-119. Elemental Carbon by TOR versus average BC by photoacoustic method

For all dynamometer tests, separated by test phase. Concentrations are in ug/m3 of diluted exhaust.

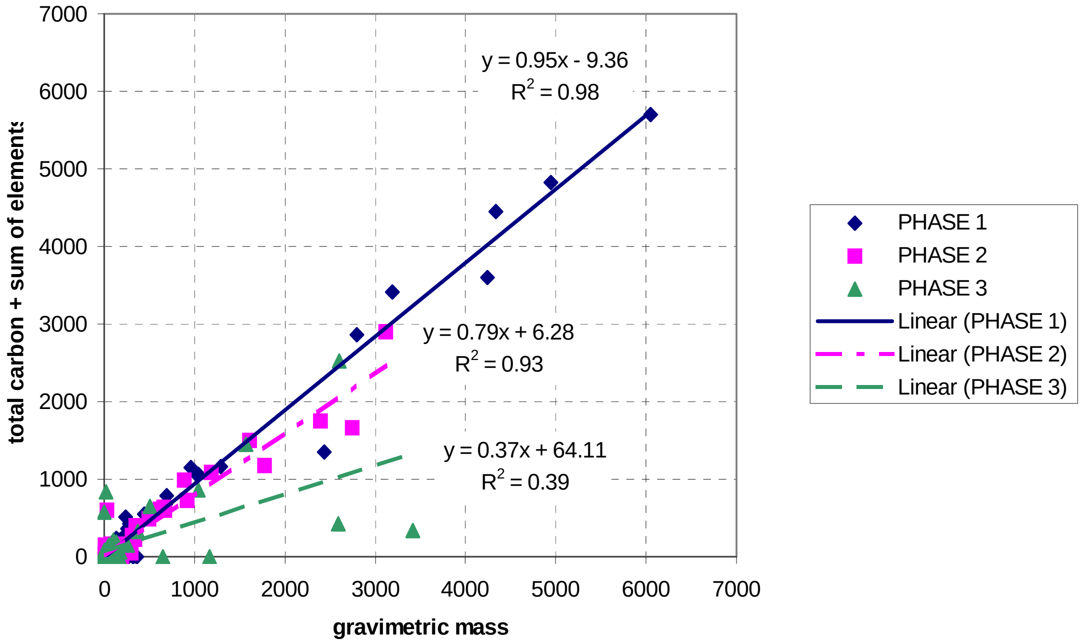


Figure 4-120. Gravimetric mass versus sum of XRF elements and total carbon by TOR

For all dynamometer tests, separated by test phase. Concentrations are in ug/m3 of diluted exhaust.

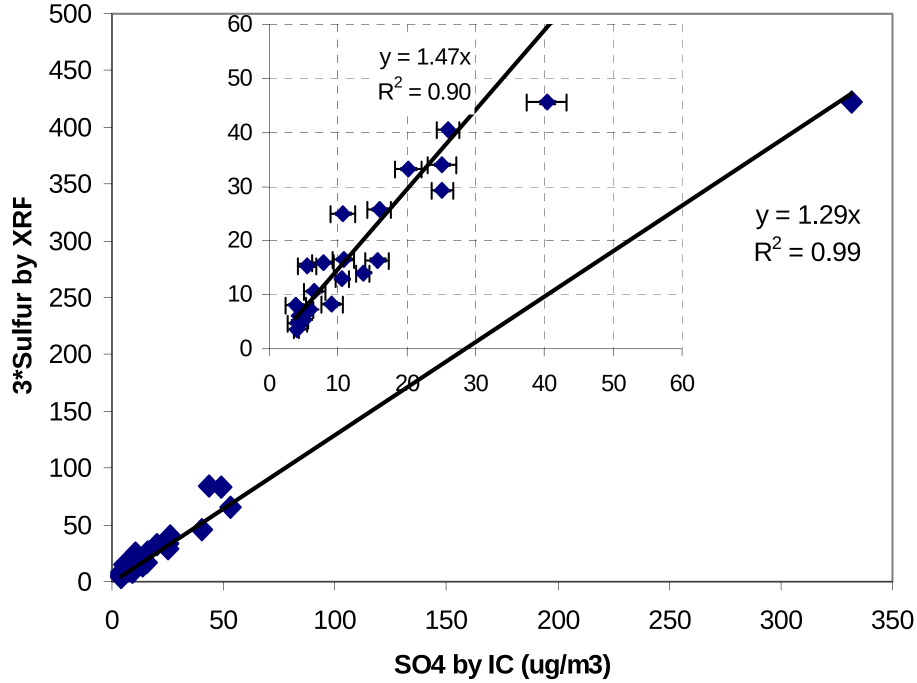


Figure 4-121. Sulfur by XRF *3 versus Sulfate by IC for all exhaust composites.

The inset shows the data without the significant outlier at SO_4=330 ug/m3. Concentrations are in ug/m3 of diluted exhaust.

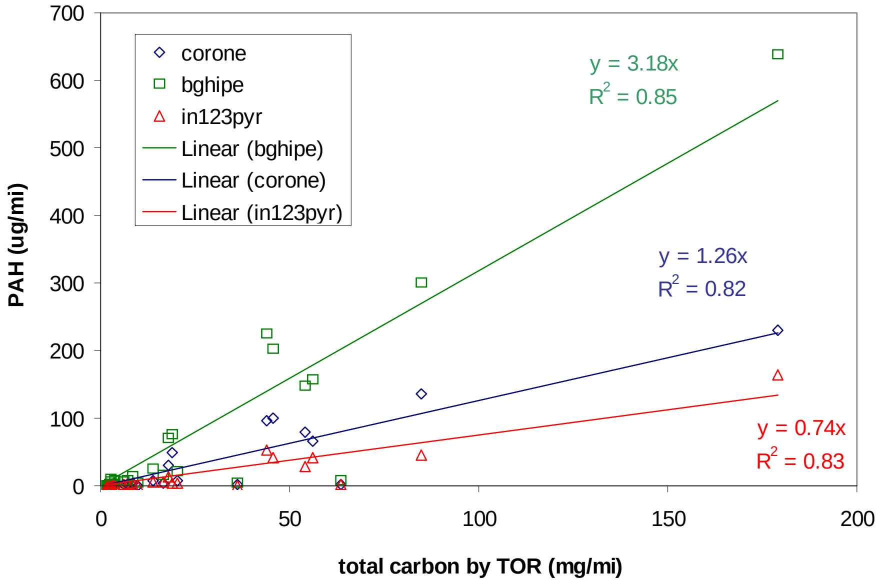


Figure 4-122. Total organic carbon by TOR versus indeno[123-cd]pyrene, benzo(ghi)perylene and coronene in mg/mile.

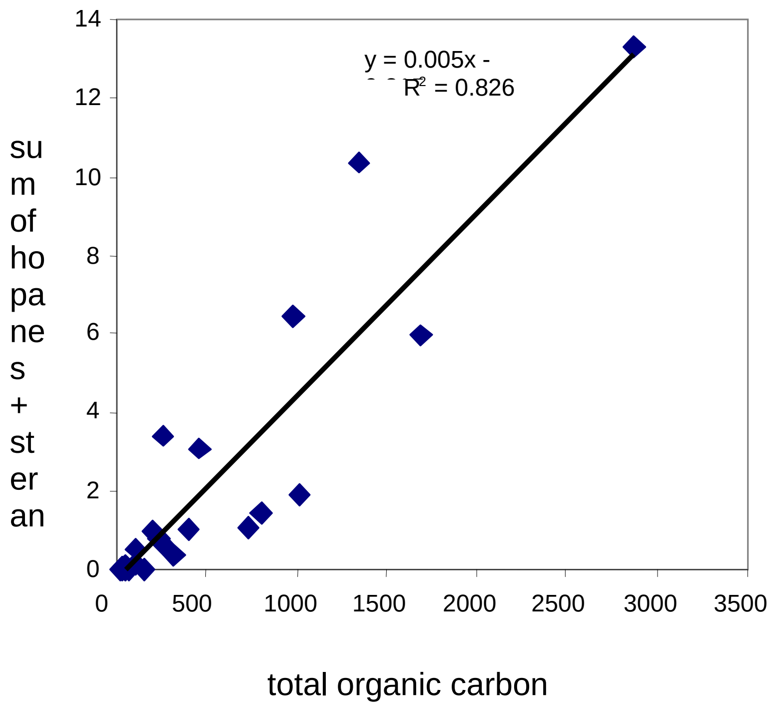


Figure 4-123. Total organic carbon by TOR versus sum of hopanes and steranes for exhaust composites.

Concentrations are in ug/m3 of diluted exhaust.

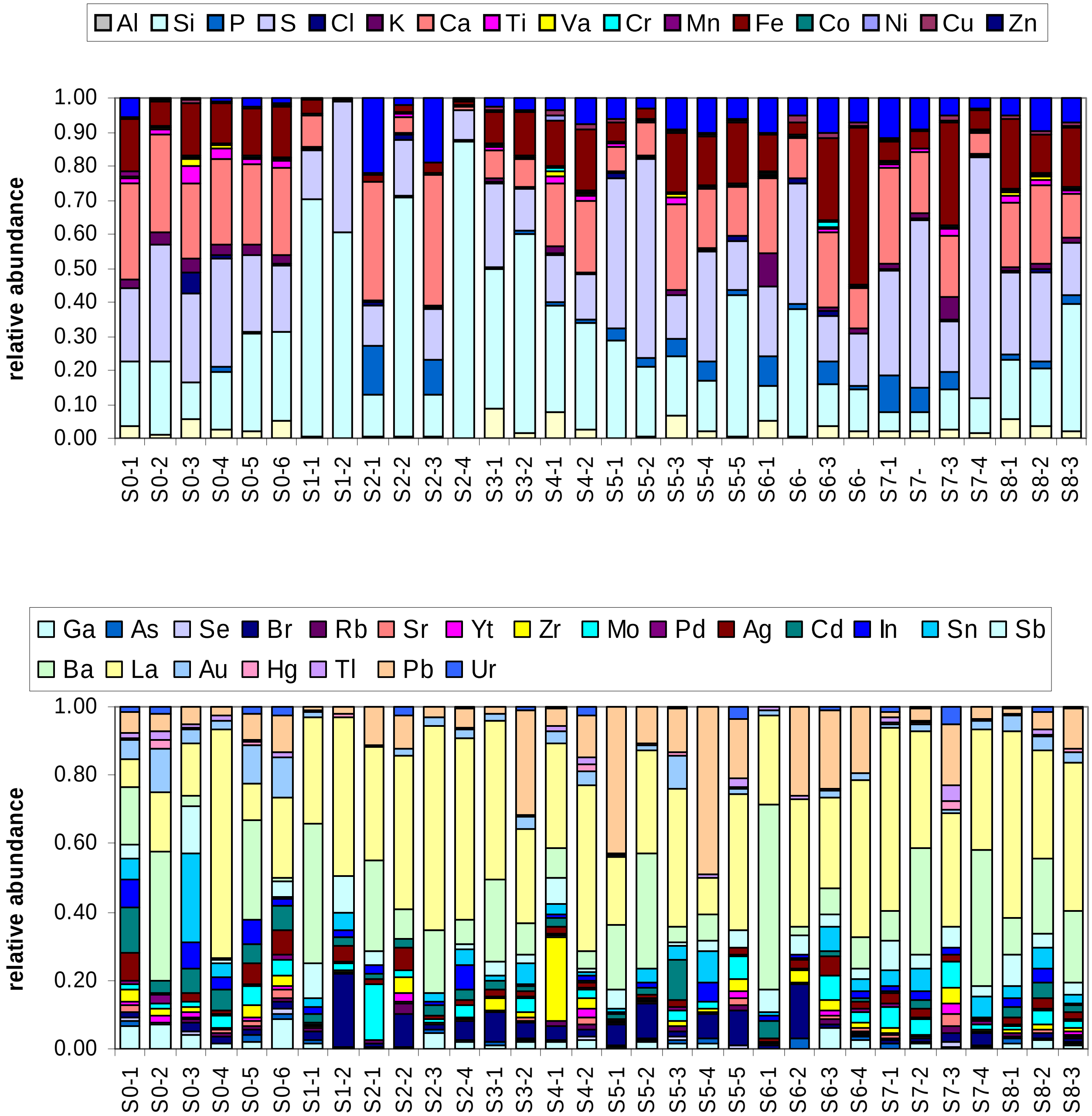


Figure 4-124. Abundances of elements and ions from XRF and IC analysis of all exhaust and dilution blank composites during Round 1.

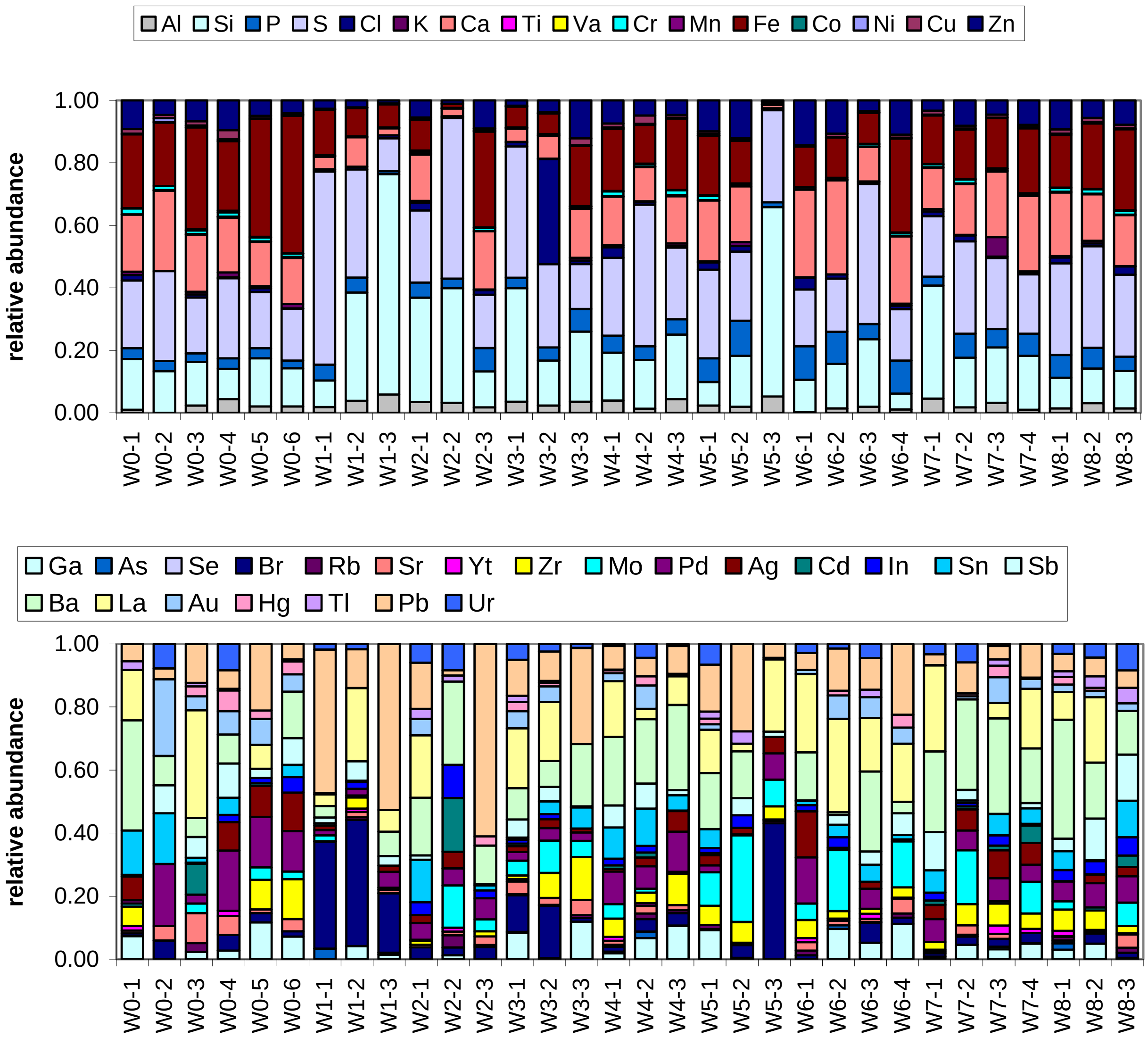


Figure 4-125. Abundances of elements and ions from XRF and IC analysis of all exhaust and dilution blank composites during Round 2.

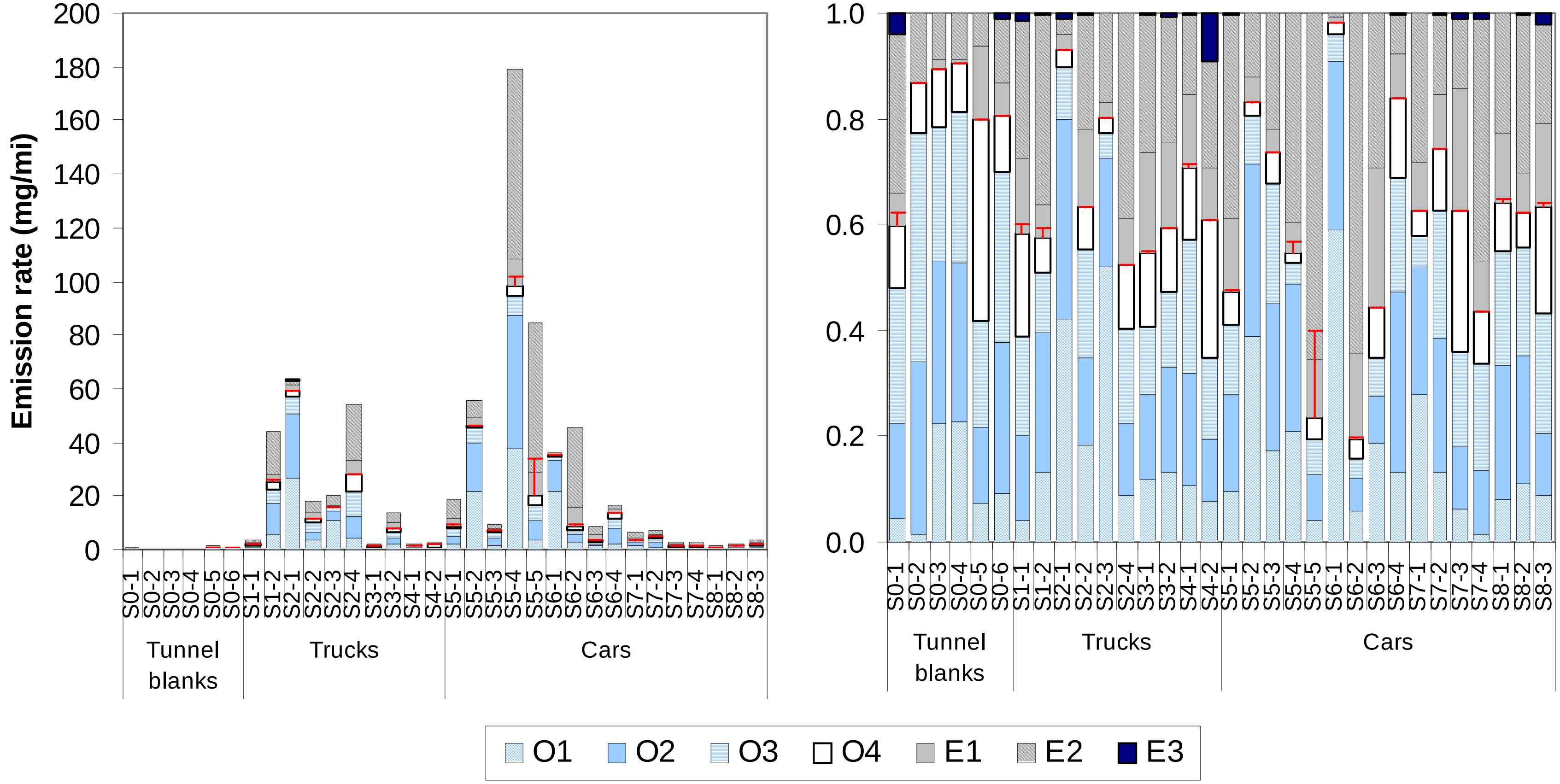


Figure 4-126. Abundances of carbon fractions from IMPROVE-TOR analysis of all exhaust and dilution blank composites during Round 1.

The error bars indicate the pyrolysis correction to OC.

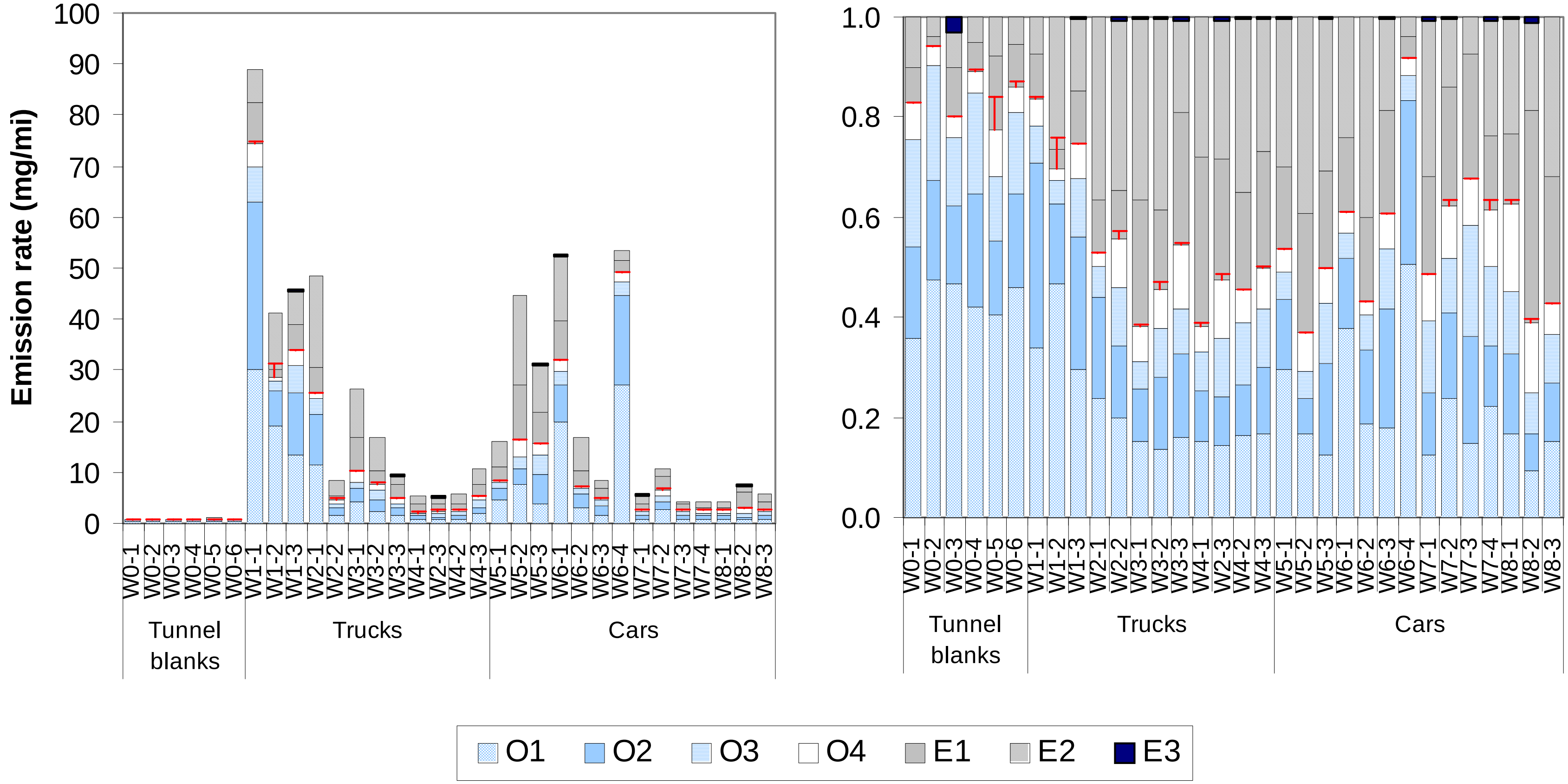
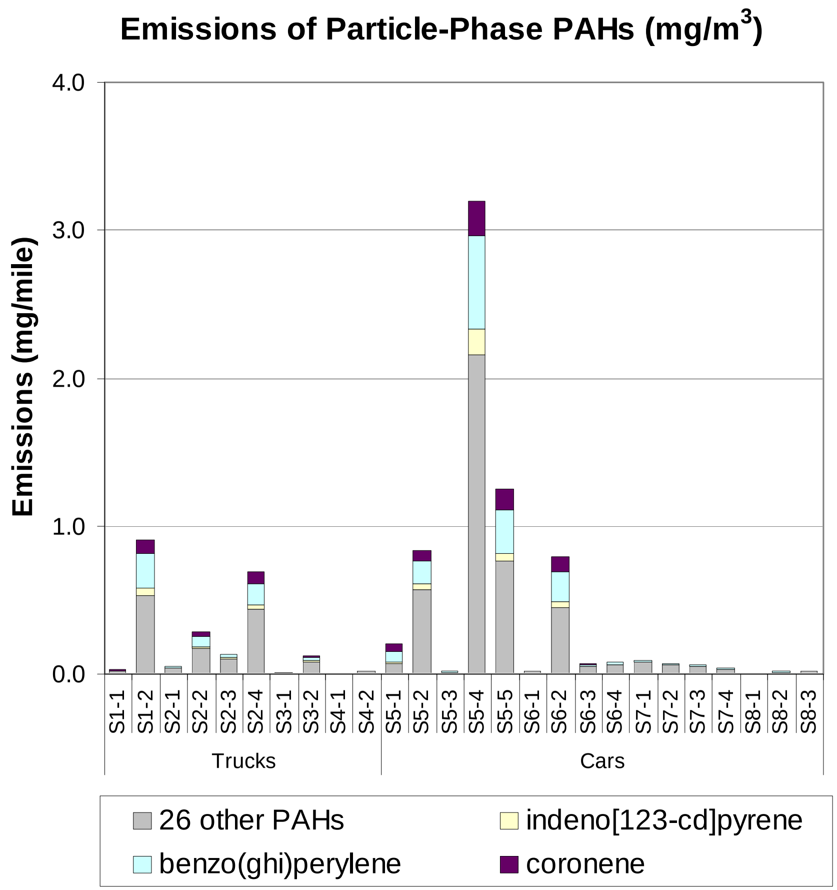


Figure 4-127. Abundance of carbon fractions from IMPROVE-TOR analysis of all exhaust and dilution blank composites during Round 2.

The error bars indicate the pyrolysis correction to OC.



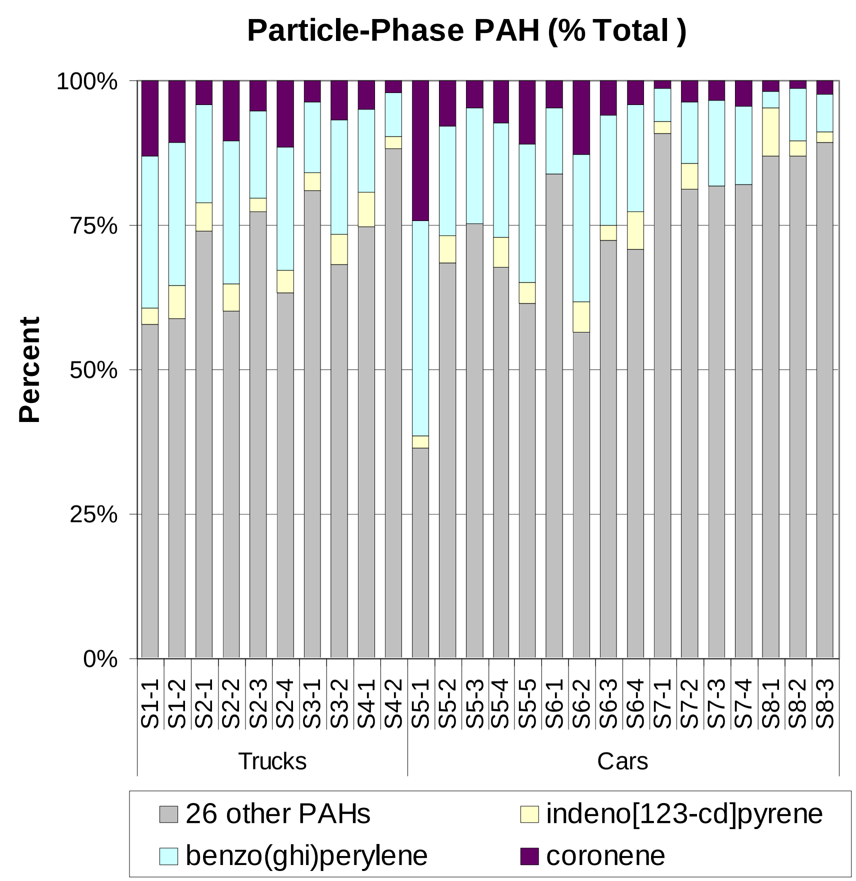


Figure 4-128. Abundances of benzo(ghi)perylene, indeno[123-cd]pyrene, coronene and sum of 26 other particulate PAH for exhaust and dilution blank composites during Round 1.

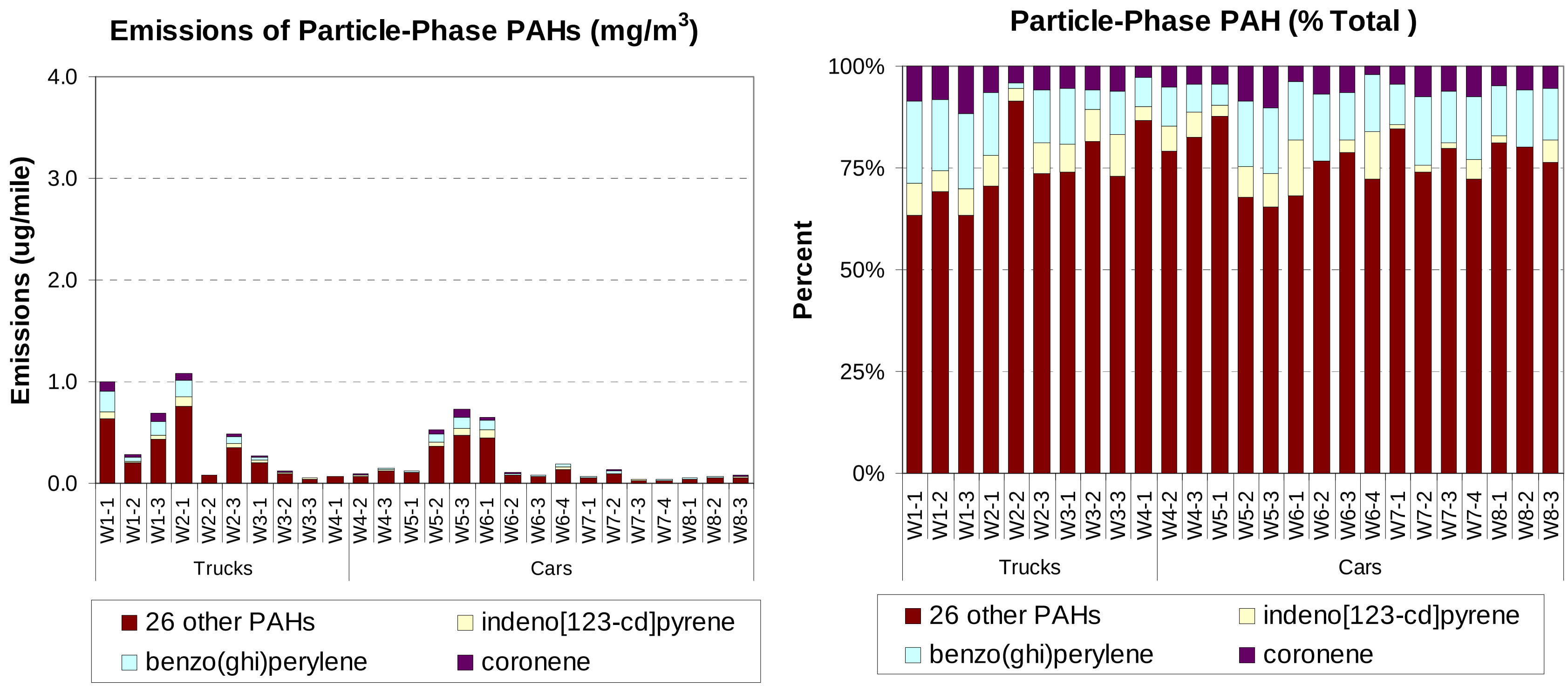


Figure 4-129. Abundances of benzo(ghi)perylene, indeno[123-cd]pyrene, coronene and sum of 26 other particulate PAH for exhaust and dilution blank composites during Round 2.

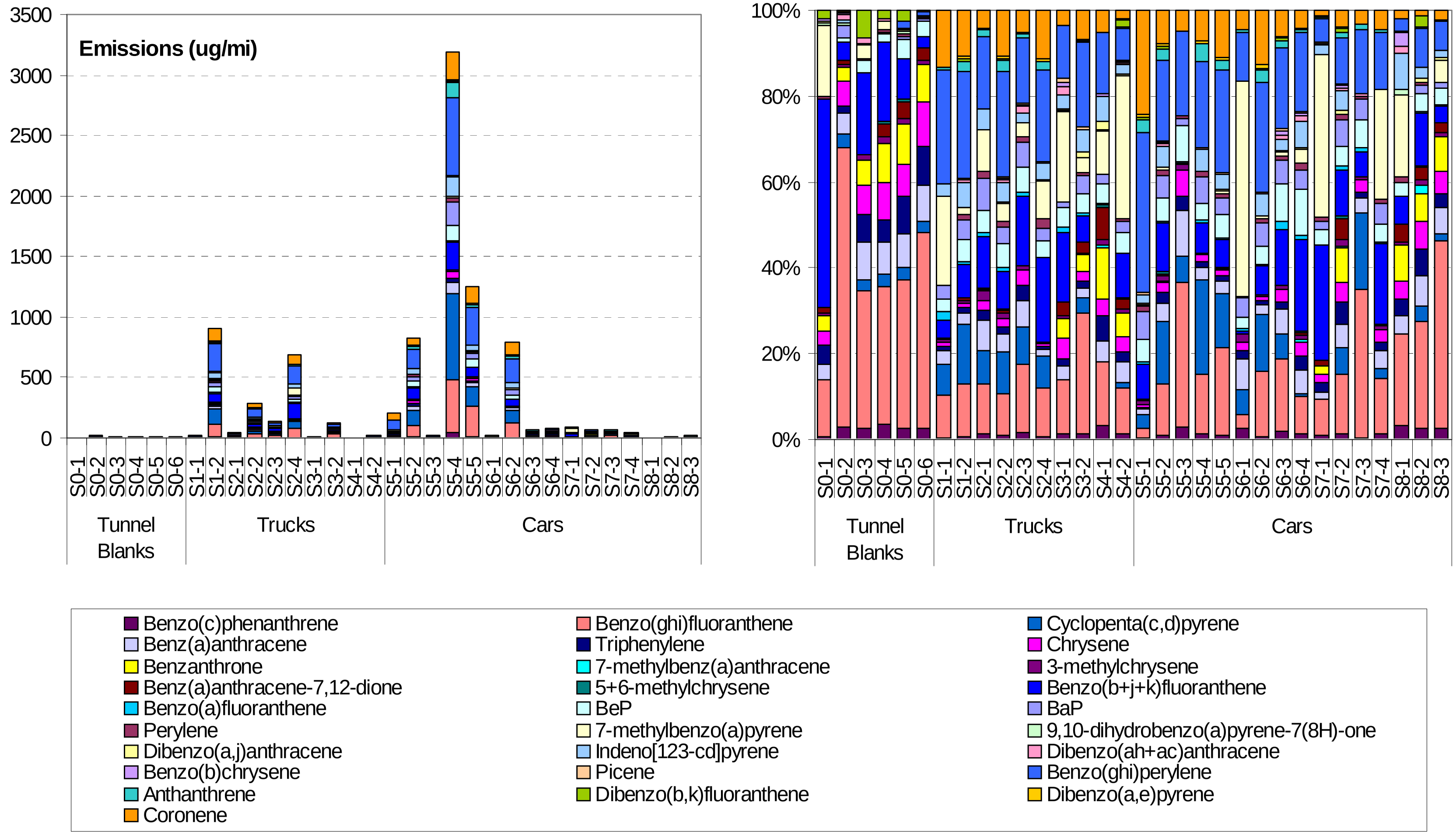


Figure 4-130. Abundances of particulate PAHs for exhaust and dilution blank composites during Round 1.

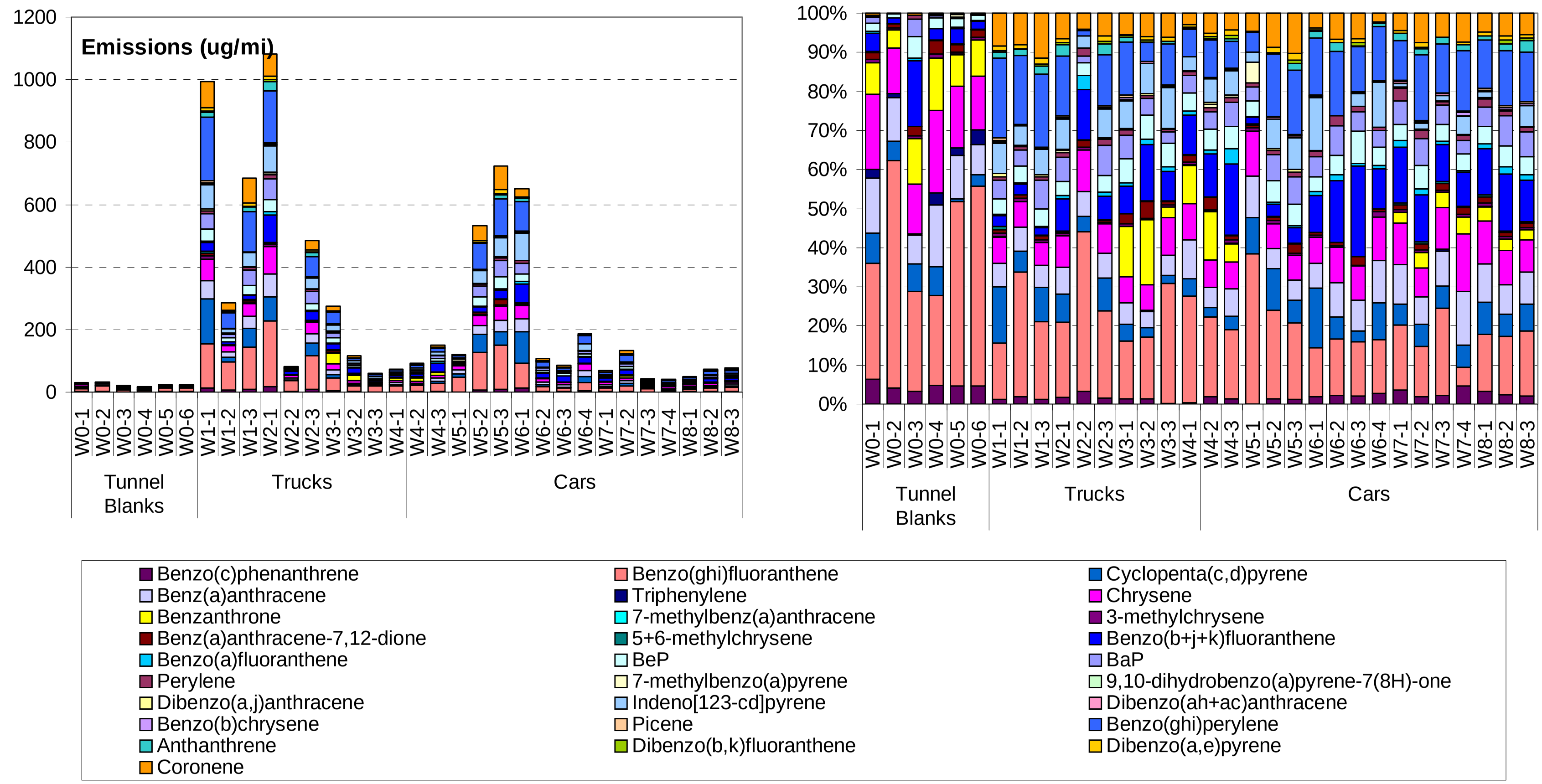


Figure 4-131. Abundances of particulate PAHs for exhaust and dilution blank composites during Round 2.

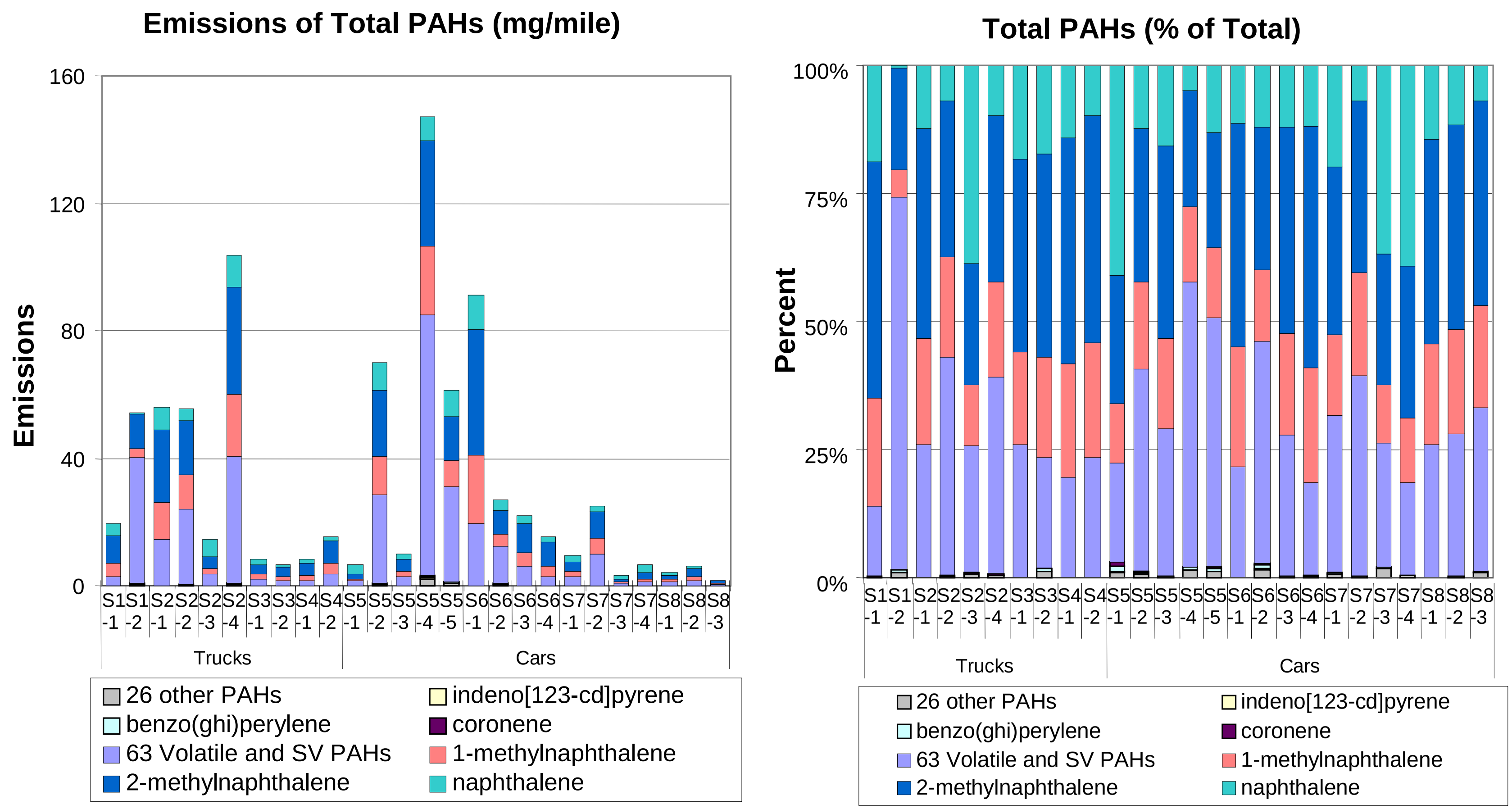


Figure 4-132. Abundances of naphthalene, 1-methylnaphthalene and 2-methylnapthalene for exhaust and dilution blank composites during Round 1 in comparison to other volatile, semi-volatile and particulate PAHs.

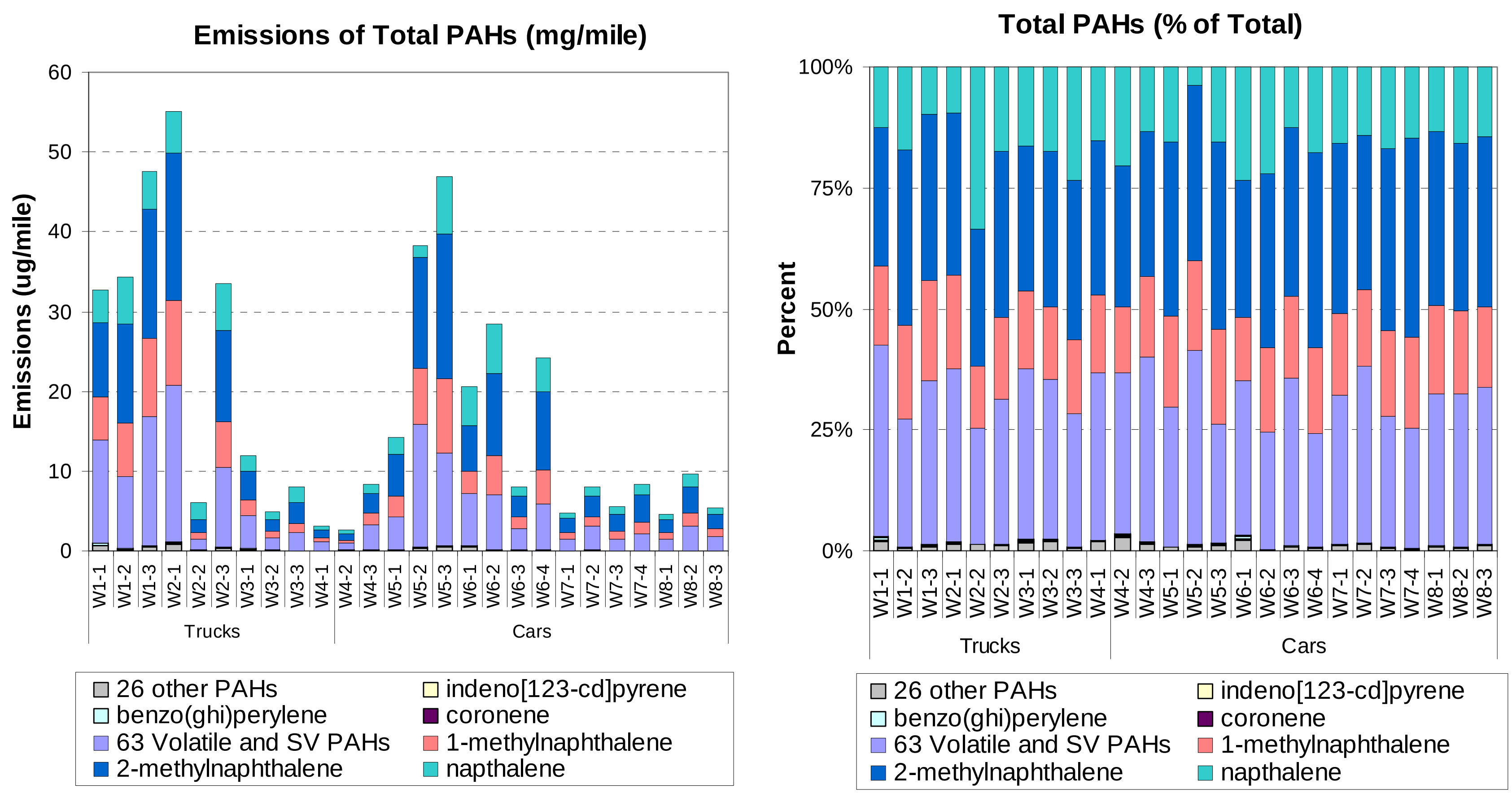


Figure 4-133. Abundances of naphthalene, 1-methylnaphthalene and 2-methylnapthalene for exhaust and dilution blank composites during Round 2 in comparison to other volatile, semi-volatile and particulate PAHs.

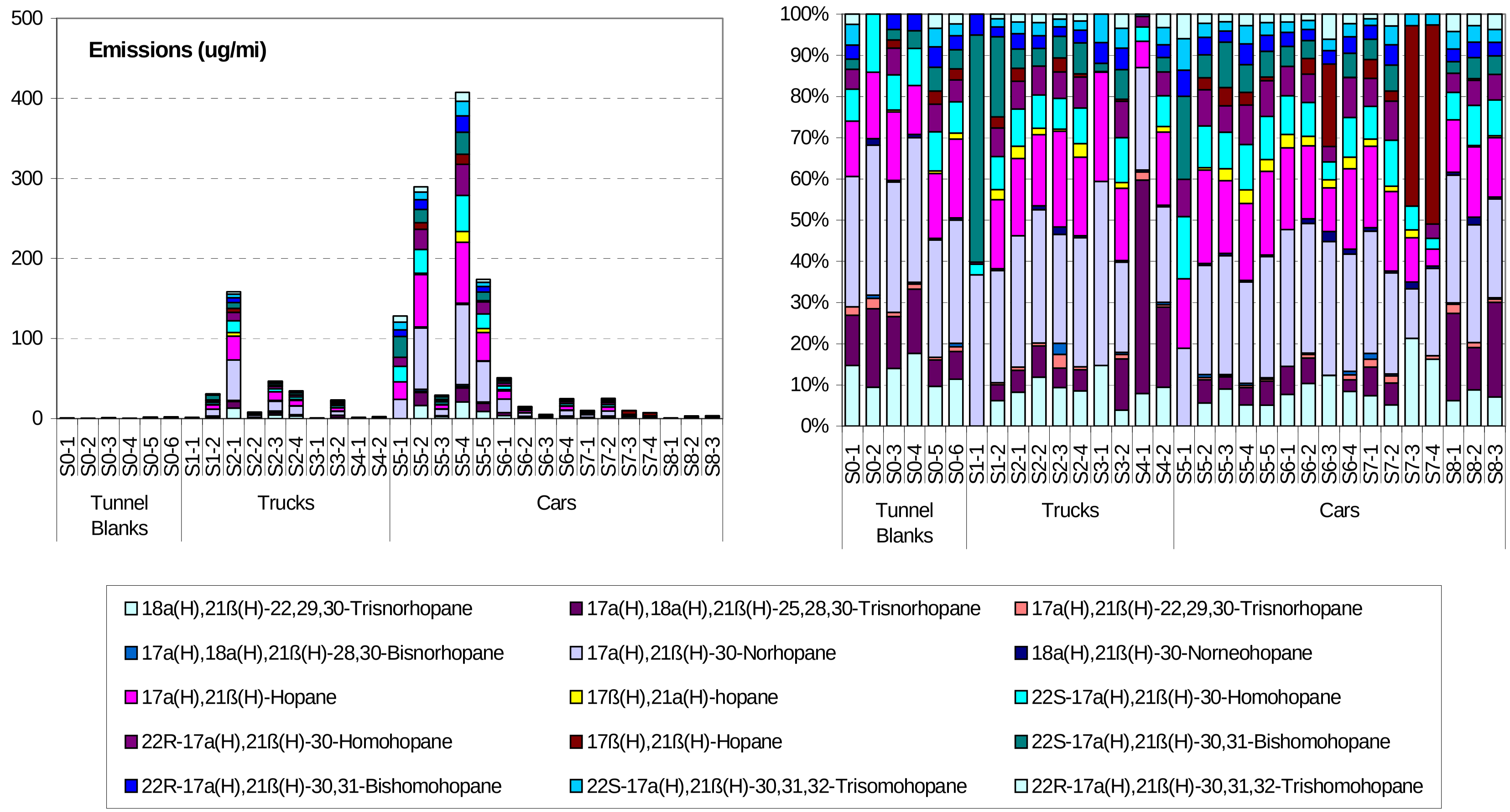


Figure 4-134. Abundances of hopanes for exhaust and dilution blank composites during Round 1.

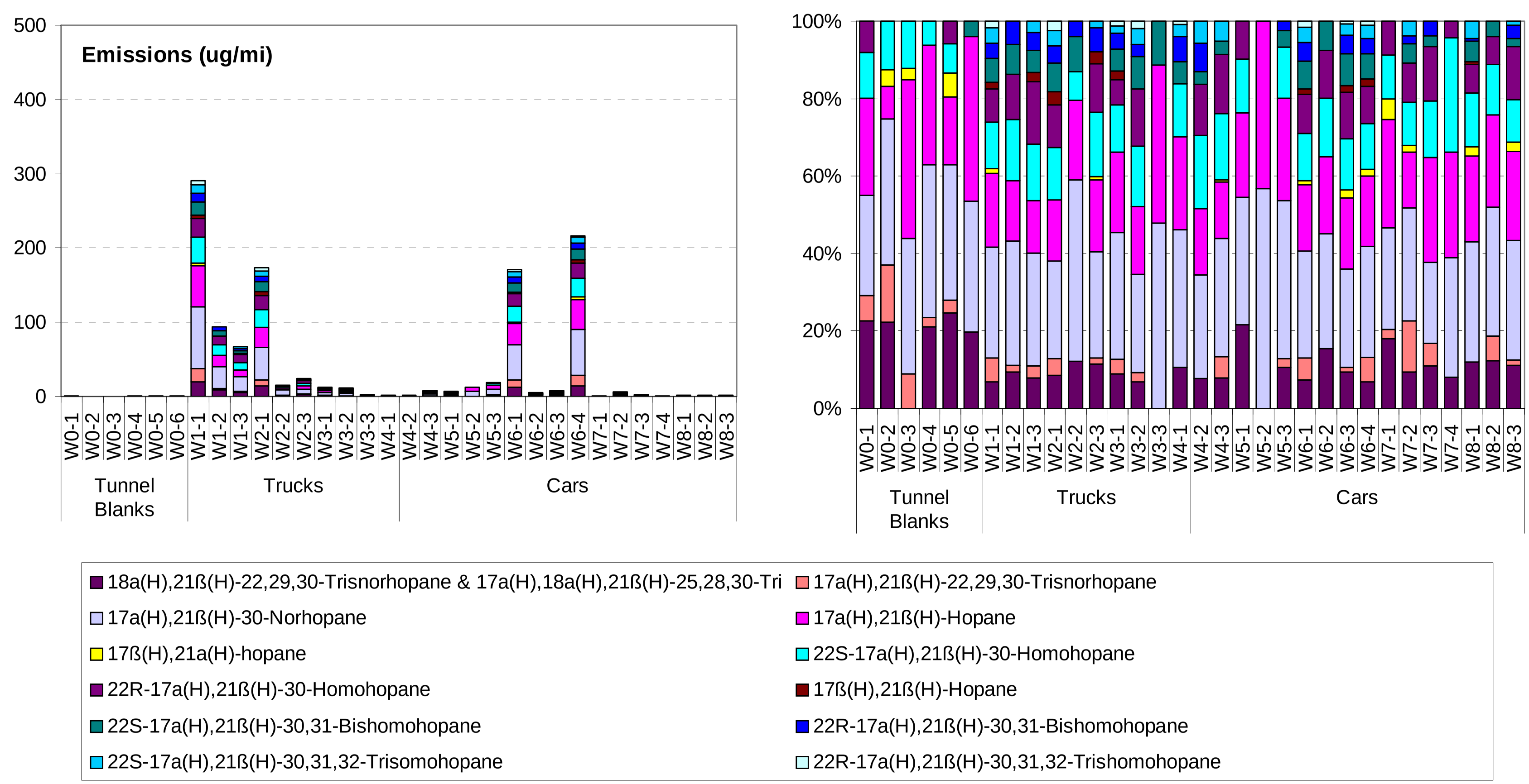


Figure 4-135. Abundances of hopanes for exhaust and dilution blank composites during Round 2.

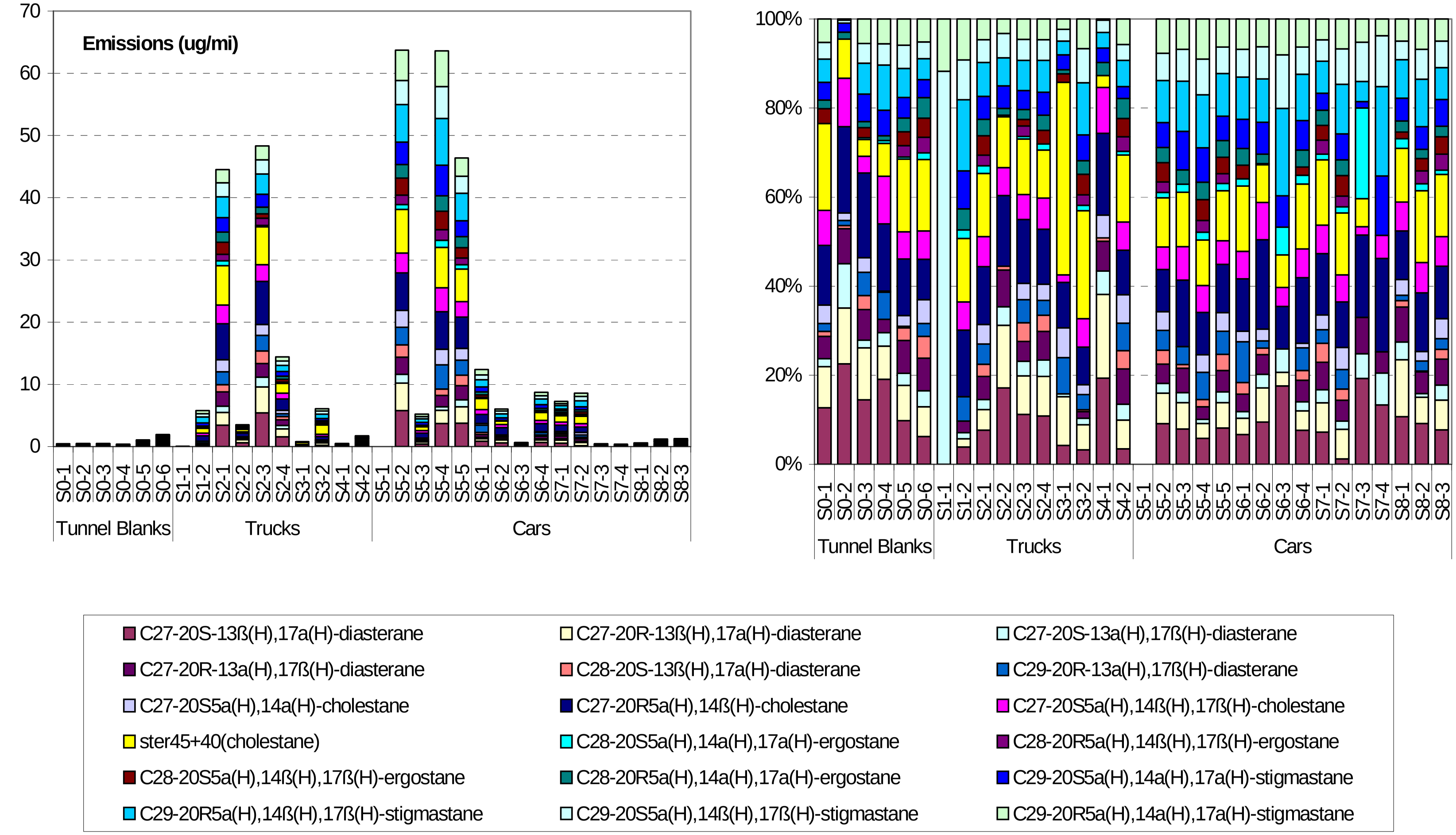


Figure 4-136. Abundances of steranes for exhaust and dilution blank composites during Round 1.

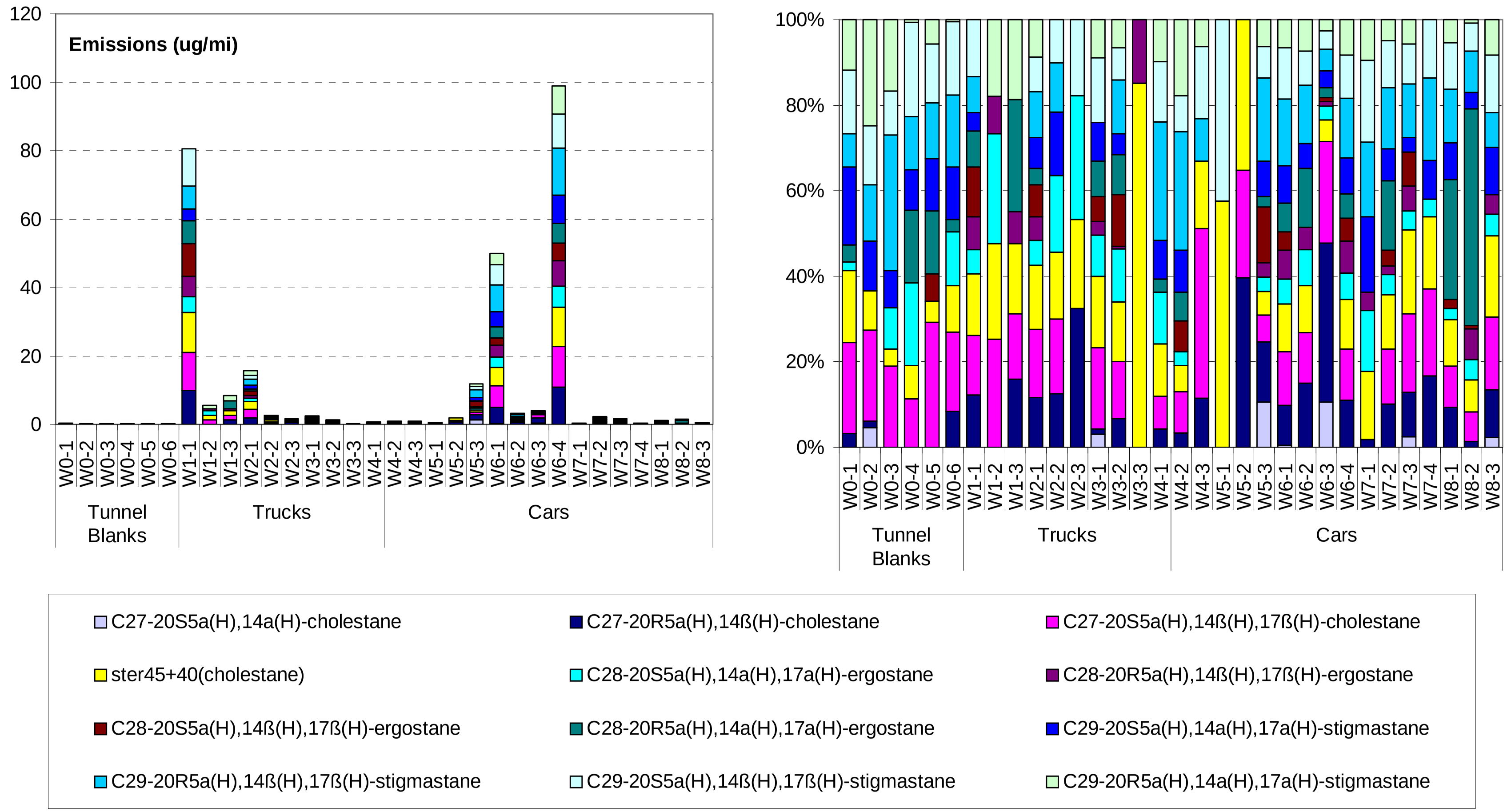


Figure 4-137. Abundances of steranes for exhaust and dilution blank composites during Round 2.

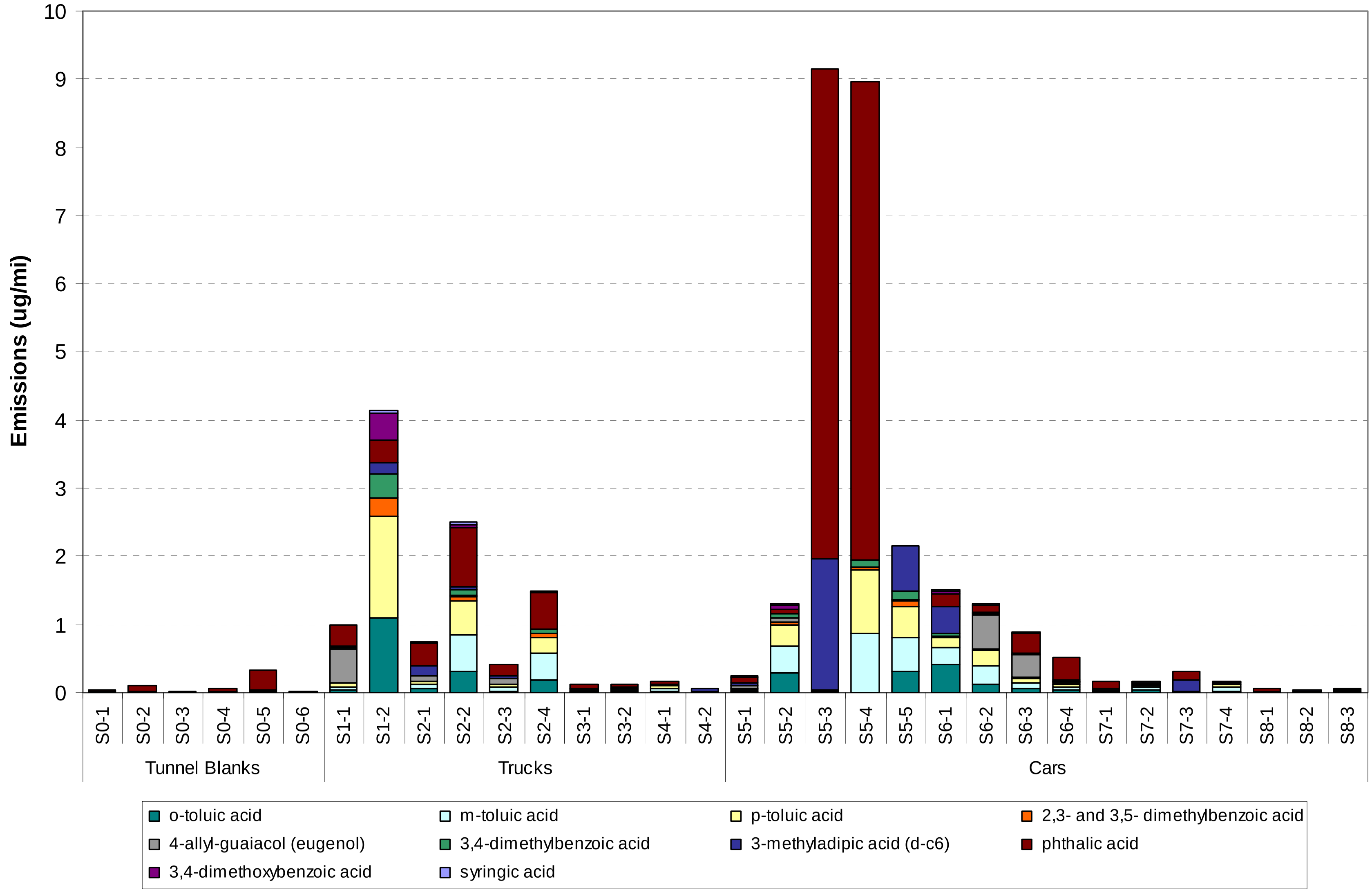


Figure 4-138. Abundances of polar compounds for exhaust and dilution blank composites during Round 1.

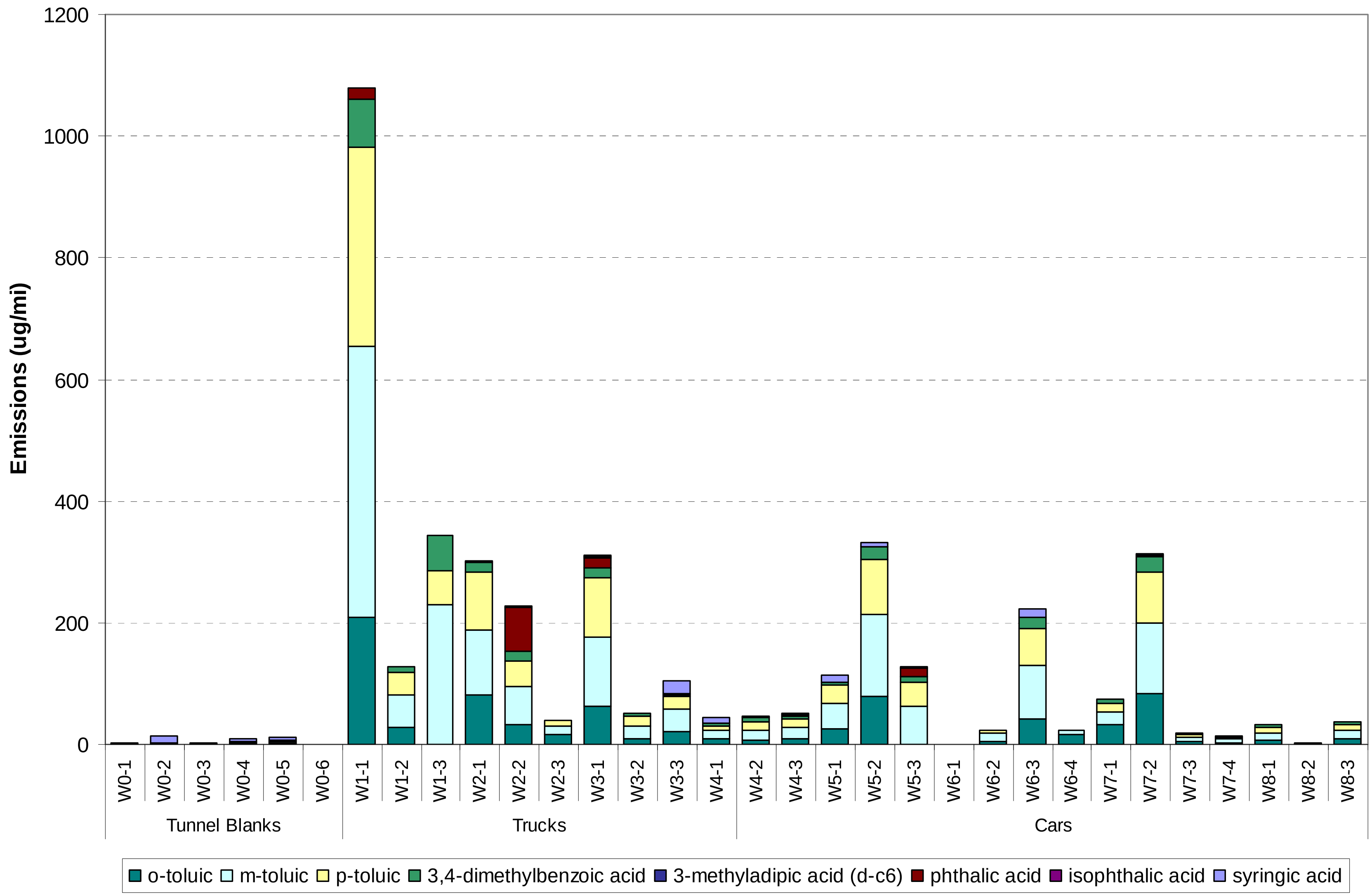


Figure 4-139. Abundances of polar compounds for exhaust and dilution blank composites during Round 2.

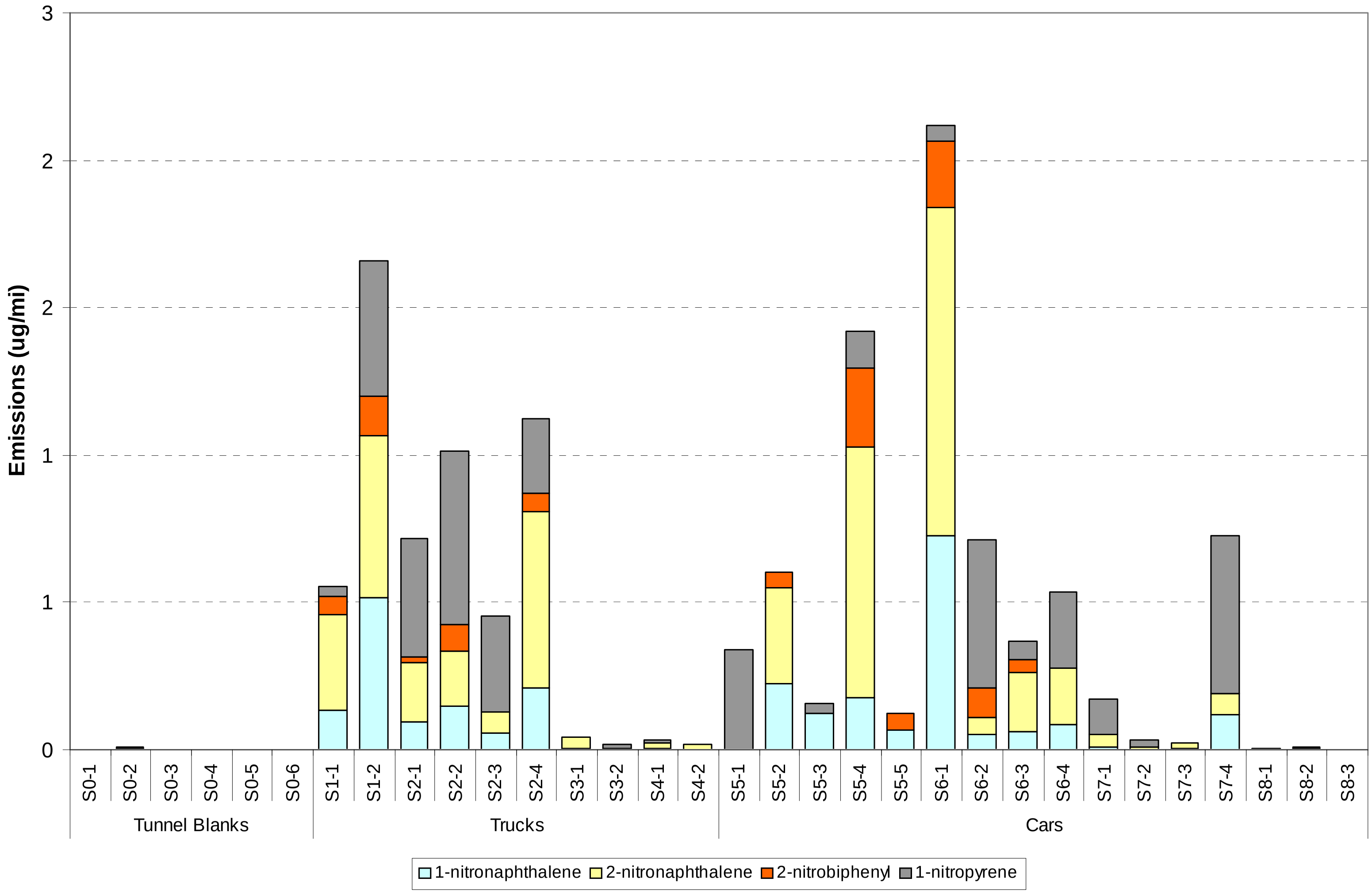


Figure 4-140. Abundances of nitro-PAHs for exhaust and dilution blank composites during Round 1.

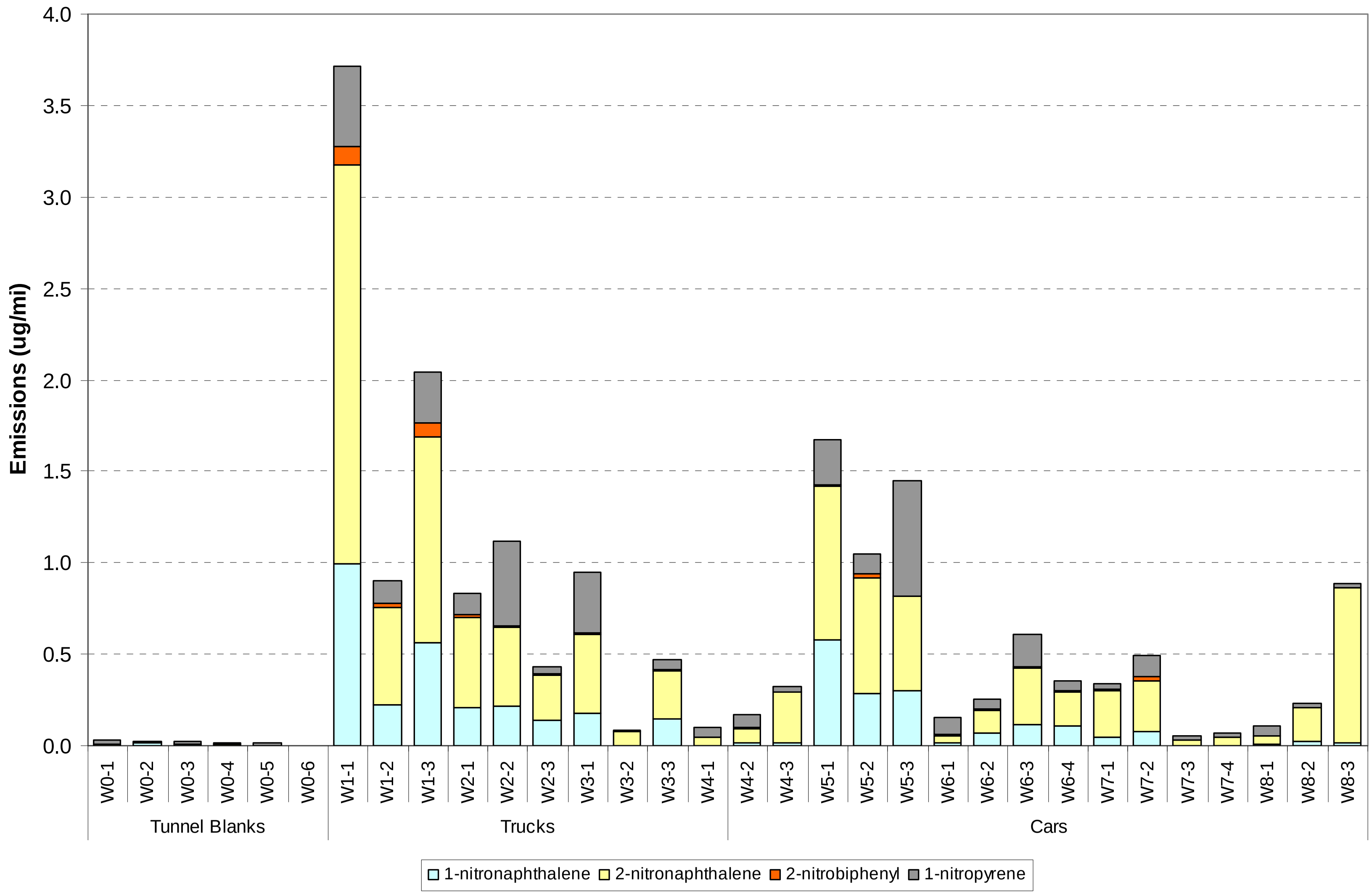


Figure 4-141. Abundances of nitro-PAHs for exhaust and dilution blank composites during Round 2.

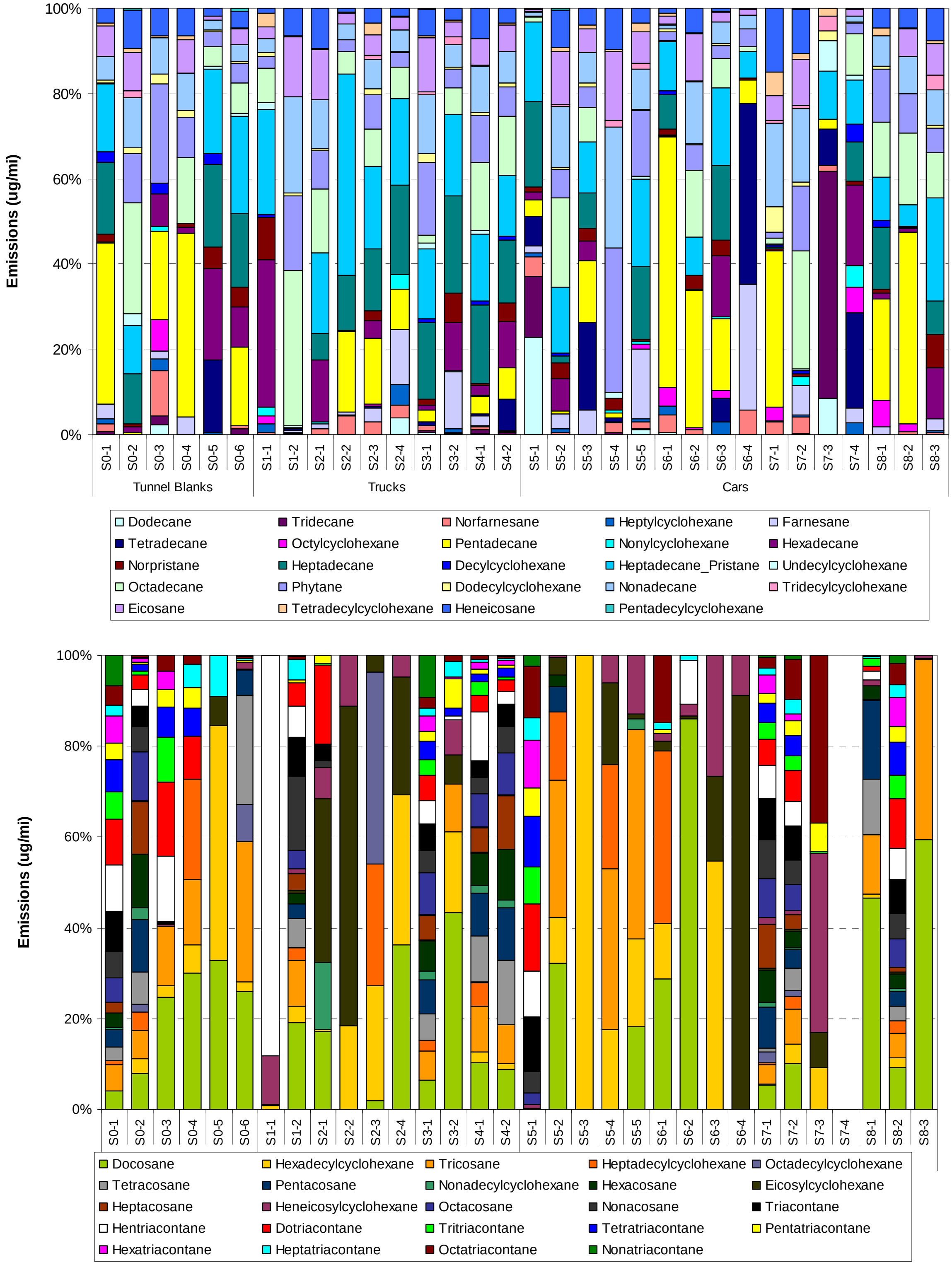
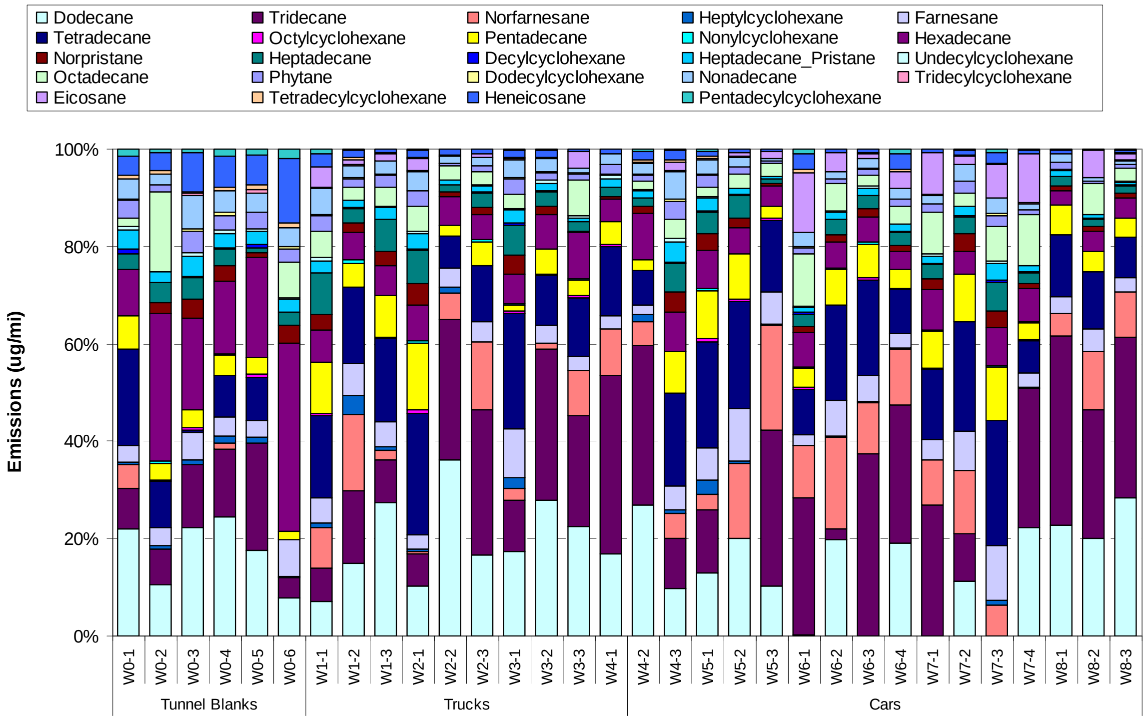


Figure 4-142. Relative abundance of alkanes in exhaust and dilution blank composites during Round 1.



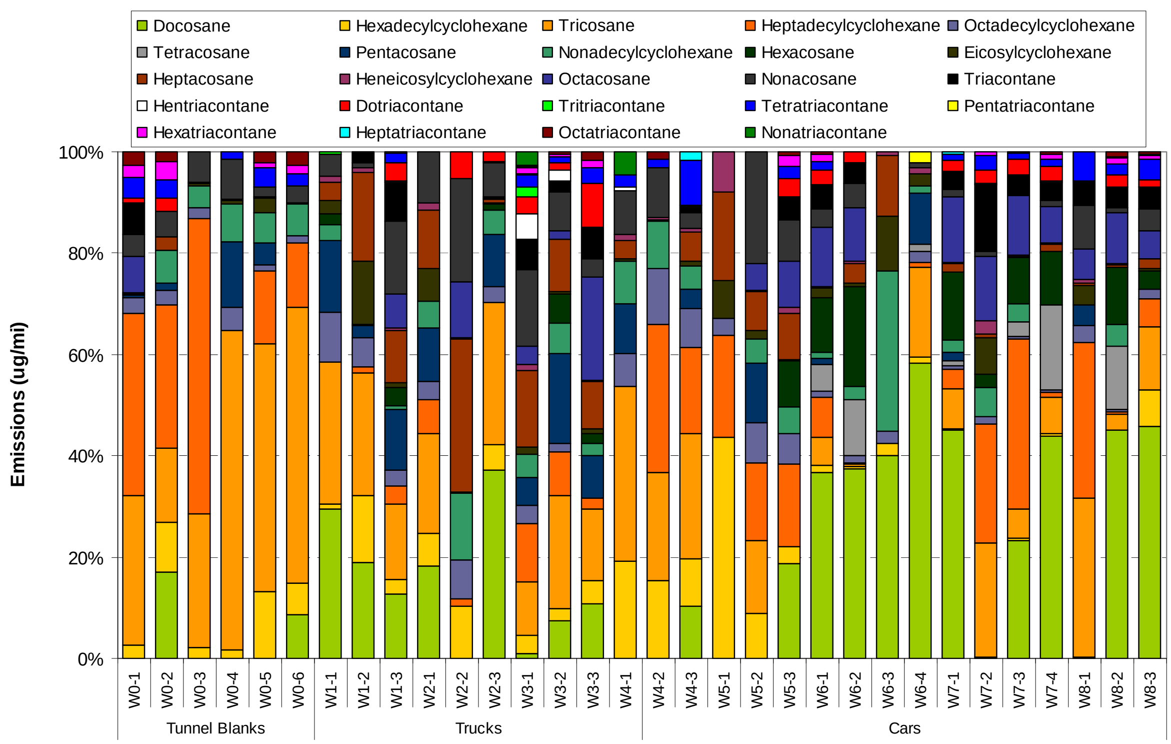


Figure 4-143. Relative abundance of alkanes in exhaust and dilution blank composites during Round 2.

4.7 Speciated VOC Emissions and Gas-Phase Mobile Source Air Toxics

4.7.1 Background

Motor vehicles are a major source of volatile organic compounds. VOCs are involved in photochemical reactions leading to the formation and accumulation of ozone in the troposphere. VOCs also include several compounds that have been identified by EPA as hazardous air pollutants (HAPs). Of the 33 HAPs identified by EPA as important urban air toxics, 21 are associated with motor vehicles. The gas-phase mobile source air toxics (MSAT) of most concern include benzene, toluene, ethyl benzene, xylenes, formaldehyde, acetaldehyde, 1,3-butadiene and acrolein. Methods for sampling and analysis of speciated VOCs are generally well developed for both ambient and source measurements. However, certain compounds are unstable and decay rapidly after sample collection. Methods were developed and applied to address these measurement issues.

1,3-butadiene is known to be unstable in canister samples in the presences of NOx. Prior work by DRI for the Gasoline/Diesel PM Split Study included dynamometer studies where a GC/MS system was installed on site to perform VOC analysis within minutes of sample collection to prevent loss of 1,3-butadiene. However there is considerable cost associated with installing and operating a GC/MS on site for the length of time involved in vehicle testing for this study. As an alternative to on-site analysis, DRI examined the feasibility of stabilizing 1,3-butadiene in canister samples by removing NO and NO_2 from the exhaust samples. The development and evaluation of a NOx denuder was funded separately by the National Renewable Energy Laboratory (NREL) of the U.S. Department of Energy and carried out during the pilot phase of the study. The methods and results are described in a separate report for NREL by Fujita et al. (2004) and briefly summarized here.

Acrolein is known to rearrange on DNPH cartridges to an unknown degradation product (acrolein-X) (Tejada, 1986). This rearrangement is sufficiently rapid that most of the acrolein may convert to acrolein-X, unless the sample is analyzed within a few hours. The problem is compounded by the fact that acrolein-X co-elutes in the HPLC analysis with butyraldehyde. A procedure was developed in a separate project conducted by the DRI for the Health Effects Institute (Fujita et al., 2006) and applied after the initial analyses to more accurately quantify acrolein and butyraldehyde.

4.7.2 Experimental Methods

BKI conducted the vehicle emissions tests on their transportable Clayton Model CTE-50-0 chassis dynamometer over the LA92 Unified Driving Cycle. The test site and dynamometer setup is described in Chapter 2. The vehicle emissions tests were conducted in Kansas City during July to September 2004 (summer/Round 1) and January to March 2005 (winter/Round 2). The cycle consists of a cold start Phase 1 (first 310 seconds), a stabilized Phase 2 (311-1427 second), a 600-second engine off soak, and a warm start Phase 3 (repeat of Phase 1 of the LA92). Cars and light-duty trucks were recruited for testing in four model year groups (Pre-1981, 1981-90, 1991-95 and 1996 and newer). The vehicle groupings for trucks and cars are designated strata 1-4 and 5-8, respectively, with the strata in each vehicle type ordered from older to newer model years. Details of the vehicle recruitment for the study are given in Chapter 2. Samples were collected for speciation of VOC and gas-phase MSATs over the entire driving cycle. Full sets of sampling media were also collected for daily 60-minute tunnel blanks and weekly (approximate) field/transport blanks. Tables 4-38 and 4-39 in Section 4.6 summarize the numbers of samples collected and subsequently selected for chemical analysis in Rounds 1 and 2, respectively.

4.7.2.1 Sampling Methods for Speciated VOC

Sampling for VOC included collection of whole air samples in canisters for analysis of speciated hydrocarbons (benzene, toluene, ethylbenzene, m-& p-,o-xylene, i.e. BTEX, styrene, n-hexane, naphthalene,1,3-butadiene, MTBE), and DNPH-coated Sep Pak cartridges sampling for carbonyl compounds (formaldehyde, acetaldehyde, acrolein). DRI installed and operated the samplers in accordance with the methods and procedures specified in the project QAPP.

During the planning phase of the study, we estimated the decay rate of 1,3-butadiene according to the chemical mechanism described by Atkinson et al. (1984). They showed that a mixture of NO and NO_2 will produce a series of reactions that will result in •OH being formed in the dark. Hydroxyl radical reacts rapidly with 1,3-butadiene resulting in its removal from a canister sample. Theoretical calculations by our colleague at DRI, Dr. William Stockwell, indicated that the loss of 1,3-butadiene would be rapid in a canister sample of diluted exhaust. At NO_2 mixing ratio of 1 ppm, 1,3-butadiene was projected to decay linearly at a rate of 25% over three days. NO at 10 ppm results in a loss of 52% in the first 24 hours and about 92% loss after three days. These simulated loss rates are also compared in Table 4-45 to loss rates of 1,3-butadiene for ambient NOx levels typically found in high exposure microenvironments and at central monitoring locations.

DRI fabricated a NOx denuder following the method of Braman et. al, (1986). Stainless steel tubes (3/8” o.d.) were coated with a saturated solution of $CO(NO_3)_2$ in water and dried. The tubes were packed inside a larger stainless steel pipe of approximately 2.5” i.d. and capped with tapped end-caps with ¼” fittings. The entire package was heated to approximately 400^{o}C with a flow of approximately 300 ml/min of air through it and left for 8 to 10 hours. The oxidation of the cobalt was confirmed by the elution of NO_2 from the denuder. The denuder was tested by challenging it with a standard of 50 ppm NO in nitrogen. The effluent was analyzed by a chemiluminescence NOx analyzer and we found approximately 30 ppb in the effluent, which was about the same as the zero at that time.

The newly constructed NOx denuder was tested during the pilot study phase of the Kansas City Study with funding provided by the U.S. Department of Energy through the Natinonal Renewable Energy Laboratory. Results of these tests were reported by Fujita et al. (2004) and are summarized in Figure 4-144. Both synthetic mixtures and vehicle exhaust samples from Kansas City were used to evaluate the stability of 1,3-butadiene in canister samples. Two sets of three synthetic samples were prepared - one containing 1,3-butadiene with purified zero air and a second and third with addition of NO and NO_2, respectively. NO and NO_2 levels were selected to correspond to the highest LDGV NOx emitter in DOE’s Gas/Diesel PM Split Study. Aliquots were analyzed by gas chromatography within the first hour, after three days, one week and three weeks.

Table 4-45. Simulated loss rate of 1,3-butadiene with varying levels of 1,3-butadiene, NO and NO_2.

	Initial Conditions					Loss Rate of 1,3-BD		
	1,3-BD ppbv	VOC ppbC	NO ppb	NO2 ppb	CO ppb	6 Hrs	24 Hrs	72 Hrs
Control								
Zero	43	0	0	0	0	0	0	0
High NO (Typical Dyno)	43	0	10,000	0	0	11.4%	52.4%	92.5%
High NO2	43	0	0	1,000	0	2.4%	9.3%	25.3%
High Exposure ME								
Underground Garage	5	3,000	1,000	100	40,000	0.5%	3.9%	17.0%
Congested Freeway	2	750	300	30	8,000	0.1%	0.7%	3.4%
Central Monitoring								
Summer	1	250	75	30	1,000	0.1%	0.3%	1.1%
Winter	1	500	200	40	3,000	0.1%	0.6%	2.4%

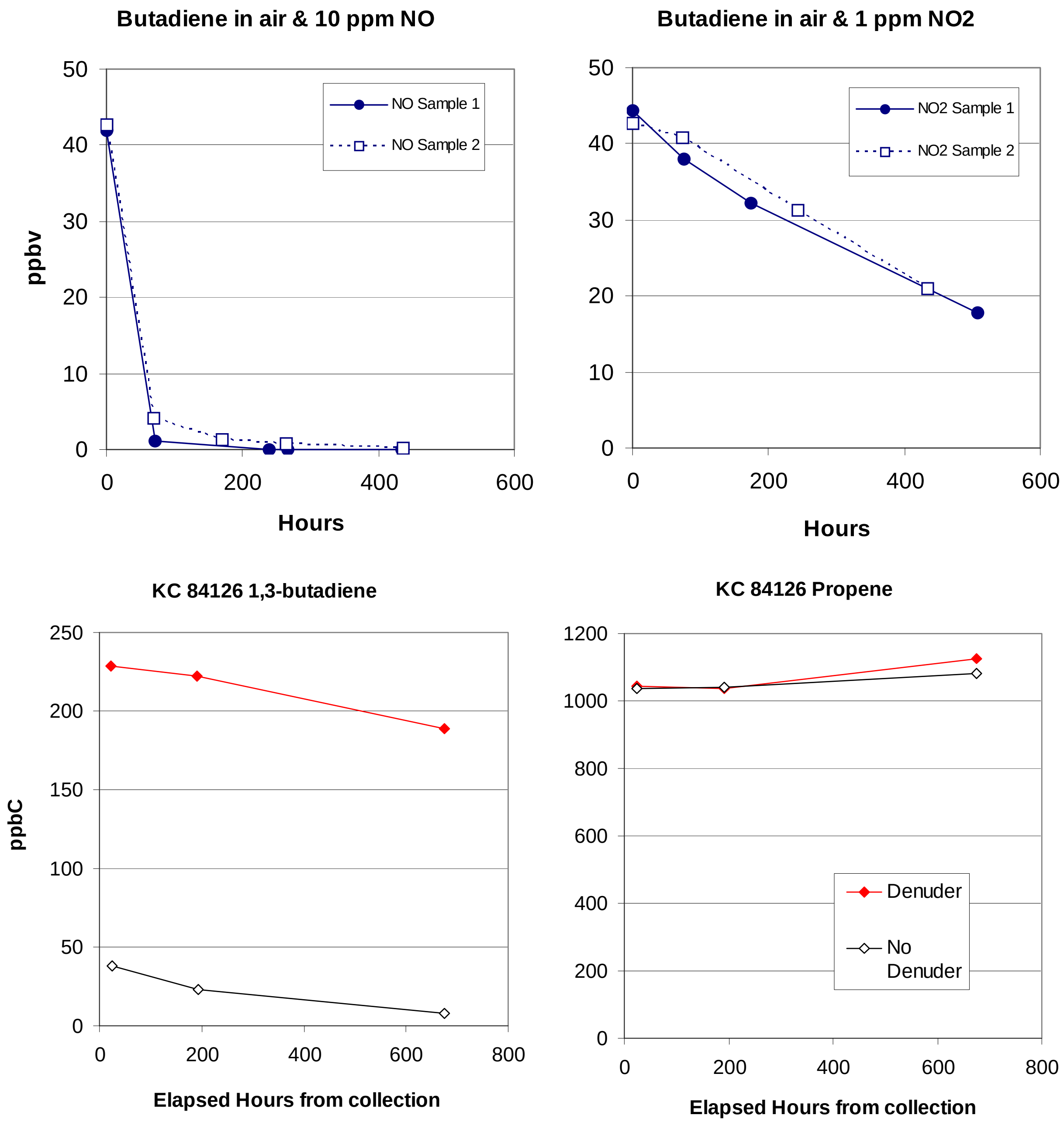


Figure 4-144. Stability of 1,3-butadiene in canister samples.

Upper two plots show loss rate for replicate laboratory test samples with 10 ppm NO (left) and 1 ppm NO2 (right). Lower two plots show loss rates of 1,3-butadiene (left) and propene (right) vehicle test samples collected in Kansas City with and without a NOx denuder (Fujita et al., 2004).

The samples with NO showed exponential decay of 1,3-butadiene. By three days, butadiene was reduced to 2.5% (first sample) and 9.8% (second sample) of the initial values. At the one-week point, both samples had nearly undetectable levels of 1,3-butadiene. The 1,3-butadiene with NO_2 samples showed a linear decay but was not as rapid as that with NO. This comparatively slower reaction reduced the concentration of 1,3-butadiene to 39.9% and 49.2% of the initial concentration after three weeks. These observations are consistent with aforementioned theoretical calculations. Exhaust from an in-use high-mileage automobile were collected during the pilot phase of the Kansas City Study in two sets of two canisters, one with an upstream NOx denuder and one without the denuder. After three weeks, the non-denuded sample had .04 as much 1,3-butadiene in the denuded sample. The three-week analysis of the denuded sample was approximately 83% of the initial analysis or a loss of 17% of the 1,3-butadiene. This suggests it is likely the denuder was not 100% efficient and some NO and possibly some NO_2 got into the canister, but clearly much less than in the non-denuded sample. A second sample showed greater loss of 1,3-butadiene, possibly due to reduced denuder efficiency. In contrast, the presence of NOx in the canister sample had no effect on the stability of propene, which served as the control.

The NOx denuder that was used during Round 1 was fitted with a heater. The denuder was regenerated once a week during the weekend by heating for several hours at 400 ^{o}C. During sample collection, the concentration of NOx was continuously measured downstream of the denuder to monitor the efficiency of NOx removal (compared to NOx concentrations in the dilution tunnel measured by BKI). Figure 4-145 shows the time-series plot of the NOx concentrations in the dilution tunnel versus downstream of the denuder for each test during Round 1. The denuded NOx concentrations are estimated from NO by applying a factor of 1.1 and are not valid above the maximum instrument range of 10 ppm. NOx removal efficiencies are given for valid (i.e., under 10 ppm) denuded NOx concentrations. These results show that while a fresh denuder was effective in removing NOx, the denuder efficiency was typically degraded after the first day of testing. The lack of backup denuders was a limitation during Round 1, which was not addressed until additional denuders could be built prior to start of Round 2. Consequently, we expected substantial loss of 1,3-butadiene in most Round 1 canister samples. Even with multiple denuders during Round 2, breakthrough of NOx was evident in many samples due to high exhaust NOx concentrations that quickly saturated the denuder.

Alternatively, we estimated 1,3-butadiene from the data for propene and the average ratio of propene to 1,3-butadiene measured in the Gas/Diesel PM Split Study (GDPMS). Canister samples were collected in that study in a similar manner to the present study. But, the samples were analyzed with an on-site GC/MS within a relatively short time after collecting the sample. Figure 4-146 shows that ethene and propene are both strongly correlated with 1,3-butadiene. Because of its long-term storage stability in canisters, the Kansas City propene values times the GDPMS 1,3-butadiene/propene ratio provide reasonable estimates of the 1,3-butadiene levels in the canister samples prior to its decay. The 1,3-butadiene/propene ratios in the Kansas City samples generally increase with decreasing post-denuder NOx concentrations and approach the mean GDPMS ratio at the lower end of the NOx distribution.

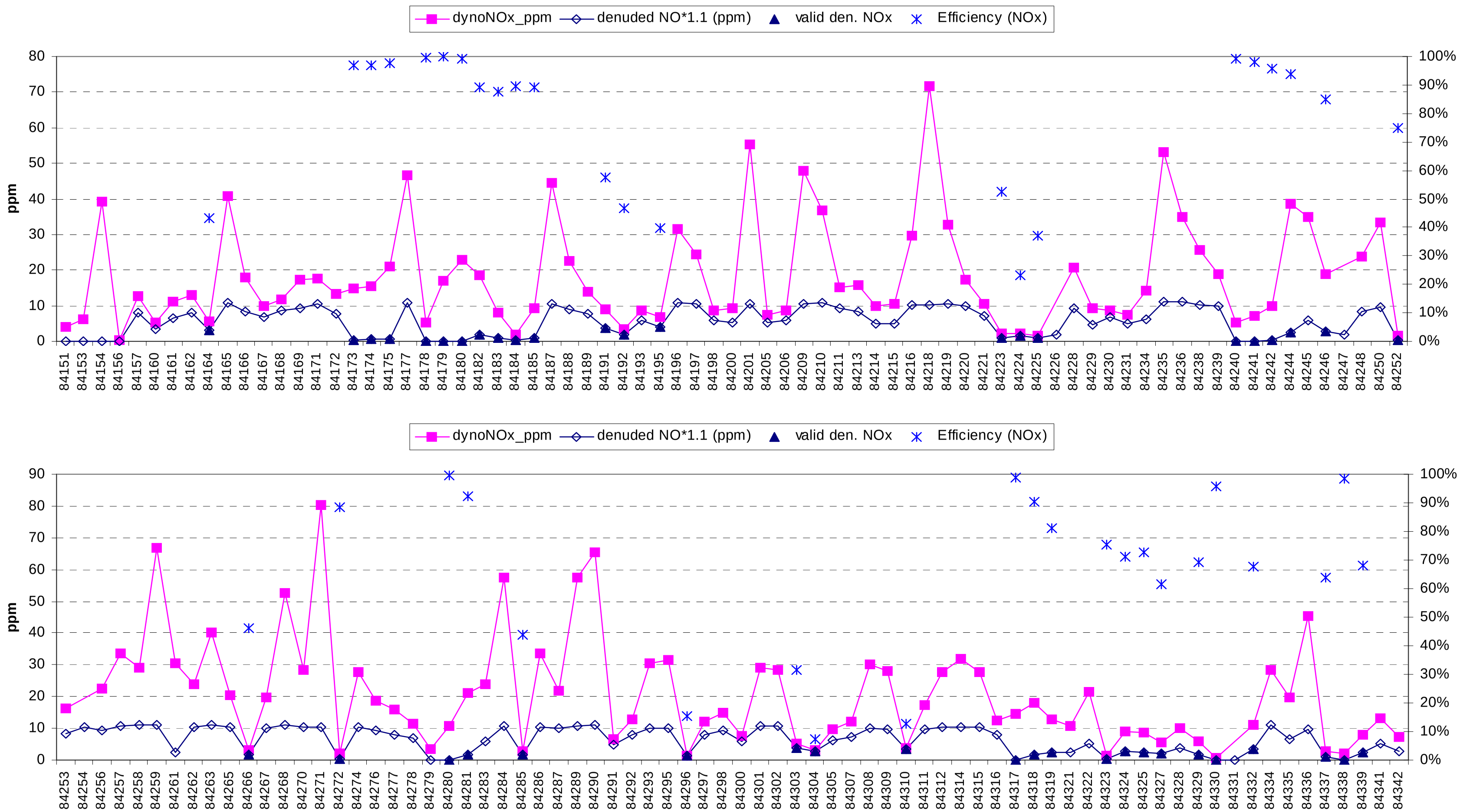


Figure 4-145. Time-series plot of the dilution tunnel versus denuded NOx concentrations for each test during Round 1.

Denuded NOx concentrations are estimated from NO by applying a factor of 1.1 and are not valid above the maximum instrument range of 10 ppm. NOx removal efficiencies are given for valid denuded NOx concentrations. While a fresh denuder was effective in removing NOx, it is clear that the denuder efficiency degrades rapidly.

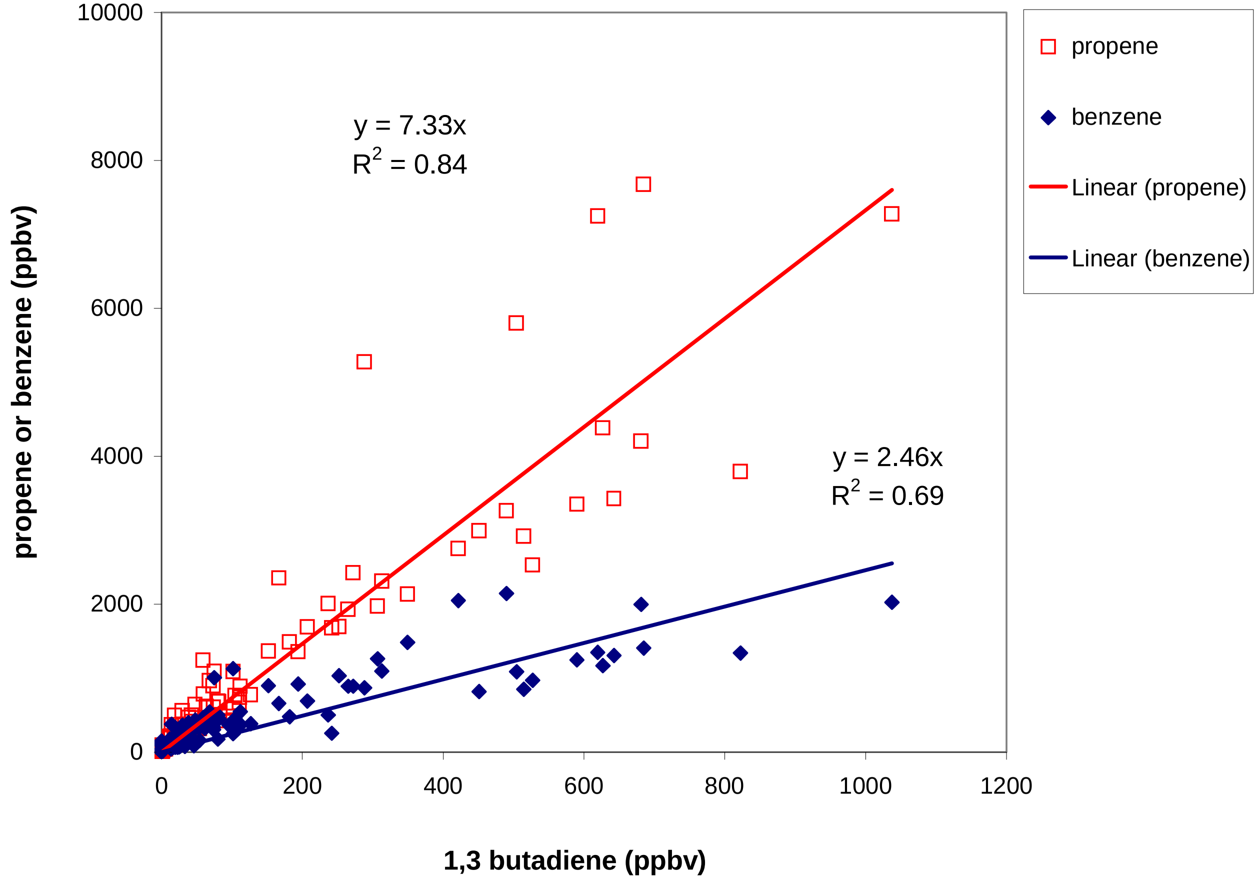


Figure 4-146. Correlations of 1,3-butadiene with propene and benzene.

(Exhaust samples from 57 light-duty gasoline vehicles tested on the LA92 cycle (Phases 1 and 2) during the Gasoline/Diesel PM Split Study. Canister samples were analyzed on site by gas chromatography with mass spectrometry soon after sample collection.)

Results from our study for the Health Effects Institute of in-vehicle exposures to air toxics in the South Coast Air Basin lends further support to this approach. Integrated canister samples were collected inside a moving vehicle over a period of one hour along freeway routes throughout the basin. The same NOx denuder that was used in the Kansas City sampling was also used to remove ambient NOx from the in-cabin samples. Saturation of the denuder was not a problem in this case since typical ambient NOx levels were at least 3 orders of magnitude lower than the typical concentrations in the dynamometer dilution tunnel. Consequently, NOx concentrations were reduced to inconsequential levels and 1,3-butadiene was stable in the HEI canister samples. A scatter plot of the propene against 1,3-butadiene for about 50 in-cabin samples yields a slope of 7.30 ($R^2 = 0.92$) (Figure 4-147), which is essentially identical to the regression results from GDPMS of 7.32 ($R^2 = 0.84$). The correlation for the ambient measurements is tighter than for dynamometer data because in-cabin measurements combine the exhaust from thousands of vehicles. Figure 4-147 also shows the scatter plot of 1,3-butadiene and propene for 24-hour samples from near-road sampling locations at Long Beach, Lynwood and Diamond Bar with a slope similar to the correlations for on-road and dynamometer samples. This empirical adjustment factor provides a way to assess the effectiveness of NOx removal during the sampling in Kansas City and adjustments of the data, if necessary.

4.7.2.2 Analysis Methods

Selected canisters were combined according to the compositing decisions and analyzed for 111 identified C_1 to C_{11} hydrocarbons with a Hewlett-Packard 5890 Series II gas chromatograph or Varian 3400 GC both equipped with a flame ionization detector. A separate analysis of the C_2 hydrocarbons was not performed since the emphasis of this analysis was volatile air toxics. Thus, ethane, ethylene and acetylene are reported as the sum of C_2 hydrocarbons. Selected DNPH cartridges were analyzed for carbonyl compounds by Waters high performance liquid chromatography (HPLC) equipped with Waters 2695 Alliance separation module, Waters 996 photodiode array detector and Empower chromatography software. Cartridge extracts were combined according to the compositing decisions and analyzed for 14 specific C_1-C_7 carbonyl compounds. The analysis methods and procedures are described in the project QAPP.

Acrolein is known to rearrange on DNPH cartridges to an unknown degradation product (acrolein-x) (Tejada, 1986). Disappearance of the acrolein hydrazone in the analytical sample matrix correlates quantitatively almost on a mole for mole basis with the growth of acrolein-x, and the sum of acrolein and acrolein-x appears to be invariant with time (Tejada, 1986). The rearrangement of acrolein occurs over time periods of days, so it was not logistically possible to avoid the effect of this artifact in this study. The sum of acrolein and acrolein-x provides an estimate of total acrolein that was originally present in the samples. However, the UV spectra from the photodiode array detector show that there is substantial overlap in the chromatographic retention time of acrolein-x with butyraldehyde. A procedure was developed in a separate project conducted by the DRI for the Health Effects Institute (Fujita et al., 2006). This procedure was applied after the initial analyses to more accurately quantify acrolein and butyraldehyde. The response factor for DNPH-acrolein-X was first determined by preparing a dilution of a known amount of acrolein in a Tedlar bag and to sample it through a DNPH cartridge. Several mixtures of DNPH-butyraldehyde and DNPH-acrolein-X with different proportion of both compounds were analyzed. The UV-VIS spectra of co-eluting compounds were recorded and a linear least squares method was used to relate the proportion of both compounds to the appearance of spectrum maxima for each compound. The correction procedure was applied to the stored UV-VIS spectra for the project samples, but for some samples the resolution of the butyraldehyde/acrolein-X peak was not sufficient to perform the re-integration due to low sample concentrations. For those samples the original, upper-bound estimates were retained for both acrolein and butyraldehyde and are reported with a "<" symbol in the data set.

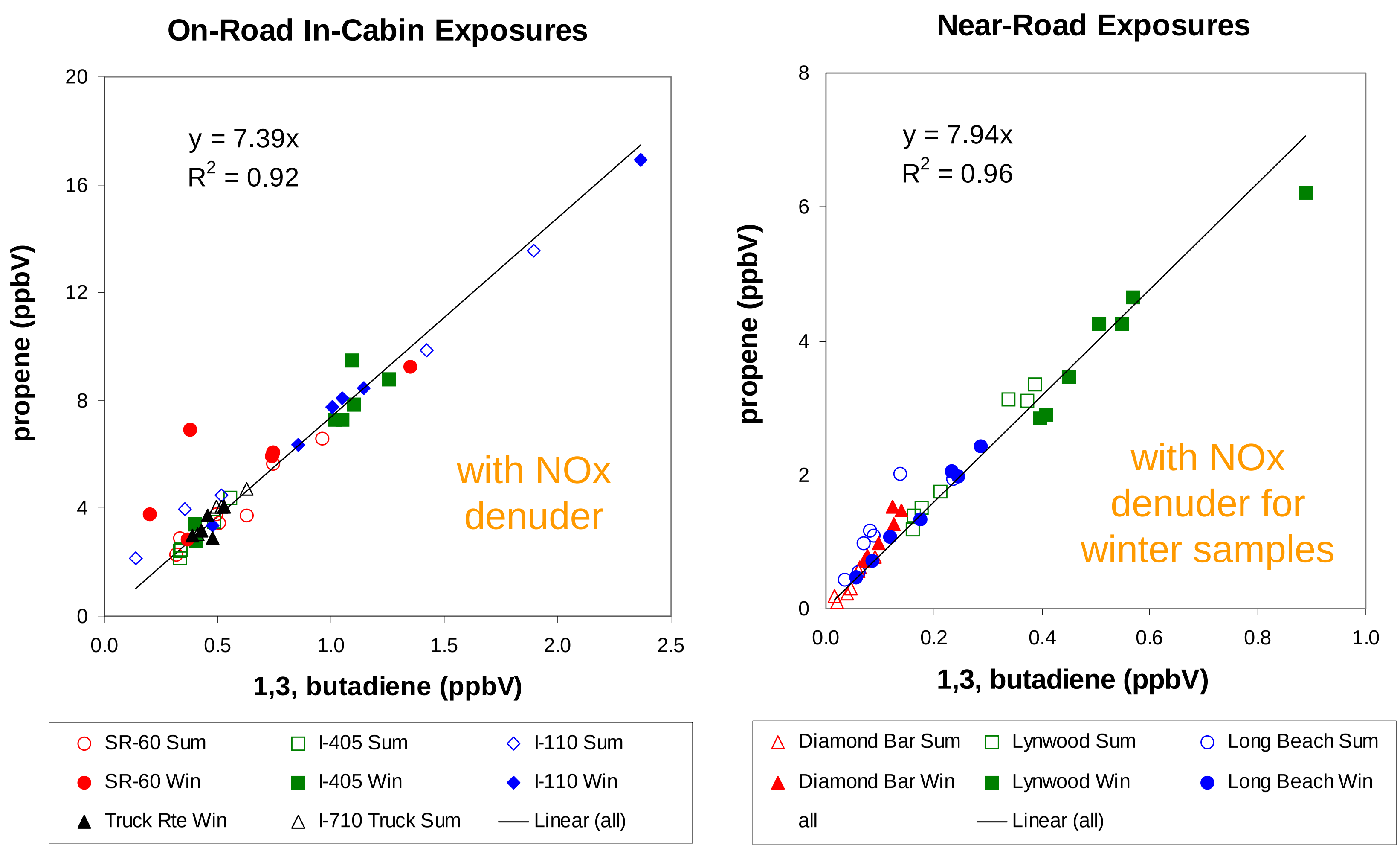


Figure 4-147. Correlations of 1,3-butadiene and propene

One-hour in-cabin (left) and 24-hour near road (right) samples collected in the Los Angeles basin during the Health Effects Institute Study of the exposures to air toxics in mobile source dominated microenvironments. (Fujita et al., 2005)

4.7.3 Results and Conclusions

VOC chemical speciation was determined for the individual/composite samples and composite dilution tunnel blanks samples shown in Tables 4-40 and 4-41 for Rounds 1 and 2, respectively. Table 4-42 lists the dilution tunnel blanks that were combined into composites. All data are field-blank corrected. The chemical composition data for dilution tunnel blanks and exhaust samples are presented in Appendix B.

The total nonmethane hydrocarbon (NMHC) values from the DRI VOC speciation samples were compared to corresponding data obtained by BKI. With the exception of two obvious outliers (S1-2 and S5-4), Figure 4-148 shows good agreement for the uncomposited samples from Round 1. However, Figure 4-149 shows that there are two distinct groups of data in Round 2; one with better agreement between DRI and BKI and a second group with DRI values consistently near zero compared to widely varying values for BKI. A chronological plot of the ratios of DRI to BKI TNMHC values for Round 2 shows that DRI consistently obtained low values during the second half of Round 2. Sampling for VOC speciation was suspended for two weeks in mid-February during the NREL experiments on the effects of sampling temperature on measured PM emission rates. The appearance of consistently low DRI/BKI ratios for TNMHC coincides with the resumption of VOC sampling on February 22. The aldehyde data also show a similar chronological pattern with consistently lower values in the second half of Round 2, though not as sharply lower as the hydrocarbon data. As shown in Figure 4-101, the aldehyde sampler was connected to the same branch of the sampling train as the canister sampler. This branch of the sampling train was disconnected from the main sampling line and capped off during the temperature experiments. A leak somewhere in this part of the sampling train, which allowed room air to mix with vehicle exhaust, is the most probable explanation for the near-zero ratios after the mid point in Round 2. Accordingly, the data for VOC and carbonyl compounds for the second half of Round 2 must be considered invalid. Figure 4-150 presents a chronological figure of the ratio of TMNHC measured by DKI and BKI. Of the 57 canisters collected and analyzed for VOC speciation in Round 2, 32 were affected.

We examined the flow check records and discussed the details of the sampling with our field technician to investigate the possible source of the leak. Flow audits were performed near the end of Round 2, and the results did not indicate any serious leaks, but due to the configuration of the interconnected samplers it would not have shown all possible leaks. Flow checks of the can sampler were made on the line that fills the cans, so they would not indicate leaks external to the sampler. Since the denuder and water filter (which were part of the inlet line to the can sampler) were changed daily there seemed to be little value to periodic leak testing of the inlet system. The NOx analyzer that was used to monitor the removal efficiency of the NOx denuder presented another source for leaks. The analyzer was connected to the inlet system in such a way that a leak there would have resulted in backflow into the can sampler and, to a lesser extent, the DNPH sampler (the NOx analyzer flow is less than the can sampler, but greater than DNPH so there is less likelihood of flow back to DNPH). Since the auto-calibrator was also connected to the inlet of the NOx analyzer using Teflon or nylon fittings, and the connections on the analyzers are also plastic, there was a potential for leaks to develop at that point. DRI field personnel visually examined all lines each day to check for disconnected or broken hoses so it is not likely that there was a major leak of that sort. One potential explanation is that a leak occurred at the connection point to the NOx analyzer due to stress on the connectors either when the system was reconnected or while it was not in use (some of the tubing was still connected during the February break), resulting in backflow to the VOC samplers. Another possibility is that an internal valve in the auto-calibrator stuck open during the audits that was done by DRI in mid-February allowing air to flow into the NOx analyzer inlet. When the NOx analyzer was returned to DRI at the end of the study and tested, it showed very low response to a gas standard, as it did during the latter part of round 2. After tightening the connections and repairing a cracked internal filter holder it worked properly, so this seems a likely possibility.

The distributions in emission rates in Figures 4-151 through 4-154 for BTEX and formaldehyde show that newer model year vehicles are generally clean and that emissions of older vehicles are highly variable with some vehicles emitting BTEX and formaldehyde at rates exceeding that of normal emitters by more than two orders of magnitude. The figures also illustrate the sampling problems that occurred during the second half of Round 2. Although unfortunate, the partial loss of VOC speciation data should be viewed in context of the two main project objectives, which are to establish the distribution of emissions for the in-use vehicles in Kansas City and chemical profiles for VOC and PM emissions. Even without the partial loss of data, the speciated emissions data alone would have not been sufficient to fully characterize the distribution of emissions of specific VOC or volatile MSAT. Rather it is the bulk hydrocarbons and PM emissions data for the larger set of test vehicles that provide the emissions distributions of the in-use vehicle fleet. The speciation profiles, averaged by appropriate factors such as season, region, or high versus normal emitters, provide the means for disaggregating total emissions to specific species.

The missing VOC speciation data were reconstructed by first calculating the ratios of reported concentration of each hydrocarbon compound to the total HC reported for each run. These ratios were then averaged for all valid canister samples and the resulting average and standard deviation of the ratios were used to estimate the hydrocarbon speciation for the invalid samples based on the total HC from BKI's bag samples. This reconstructed data are included with the data set for completeness in a separate table. The previous plots for BTEX emissions are shown in Figures 4-155 and 4-156 as fractions of individual species to the sum of BTEX. The abundances of benzene, toluene, ethylbenzene and xylenes are similar among the samples and between Rounds 1 and 2. Figure 4-157 shows the strong correlations among related aromatic hydrocarbon species for all exhaust composites.

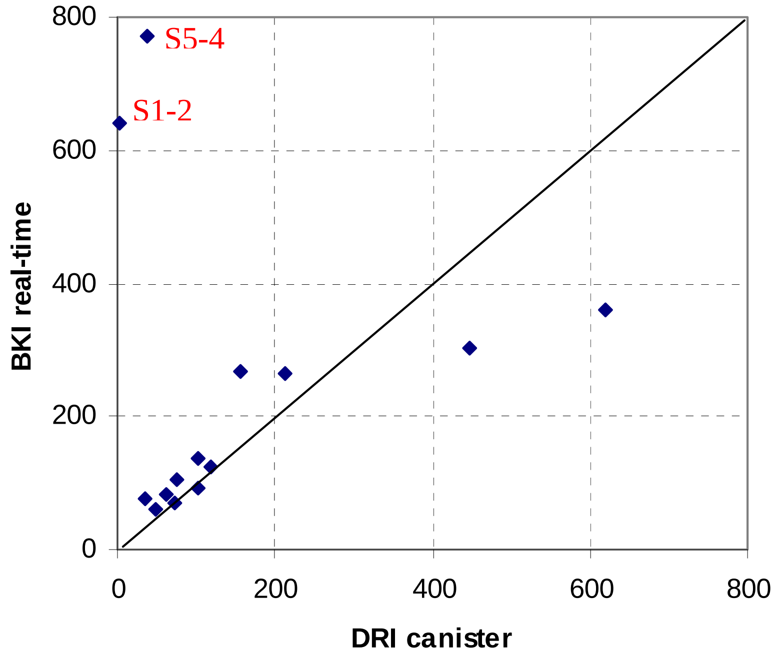


Figure 4-148. Correlation plot of BKI total TNMHC (ppmC) and DRI NMHC (ppmC) for Round 1.

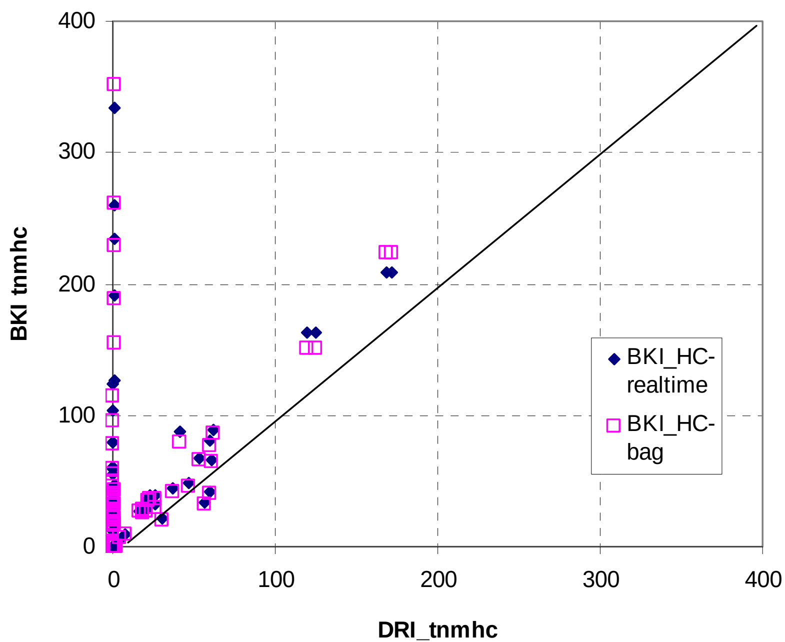


Figure 4-149. Correlation plots of BKI total TNMHC (ppmC) and DRI NMHC (ppmC) for Round 2.

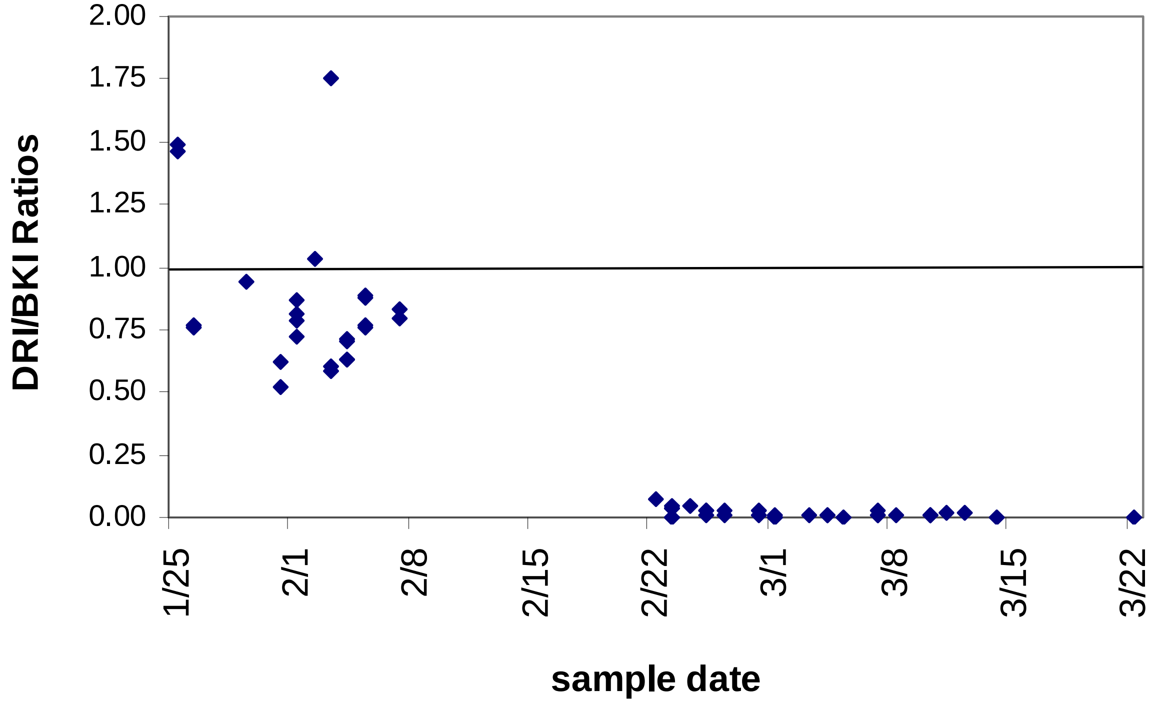


Figure 4-150. Ratios of the TNMHC measured by DRI to BKI during Round 2 shown chronologically.

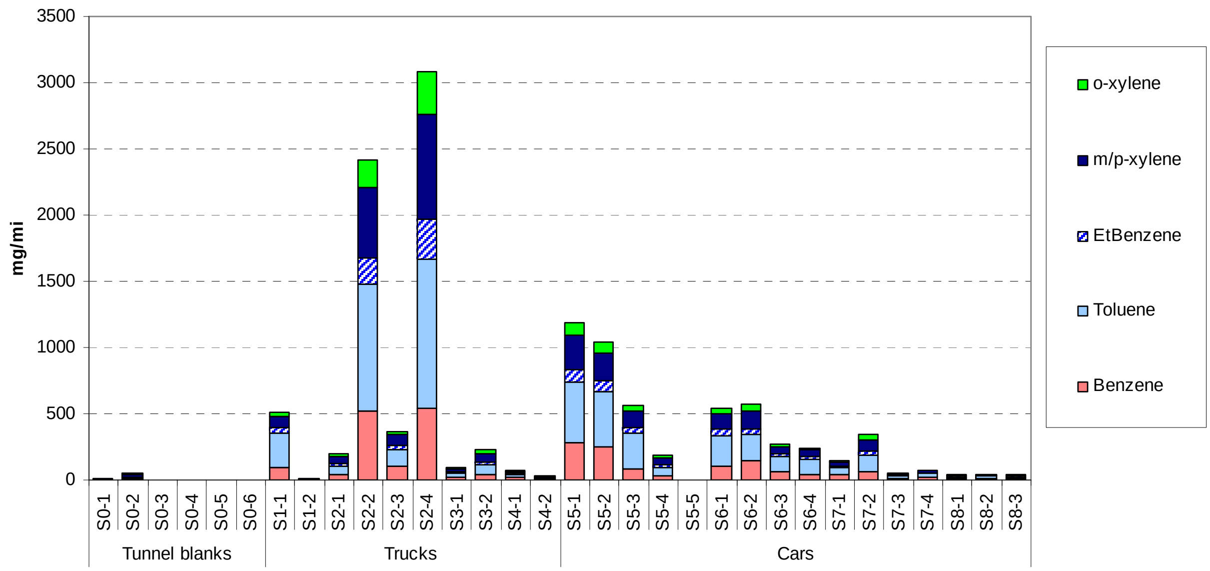


Figure 4-151. Emission rates (mg/mile) of BTEX for individual/composite samples from Round 1.

(Data for S1-2, S5-4 and S5-5 are suspect.)

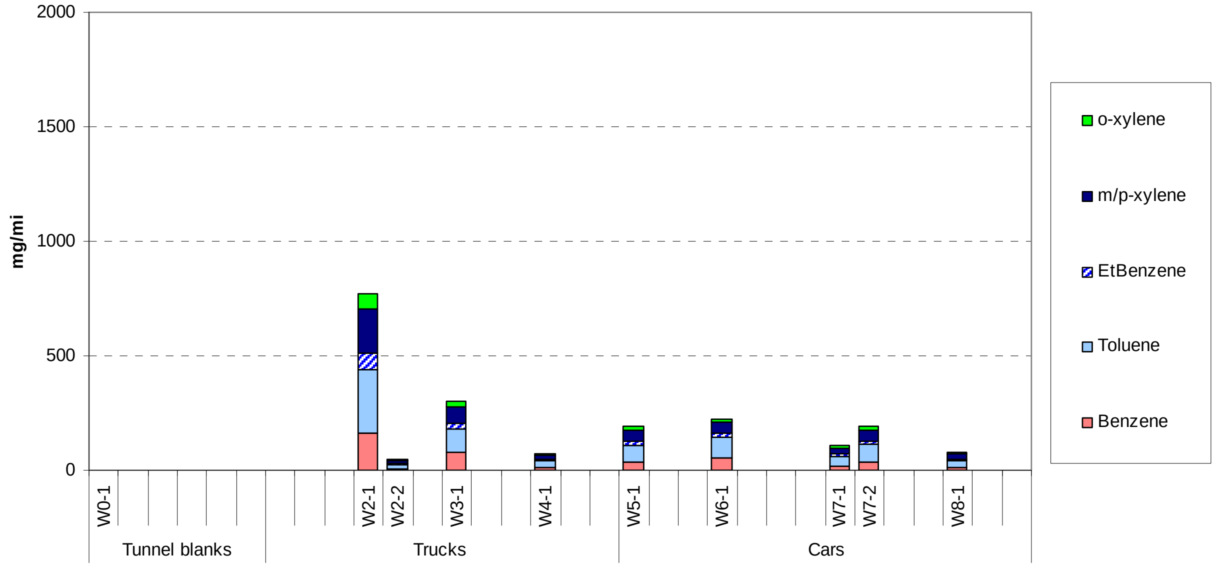


Figure 4-152. Emission rates (mg/mile) of BTEX for individual/composite samples from Round 2.

(Samples collected after mid-February 2005 are invalid and are not shown in the figures.)

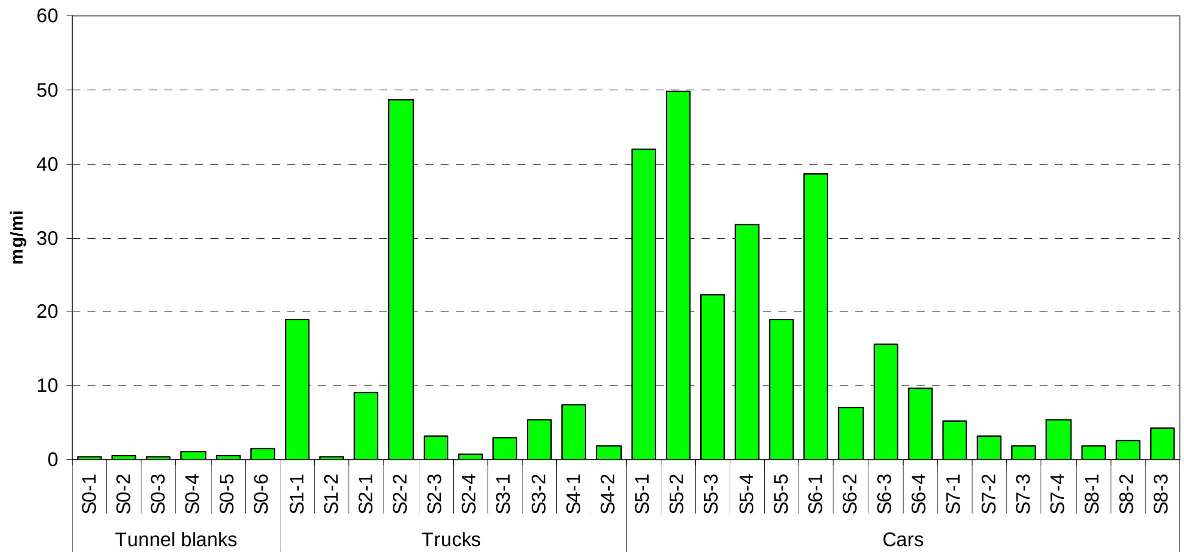


Figure 4-153. Emission rates (mg/mile) of formaldehyde for individual/composite samples from Round 1.

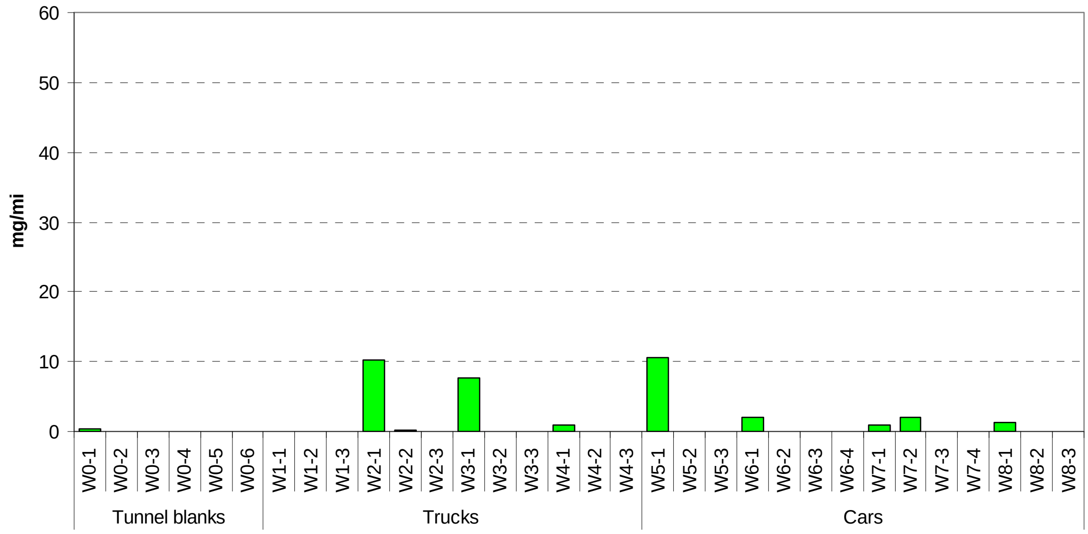


Figure 4-154. Emission rates (mg/mile) of formaldehyde for individual/composite samples from Round 2

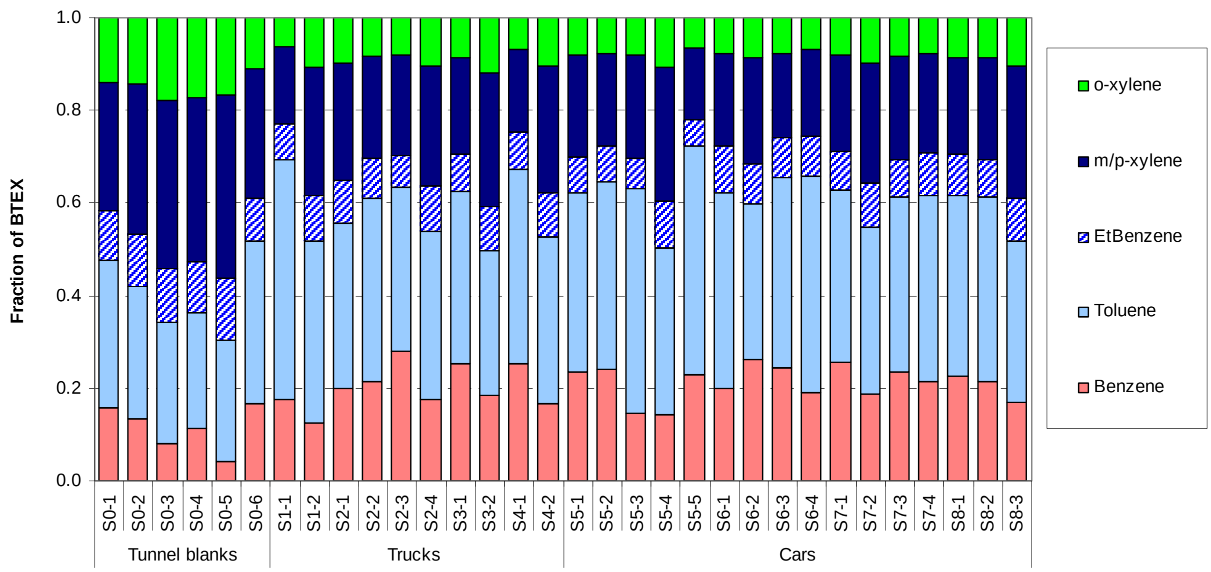


Figure 4-155. Fraction of BTEX for individual/composite samples from Round 1.

(Data for S1-2, S5-4 and S5-5 are suspect.)

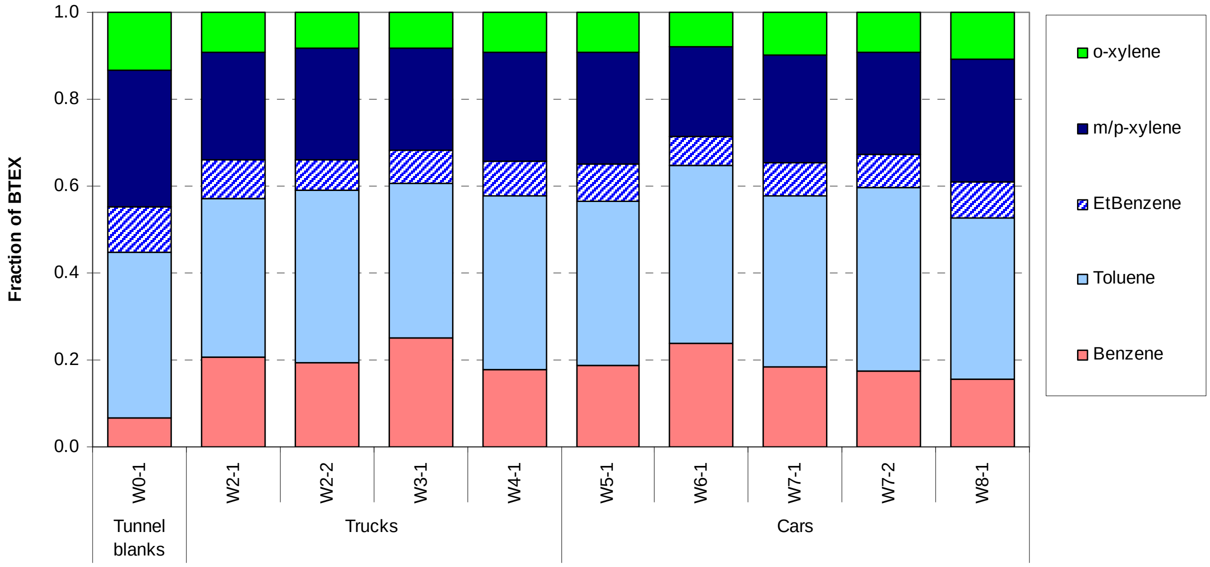


Figure 4-156. Fraction of BTEX for valid individual/composite samples from Round 2.

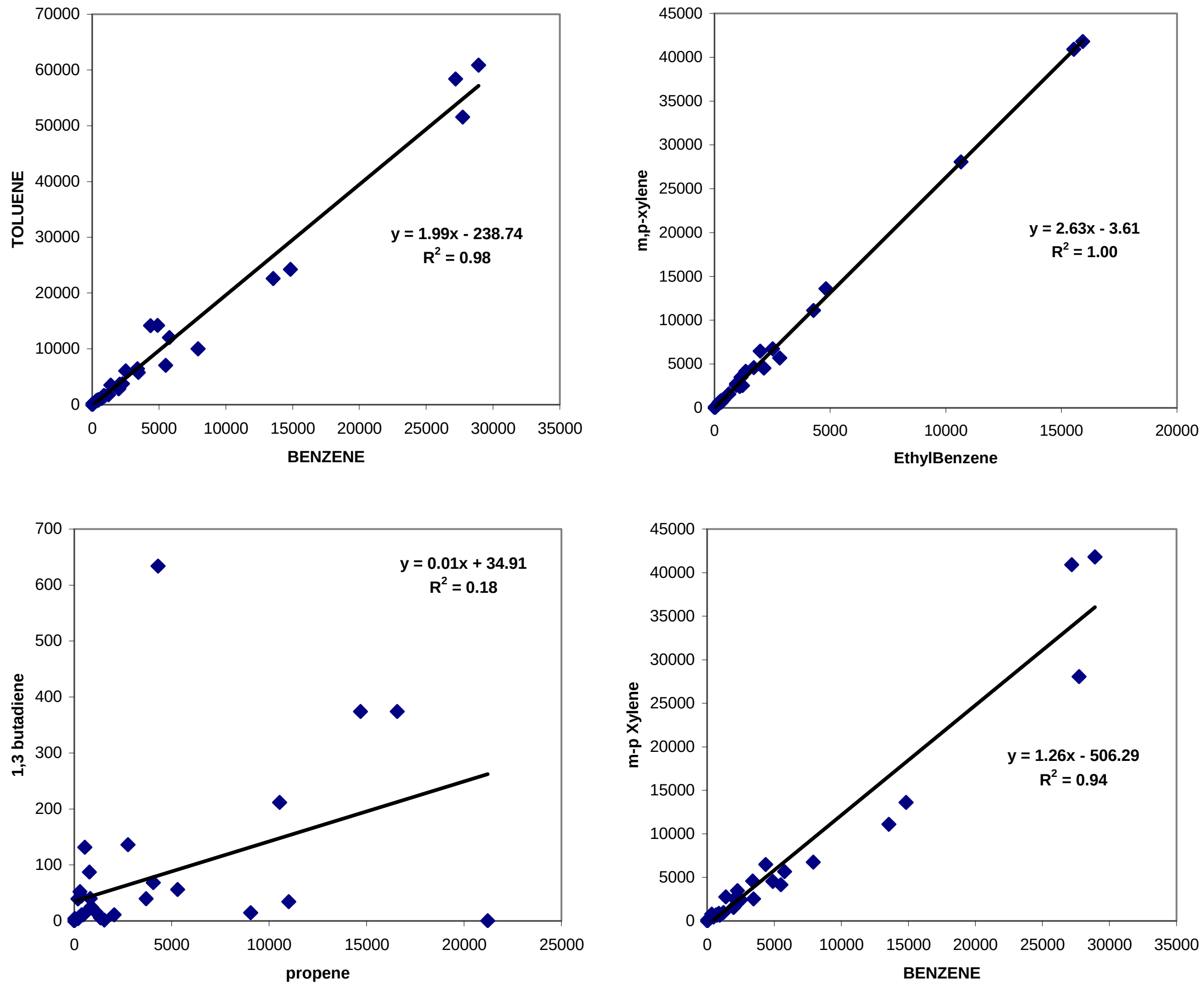


Figure 4-157. Correlation plots of related VOC species for all exhaust composites.

Concentrations shown are ppbC of diluted exhaust.

The lack of correlation and the low 1,3-butadiene/propene ratios shown in Figure 4-157 indicate that a substantial fraction of the 1,3-butadiene had been lost in most of the samples due to reaction with NOx. As previously mentioned, the true values are estimated by multiplying the propene values by the 1,3-butadiene/propene ratio from the DOE/NREL Gasoline/Diesel PM Split Study. Figures 4-158 through 4-161 show the measured and adjusted 1,3-butadiene emissions rates for individual/composite samples The corrected emission rates for acrolein are shown in Figures 4-162 through 4-163. As previously discussed, acrolein transforms into an unknown rearrangement product which coelutes with butyraldehyde, so a re-calculation of the sample concentrations using specially prepared standards was required to derive the total acrolein emission rate.

In summary, the VOC profiles are very consistent across all categories for major air toxics (BTEX). Emission rates were highly variable, but higher for strata 1, 2, 5, and 6. Tunnel blanks showed very low concentrations relative to exhaust samples.

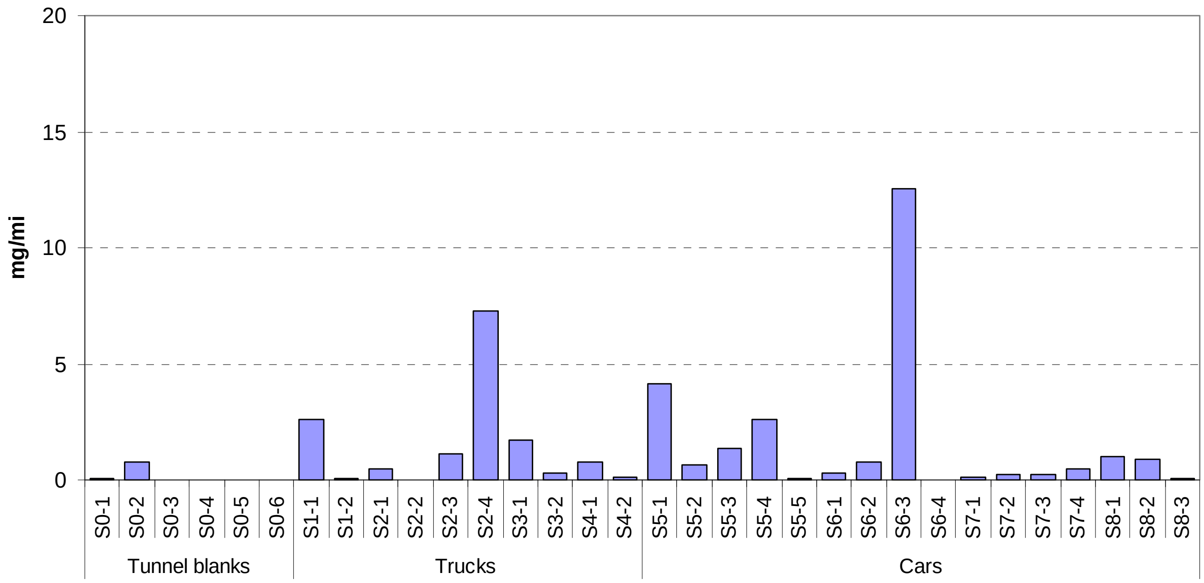


Figure 4-158. Emission rates (mg/mile) of 1,3-butadiene (measured) for individual/composite samples from Round 1.

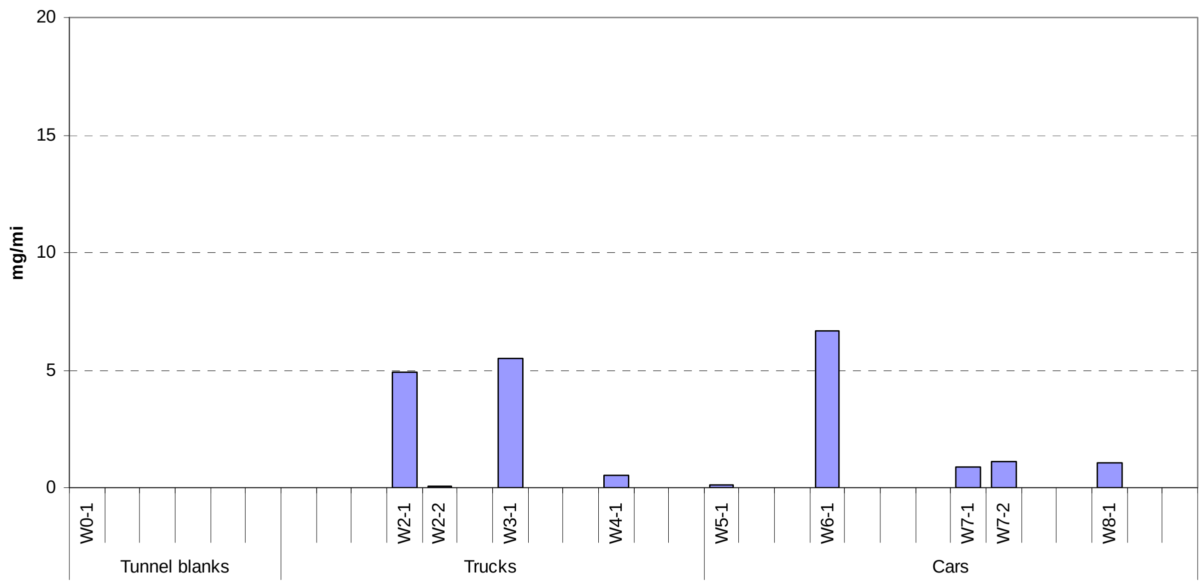


Figure 4-159. Emission rates (mg/mile) of 1,3-butadiene (measured) for individual/composite samples from Round 2

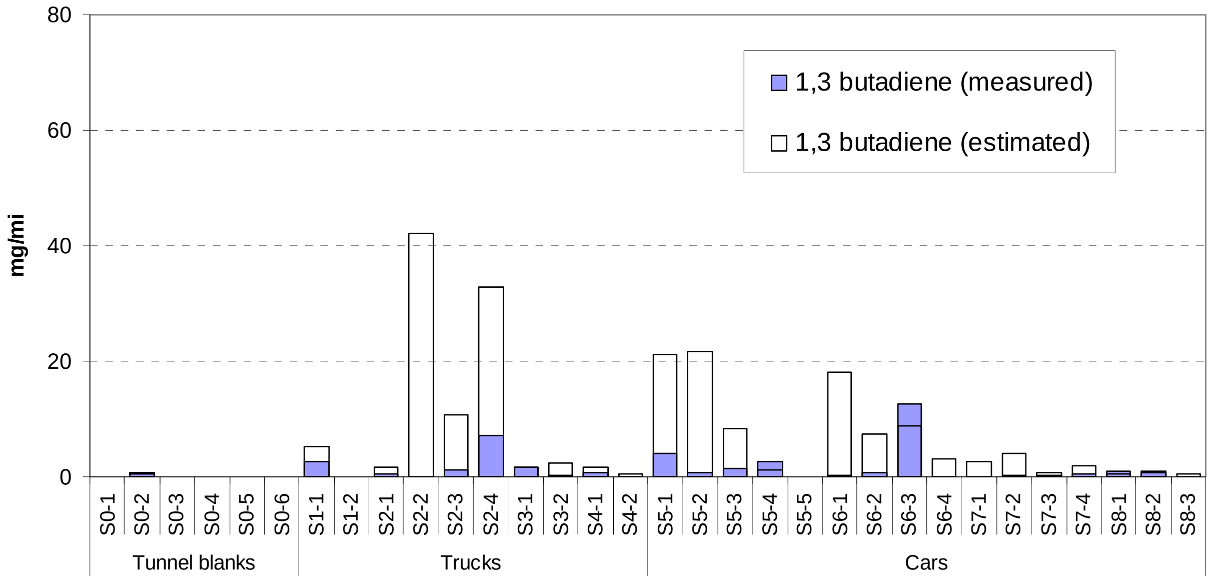


Figure 4-160. Emission rates (mg/mile) of 1,3-butadiene (measured) for individual/composite samples from Round 1 and estimated from regression with propene.

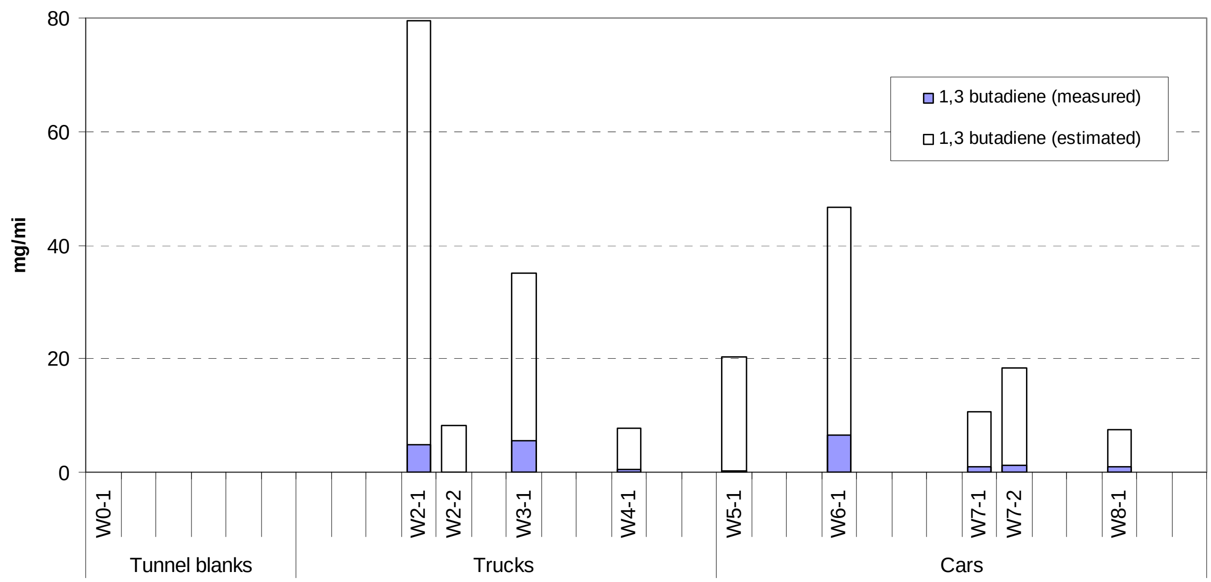


Figure 4-161. Emission rates (mg/mile) of 1,3-butadiene (measured) for individual/composite samples from Round 2 and estimated from regression with propene.

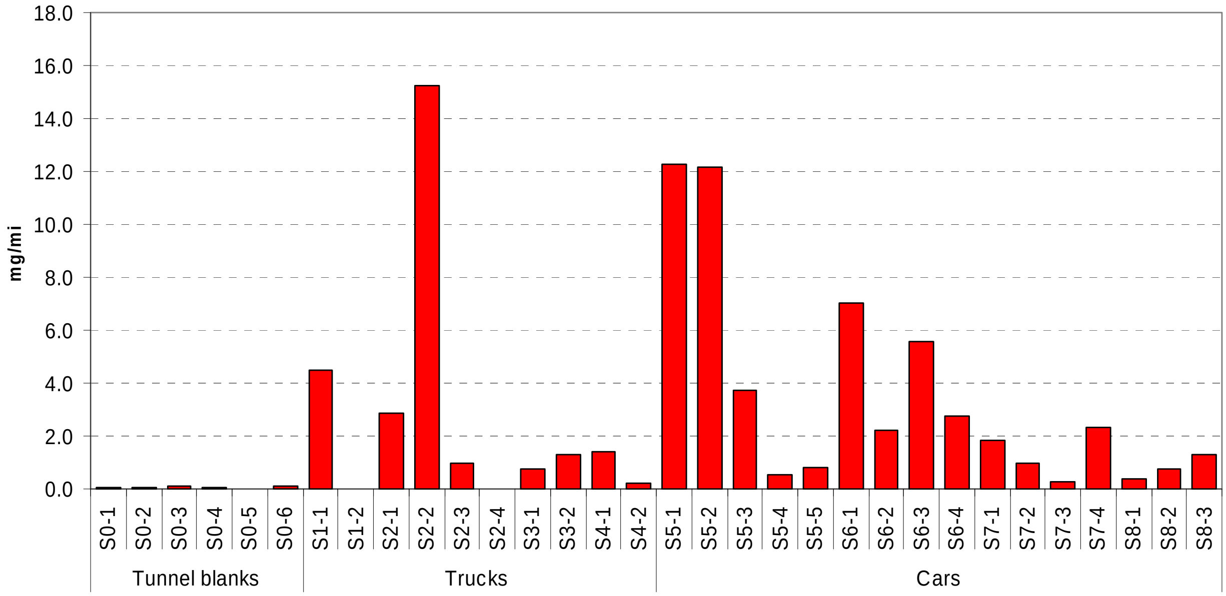


Figure 4-162. Emission rates (mg/mile) of acrolein for individual/composite samples from Round 1.

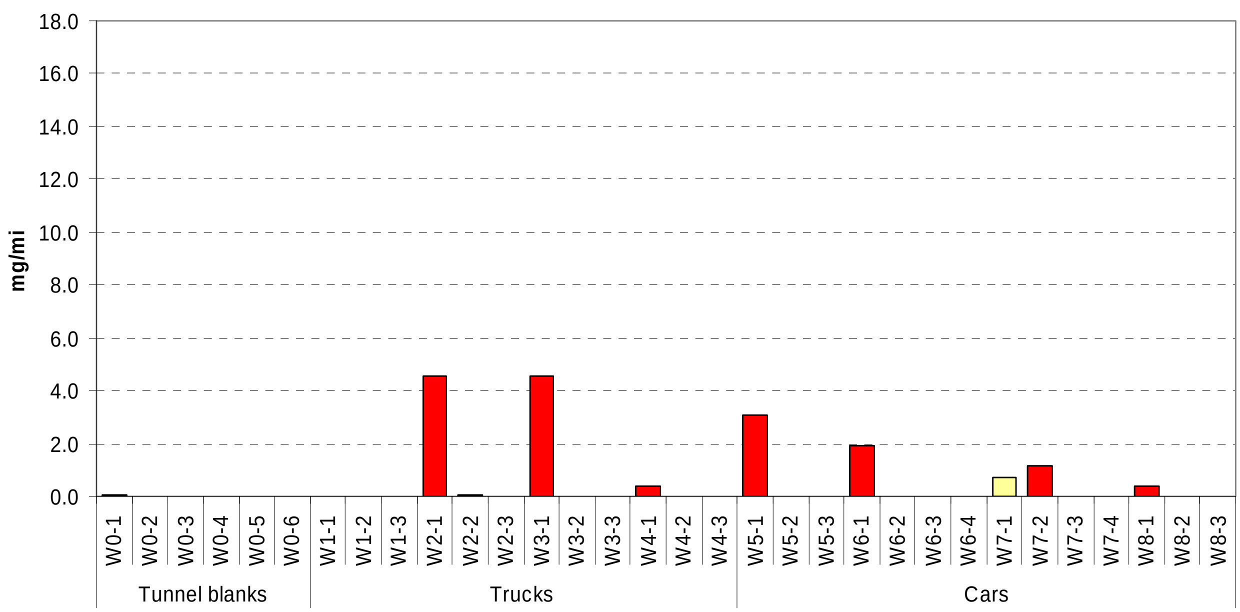


Figure 4-163. Emission rates (mg/mile) of acrolein for individual/composite samples from Round 2. Lighter bars are upper bound estimates.

4.8 RSD Data Collection Process and Data Summary

During Rounds 1 and 2 of the project, on-road data were collected using Remote Sensing Devices (RSD). The purpose of these deployments was to document the on-road fleet in the Kansas City area and to measure on-road emissions. ERG subcontracted with Environmental Systems Products (ESP) to collect RSD data for this project. ESP used RSD equipment and personnel from the Saint Louis Clean Screen program. They also deployed a newer generation of RSD equipment (RSD 4000, as opposed to the older generation RSD 3000) in parallel to the equipment from their St. Louis program, so side-by-side data were collected using both generations of equipment. Note that for Round 2, only RSD 4000 equipment was used.

4.8.1 Site Selection

During Round 1, ESP had surveyed approximately 57 potential sites in the Kansas City area. They were evaluated for safety, physical layout, traffic volume, and geographical coverage of the area. During Round 2, ERG asked ESP to look at another site, nearer to the area where vehicles were being tested. The intent of using the additional site was to obtain RSD measurements on a bigger subset of the vehicles being tested using other methods than was obtained during Round 1. The new site chosen for use during Round 2 is labeled as “21” in Figure 4-164. The “Top 10” best sites chosen during Round 1 are also shown in Figure 4-148 They are labeled with numbers “1” through “10.” The EPA test site is labeled with the number “0”. The blue line estimates a 20-minute drive-time from the EPA test facility.

Sites 1 through 8 of the “Top-10” sites were used during Round 1 testing. The ESP team collected data during 5-consecutive days in each of July, August, and September 2004. During the July deployment, data were collected at five of the most promising sites to help select the single site that would be used during the August deployment. In August, RSD data were collected only at site 2 (Johnson Drive onto I-35 South). This was done to replicate the technique used in the Coordinating Research Council’s Project E-23.

Sites 2, 4, 6, and 7 of the “Top-10” sites and site 21 were used during Round 2 testing. The ESP team collected data during 5-consecutive days in each of January, February, and March of 2005. In January, RSD data was collected only at site 2 (Johnson Drive onto I-35 South). As with Round 1 testing, this was done to replicate the technique used in the Coordinating Research Council’s E-23 studies. In February, data was collected only at site 21. Although the site proved not to be a good location for obtaining RSD measurements and had very low traffic volumes, it was the only acceptable site for obtaining RSD readings on the vehicles tested using other methods at the EPA facility. Details for all RSD sites listed used during the study are provided in Appendix Y.

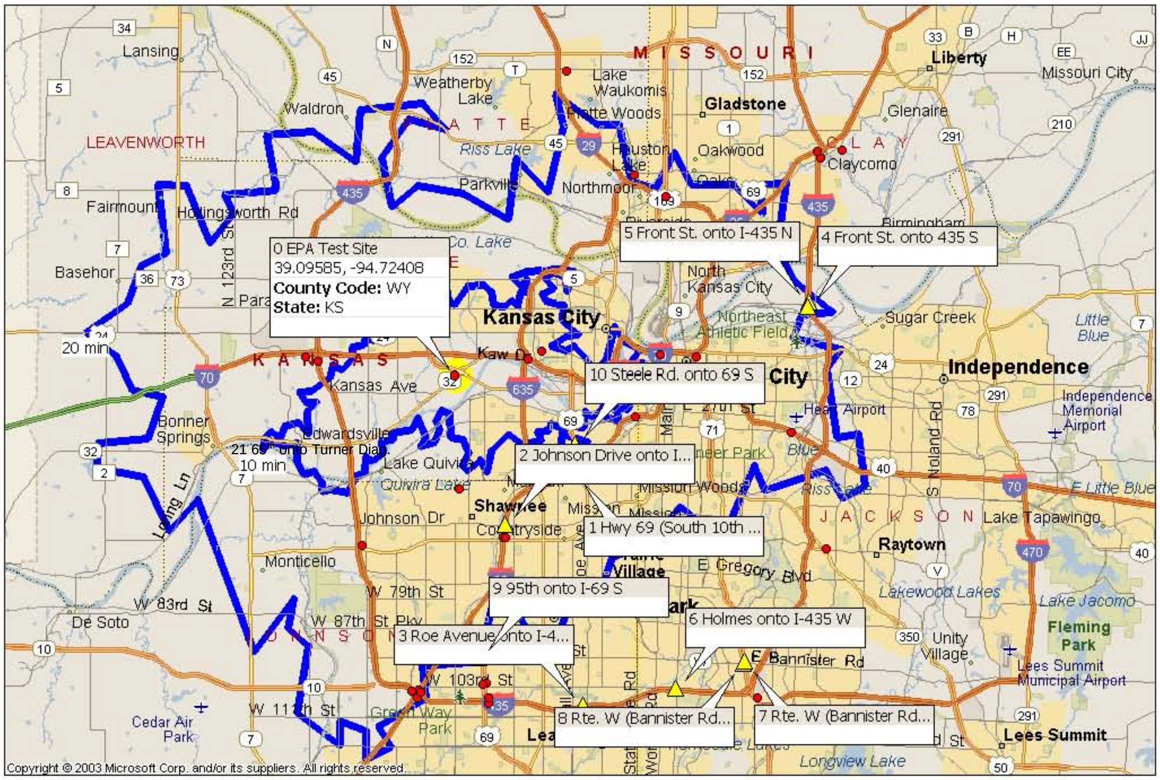


Figure 4-164. RSD Sites Chosen in the Kansas City Area

4.8.2 Summary of RSD Data from Rounds 1 and 2

In this section, we summarize the data collected by the most recent RSD technology deployed, named RSD-4000.

When RSD data are collected, they are automatically screened in the field for validity, and a digital photograph of the vehicle's license plate is linked to the results for that vehicle. During post processing, the license plate number in each photograph is transcribed and appended to the RSD measurement results in the database. For various reasons some license plate numbers are not readable, so the measurement results cannot be linked to a specific vehicle. After license plate numbers are appended to the database, it is merged with local registration records, typically obtained from the Department of Motor Vehicles. In this project, both Kansas and Missouri provided their registration databases for this purpose. When a license plate from the measurement database is successfully merged with registration information, the RSD measurements have been uniquely linked to a specific vehicle. At that point, the vehicle make, model, model year, and other important information are linked to the measurements taken by the RSD equipment, and the data are ready for meaningful analysis. Approximately 48,400 of the Round 1 RSD-4000 records, and 23,300 of the Round 2 RSD 4000 records, made it to this point in post-processing.

The pie charts in Figures 4-165 and 4-166 show the number of RSD-4000 records taken at each site during Rounds 1 and 2, respectively. Almost two-thirds of the RSD data were collected from sites in Kansas, with almost half coming from the site used to collect data in a manner similar to that used in CRC's Project E-23. Site 21 produced relatively few data points because it had very low traffic volume. Site 7 produced few data points because it was only used on one occasion (March 15). Location information for all RSD sites listed in Figures 4-165 and 4-166 is provided in Appendix Y.

The bar charts in Figures 4-167 and 4-168 show the distribution of vehicle model years in the RSD data. This is the distribution of vehicles for which RSD data was collected (vehicles that drove past the RSD site). According to the data, the Kansas City area fleet has an average model year of 1998 and a median model year of 1999. The modal range of model years was from 2000 to 2002, with 2001 having slightly fewer observations than either 2000 or 2002.

The scatter charts in Figures 4-169 and 4-170 show the average speed observed by RSD-4000 for each model year. Site selection guidelines dictate that a moderate speed be the norm. The average speed observed was 26.9 mi/hr for Round 1, and 25.5 mi/hour for Round 2. As expected, the average speed increased with model year.

Figures 4-171 through 4-176 show the average emissions measurement results by vehicle model year for CO, HC, and NO, for both Rounds of testing. The average Round 2 CO results are nearly identical to those observed during Round 1, but the HC results are much higher during Round 2 and NO results are slightly higher. These changes could be due to differences the weather and in the driving patterns observed during Round 1 and during Round 2.

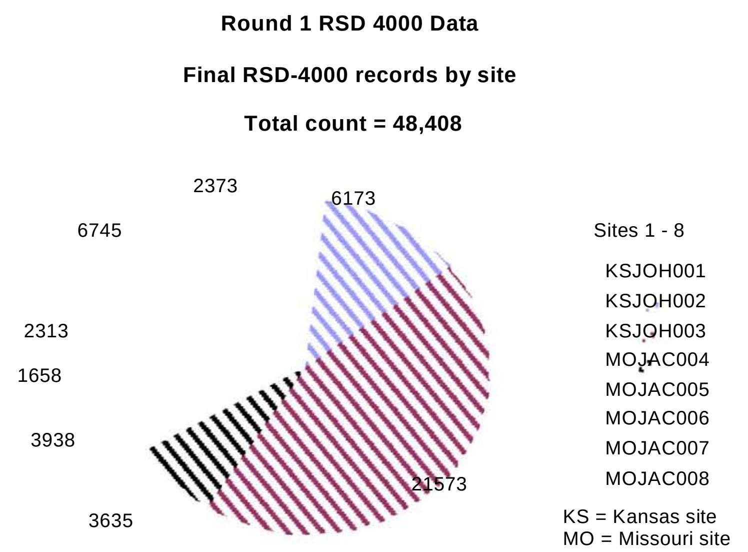


Figure 4-165. RSD-4000 Data Counts at each Round-1 Site

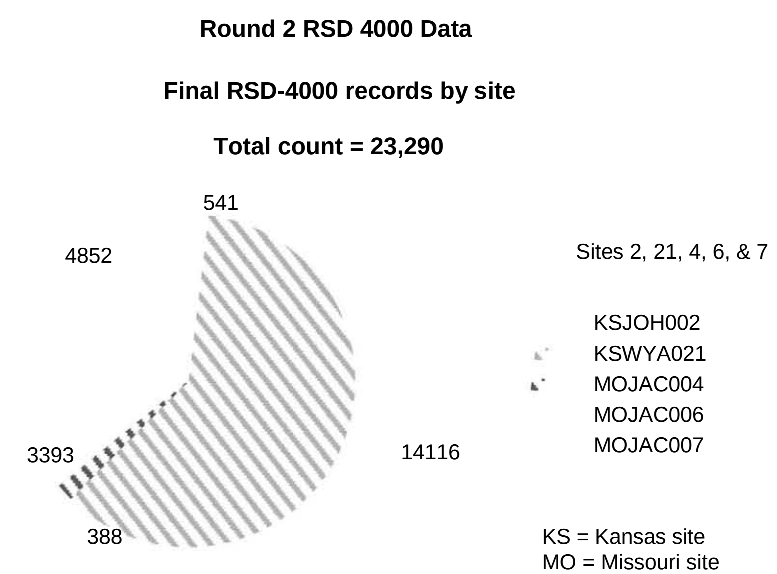


Figure 4-166. RSD-4000 Data Counts at each Round-2 Site

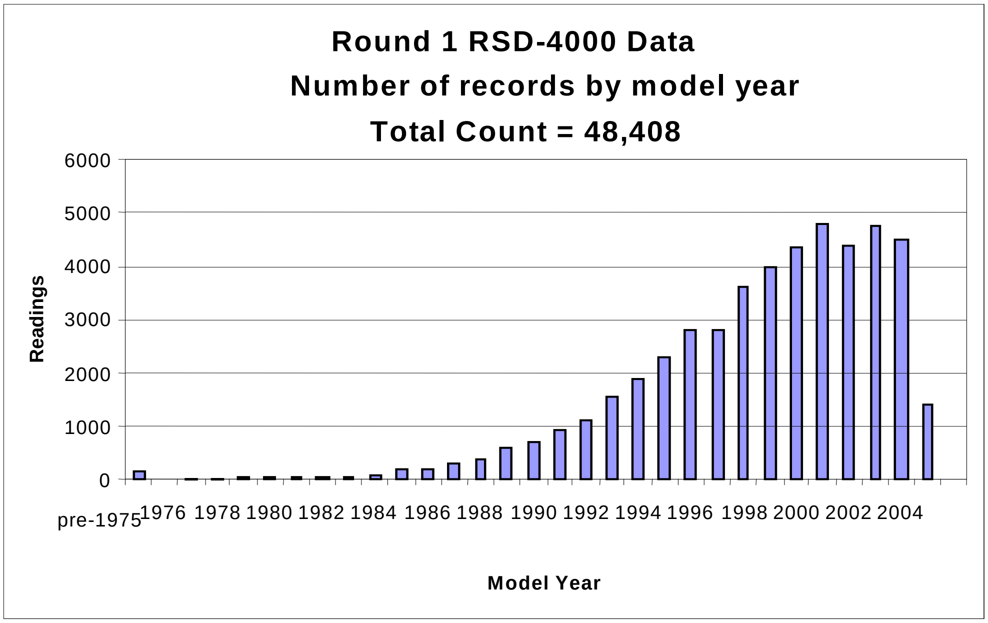


Figure 4-167. Round 1 RSD-4000 Vehicle Counts, by Model Year

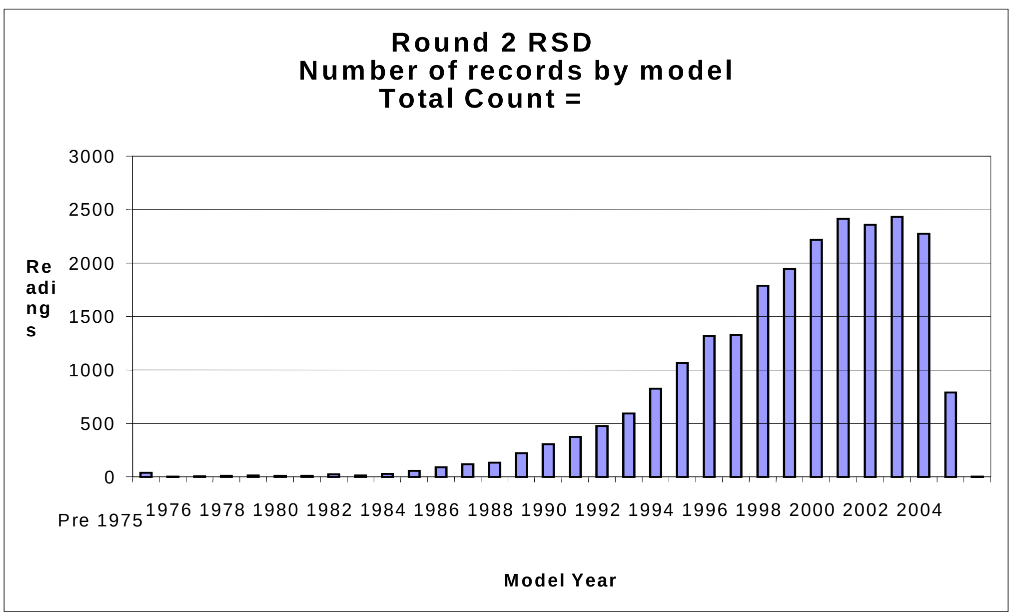


Figure 4-168. Round 2 RSD-4000 Vehicle Counts, by Model Year

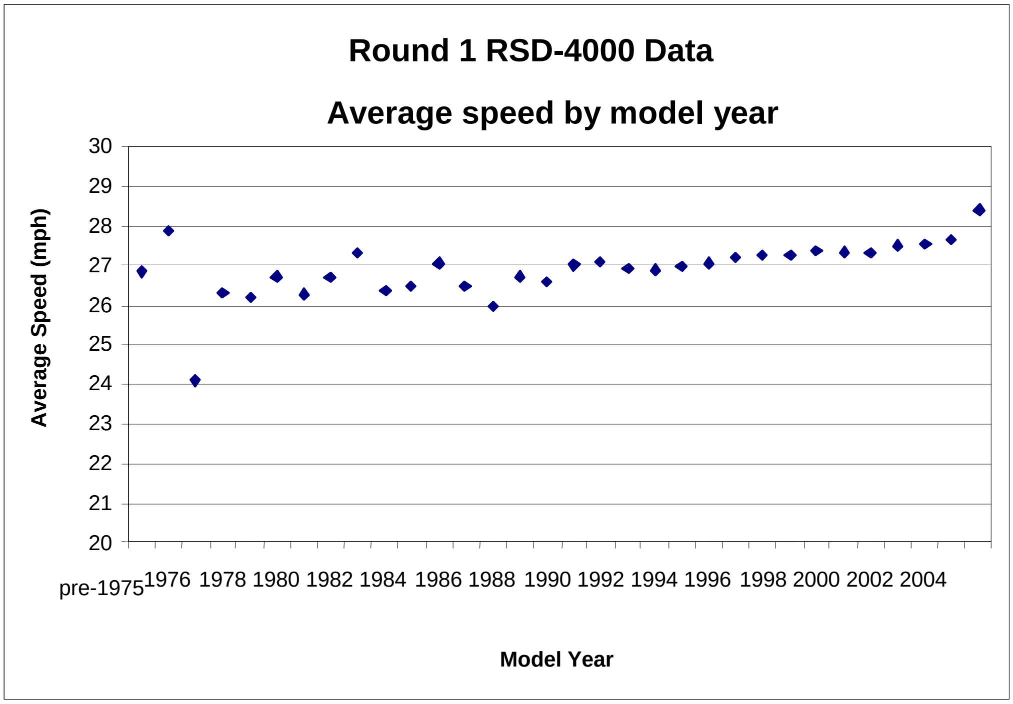


Figure 4-169. RSD-4000 Average Vehicle Speed, by Model Year, of Round-1 Data

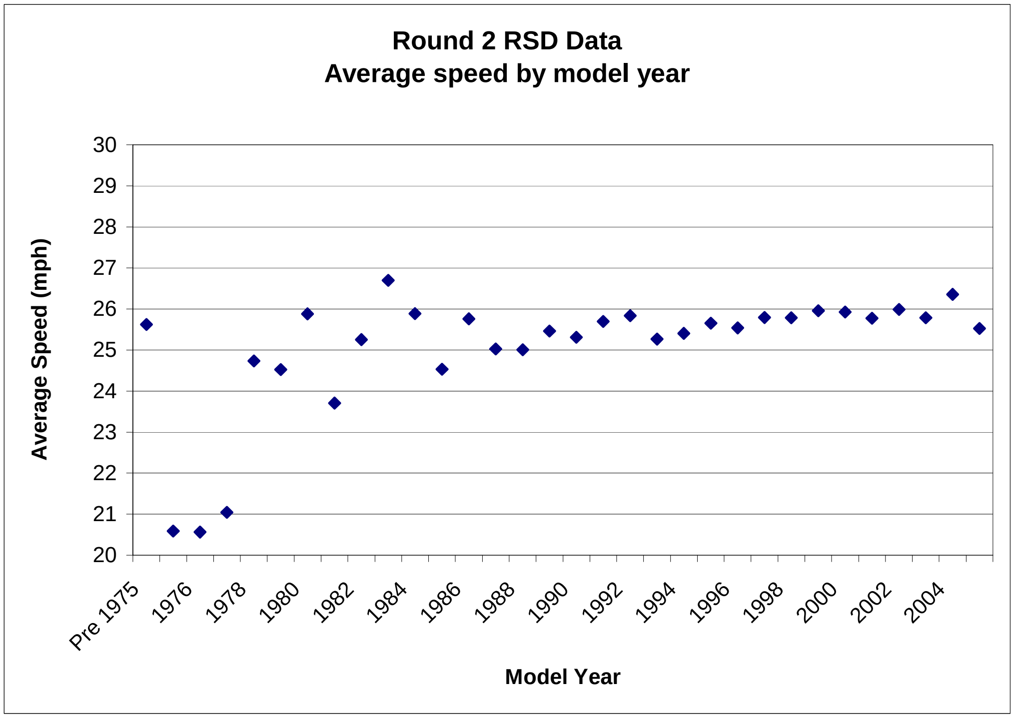


Figure 4-170. RSD-4000 Average Vehicle Speed, by Model Year, of Round-2 Data

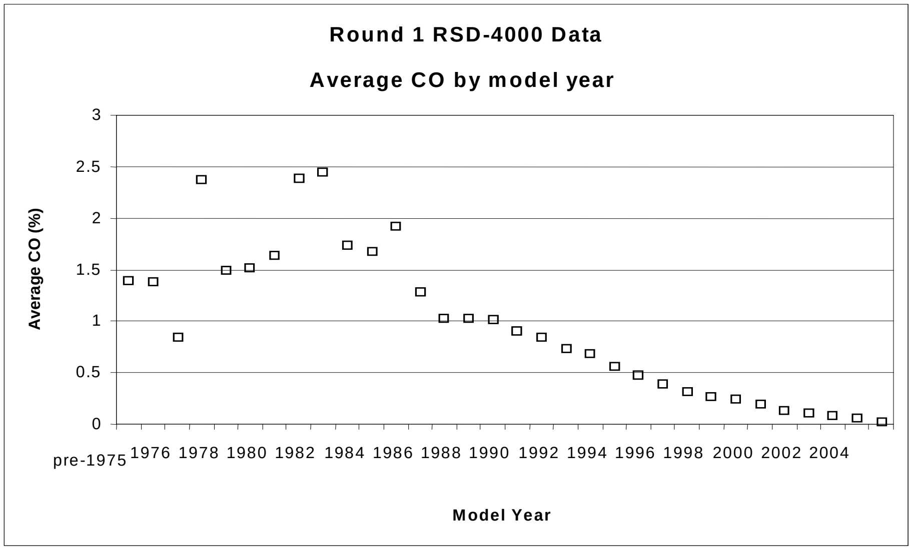


Figure 4-171. RSD-4000 Average CO Percentage, by Model Year, of Round-1 Data

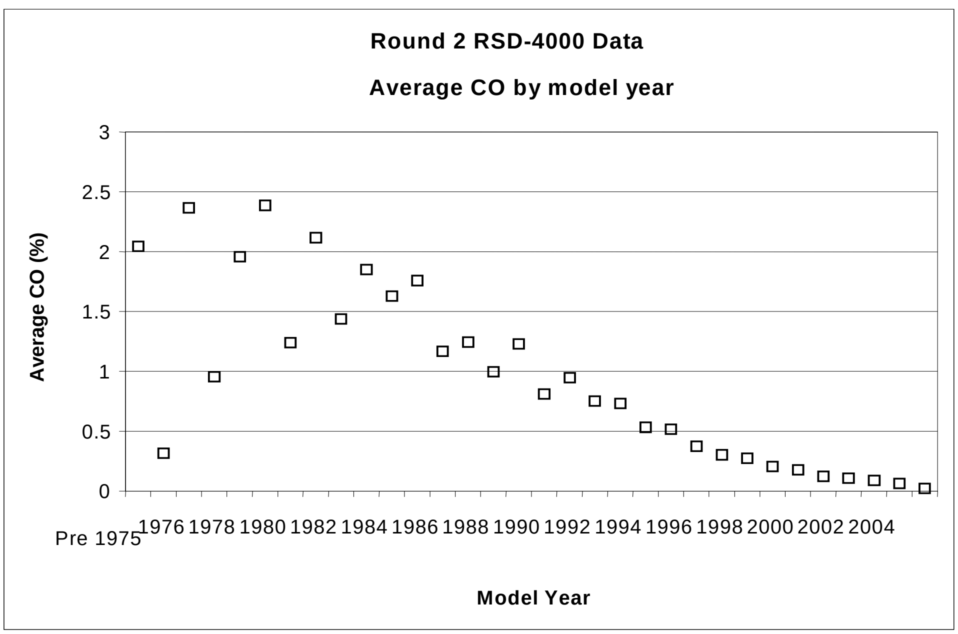


Figure 4-172. RSD-4000 Average CO Percentage, by Model Year, of Round-2 Data

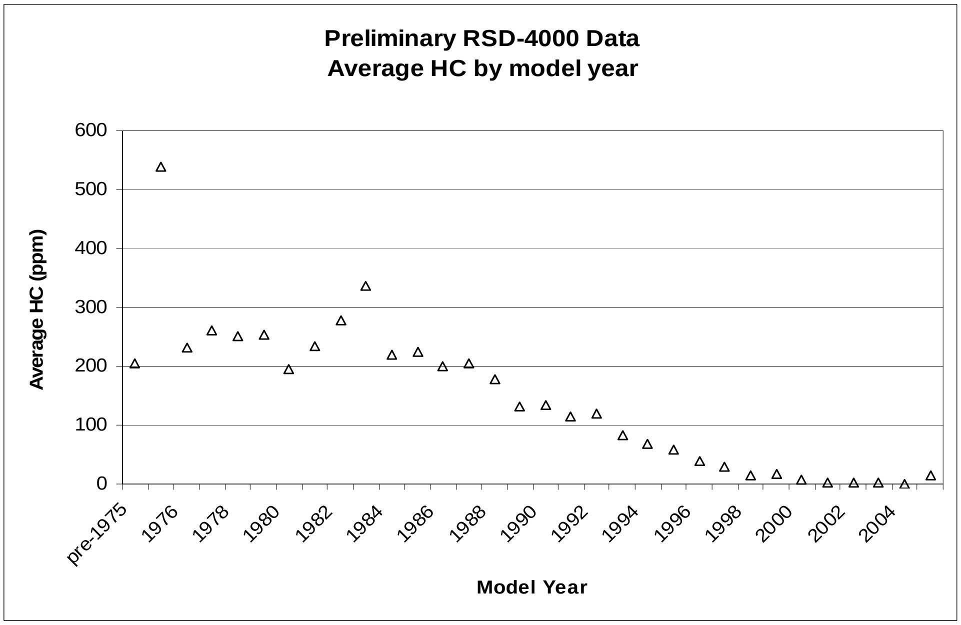


Figure 4-173. RSD-4000 Average HC Concentration, by Model Year, of Round-1 Data

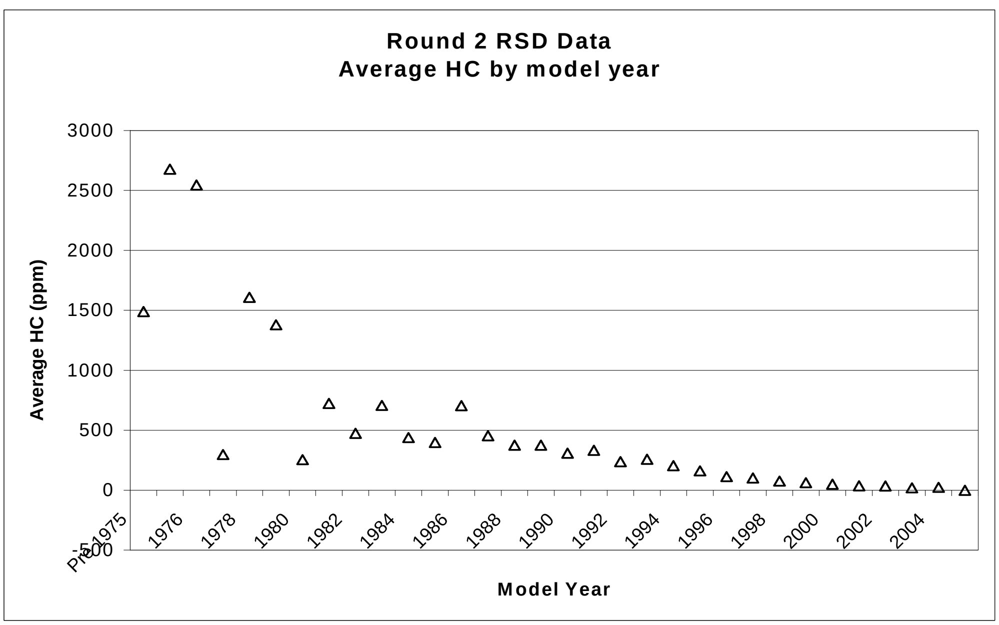


Figure 4-174. RSD-4000 Average HC Concentration, by Model Year, of Round-2 Data

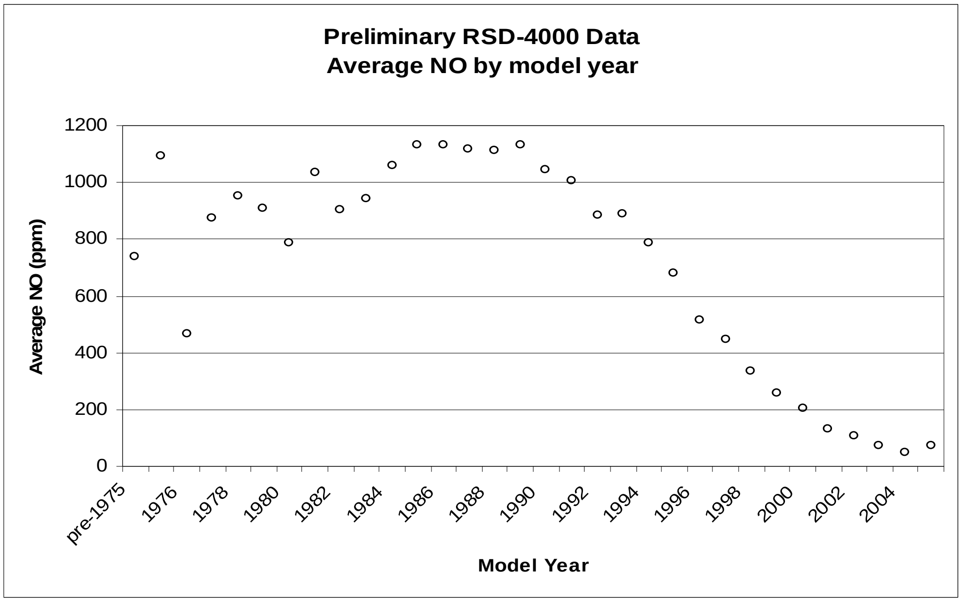


Figure 4-175. RSD-4000 Average NO Concentration, by Model Year, of Round-1 Data

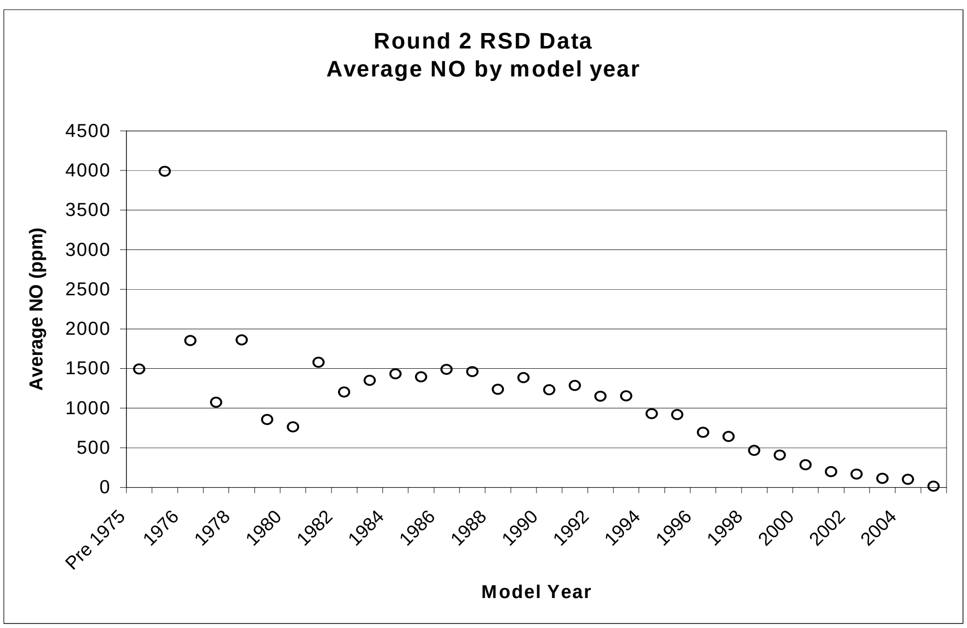


Figure 4-176. RSD-4000 Average NO Concentration, by Model Year, of Round-2 Data

4.8.3 Comparison of RSD Observations with PEMS Data

ERG performed a comparison of RSD data collected in the Kansas City area with second-by-second (SBS) observations from the PEMS unit connected to the dynamometer.

Thousands of RSD observations yielded VINs, speed, acceleration, and concentrations of HC, CO, and NOx for a wide variety of vehicles in the Kansas City fleet. This data, along with measured RSD site grades and vehicle weights from the ERG VIN Decoder, were used to calculate vehicle specific power (VSP) for each instantaneous observation. The calculation was based on equations used by EPA in MOVES2004, using SAS code provided by Jim Warila.

The same calculations were performed on second-by-second observations obtained from a PEMS unit on the dynamometer. Having determined VSP for each instantaneous observation, the data were segregated into by model year VSP bins for further analysis. Since the valid VSP range for RSD is 5 to 20 kW/tonne, only those measurements were retained. The VSP bins were created using ranges of 6 – 9, 9 – 12, and 12 – 18 kW/tonne. All observations gathered during Phase 1 of the LA92 test were dropped, since these would represent cold-start emissions, a scenario unlikely at the RSD sites selected for this study.

For each **model year -VSP** bin combination, the mean and variance of HC, CO, and NOx were calculated for both RSD and SBS data sets. For the SBS data, for a given bin, a test vehicle's measurements were averaged first, then the average of the averages were calculated to produce the cell average.

Summary tables of the data, for both Rounds 1 and 2, is provided in Appendices W and X. Graphs of pollutant concentrations of RSD versus Dyno SBS for CO, CO_2 and NO_x for Rounds 1 and 2 are provided in Figures 4-177 through 4-182.

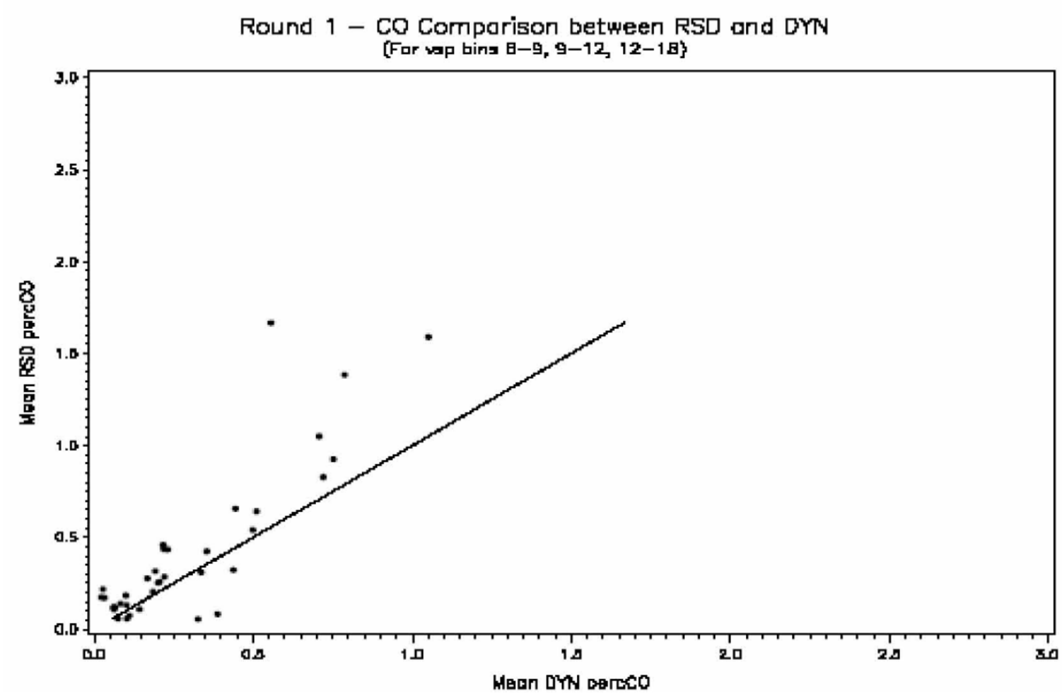


Figure 4-177. Round 1 RSD vs. Dynamometer CO Comparison

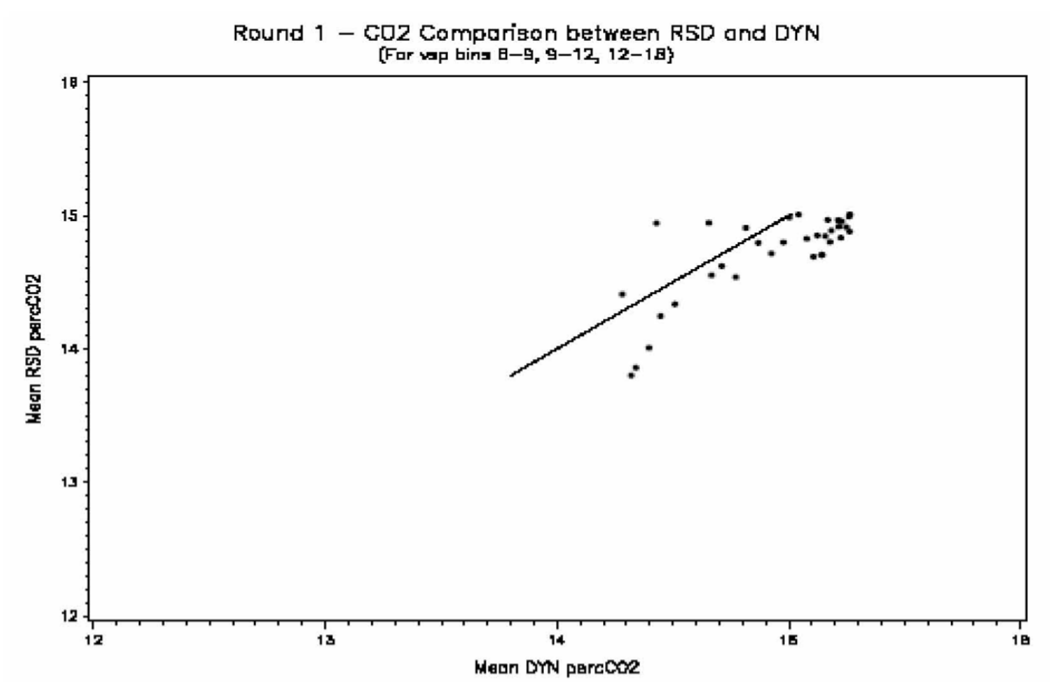


Figure 4-178. Round 1 RSD vs. Dynamometer CO_2 Comparison

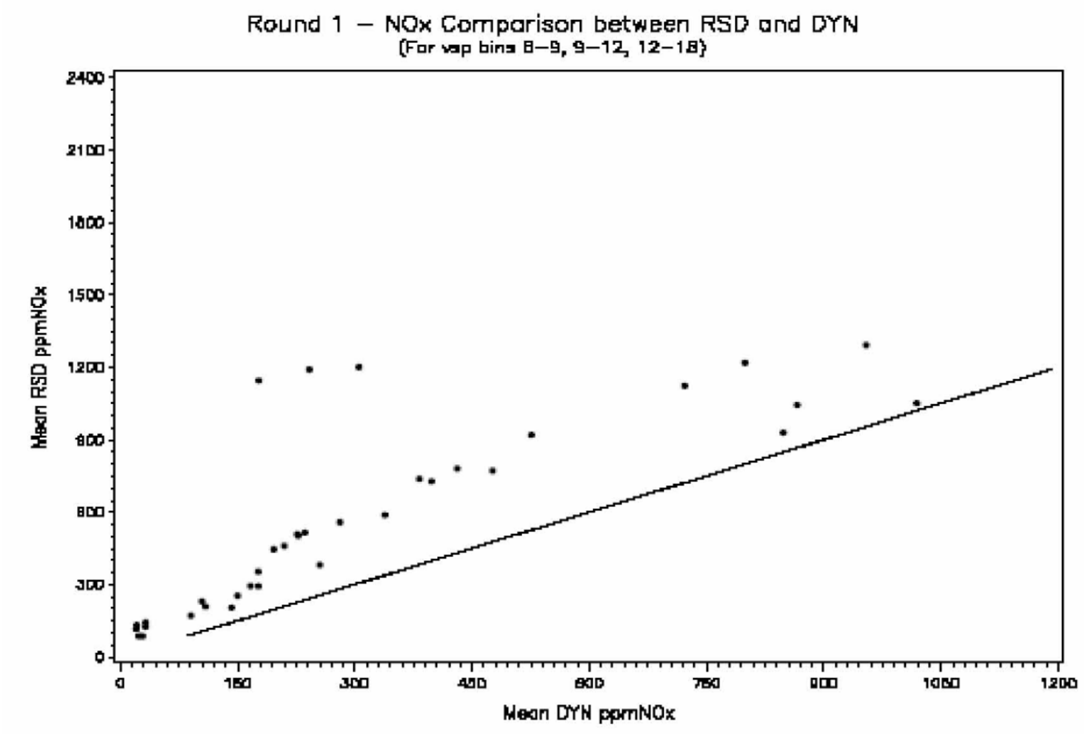


Figure 4-179. Round 1 RSD vs. Dynamometer NO_x Comparison

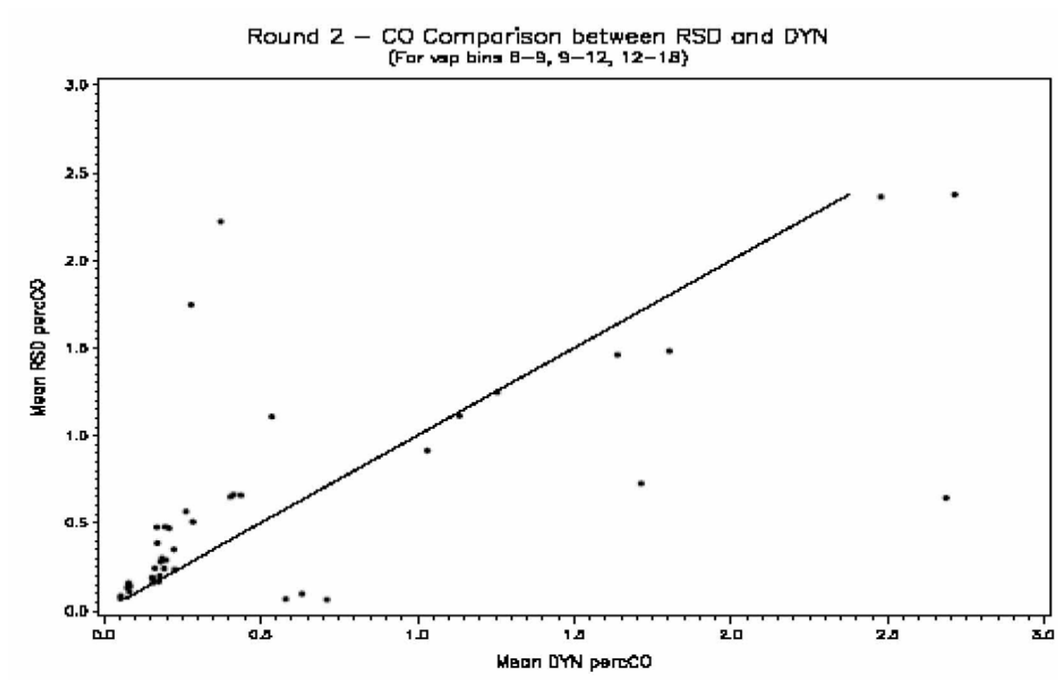


Figure 4-180. Round 2 RSD vs. Dynamometer CO Comparison

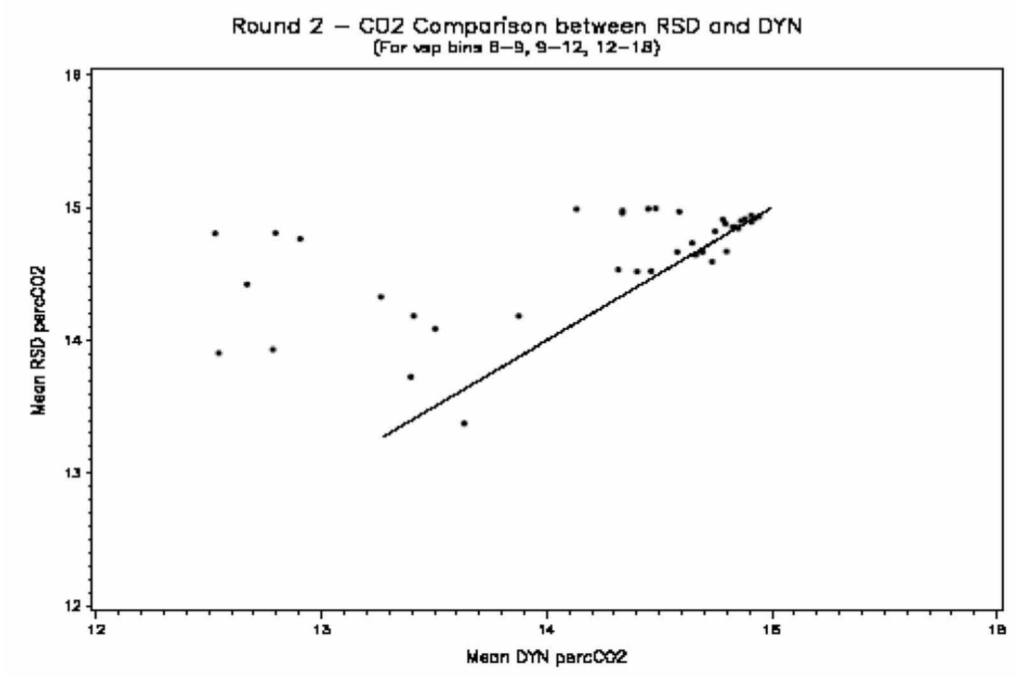


Figure 4-181. Round 2 RSD vs. Dynamometer CO_2 Comparison

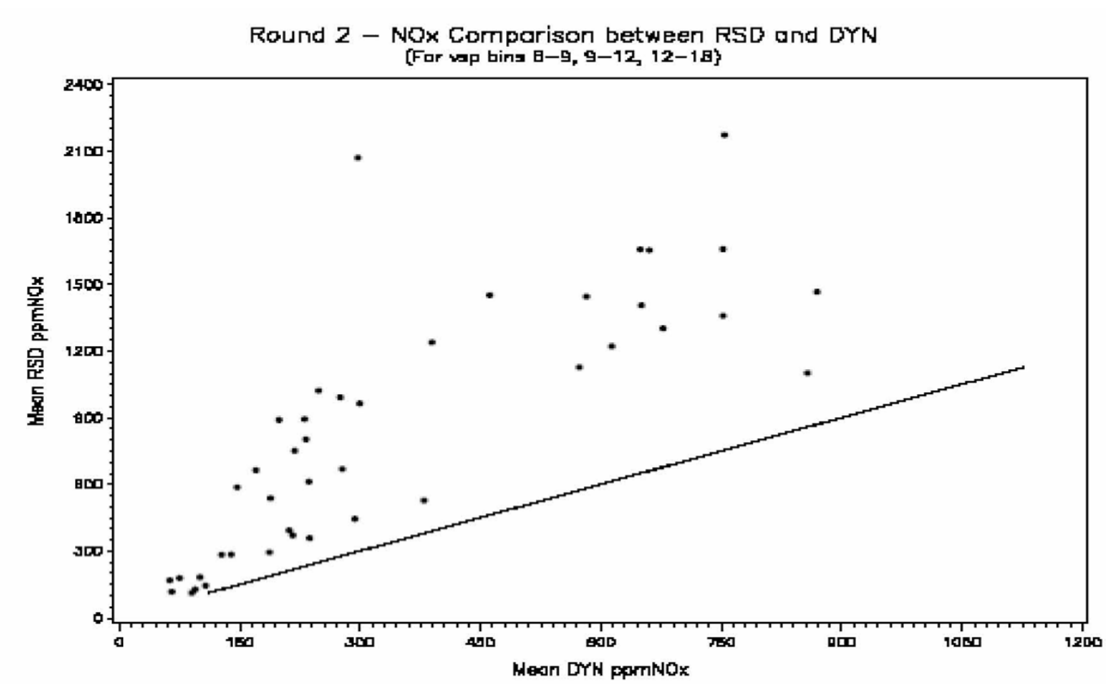


Figure 4-182. Round 2 RSD vs. Dynamometer NO_x Comparison

Comparisons of emissions measured by the PEMS unit as a vehicle passed RSD Site 21 with that measured by the RSD system was also performed. In order to perform this comparison, PEMS files were reviewed to identify second-by-second observations when vehicles were within the GPS coordinate range of the RSD unit, with similar speed readings for PEMS vs. RSD and with similar time stamps (time stamps alone were insufficient for identifying matches because the RSD timestamps were inconsistent with the PEMS timestamps). In order to confirm good readings were obtained, occasionally the test vehicle was driven through the RSD site two or more times (prior to beginning the vehicle conditioning run). In this situation, multiple RSD readings were available for a single vehicle.

In order to perform a PEMS to RSD comparison using this data, the RSD reading (or average of multiple readings) for each vehicle was compared with an average of PEMS readings (generally 4 readings) as the vehicle passed through the RSD site. Because of the GPS and exhaust transport delays, and because of the consistency of the PEMS readings as the vehicle passed through the RSD site, taking an average of PEMS readings was felt to be more representative of its emissions at the RSD site rather trying to identify the specific second the vehicle received the RSD reading. Second-by-second PEMS results and RSD readings are provided at the end of Appendix X, and a summary of comparison of average readings for PEMS vs. RSD is provided in Table 4-46, and also is shown graphically in Figures 4-183 through 4-186 (along with a 1:1 reference line).

Table 4-46. Summary of RSD vs. PEMS results at RSD Site 21

Test Date	Veh ID #		RSD Speed (mph)	PEMS GPS Speed (mph)	RSD HC (ppm)	PEMS HC (PPM)	RSD CO (%)	PEMS CO (%)	RSD CO2 (%)	PEMS CO2 (%)	RSD NOx (ppm)	PEMS NOx (ppm)
2/22/2005	729	**Avg**	25.2	24.55	14.94	279.83	0.26	0.03	14.85	13.05	230.16	1073.30
		Median	25.2	24.50	14.94	280.46	0.26	0.04	14.85	13.06	230.16	983.40
		StdDev	N/A	1.43	N/A	14.29	N/A	0.00	N/A	0.03	N/A	362.34
		N	1.0	4.00	1.00	4.00	1.00	4.00	1.00	4.00	1.00	4.00
2/22/2005	728	**Avg**	27.4	27.03	-67.35	106.03	0.06	0.05	14.99	12.96	580.28	508.83
		Median	27.4	28.55	-67.35	104.23	0.06	0.03	14.99	12.94	580.28	432.09
		StdDev	3.1	3.12	49.55	38.70	0.01	0.04	0.04	0.18	686.11	228.43
		N	2.0	8.00	2.00	8.00	2.00	8.00	2.00	8.00	2.00	8.00
2/23/2005	731	**Avg**	29.4	28.03	-34.70	105.92	0.27	0.21	14.83	13.01	695.36	819.61
		Median	29.2	27.90	-25.32	105.45	0.16	0.21	14.90	13.02	685.49	831.36
		StdDev	0.3	1.40	22.21	5.21	0.19	0.02	0.13	0.02	194.21	45.57
		N	3.0	4.00	3.00	4.00	3.00	4.00	3.00	4.00	3.00	4.00
2/24/2005	737	**Avg**	31.1	30.08	123.10	1268.51	1.02	4.52	14.29	10.30	496.48	195.46
		Median	31.1	30.10	123.10	1274.04	1.02	4.71	14.29	10.31	496.48	191.26
		StdDev	N/A	0.15	N/A	349.27	N/A	2.77	N/A	1.70	N/A	73.31
		N	1.0	4.00	1.00	4.00	1.00	4.00	1.00	4.00	1.00	4.00
2/25/2005	747	**Avg**	28.3	31.90	-29.42	176.20	0.17	0.13	14.91	13.09	610.92	967.78
		Median	30.0	31.65	-31.10	175.95	0.13	0.12	14.93	13.08	612.23	1036.04
		StdDev	5.7	1.35	29.81	9.91	0.09	0.03	0.07	0.02	560.86	264.72
		N	4.0	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
2/25/2005	744	**Avg**	34.6	30.05	-30.57	32.62	0.61	0.10	14.61	9.37	93.67	77.50
		Median	35.1	30.10	-38.29	32.75	0.19	0.11	14.91	9.37	52.34	77.68
		StdDev	2.5	1.22	33.78	2.02	0.90	0.02	0.65	0.01	121.23	22.36
		N	4.0	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

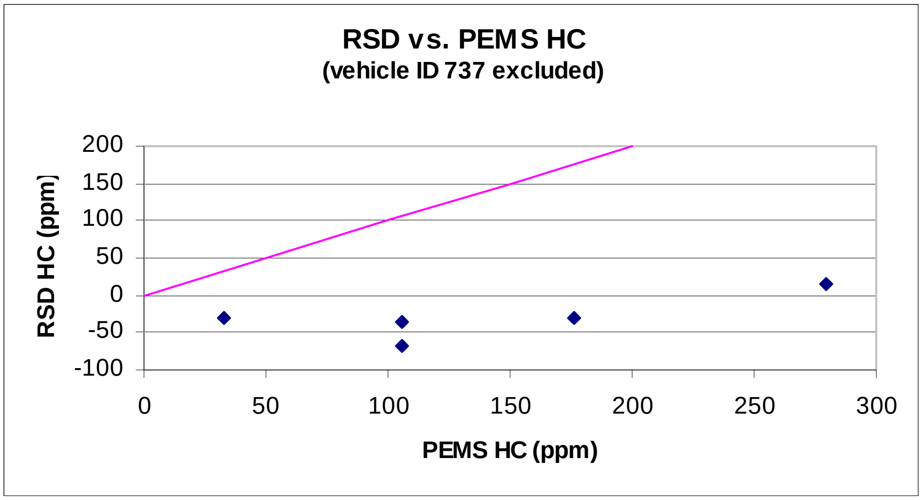


Figure 4-183. RSD vs. PEMS HC readings at RSD Site 21

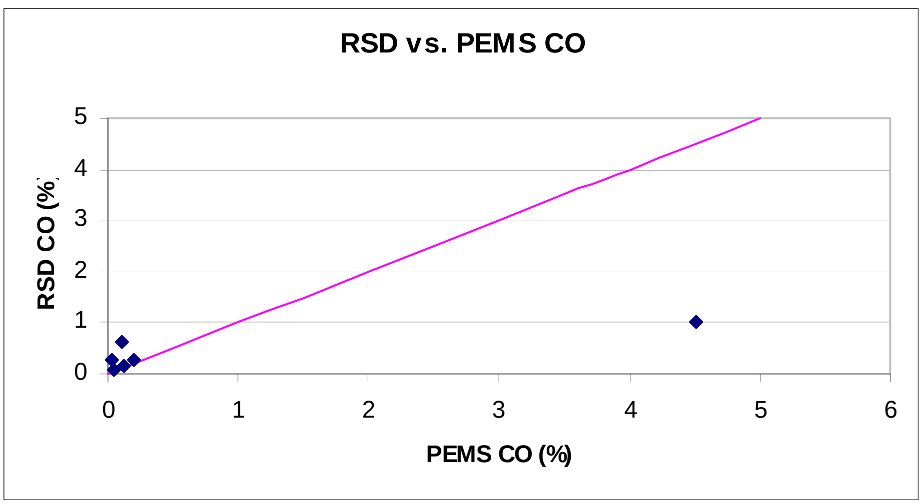


Figure 4-184. RSD vs. PEMS CO readings RSD Site 21

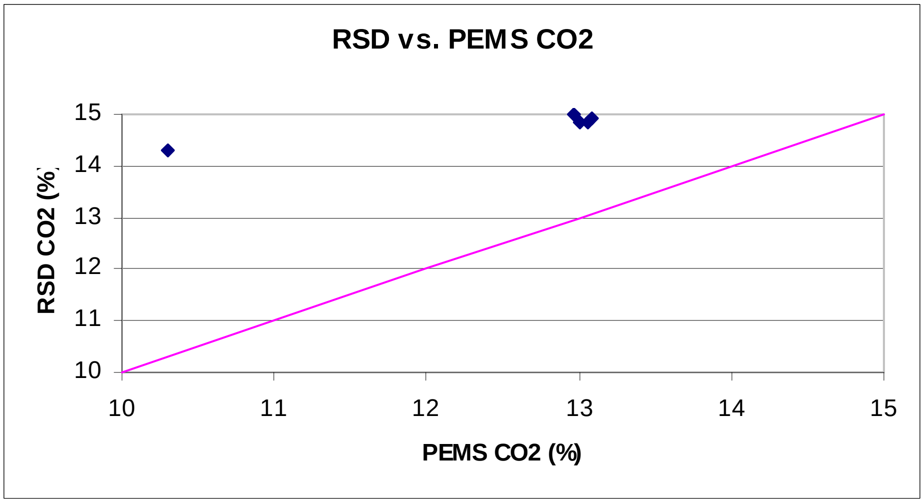


Figure 4-185. RSD vs. PEMS CO_2 readings RSD Site 21

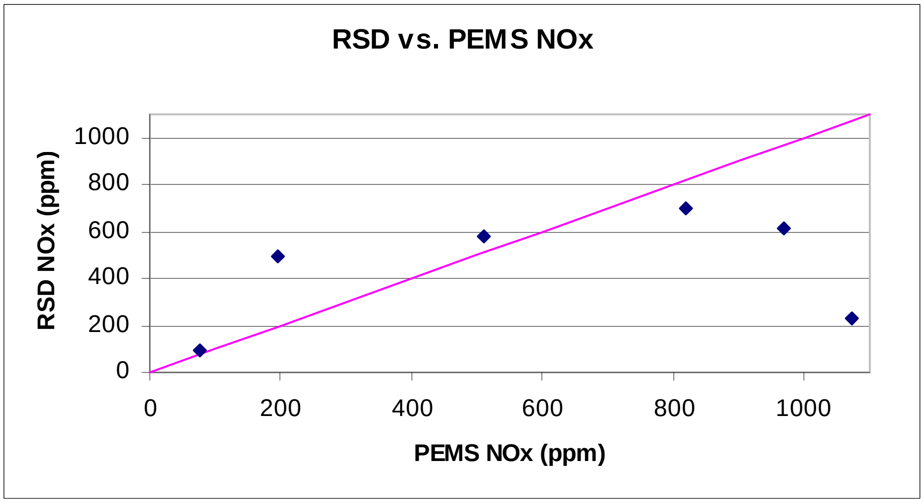


Figure 4-186. RSD vs. PEMS NO_x readings RSD Site 21

4.9 PAMS testing

PAMS testing was commenced near the end of Round 2. Six PAMS units, Ease OBDII dataloggers, were provided to ERG by the USEPA. New software and batteries were purchased for these units, and all units were configured for auto activation for driveaway testing. One unit was found to be malfunctioning, and was returned to Ease for warranty repair. This unit was repaired and returned, but not until after the end of Round 2 field activities.

Since PAMS testing didn't begin until the end of Round 2, only eight vehicles received PAMS tests, as listed in Table 4-47.

Table 4-47. PAMS Vehicle Summary

Veh ID	Mfr	Model	MY	Odo	Install Date	PAMS ID	Notes
694	Oldsmobile	Silhouette	2002	61190	2/16/05	P1	No data were available on datalogger when it was removed. Acquired software and configured unit.
696	Dodge	Durango	2002	28730	2/16/05	P4	unit sparked and participant pulled it out along with DLC, paid $1800 in repairs. No data were recorded, datalogger required configuration. Acquired software and configured unit.
755	Toyota	Avalon	1998	29610	3/2/05	P5	No data werte recorded on datalogger when it was removed. Acquired software and configured unit for future testing.
740	Ford	Escape	2002	44901	3/22/05	P3	Data available and downloaded.
724	Chevrolet	Blazer	1996	94372	3/25/05	P1	No data on this datalogger for some reason (unit had been configured but still didn't acquire data).
909	Honda	Civic	2002	30600	3/29/05	P2	Data available and downloaded. However, data appears to have been configured as "Visible Grid Parameters" (rather than "Sensors"), so data has no VSS field (vehicle speed). Also, data exported as one large datafile (rather than small datasets).
905	Toyota	Camry	2001	46891	3/29/05	P5	Data available and downloaded.
906	Ford	Escape	2002	36230	3/29/05	P4	Data available and downloaded.

As can be seen in the table, three PAMS units were installed prior to the purchase of software and operating batteries, and no data were available on these units. Once the software and batteries were received, the PAMS units were configured to acquired the following data: elapsed time, engine RPM, calculated load, air flow rate, vehicle speed, absolute throttle position, engine coolant temp, and emission related DTC count. One unit was apparently configured to acquire different parameters, and therefore didn't obtain vehicle speed, a necessary parameter in activity data logging. The data that were gathered with the other units will be included in the MSOD data tables provided for this study.

5.0 MSOD

In accordance with the requirements set forth in the original Scope of Work, data procured over the course of the project was processed and delivered in the EPA's MSOD format. Field data collection procedures were designed with MSOD data collection requirements in mind.

After collecting and compiling data from the vehicle test program, datasets were prepared for import into the EPA MSOD. Data integrity and accuracy are of the utmost importance, and in order to ensure that the data prepared for the MSOD accurately represents the data that was originally received, the following four step approach for electronic data handling and manipulation was developed.

- Import raw data into SAS dataset(s);
- Review and convert data to match MSOD format and export to text files;
- Import text files into the final MSOD .DBF format using Foxpro; and
- Verify the validity of the output database and files.

This approach separates raw import and data cleanup issues from project-specific issues of data format conversion and validation. In the first three stages, emphasis was placed on automation. Scripts and programs were used as much as possible, to provide repeatable steps for the verification stage and documentation. Appendix Z presents a detailed data map of raw input files imported, SAS programs used for aggregation and analysis, intermediate SAS datasets used in data cleanup and conversion, and final output text files imported into .DBF format for Rounds 1 and 2 of the study.

In the first import stage, the raw input data, which was generally in comma-separated variable (CSV) format, was loaded into SAS datasets. The data was imported into datasets that mimicked, to the extent possible, the design of the original files. In this way, each raw input file mapped to one or more specific SAS datasets, with close agreement in table content and layout. While some data cleanup was needed for a successful data import, no data manipulation (such as unit conversions or factor manipulation) was performed at this stage. Minor data cleanup was required in some cases because of conflicts between file types, such as end-of-record or end-of-data discrepancies, differences in character sets, conflicting numeric formats, or data types that did not convert directly. After the data was loaded into SAS datasets, it was reviewed for data integrity and completeness. SAS programs used during this stage included the following:

- rdBKI_Aligned.sas. This program reads in both second-by second dynamometer observations for each vehicle, as well as a summary of total bag readings for each phase of the dynamometer testing. Both datasets were provided by BKI. Although the bag data presented in this dataset is suspect for reasons discussed in Section 4.2, it was important to record and preserve the bag data in MSOD, which may be used to provide a rough comparison with modal data. Cumulative by-phase modal observations can be derived from the second-by-second data if required. The program returns two output SAS datasets:

- ✧ bki_bag_aligned, containing by-phase dynamometer bag observations, and
- ✧ bki_sbs_aligned, containing second-by-second dynamometer modal readings.

- rdSEMTECH.sas. This program reads in raw files from the PEMS units, encompassing all dyne PEMS, conditioning, and driveaway files. It also incorporates the bki_sbs_aligned SAS dataset described above to provide second-by-second speed readings where those observations were missing in the PEMS data. This program returns several SAS datasets:
    - ✧ *semtech_sbs_dyno*, containing second-by-second data for the dyne PEMS,
    - ✧ *semtech_bag_dyno*, containing PEMS data at the phase level for comparison with observations taken on dynamometer itself, for QC purposes,
    - ✧ *semtech_veh_short*, containing summary data from the headers of all dyne PEMS records,
    - ✧ *semtech_precond_sbs*, containing second-by-second data for the PEMS conditioning runs,
    - ✧ *semtech_precond_veh*, containing summary data from the headers of all PEMS conditioning run records,
    - ✧ *semtech_driveaway_sbs*, containing second-by-second data for the PEMS driveaway runs, and
    - ✧ *semtech_driveaway_veh*, containing summary data from the headers of all PEMS driveaway records.
- rdDRI.sas. This program reads in by-phase particulate measurements from all PM instruments, obtained from a QC'ed dataset provided by EPA. It also reads in mass, EC, OC, and elements data, as well as speciated VOC observations from vehicle composites, both provided by DRI. The program returns a single SAS dataset:
    - ✧ *dri_all_baglevel*, containing all of the by-phase information detailed above.
- Rdveh.sas. This program reads in vehicle information gathered from onsite logs, along with several of the datasets described above. The program assigns flags to vehicle records that describe what tests were performed on each vehicle, and whether those tests were sufficiently valid for later inclusion in MSOD. The program returns 2 datasets:
    - ✧ *vehID_dyn_pre_drw*, containing basic vehicle information and flags identifying valid tests, and
    - ✧ *vehround1_2*, containing more detailed information on each vehicle that is specifically required for MSOD.
- rdDRI_SbS.sas. This program reads in second-by-second PM observations for each vehicle tested, as provided by DRI. It returns two datasets:
    - ✧ *top_file*, containing summary information on the data file read in for each vehicle, later used for QC purposes, and

- ✧ *sbs_file*, containing the actual second-by-second observations for each PM instrument used.

- Rdfuel.sas. This file reads in data from laboratory fuel analysis, as provided by EPA. It returns a single dataset:

  Fuel¸ containing all available fuel parameters required for the MSOD.

Figure 5-1 depicts data flow during the first import stage of the process during Round 1. Round 2 followed a very similar process, with slight differences in filenames.

Once the data were imported into SAS datasets and reviewed , the datasets were remapped from a format similar to the original raw data files, to a scheme more closely resembling that needed for import to MSOD. All required conversions and data manipulation were performed in SAS at this point, and the datasets were converted from an intermediate form into final output text files. SAS programs used during this stage generally took datasets prepared as described above as inputs, and returned text files ready for import into Foxpro as output. These output files were named according to standard MSOD nomenclature, and each output file generally corresponds to an individual MSOD table. Figure 5-2 depicts data flow during the review and conversion stages of the process.

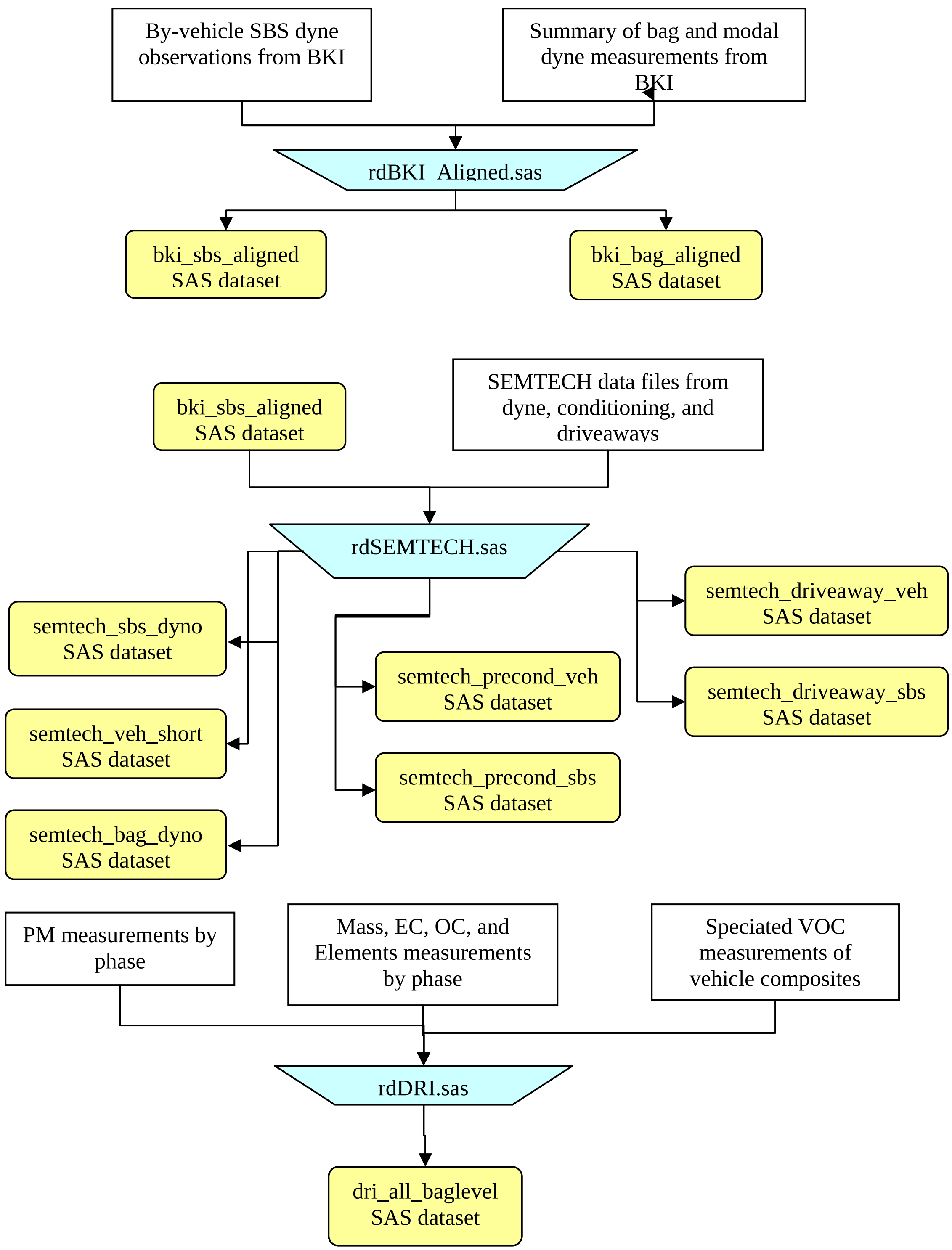


Figure 5-1. Data Flow During First (Raw Data) Import Phase

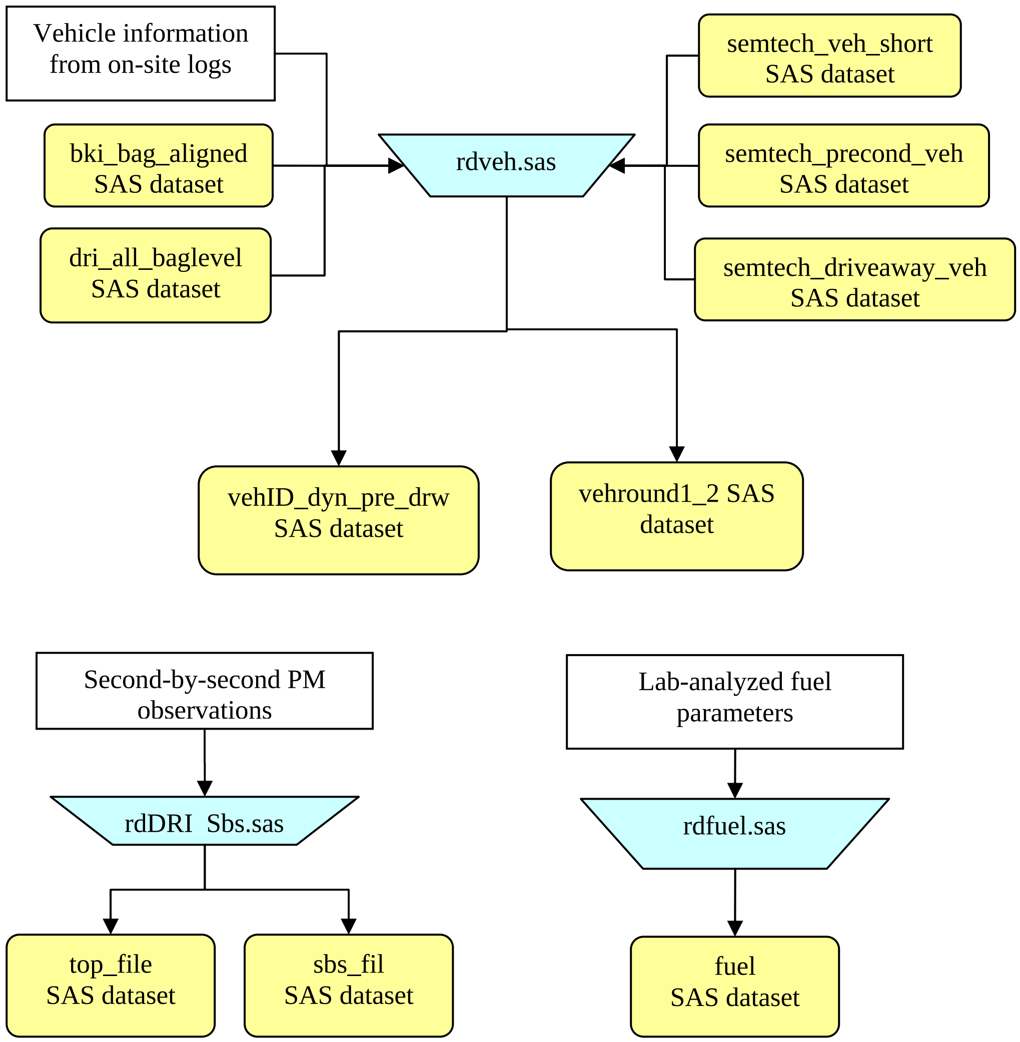


Figure 5-1. Data Flow During First (Raw Data) Import Phase (continued)

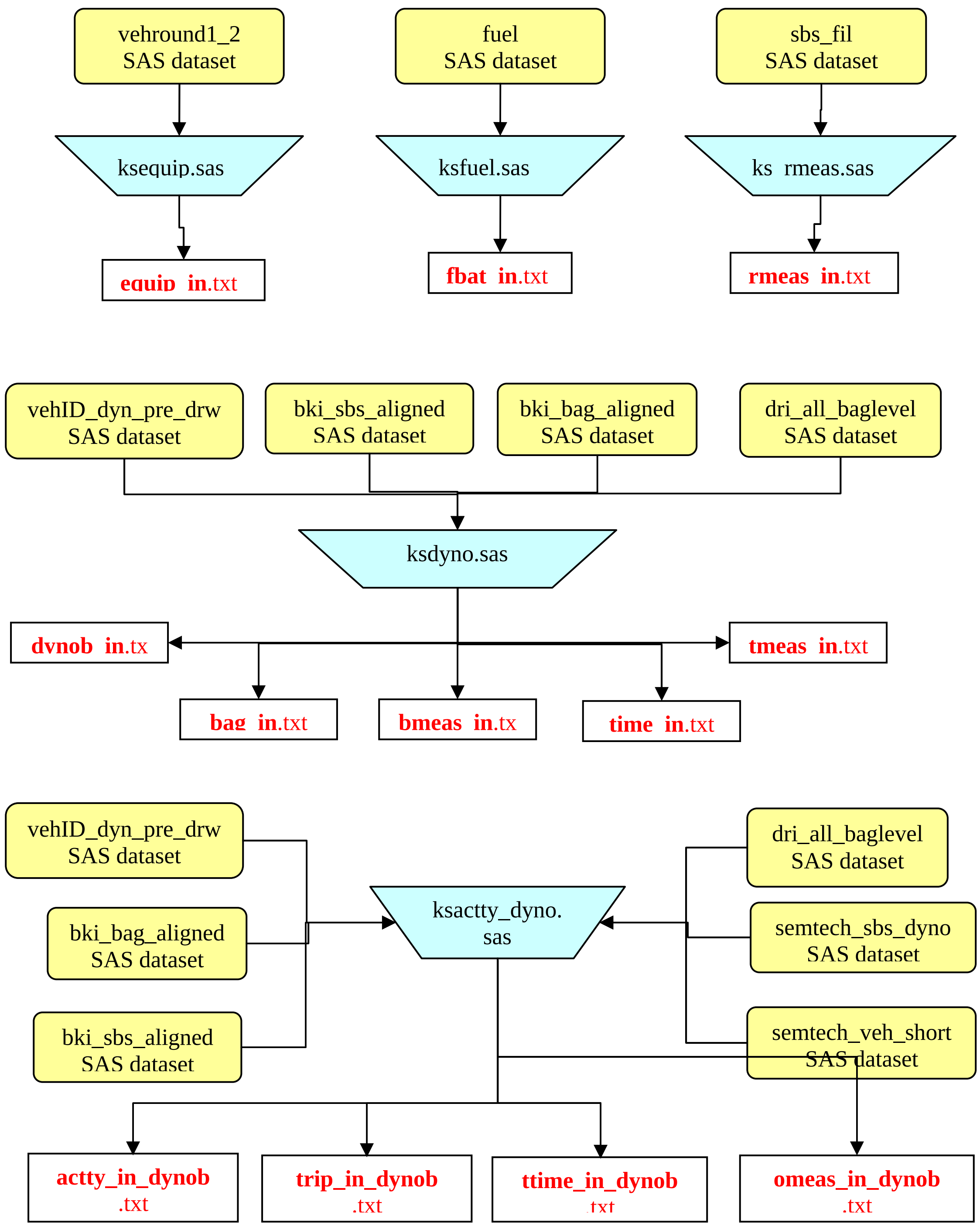


Figure 5-2. Data Flow During Review and Conversion Phase

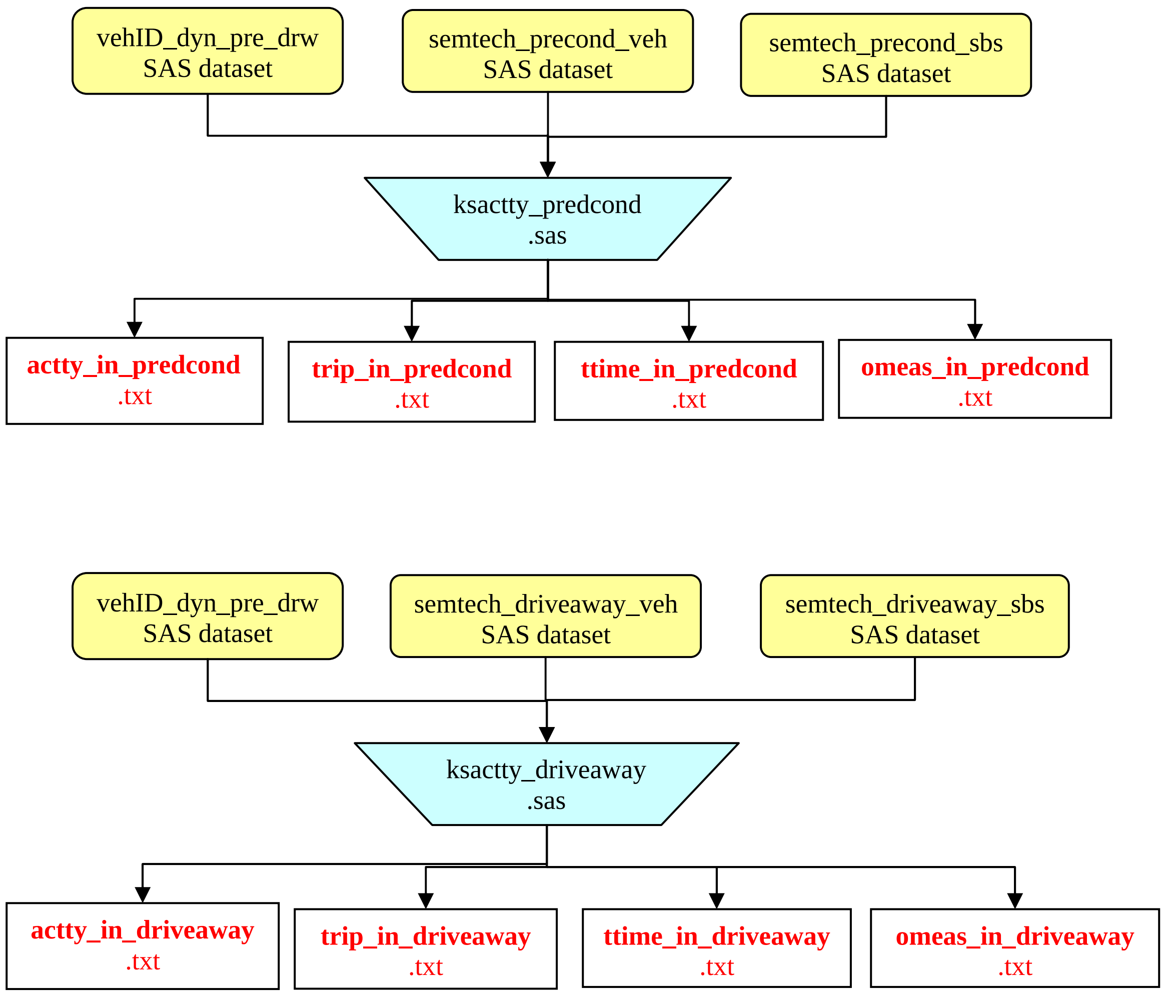


Figure 5-2. Data Flow During Review and Conversion Phase (continued)

These text files were then loaded into DBF format with scripts developed using Foxpro version 8.0. The scripts incorporated some basic validity and range checks for the data, and converted the final text files into individual database tables required for MSOD and checkable by EPA's validation software. Note that during this stage, the actty_in, trip_in, and ttime_in files generated for each of the dyne PEMS, conditioning run, and driveaway datasets (and PAMS data during Round 2) were merged into one Foxpro database file for import into MSOD. Also, in lieu of generating a database table for pmeas_in, EPA approved the creation of compact omeas_in text files containing a wide array of non-emission related second-by-second measurements from the PEMS units. These omeas_in tables will be converted to MSOD format by EPA staff at a later date.

It is important to mention a problem that arose during processing of second-by-second observations in the rmeas_in table. Specifically, the dynosecs field in the MSOD rmeas_in table is defined as an integer. Many of the observations recorded in rmeas_in have a time resolution of tenths of hundredths of a second, and Foxpro was rounding these seconds to the nearest whole integer. Apart from the obvious problem of the unacceptable loss of time resolution in the data, this also caused some otherwise separate measurements to be recorded in the database as having duplicate dynosecs values. Because the dynosecs field is defined as a primary key in the database, these duplicate observations were not passing validation tests. In order to preserve the original time resolution in the data, a separate table, rmeas_in_adjusted, was created. This table was identical to rmeas_in, except that it contained an additional field, secs_adj, in which a non-rounded time measurement was recorded.

The final step in the data management process involved running EPA's EPAVALDATA program against each of the DBF import tables. This program quality assures each of the tables and log all errors encountered. Each of the errors were reviewed and addressed accordingly. Once the automated review of the tables for each dataset were complete they were delivered to EPA for further verification and loading into the MSOD.

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Appendices will be provided electronically. The following is a list of the appendices, their filename, and their contents.

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Appendix A. Concentration of Species Normalized to Larger of Mean Field Blank Value or MDL – Analytical sensitivity Relative to Emission Levels Based Upon Round 1 Data.

Appendix B1. Chemical Composition of Dilution Tunnel Blanks and Vehicle Exhaust Samples for Round1.

Appendix B2. Chemical Composition of Dilution Tunnel Blanks and Vehicle Exhaust Samples for Round2.

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