CENTRAL CAROLINA VEHICLE PARTICULATE EMISSION STUDY

Final Report

by

Kenneth T. Knapp and Silvestre B. Tejada
US Environmental Protection Agency
MD-46
Research Triangle Park, NC 27711

Steven H. Cadle
General Motors R&D Center
MD 480-106-269
Warren MI 48090-9055

Douglas R. Lawson
National Renewable Energy Laboratory
1617 Cole Blvd
Golden CO 80401

Richard Snow
Clean Air Vehicle Technology Center, Inc
Research Triangle Park, NC 27711

Table of Contents

Executive Summary

Recent studies on light-duty motor vehicle exhaust particles have shown that the emission factors in use have greatly under predicted the contribution of motor vehicles to the particulate pollution problems. One of the first studies to show this under prediction was conducted in Nevada where the particulate emissions from smoking vehicles (i.e., high emitters) were studied. However, when non-smoking vehicles were tested for comparison, it was found that they too had significant particulate emissions. The Nevada study was followed by studies in California, Alaska, and a major study in the Denver, Colorado area. The Denver study was part of a major air quality study to determine the causes of the winter "Brown Cloud" pollution problem. This study has been completed and reported in several publications as part of the Northern Front Range Air Quality Study (NFRAQS, http://nfraqs.cira.colostate.edu).

All of these previous studies have been conducted on vehicle fleets in the western United States. Particulate emissions data from vehicle fleets in the southeastern United States were needed for comparison and for determining their contribution to the particulate pollution of this region. In addition, source profiles were needed for input to source apportionment modeling. To obtain the needed data, a study in central North Carolina was planned and carried out. This report presents data from this study.

The distribution of test vehicles chosen to represent the central Carolina vehicle fleet was based on the light-duty vehicle registration data for the four counties in the Research Triangle Park (RTP) area of North Carolina as recorded in the North Carolina vehicle registration data base. The study was divided into two phases, a winter 1999 phase and a summer 1999 phase. The vehicle testing was conducted by the U. S. Environmental Protection Agency (EPA) and its on-site contractors in the parking lot of the Home Depot hardware store in Cary, North Carolina. Funding, assistance in planning, and sample analyses arrangements at the Desert Research Institute (DRI) were provided by the U.S. Department of Energy's Office of Heavy Vehicle Technologies through the National Renewable Energy Laboratory (NREL) and by the Coordinating Research Council (CRC). A separate report with the chemical analyses conducted by DRI will be prepared by DRI.

The recruited vehicle distribution was divided into four model year categories and further divided into cars and pickup trucks. In the winter and summer phases, 120 gasoline fueled vehicles and four diesel fueled vehicles were tested on chassis dynamometers with the IM240 driving cycle which is a test cycle for warmed-up vehicles. The testing in the Home Depot in Cary the parking lot was run on EPA's transportable dynamometer. Because of a malfunction in the particle sampling system, an additional 15 vehicles were run in the winter phase. A total of 135 gasoline-fueled and three diesel-fueled vehicles were tested in the winter phase. But only 106 gasoline-fueled vehicles were run on the transportable dynamometer in the Cary parking lot for particulate emissions. The additional 14 gasoline-fueled and three diesel-fueled vehicles tested for particulate emissions were run on the Cold Cell Research dynamometer located in the EPA ERC

Annex in RTP, NC. Recruiting problems limited the diesel fueled vehicle testing in the winter phase. All 125 vehicle test runs in the summer phase were conducted on the transportable dynamometer located in the parking lot of the Home Depot in Cary, NC.

The regulated gaseous emissions, [carbon monoxide (CO), total hydrocarbons (HC), and nitrogen oxides (NOx)], carbon dioxide (CO_2), quartz and Teflon filter samples, and aldehydes and ketones samples were taken on every test run. In addition, 25 PUF/XAD samples for semi- and non-volatile organic emissions were collected in each test phase. Four Tedlar bag samples for speciation of gaseous organics were taken each day. The number of organic speciation samples was limited so that all collected speciation samples could be analyzed on the day of collection. Forty-eight PM2.5 samples were collected in the winter phase and 14 PM 2.5 samples were collected in the summer phase for comparison to the PM10. The small number of PM2.5 samples in the summer phase was due to limited filters and time. Every tenth vehicle was tested twice for QA purposes.

The combined summer and winter results of the particulate emissions measurements for the gasoline vehicles were similar to those found in the NFRAQS Denver study. In both studies, the late model 1993-1997 vehicles generally had low particulate emissions (< 7 mg/mi). The overall (summer and winter) average particulate emission rate found in this study was 19.40 mg/mile compared to 20.85 mg/mile found in the Denver study. In the winter phase, the average PM10 emission rate was 27.62 mg/mile, while in the summer phase, PM10 averaged 10.56 mg/mile. No correlation between PM10 and the regulated emissions was found. A slight correlation between the vehicle model year and PM10 was found. The average PM10 emissions rate for the 8 diesel fueled vehicles was 445 mg/mile. This value is lower than the 550 mg/mile average for 20 diesel vehicles in the Denver study All the averages given in this report are fleet averages of the recruited test fleets and were not corrected for actual on-road fleet distribution nor of the vehicle miles traveled of the on-road fleet.

The average 18.4 mg/mile emission rate of formaldehyde in the winter phase was twice as high as that observed in the summer phase. Ethanol was observed only in the emissions in the winter phase. As expected, about half the gaseous organic emissions was alkanes with aromatic hydrocarbons making up another fourth. The average 47 mg/mile benzene emission for the summer phase was twice that of the winter phase. From the X-ray analyses, only zinc and sulfur were found in the emissions of most vehicles. A few vehicles emitted iron and phosphorus. The zinc, phosphorous, and some of the sulfur are due to additives in the motor oils.

The analyses for the elemental and organic carbon, PAHs, nitro-PAHs, oxy-PAHs, and the hopanes and steranes are being performed by the Desert Research Institute and the results will be given in their report.

Tables and Figures

List of Abbreviations and Acronyms Used in this Report

amps	Electrical amperes
CO	Carbon monoxide
CO_2	Carbon dioxide
CRC	Coordinating Research Council
CVS	Constant volume sampling system
DOE	U.S. Department of Energy
DRI	Desert Research Institute, Las Vegas, Nevada
dyno	Dynamometer
EC	"Elemental" carbon as measured by thermal/optical reflectance method
EPA	U.S. Environmental Protection Agency
ERC	U.S. EPA Environmental Research Center, RTP, NC
FTP	Federal Test Procedure
gm/mile	Grams per mile
GC	Gas chromatography
GM	General Motors
HC	Hydrocarbons
ID	Identification
IM240	Emission test for motor vehicles lasting 240 seconds
Hp	Horse power
KVA	Kilovolt-amps
LD	Light-duty
LDD	Light-duty diesel vehicle
LDG	Light-duty gasoline vehicles
lpm	Liter per minute
mg/mile	Milligrams per mile
mph	Miles per hour
ND	Not detected
NFRAQS	Northern Front Range Air Quality Study
NOx	Oxides of nitrogen
NREL	National Renewable Energy Laboratory
OC	"Organic" carbon as measured by thermal/optical reflectance method
PAH	Polynuclear aromatic hydrocarbon compounds
PM	Particulate matter
PM10	Particulate matter having an aerodynamic diameter less than 10 microns
PM2.5	Particulate matter having an aerodynamic diameter less than 2.5 microns
Ppm	Parts per million
PUF	Polyurethane foam used for collecting semi-volatile organic compounds
QA/QC	Quality assurance/quality control
RTP	Research Triangle Park, North Carolina
SACB	U.S. EPA Source Apportionment and Characterization Branch
TC	Total carbon

THC	Total hydrocarbons
UDDS	Urban dynamometer driving schedule
vac	Volts AC
VIN	Vehicle identification number
XAD	A polymer resin used to collect semi-volatile organic compounds
XRF	X-ray fluorescence

Acknowledgments

Many people assisted in this program and the authors are greatly indebted to them. Mark Smith of the North Carolina Environmental Management Division for providing the vehicle distribution of the Research Triangle area of North Carolina. DOE through NREL and CRC for providing funding and planning assistance. Jerroll Faircloth and Versal Mason for operating the dynamometers and driving the test vehicles. We also thank the CAVTC crew of William Crews, Colleen Loomis, Jason Mills, and Ned Perry for their assistance in vehicle recruitment and vehicle data collection. Michael Kirby is also recognized for filter changing and general maintenance of the dynamometers. Desert Research Institute for providing the PUF samples and performing the various analyses. And finally we thank Home Depot of Cary, NC for the use of their parking lot and all the vehicle owners who participated in the study.

Chapter 1
Introduction

The recent concern about the health effects of atmospheric particulate matter has led to several studies of exhaust particles emitted from in-use motor vehicles. One of the first was the vehicle emission study in Nevada where PM-10 samples were collected.[1] The original intent of this study was to measure the particulate emissions from smoking vehicles. As a reference, the particulate emissions from the same number of non-smoking vehicles were collected. Unexpectedly, most of the non-smoking vehicles had measurable particulate emissions and a few non-smoking vehicles had as high or higher particulate emissions than the smoking vehicles. These results led to several additional studies and the suggestion that vehicle emissions are significant contributors to atmospheric particulate matter.[2,3] A cold temperature study was conducted in Alaska to determine the effect of temperature on particulate emissions,[4] and it demonstrated that the particulate emissions increase with decreasing temperature.

While these studies provide some indication of the contribution of motor vehicles to the particulate pollution problem, more data were needed to provide the emission factors to be used in the large Colorado Northern Front Range Air Quality Study (NFRAQS, http://nfraqs.cira.colostate.edu) designed to determine the cause of the winter "Brown Cloud" pollution problem which occurs in Denver and other areas. As part of this study, a program for measuring particulate emissions from in-use vehicles of the Denver fleet was planned and carried out. The plan and results of this study are presented in a report and journal articles by Cadle et al.[5,6] Particulate emission rates for various vehicle classes and model years are presented. However, these are for vehicles tuned for operation at high altitude, so the question was asked are they representative of other areas? A comparison of these data and data from California and Texas was made and published.[7] This comparison did not include data from the southeastern area of the U.S.; therefore, a study to determine the emission rates from an in-use fleet of central North Carolina area was planned. The study was also planned to include measurements that can be used to create source profiles of the exhaust particulate emissions of this fleet, which is to be used as input to source apportionment modeling.

The study objective was to measure the tailpipe emissions from a vehicle fleet representative of the central North Carolina area. North Carolina vehicle registration for the four counties in the Research Triangle Park (RTP) area was used to determine the in-use fleet distribution. The vehicle registration information was provided by the State of North Carolina Environmental Management Division. The fleet categories were divided into model year classes, which were subdivided into cars and pickup trucks. In addition, eight diesel-fueled vehicles were also to be tested.

Chapter 2
Conclusions

The study was designed to measure the particulate emissions from vehicles representative of the central North Carolina area. Vehicle registration data were provide by the State of North Carolina Environmental Management Division and used to establish the model year and vehicle distribution to be tested. The test fleet was divided into model year and cars, pickup trucks, and diesel fueled vehicles. Vehicles were tested on the IM 240 driving cycle.

The major conclusions from this study are similar to those found in the NFRAQS of Colorado and are given below:

- The late model 1993-1997 gasoline vehicles generally had low particulate emissions. However, in the summer 1999 phase, two vehicles, a 1993 and a 1996, had PM10 emission rates of 15.5 and 16.6 mg/mile. Other 1993 vehicles also had moderately high emissions. Excluding these two moderately high emitters and the 1993 vehicles, the average summer emission rate for the1994-1997 vehicle was 3.79 mg/mile; more in line with the other studies. The winter average for the 1993-1997 vehicles was 7.79 mg/mile and the summer was 4.60 mg/mile.
- The PM10 summer average at 10.6 mg/mile was about one third that of the winter average (27.6 mg/mile). However, if the high emitters (>100 mg/mile) are excluded, the summer average drops to 7.88 mg/mile and the winter average drops to 13.3 mg/mile, a factor of 1.68 difference. The winter value is lower than that found in the Denver study which had an overall emission rate of 33.7 mg/mile. The overall (summer and winter) PM10 average for all gasoline fueled vehicles for this study is 19.34 mg/mile.
- The summer and winter average emission rates for gasoline vehicles suggest that the ambient temperature has a significant effect on the tailpipe emitted particles, although fuel changes and fleet composition may also be affecting the results.
- The average emission rates for the gasoline-fueled vehicles in the winter phase for the PM10 and the PM2.5 are 27.62 mg/mile (117 vehicles) and 32.24 mg/mile (45 vehicles) respectively.
- No correlation was found between the PM10 emission rates and the regulated gaseous emission rates and fuel economy for the gasoline fueled vehicles.
- A slight correlation was seen between the PM10 emission rates and model year for the gasoline fueled vehicles.
- The PM10 emission rates from the diesel fueled vehicles was about 20% lower than that from the diesels in the Denver study. The average PM10 emission rate from this study is 445.33 mg/mile versus an emission rate of about 550 mg/mile from the Denver study.
- The average formaldehyde emission rate for the winter phase, 18.4 mg/mile, was about twice that of the summer phase.
- In both study phases the alkanes were the major class of organics hydrocarbons with aromatics second at about half the average emission rate of the alkanes.

- Ethanol emissions were only observed in the winter phase.
- The average emissions of benzene for the summer phase, 47 mg/mile was twice that of the winter phase.
- Only zinc and sulfur were found in the emissions from almost every vehicle. These elements are expected since they are elements in the additives in motor oil and sulfur is also in gasoline.
- A few vehicles had calcium, iron and phosphorus in their emissions. No other trace elements were detected.
- MTBE was much higher from the vehicles tested in the winter phase.
- The summer emissions of acetylene were about 3.5 time higher than in the winter.

The analyses for the elemental and organic carbon, PAHs, nitro-PAHs, oxy-PAHs, and the hopanes and steranes are being performed by the Desert Research Institute and the results will be given in their report.

Chapter 3
Experimental

The study was conducted in the parking lot of the Home Depot in Cary, North Carolina and at EPA's Environmental Research Center (ERC) Annex located in Research Triangle Park (RTP), NC. In the 1999 winter phase of the study, 106 gasoline-fueled vehicles were tested for particulate emissions on the EPA transportable dynamometer in the Home Depot parking. An additional14 gasoline-fueled and three diesel-fueled vehicles were tested at the EPA ERC Annex on the cold cell research chassis dynamometer. Another 15 vehicles were run on the transportable dynamometer, which then had a malfunction in its particle collection system. The particulate emissions for these 15 vehicles are not measured but their regulated emissions and aldehydes are and these pollutants are included in the study. The vehicles tested on the transportable dynamometer were run at ambient temperatures. It should be noted that the temperature difference between the *summer* tests and the *winter* tests was only about 15 °F. Summer test temperatures averaged 78 °F, while winter temperatures averaged 63 °F, due to unseasonal warming. The 14 vehicles tested at EPA ERC annex chassis dynamometer were all run at 35°F. In the summer phase of the study, all the vehicles tested were run on the transportable dynamometer in the Home Depot parking lot at ambient temperatures. A total of 120 gasoline fueled vehicles and 5 diesel fueled vehicles were tested. All vehicles were run on the I/M 240 driving cycle which is a test cycle for warmed-up vehicles.

Vehicle Recruitment

After considering the time and funding available for this study, the number of vehicles to be tested was set at 120 gasoline-fueled and 4 diesel-fueled vehicles in each of the winter and summer phases of the study. The distribution of the gasoline fueled vehicles was divided into four categories; pre-1982, 1982-86, 1987-91, and 1992-97. Each category was to have at least 10 vehicles and was to be based on the vehicle registrations in the Research Triangle Park area of North Carolina. Table 3-1 gives the projected distribution. One change over the registration distribution was to move vehicles into the pre-1982 category, so the minimum number of 10 could be reached. The distribution was further divided into cars and pickup trucks. This distribution was generally followed in the winter phase since enough time was available for recruiting this distribution. However, due to the limited selection time in the summer phase, vehicles were taken as available. The categories used in the data analyses differ from the recruiting categories to get a more even distribution.

The approach for recruiting vehicles in the winter phase was to use several media to notify prospective participants. These approaches included handbills, articles in the local newspapers, and advertisements on local television news programs. With all media, a contact phone number was provided for setting-up appointments. The requests asked for participation in an environmental study for testing the exhaust emissions from light-duty vehicles, cars and pickup trucks. We asked that the prospective participant's vehicle have an intact exhaust system, good tires, and no fluid leaks. The accepted participants would be given a $25 gift check for the 20 minute test. All vehicles were tested with the fuel on-board and no fuel was added to any vehicle.

The recruiting went well and all appointments were filled. When a few people did not show for their appointment, their place was filled by onlookers inquiring as to what we were doing. Some of the diesel-fueled vehicles were obtained by contacting the owners.

Table 3-1. Triangle Area Vehicle Distribution

	Number of Vehicles per Study Phase		
Vehicle Class	Cars	Pickup	Total Vehicles
1992-1997	52	10	62
1987-91	24	6	30
1982-86	12	4	16
Pre-82	8	4	12
Total	96	24	120

In the summer phase, because of the time and funding constraints, no handbills were prepared but we did have newspaper and television advertising. The response was very good to these two forms of advertising. In the summer phase, 120 gasoline-fueled vehicles and five diesel-fueled vehicles were tested. The total number of diesel-fueled vehicles was three from the winter and five from the summer for the planned eight vehicles.

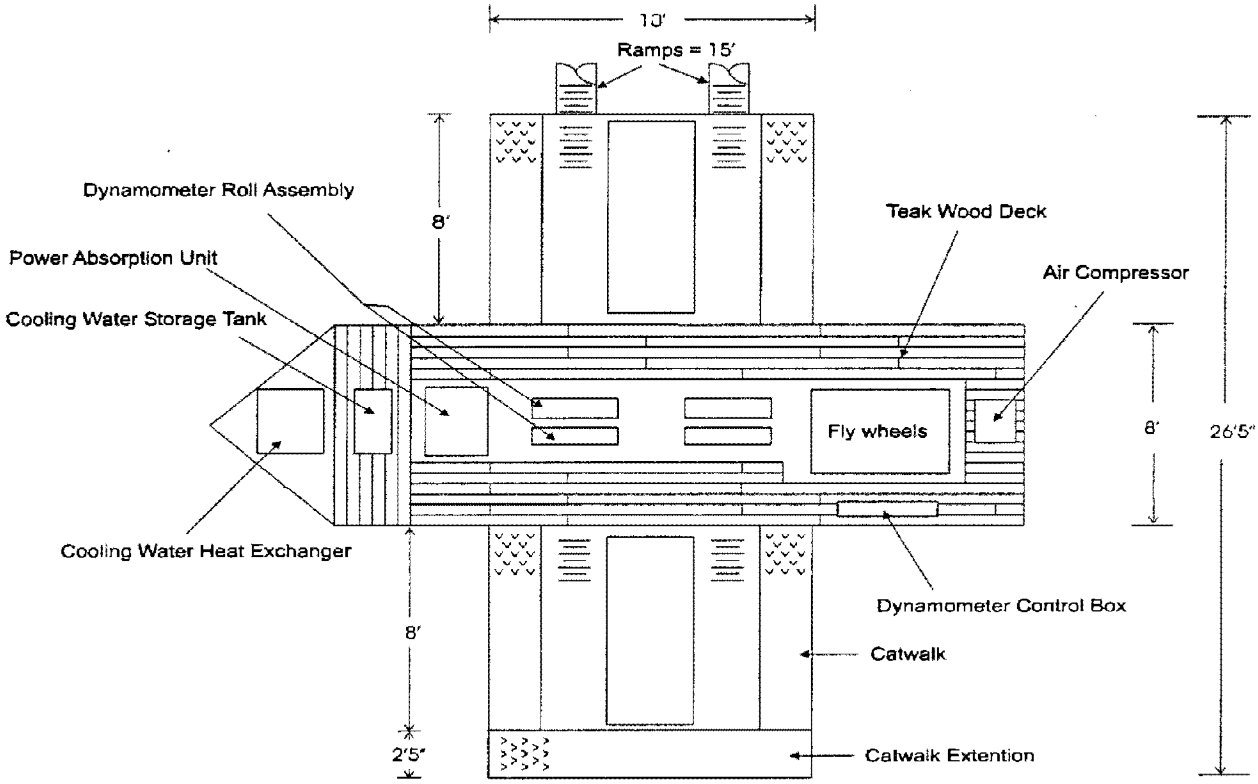
Dynamometers

In the winter phase of the study, two different dynamometers were used, the EPA transportable dynamometer (which was set up outside in the Cary parking lot) and the EPA/ERC Annex cold cell research chassis dynamometer (inside).

Transportable Dynamometer

The transportable dynamometer is a unique dynamometer set-up that can be transported to sites where in-use vehicles can be tested for their tailpipe exhaust emissions. The system is designed so that it can be used to measure the regulated emissions (CO, THC, and NOx) and CO2 for fuel economy on the driving cycles that do not exceed 60 mph and an acceleration of more than 6 miles/hr/sec. The system can also collect samples for particulate emissions, gaseous speciation, and aldehydes and ketones. It is a self-contained system that operates with portable generators. The set-up requires a space of about 30 by 26 feet and a drive up area.

If the owner of the vehicle consents to testing, a vehicle ID sheet is filled out which records the make, model, model year, vehicle identification number (VIN), and other pertinent information



VEHICLE TEST CELL LAYOUT

Figure 3-1. Transportable Dynamometer

concerning the vehicle. Dynamometer inertial weight and road load horsepower (Hp) at 50 mph are determined from test tables provided by EPA. The vehicle is then driven onto the dynamometer, secured, and driven at 50 mph steady state to set the proper road load Hp at 50 mph. Depending on the driving cycle to be used, a warm-up run will be made, followed immediately by the testing driving cycle. Regulated emissions and unregulated emissions are sampled. The test data are stored on the dedicated computer with a hard copy of the regulated emissions and fuel economy prepared in less than five minutes. For the IM 240, the total test time per vehicle is in the order of 20 minutes. Other test times will depend on the length of the driving cycle employed, with three minutes required to drive the vehicle on and off the dynamometer, and about five minutes for the data processing. Regulated emissions are determined with a constant volume sampling system (CVS) dilution technique and continuous monitors for CO, CO2, THC, and NOx. The diluted exhaust is sampled "real-time" (the data is transferred to the computer once per second) during the driving cycle with the results logged onto a computer. Once the driving cycle is completed, the acquired data is calculated to yield emission rates in terms of grams/mile. However, other types of emission rates can be determined. The CVS is equipped to collect bag samples for gaseous emissions, cartridge samples for aldehydes and ketones, and three cyclone systems with filters for emitted particle collection. In the winter phase, all sample transfer lines were heated. In the summer phase only the aldehyde cartridge line was heated.

The layout of the transportable dynamometer is shown in Figure 3-1. The drive-on ramps are 15 feet and requires about a 25 foot approach. The overall width needed is about 30 feet and the length including the drive-up ramps and approach is about 70 feet. The power requirement for operating the dynamometer is 15 KVA or about 70 amps at 230 volts. The overall system (dynamometer and analysis bench) requires about 50 KVA. When the system was operated in the winter phase, a dilution air heater was used that required about 25 KVA and was powered by a separate generator because of the off-and-on operation of the heaters which could have interfered with the dynamometer and computer operations. A weather-proof mobile home was used as the operational center and contained the regulated emissions monitors and the bag and aldehyde/ketone sampling systems.

The vehicle test cell consists of a Clayton model CTE 50-0 water brake chassis dynamometer mounted on a Freuhauf trailer. The dynamometer is coupled to a Clayton direct drive variable inertia flywheel system allowing vehicle testing at inertia weights of 1750 to 5500 pounds. Vehicle road load (Hp at 50 mph) may be set either in an automatic or a manual mode. In the automatic mode, road load is selected automatically by the dynamometer controller as a function of the inertia class used. In the manual mode, road load is selected by the operator via driver's pendant switch.

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

ERC Annex Cold Cell Research Dynamometer

This dynamometer system can be used to test vehicles at temperatures between 110 and -20°F. The system is a Horiba Model CDC800/DMA915 computerized DC electric chassis dynamometer housed in a temperature controlled chamber. All current driving cycles now in use can be run with this system. The test procedures used in this part of the winter phase were the US EPA Federal Test Procedure (FTP) and the I/M 240.[8] Only the Urban Dynamometer Driving Schedule (UDDS) part of the FTP was used since no evaporative emissions measurements were to be included. Only the IM240 data are given in this report. This system is equipped with monitors for the regulated gaseous emissions, CO_2, aldehyde/ketone cartridges, bag samples for speciation, and cyclone systems for exhaust particle collection. All sampling lines and make-up air in the ERC cold cell research dynamometer are heated.

Emission Sampling

The regulated gaseous emissions, aldehyde and ketone samples, and the organic speciated bag samples were collected through a Teflon transfer line from the CVS to the monitors and sample collection systems. A separate line was used for each sampling system. On the portable dynamometer, all lines were heated in the winter phase but only the aldehyde and ketone sampling system were heated in the summer phase. All sampling lines and make-up air in the ERC cold cell research dynamometer were heated. The particulate emission samples were collected through a cyclone system that had probes directly inserted into the CVS duct. Two 10 micron and one 2.5 micron cyclones were used. The probes for each cyclone were designed so that the particle sampling was isokinetic with the 10 micron system operating at a flow of 28.3 lpm and the 2.5 micron system operating at a flow of 16.7 lpm. The flows were controlled by mass flow controllers and were checked periodically for proper flow. For all runs, samples were taken with the two 10 micron systems. One of the 10 micron used quartz filters used carbon analyses, "elemental" and "organic" carbon (EC and OC). The other system used Teflon filters for mass measurements and X-ray fluorescence analyses for elemental composition. In the winter phase, at about every fifth test, a 2.5 micron cyclone Teflon filter sample was collected to compare to the 10 micron particle collection. Even fewer 2.5 micron samples were taken in the summer phase because of time constraints. The 10 micron system was used as the main sampling system because of its higher volume through-put and its availability.

The speciated organic samples were collected from the first four vehicles each day in Tedlar bags and sent immediately to the ERC annex laboratory for analyses. The aldehyde and ketone samples were collected from every test run on Waters Sep-Pak DNPH-Silica Cartridges and returned to the ERC Annex laboratory each day. These samples were stored in a freezer until analyzed.

Twenty-five samples were taken in each phase on vapor phase traps consisting of five grams of XAD-4 resin (polystrene/divinylbenzene polymer) sandwiched between two polyurethane foam

(PUF) plugs. The PUF sampling system was located down stream of the quartz filter on the 10 micron cyclone system.

Sample Analyses

As stated above, the regulated gaseous emissions were measured real-time with continuous monitors with the data collected once per second and logged onto a computer. The regulated emission rates were determined at the test site from these data within a few minutes after each test run.

The Teflon filters were pre-weighed and stored in numbered plastic Petri dishes. The quartz filters were also pre-weighed and stored in numbered plastic Petri dishes. The Teflon and quartz filters were carefully loaded into the labeled filter holders of the cyclone sampling systems. After the test run, the filters were removed from the filter holders and returned to the numbered plastic Petri dishes, sent to the laboratory, and stored in a freezer until analyzed. The Teflon filters were re-weighed on the same microbalance as used in the pre-weighing and sent off for XRF elemental analyses. The quartz filter and the PUF samples were shipped to Desert Research Institute (DRI) in coolers under "blue ice".

DRI will analyze the quartz filters for "elemental" carbon (EC) and "organic" carbon (OC) and the PUF samples for polynuclear aromatic hydrocarbons (PAH), nitro-PAHs, oxy-PAHs, and hopanes and steranes. DRI will also analyze about a dozen Teflon filters by XRF for QA comparison. These results are not yet available.

On each test day, gaseous samples were collected in Tedlar bags from the first four vehicle tests. These samples were then taken to the EPA ERC Annex mobile source laboratory and analyzed by their standard speciated organic gas chromatography (GC) method. This method uses a temperature program procedure that begins at -80° C, where about 70 cc of sample are cryogenically trapped on the end of the 105 meter methyl silicone coated capillary column. The temperature is then programmed to a final temperature of 270° C. More than 300 compounds are speciated by this GC procedure.

The collected aldehyde and ketone samples were analyzed by the standard mobile source aldehyde method developed by Tejada.[9] In this method, the collected samples are extracted with acetonitrile. Aliquots of the extracts are then analyzed by high performance liquid chromatography (HPLC). About 24 components are measured, but only 9 are reported in this report.

Chapter 4.
Emission Rates of Regulated Gaseous Pollutants and PM

Regulated Gaseous Emission Rates

Gasoline Fueled Vehicles

Both the transportable dynamometer and the in-house cold cell dynamometer have the capabilities to monitor continuously the regulated gaseous emissions, carbon monoxide (CO), total hydrocarbons (detection from a flame ionization detector, HC), and oxides of nitrogen (NOx). The system also continuously measures carbon dioxide (CO_2) from which fuel economy (FE) is calculated. The CO_2 measurements is also used to determine if there are any major exhaust leaks. The results from all of these measurements, for both the winter and summer phases, are given in Appendix A, Table A-1. The mean, minimum, maximum, and median results for the regulated emissions, PM, and FE for both phases for the gasoline vehicles are given in Table 4-1. As shown in this table, the average CO emissions are similar for the winter and summer testing with values of 14.53 and 15.32 gm/mile. The maximum CO for the summer is about twice that for the winter and came from a high emitter, a 1988 Plymouth Voyager . The highest winter emission rate came from a 1975 Ford Bronco. The median values for both phases were also similar.

Table 4-1. Regulated and PM Emission Rates and Fuel Economy, Gasoline Vehicles

Summer							
	HC	CO	NOx	CO2	FE-fuel economy	PM10	PM2.5
	gm/miles	gm/miles	gm/miles	gm/miles	miles/gal	mg/miles	mg/miles
Mean	0.63	15.32	1.82	375.35	21.61	10.56	7.72
Minimum	0.02	0.18	0.03	194.38	7.45	0.42	0.70
Maximum	7.11	320.18	8.23	584.55	35.20	300.07	33.56
Median	0.30	4.83	1.40	365.60	21.34	3.70	3.47
Count	120	120	120	120	120	120	16
Winter							
	HC	CO	NOx	CO2	fuel economy	PM10	PM2.5
	gm/mile	gm/mile	gm/mile	gm/mile	mile/gal	mg/mile	mg/mile
Mean	1.08	14.53	2.06	397.80	19.82	27.62	32.24
Minimum	0.03	0.46	0.09	141.58	6.13	0.98	0.34
Maximum	9.84	173.07	8.39	663.48	31.64	451.87	289.45
Median	0.55	6.15	1.52	403.25	19.76	6.37	8.84
Count	119	119	119	119	119	117	45

The mean, maximum and median of the HC emission rates were higher for the winter than for the summer testing. The average values were 1.08 mg/mile for the winter testing and 0.63 mg/mile for the summer. The maximum values were 9.84 mg/mile for the winter and 7.11 mg/mile for the summer. These emission rates came from the same Ford Bronco in the winter phase and from a 1985 Ford F150 pickup in the summer. The mean, maximum, and median emission rates for NOx were about the same for both winter and summer. Similarly, the CO_2 emission rates and the fuel economy are about the same.

The average PM10 emission rate is 27.62 mg/mile for the winter and 10.56 mg/mile for the summer. This is almost a threefold increase in emission rate from summer to winter. The observed seasonal difference may be impacted by fuel changes and fleet composition. However, if the high emitters (>100 mg/mile) are excluded, the winter average drops to 13.3 mg/mile and the summer average to 7.88 mg/mile, a factor of 1.69 difference. This observation suggests that the temperature plays a significant role in the formation of primary particles.

Figure 4-1 shows the PM10 emission rates of the gasoline vehicles categorized by model year and vehicle styles. Two high emitters (> 100 mg/mile) are identified in the summer data set and eight in the winter set.

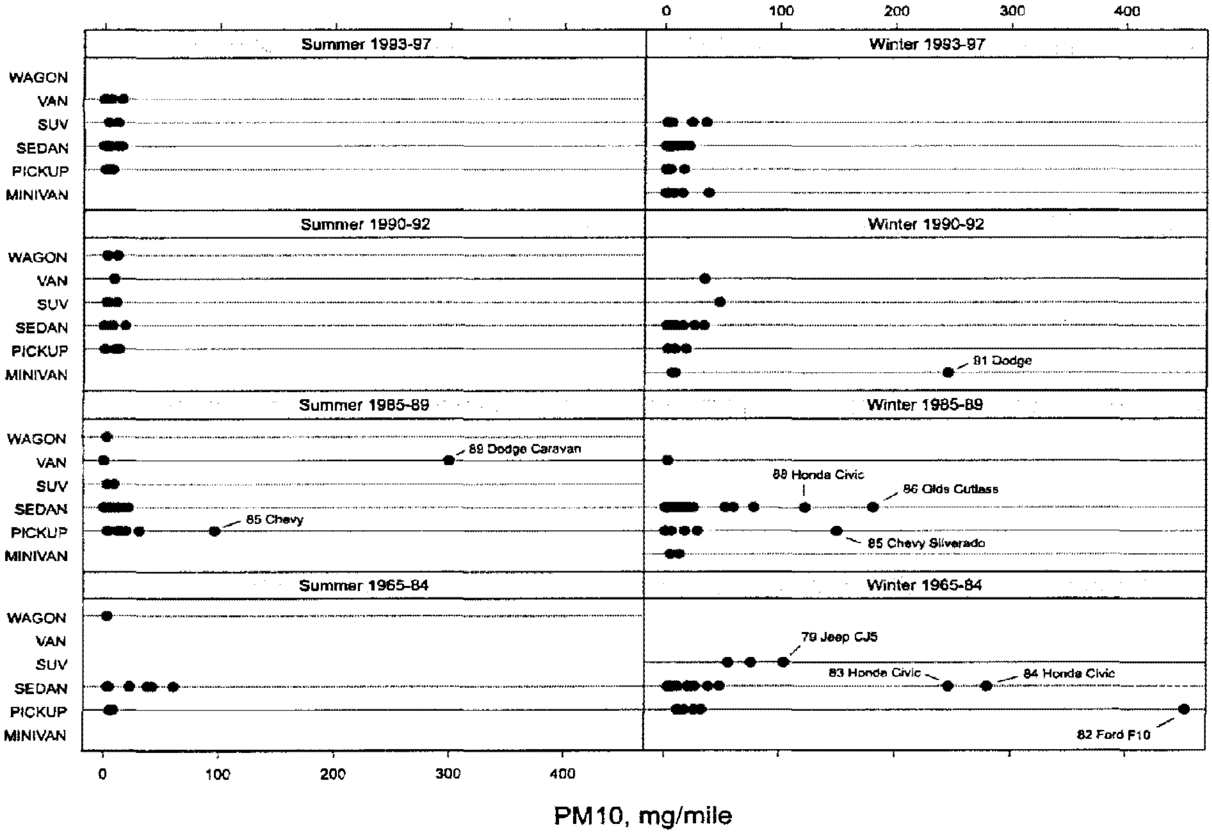


Figure 4-1. PM10 Emissions by Model Year and Vehicle Style

The PM10 and PM2.5 average emission rates from the gasoline fueled vehicles from the winter testing are 27.62 and 32.24 mg/miles respectively, a difference of about 15%. The average for the PM10 is from 117 vehicles and that for the PM2.5, from 45 vehicles. However, when the emission rate averages were calculated from the subset of forty four winter vehicles that have complete PM10 and P2.5 data, the average emission rates dropped to 23.76 and 26.02 mg/mile respectively. The difference here is less than 10% and may be due the difference in face velocity and/or absorption of organics on the filters. If the eight high emitters (>100 mg/mile) are excluded in the statistics, the hundred and nine (109) PM10 data average is 13.30 and the forty one (41) PM2.5 data average is 13.23 mg/mile indicating excellent agreement between PM10 and PM2.5 values.

The results from the summer testing of gasoline vehicles gave average emission rates of 10.56 mg/mile for the PM10 and 7.72 mg/mile for the PM2.5, a difference of about 27%. However, as seen in Figure 4-1 and Table 4-1, the PM10 average is heavily influenced by a few high emitters. When the high emitter data was excluded, the PM10 average was reduced to 7.88 mg/mile, in very good agreement with the PM2.5 average of 7.72 mg/mile. Fewer PM2.5 samples were taken in the summer due to time constraints. The main difference in the two rates is that only 16 usable PM2.5 samples were collected versus 120 for PM10 and no PM2.5 samples were taken on several high emitters. When the 17 vehicles with PM2.5 data are averaged for PM10, the PM10 average (8.11 mg/mile) is practically the same as that of the PM2.5 average (8.13 mg/mile). The excellent agreement between the PM10 and the PM2.5 average values when high emitters are excluded for both the summer and the winter phases, indicates that the primary exhaust particles are mostly fine particles. This agrees with data generated in previous particulate studies.[6]

The PM10 average for all runs in the summer phase is 10.56 mg/mile. This average is about a third of the average found in the summer study of the IM240 vehicle testing phase of the Northern Front Range Air Quality Study (NFRAQS) of the Denver, Colorado area. The value from Denver is 33.7 mg/mile.[5] The mean, minimum, maximum, and median emission rates for both the winter and summer testing are also given in Table 4-1. The overall PM10 emission rate average, for both summer and winter, found in this study is 19.40 mg/mile. This number compares surprisingly well with the overall 20.85 mg/mile value observed in the IM240 phase of the Denver study. Taking all runs from both summer and winter and from both the PM10 and PM2.5 the grand average is 20.7 mg/mile. All the data for PM10 and PM2.5 are given in appendix A, Table A-1 along with the regulated emission rates.

The PM10 emission rates summarized by season, model year and vehicle styles are given in Table 4-2. A comparison of the average and median values in conjunction with the PM10 distribution shown in Figure 4-1, indicates that some averages are heavily skewed by a few high emitters. A good example of this is the summer 1985-89 year statistics, which shows a PM10 average of 17.27 , a maximum of 300.07 and a median of 3.91 mg/mile. If this apparent outlier is excluded, the average PM10 emission rate for the 1985-89 model year drops to 9.63 , the maximum to 96.95, and the median to 3.75 mg/mile. In the VAN category, the average drops to 5.41, the maximum to 16.59, and the median to 3.82 mg/mile. Similarly, if the eight high emitters identified in the winter testing in Figure 4-1 are excluded, the average PM emission rate drops from about 24 to 8 mg/mile. Late model vehicles emit less PM10 particles than older models. For the same model year category, the summer average is generally lower than the winter average. The same trend is similarly observed in the vehicle style or type category.

Table 4-2. IM 240 PM10 Emission Rates

Period	Category	Average Temp., °F	Number	Average mg/mile	Minimum mg/mile	Maximum mg/mile	Median mg/mile
Summer	Pre85	77.6	10	19.59	3.18	60.91	7.41
Summer	1985-89	78.6	38	17.27	0.42	300.07	3.91
Summer	1990-92	79.3	25	5.34	0.43	18.68	3.46
Summer	1993-97	78.7	36	4.60	0.43	16.59	3.49
Summer	Diesels	82.4	5	487.09	135.13	895.6	429.86
Total			114				
Winter	Pre85	62.8	22	69.39	3.24	451.87	26.31
Winter	1985-89	62.2	35	25.96	0.98	181.91	6.37
Winter	1990-92	63.4	20	24.27	1.9	245.68	7.63
Winter	1993-97	63.3	40	7.79	1.13	38.44	4.31
Winter	Diesels	35	3	375.72	228.48	450.2	448.47
Total			120				
Summer	PICKUP	78.3	20	12.81	1.09	96.95	5.93
Summer	SEDAN	79.1	68	7.04	0.42	60.91	3.48
Summer	SUV	78.2	8	6.33	2.60	12.55	6.33
Summer	VAN	78.2	9	38.15	0.64	300.07	6.35
Summer	WAGON	75.5	4	5.60	3.18	12.15	3.53
Total			109				
Winter	MINIVAN	65.1	11	31.69	1.18	245.68	31.69
Winter	PICKUP	61.1	23	36.95	0.98	451.87	36.94
Winter	SEDAN	63.2	72	22.75	1.13	279.70	5.84
Winter	SUV	62.6	9	39.75	2.18	104.09	39.75
Winter	VAN	64.1	2	19.09	3.25	34.93	19.09
Total			117				

While the categories listed in Table 4-2 differ slightly from those used in the NFRAQS, a comparison can be made with Table 4.8 in the final report of the vehicle testing phase of NFRAQS.[5] The CCVPES diesel emission rates averaged 375.72 mg/mile for three vehicles in the winter and 487.09 mg/mile for five vehicles in the summer. The winter average compares favorably with the 350-403 mg/mile average for twelve vehicles in the NFRAQS study while the summer average is 40% lower than the 762 mg/mile NFRAQS average for eight vehicles. The overall (winter and summer) diesel PM10 average is about 20% lower than the corresponding NFRAQS average.The gasoline summer emission rates for the two studies are similar for the 1985-97 model year.

A matrix scatter plot of the regulated emissions (HC, CO, NO), fuel economy and PM10 emissions did not show PM10 correlation with any of the other variables. The matrix plot is shown in Appendix A as Figure A-1. A similar matrix plot of the data subset of the 20 highest PM10-emitting vehicles did not show PM10 correlation with any of the emission variables. Figure 4-2 shows a regression plot of model year versus PM10 for the summer, the winter and the combined winter and summer gasoline vehicle data sets. The high emitters were included in the regression but not shown in the plot to graphically magnify the difference between the winter and summer data sets. The summer data set has a slope of -0.0230 and an R-square value of 0.0235. The winter data set has slope of -0.0277 and an R-square of 0.08975. The combined winter and summer data has a slope of -0.0274 and an R-square of 0.06895. When the high emitters identified in Figure 4-1are excluded, the overall slope is -0.1502 and the R-square is 0.1763.

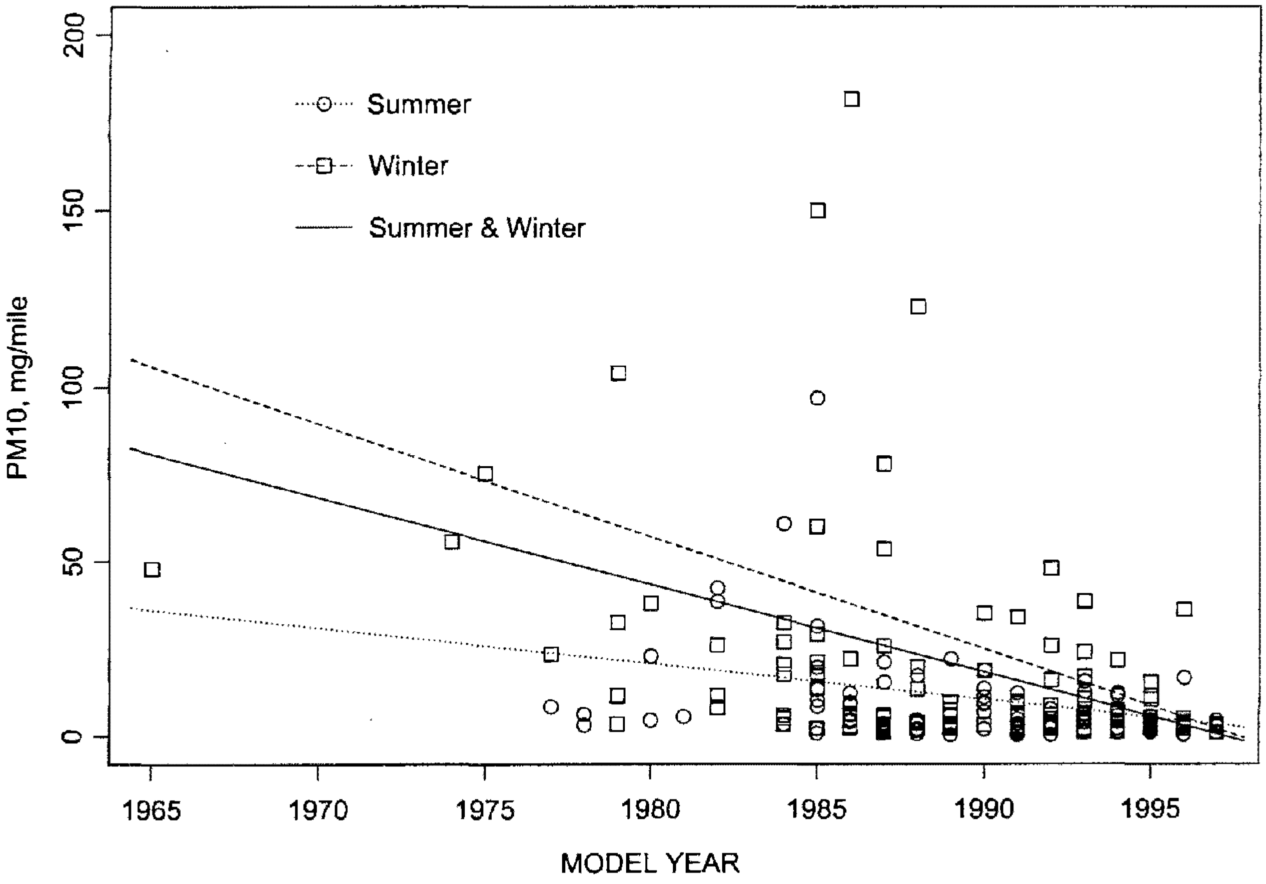


Figure 4-2. PM10 vs Vehicle Model Year

Diesel Fueled Vehicles

A total of eight diesel-fueled vehicles were tested in this program. Three were tested in the winter phase and five in the summer phase. Emission rates are given in Table 4-3 for these vehicles.

Table 4-3. Diesel Fueled Vehicle Emission Rates

YEAR	STYLE	MAKE	HC gm/mi	CO gm/mi	NOx gm/mi	CO2 gm/mi	FE mpg	PM10 mg/mile
Winter								
1983	Pickup	Chevy	0.16	1.27	1.77	501.79	19.80	228.48
1977	Sedan	Mercedes	0.17	1.32	1.67	422.41	23.49	450.20
1980	Wagon	VW	0.45	2.06	0.98	275.63	35.62	448.47
Average			0.26	1.55	1.47	399.94	26.30	375.72
Summer								
1983	Sedan	Mercedes	0.18	1.44	1.72	400.69	24.00	895.60
1985	Wagon	Mercedes	0.23	1.11	1.92	414.41	23.29	253.92
1981	Pickup	VW	0.48	2.39	1.00	318.38	30.44	429.86
1989	Sedan	VW	0.06	1.00	0.98	266.49	36.40	135.13
1982	Sedan	AUDI	0.26	5.18	2.04	286.34	33.51	720.96
Average			0.24	2.22	1.53	337.26	29.53	487.09
All Diesels								
Mean			0.25	1.97	1.51	360.77	28.32	445.33
Minimum			0.06	1.00	0.98	266.49	19.80	135.13
Maximum			0.48	5.18	2.04	501.79	36.40	895.60
Median			0.20	1.38	1.69	359.54	27.22	439.17

The overall PM10 average for all the diesels is 445 mg/mile which is comparable to that obtained in NFRAQS which had average values of 394 mg/mile from the winter study and 762 mg/mile for the summer study for an overall average of 543 mg/mile. The regulated gaseous emissions were about the same between winter and summer for all vehicles.

Chapter 5.
Chemical Composition of Emissions

Aldehydes and Ketones

Aldehyde and ketone samples were collected for all runs. In the winter study, on the second study day, a malfunction in the particle collection system was detected and those particulate samples were discarded. However, the aldehyde and ketone sample results from these runs were not affected and are included in the data analyses. A total of 135 gasoline and 3 diesel vehicles were tested in the winter phase of the study for aldehydes and ketones. One hundred and twenty one of the vehicles were tested in the field at the Cary, NC test site on the EPA transportable dynamometer. The remaining 14 gasoline fueled and the three diesel fueled vehicles were tested on the EPA in-house cold cell research dynamometer located in the EPA ERC annex in Research Triangle Park, NC. For quality assurance, 27 repeat runs were made in this phase. These results are given in Appendix A, Tables A-5 and A-6. The two runs on the same vehicle were averaged and the average value used for the data analyses. The analytical reports included 24 compounds for each sample analyzed. However, for several of these compounds reported, only a few samples had values. To reduce the number of reported compounds, these compounds were eliminated and the three isomers of tolualdehyde were combined. Nine compounds are included in the data analyses for both the winter and summer phases. Table 5-1 gives the mean, minimum values that are 0.01 mg/mile or greater, the maximum, and the median values for the 135 gasoline vehicles tested in the winter and 120 vehicles tested in the summer phases. The minimum values for all nine compounds reported are 0.01 mg/mile. The maximum value found in the winter phase for formaldehyde is 210 mg/mile from a 1985 Ford F150 pickup. This vehicle was tested twice and the two values are 205.61 and 216.23 for the average of 210.92 which is only about a 2.5 % difference in the two runs. The overall average from the winter phase for formaldehyde from the gasoline vehicles is 18.39 mg/mile. Table 5-2 gives the results of the three diesels. As is seen in this table, the three diesels gave about the same results for the nine reported compounds. Formaldehyde values were 39, 52, and 34 mg/mile. The values for the nine compounds for all vehicles tested are given in Appendix A, Tables A-3 and A-4.

In the summer phase of the study, 120 gasoline-fueled and five diesel-fueled vehicles were tested at the same Cary, NC site on the EPA transportable dynamometer. As planned for in the study, eight diesels were tested. However, because only three were tested in the winter phase, five were then tested in the summer phase to achieve the total of eight. As in the winter phase, duplicate tests were made randomly on selected vehicles. Table 5-1 gives the mean results of the 120 gasoline-fueled vehicles tested in the summer phase. As in the winter data, the results given for the vehicles tested twice are the average values from the two tests for each vehicle. The highest formaldehyde emission rate in the summer phase was 131 mg/mile from a 1985 Ford Ranger pickup. The overall average for formaldehyde from the summer phase is 9.21 mg/mile. The maximum and the average formaldehyde emissions rates from the summer phase are about half those of the corresponding values from winter phase. The results for all summer vehicle tests are given in Appendix A, Table A-4.

Table 5-2 shows the results from the three diesels tested in the winter phase. Table 5-3 gives the mean, minimum, maximum and median results of the summer diesel vehicles. These data show that the summer values of diesel fueled vehicles are also lower than those from the winter phase as was the case for the gasoline fueled vehicles.

Table 5-1. Selected Aldehyde and Ketone Emission Rates

Winter from 135 Vehicles				
	Mean	Minimum	Maximum	Median
Compound	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	18.39	0.01	210.92	6.33
Acetaldehyde	2.53	0.01	22.33	0.86
Acrolein	0.54	0.01	4.22	0.15
x-Acrolein	0.42	0.01	3.10	0.16
Benzaldehyde	0.44	0.01	4.48	0.17
Tolualdehydes	0.56	0.01	5.36	0.23
2-Butanone	0.16	0.01	1.03	0.08
Methacrolein	0.30	0.01	1.88	0.13
Acetone	0.85	0.01	6.06	0.37
Summer from 120 Vehicles				
	Mean	Minimum	Maximum	Median
Compound	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	9.21	0.01	131.63	3.22
Acetaldehyde	1.71	0.01	20.63	0.50
Acrolein	0.29	0.01	7.99	0.00
x-Acrolein	0.12	0.01	2.16	0.00
Benzaldehyde	0.29	0.01	4.49	0.08
Tolualdehydes	0.35	0.01	4.97	0.09
2-Butanone	0.08	0.01	1.08	0.02
Methacrolein	0.16	0.01	2.62	0.04
Acetone	0.62	0.01	5.86	0.25

Table 5-2 . Winter Diesel Fueled Vehicle Emissions Rates From Three Vehicles

	Vehicle run nos.					
	33060	33061	33062	Mean	Minimum	Maximum
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	39.92	52.24	34.35	42.17	34.35	52.24
Acetaldehyde	7.98	6.65	6.85	7.16	6.65	7.98
Acrolein	2.08	0.74	0.84	1.22	0.74	2.08
x-Acrolein	0.63	0.69	0.70	0.67	0.63	0.70
Benzaldehyde	0.23	0.45	0.36	0.35	0.23	0.45
Tolualdehydes	0.07	0.00	0.18	0.08	0.00	0.18
2-Butanone	0.23	0.12	0.17	0.17	0.12	0.23
Methacrolein	0.62	0.00	0.31	0.31	0.00	0.62
Acetone	1.45	1.08	1.51	1.35	1.08	1.51

Table 5-3. Summer Diesel Fueled Vehicle Emission Rates From Five Vehicles

	Vehicle run nos.								
	9077	9080	9085	9114	9125	Mean	Min	Max	Median
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	9.27	9.17	20.36	11.69	26.59	15.42	9.17	26.59	11.69
Acetaldehyde	2.63	2.76	6.85	3.15	5.73	4.22	2.63	6.85	3.15
Acrolein	0.54	0.64	1.59	0.55	1.66	0.99	0.54	1.66	0.64
x-Acrolein	0.34	0.31	1.00	0.43	0.48	0.51	0.31	1.00	0.43
Benzaldehyde	0.12	0.11	0.39	0.09	0.25	0.19	0.09	0.39	0.12
Tolualdehydes	0.12	0.07	0.33	0.04	0.25	0.16	0.04	0.33	0.12
2-Butanone	0.10	0.08	0.20	0.13	0.27	0.16	0.08	0.27	0.13
Methacrolein	0.12	0.12	0.28	0.14	0.23	0.18	0.12	0.28	0.14
Acetone	0.39	0.43	1.00	0.60	1.02	0.69	0.39	1.02	0.60

Speciated Hydrocarbons (Organics)

The standard EPA/SACB mobile source gas chromatographic (GC) method for speciating organic emissions was used. Since this method requires about two hours per run and each run analyzes two samples, the number of vehicle gaseous emission samples was limited. Considering the time needed to transport the collected samples from the test site and to run the analyses, only the gaseous emission samples from the first four tests each day were collected and analyzed. This amounted to analyzing 33 samples in the winter phase and 31 samples in the summer phase. The results of these analyses are given in Tables 5-4 and 5-5.

Table 5-4. Organic Class Distribution

	Counts	Distribution	Average	Minimum	Maximum	Median
		%	mg/mile	mg/mile	mg/mile	mg/mile
Winter						
Alkanes	33	49.59	378.55	35.81	1739.69	266.02
Alkenes	33	11.74	157.31	0.84	1137.28	59.18
Aromatics	33	21.70	249.13	3.30	1853.96	118.53
Alkynes	33	0.92	19.50	0.00	189.41	1.14
Alcohols/Ethers	33	15.68	226.13	1.47	4125.43	13.07
Unknowns	33	0.38	4.25	0.06	27.90	1.71
Total		100.00				
Summer						
Alkanes	31	41.46	514.41	51.36	3616.33	238.12
Alkenes	31	21.99	272.86	4.41	1796.05	65.90
Aromatics	31	28.71	356.25	25.77	2195.02	112.46
Alkynes	31	5.69	70.64	0.00	951.69	1.95
Alcohols/Ethers	31	1.65	20.42	1.35	159.17	4.41
Unknowns	31	0.49	6.13	0.89	33.24	2.44
Total		100.00				

Table 5-4 presents the data by organic class with alkanes making up about half the winter organic emissions and 41% of the summer organic emissions. Aromatics were the second most abundant class with 22% in the winter and 29% in the summer. The largest absolute seasonal difference in the emissions are observed with the alcohols/ethers (oxygenates) and alkenes. As seen in Table 5-5 MTBE changes from 261mg/mile in the winter emissions to only 15mg/mile in the summer emissions. In addition ethanol was only found in the winter emissions. All the alkenes emissions presented in Table 5-5 had a higher rate for the summer versus the winter. Similarly, the same distribution of the aromatics is seen. The average emission rates for benzene and toluene from the summer phase were about double that of the winter phase. Another significant increase in the summer emission rates is that for acetylene. These increases in summer versus winter can have several causes ranging from fuel types to vehicle distributions. One surprising observation is that these speciated organic emission rate differences between the summer and winter are not reflected in the regulated emission rates. The summer and winter regulated HC emission rates are about the same.

Table 5-5. Selected Organic Species Emission Rates

	Winter					**Summer**				
	Count	Ave	Min	Max	Median	Count	Ave	Min	Max	Median
		mg/mile	mg/mile	mg/mile	mg/mile		mg/mile	mg/mile	mg/mile	mg/mile
METHANE	33	109.79	33.92	427.11	91.29	31	136.56	40.83	876.37	84.88
ETHANE	27	21.37	2.16	63.77	16.43	29	20.15	4.42	63.77	16.35
ISO-BUTANE	31	7.26	0.02	42.79	4.85	31	3.01	0.01	16.16	1.40
N-BUTANE	33	36.55	0.08	221.52	22.37	30	12.83	0.14	89.48	4.26
ISO-PENTANE	33	40.12	0.07	194.15	26.74	31	64.26	1.42	540.01	22.51
N-PENTANE	33	14.88	0.07	70.43	9.99	30	25.57	0.51	204.30	9.12
ETHYLENE	28	82.52	1.40	469.18	32.46	29	117.76	1.55	676.51	40.55
PROPYLENE	27	35.86	1.00	204.67	15.04	31	46.68	0.37	271.21	11.78
PROPADIENE	27	2.30	0.00	23.94	0.31	25	2.53	0.01	15.75	0.50
1-BUTENE	27	6.77	0.02	38.03	2.19	24	11.58	0.01	58.74	2.73
ISO-BUTYLENE	30	9.62	0.00	82.45	3.11	28	16.92	0.03	158.96	4.34
1,3-BUTADIENE	25	4.62	0.14	41.22	1.42	28	7.82	0.02	58.08	1.46
BENZENE	33	24.20	0.30	133.62	16.00	31	47.97	0.85	290.94	21.72
TOLUENE	33	35.41	0.15	173.43	16.26	31	76.25	1.00	504.93	26.17
ETHYLBENZENE	33	10.06	0.06	77.17	4.13	31	16.14	0.42	95.72	4.37
M&P-XYLENE	33	32.40	0.16	223.57	13.14	31	53.53	1.44	337.97	15.14
O-XYLENE	33	13.76	0.10	108.94	5.49	31	20.90	0.59	138.65	5.77
1-METHYL-4-ETHYLBENZENE	31	7.80	0.08	52.64	5.54	31	11.66	0.33	67.84	3.91
1,2,4-TRIMETHYLBENZENE	33	20.11	0.12	171.79	6.87	31	23.45	0.82	175.14	7.50
ACETYLENE	14	39.11	0.60	174.51	18.40	15	133.56	1.07	921.63	4.13
METHYLACETYLENE	29	1.40	0.00	18.60	0.28	23	4.04	0.01	25.56	0.54
MTBE	27	261.64	0.35	4122.90	1.22	31	15.31	1.35	102.32	4.04
METHANOL	33	8.29	0.95	58.72	3.79	22	7.21	0.37	99.26	0.93
ETHANOL	31	4.01	0.91	11.80	3.40	-	ND*	ND	ND	ND

* ND None Detected

More than 300 GC peaks were measured in all 64 samples. The database for these analyses is too large to be included in this report but can be obtained from EPA/NERL/SACB laboratory in Research Triangle Park, North Carolina. One compound not given in Table 5-5 is propane. It was not detected in the winter samples and was found in only about half of the summer samples. This is probably due to the Reid vapor pressure adjustments. One other compound of note is that no ethanol was found in the summer samples.

Elemental Composition

The Teflon samples used for weighing were also submitted for X-ray fluorescence (XRF) analyses to determine the elemental composition of the collected particulate emissions. The XRF data reported in this study are from analyses done at EPA/RTP. A subset of the samples are also being analyzed by Desert Research Institute (DRI) in Reno, Nevada. These data will be provided later in the DRI report. Sulfur and zinc were found in most samples. Calcium was detected in about 60% of the samples, iron, in about one third of the samples, and phosphorus, in about one fourth of the samples. The zinc and phosphorus are oil-additive derived, while the sulfur is fuel-derived.

Other Analyses

Besides the Teflon filter collected to determine the particulate emission rate, the regulated emission measurements, the aldehyde and ketone cartridge samples, and the organic gaseous samples, additional quartz filters and PUF/XAD samples were taken. The quartz filter samples are being analyzed for "elemental" and "organic" carbon, EC and OC. The PUF/XAD samples are being analyzed for polynuclear aromatic hydrocarbons (PAH), nitro-PAHs, oxy-PAHs, and hopanes and steranes. These analyses are being performed by DRI and the results will be given later in a report from them. Some extraction analyses will also be done on the quartz filters at a later date.

Disclaimer

The information in this document has been funded wholly or in part by the United States Environmental Protection Agency through Contract 68-D5-1056 to CAVTC. It has been subjected to Agency review and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

References

1. Sagebiel, J.,et al,"PM-10 Exhaust Samples Collected during IM-240 Dynamometer tests of In-Service Vehicles in Nevada," *Environ. Sci. and Technol.*, **31**, 75 - 83, 1997.

2. Lawson, D. R., et al, "Program for the Use of Remote Sensing Devices to Detect High-Emitting Vehicles," Final Report to the South Coast Air Quality Management District, Diamond Bar, CA, 1996.

3. Cadle, S. H., et al, "Particulate Emission Rates from In-Use High-Emitting Vehicles Recruited in Orange County, California," *Environ. Sci. and Technol.*, **31**, 3405-3412, 1997.

4. Mulawa, P. A., et al, "Effect of Ambient Temperature and E-10 Fuel on Primary Exhaust Particulate Matter Emissions from Light-Duty Vehicles," *Environ. Sci. and Technol.*, **31**, 1302-1307, 1997.

5. Cadle, S. H., et al, "Measurement of Exhaust Particulate Matter Emissions from In-Use Light-Duty Motor Vehicles in the Denver Colorado Area," CRC Project E-24-1 Final Report, 1998.

6. Cadle, S. H., et al, "Composition of Light-Duty Motor Vehicle Exhaust Particulate Matter in the Denver, Colorado Area," *Environ. Sci. and Technol., 33, 2328-2339, 1999.*

7. Cadle, S. H., et al., "Exhaust Particulate Matter Emissions from In-Use Passenger Vehicles Recruited in Three Locations," SAE 99FL-215, 1999.

8. *Code of Federal Regulations,* Title 40, Part 86, U.S. Government Printing Office, Washington, DC, 1994.

9. Tejada, S., "Evaluation of Silica Gel Cartridges Coated in situ with Acidified 2,4 Dinitrophenylhydrazine for Sampling Aldehydes and Ketones in Air." *Intern. J. Environ. Anal. Chem.* **26**:167(1986).

APPENDIX A

Table A-1. Run Number, Vehicle ID and Regulated PM Data

Table A-1. Summer Phase, Gasoline Vehicles

RUN	YEAR	STYLE	MAKE	MODEL	HC	CO	NOX	CO2	FE	PM10	PM2.5	Odometer	Temp.
					g/mile	g/mile	g/mile	g/mile	mi/gal	mg/mile	mg/mile	mile	°F
9000	1992	SEDAN	FORD	TAURUS	0.13	5.70	1.03	412.36	20.61	2.20		72400	100
9001	1992	SEDAN	MAZDA	626.00	1.02	2.41	2.24	316.93	22.66	7.71		106000	78
9002	1992	SEDAN	HONDA	CIVIC	1.18	8.62	5.72	311.81	21.81	7.61		137268	73
9003	1993	VAN	MERC	VILLAGER	0.47	8.53	0.96	427.13	18.75	1.29		210000	74
9004	1992	SUV	ISUZU	RODEO	0.80	77.10	1.37	584.55	11.66	2.60		99837	74
9005	1990	SEDAN	GEO	PRIZM	0.20	2.62	1.49	296.94	28.15	6.80		92876	74
9006	1987	SEDAN	AUDI	QUATTRO	0.20	2.13	0.86	310.97	27.00	1.37		148000	73
9007	1990	PICKUP	FORD	F250	1.50	19.06	4.26	493.66	14.13	13.48	33.56	154000	70
9008	1987	VAN	CHEVY	ASTROVAN	0.80	7.74	3.90	364.17	20.54			163000	70
9009	1991	SEDAN	HONDA	CIVIC	0.46	14.63	2.04	197.16	35.20	4.74		155000	70
9010	1989	SEDAN	TOYOTA	COROLLA	0.23	7.25	1.23	298.50	27.23	21.93		151000	71
9011	1985	SEDAN	HONDA	PRELUDE	0.19	4.32	2.62	289.30	28.71	2.17		165000	70
9012	1994	SEDAN	FORD	ESCORT	0.10	2.86	0.74	290.19	29.41	12.17	19.50	96582	69
9013	1987	SEDAN	MAZDA	626.00	0.21	7.14	0.86	263.86	30.62	21.09		187000	70
9014	1980	SEDAN	DODGE	OMNI	1.66	60.21	2.22	267.86	18.59	4.59		198000	73
9015	1993	VAN	PLYMOUTH	VOYAGER	0.20	4.83	1.55	391.43	21.47	6.35		86300	73
9016	1995	PICKUP	DODGE	DAKOTA	0.28	6.23	2.18	479.46	17.43	3.45		52100	73
9017	1994	SEDAN	BUICK	CENTURY	0.02	0.34	0.93	451.04	19.57	3.93	7.41	85000	72
9018*	1988	WAGON	FORD	ESCORT	0.16	3.73	0.47	343.46	24.618	3.64		62000	72
9020	1992	WAGON	OLDS	CUT CIERRA	0.17	0.54	1.26	363.42	23.60	3.42		73004	73
9021	1989	PICKUP	CHEV	1500.00	0.57	7.99	1.02	456.77	17.44	3.56		66859	71
9022	1995	PICKUP	FORD	RANGER	0.26	5.43	1.18	347.69	23.69	3.21	4.71	86500	72
9023	1986	SUV	FORD	BRONCOII	0.50	8.09	3.66	449.68	17.85	9.05		115000	73
9024	1995	VAN	MERC	VILLAGER	0.06	1.58	0.53	415.04	21.04	1.09		68000	75
9025	1992	SEDAN	NISSAN	SENTRA	0.30	3.28	1.10	281.14	28.91	2.17	3.68	97000	76
9026	1989	VAN	DODGE	CARAVAN	1.01	8.48	2.63	374.51	19.38	300.07		117000	76
9027*	1987	SEDAN	CHEV	CELEBRITY	0.46	7.28	1.98	315.98	24.710	3.49		142000	77
9029	1993	SUV	ISUZU	RODEO	0.40	7.11	2.25	466.52	17.55	12.55		85000	78
9030	1982	SEDAN	OLDS	CUTLASS	1.81	24.95	4.03	365.72	16.72	38.45		138000	80
9031	1995	SEDAN	SATURN	SL	0.26	2.55	0.36	339.73	24.50	3.95		38000	80
9032	1996	SEDAN	HONDA	ACCORD	0.16	0.61	0.10	338.70	25.28	3.33		67720	81

APPENDIX A

Table A-1. Summer Phase, Gasoline Vehicles

RUN	YEAR	STYLE	MAKE	MODEL	HC	CO	NOX	CO2	FE	PM10	PM2.5	Odometer	Temp.
					g/mile	g/mile	g/mile	g/mile	mi/gal	mg/mile	mg/mile	mile	°F
9033	1989	SUV	FORD	BRONCOII	0.63	9.33	1.59	371.49	20.63	3.33		110000	82
9034	1996	VAN	PLYMOUTH	VOYAGER	0.05	0.58	0.44	446.05	19.69	16.59	14.59	38159	
9035	1993	PICKUP	CHEVY	S10	0.22	3.09	1.01	364.49	23.06	3.85		67000	71
9036	1986	SEDAN	TOYOTA	CAMRY	0.29	2.02	0.78	289.64	28.36			133848	75
9037	1993	SEDAN	FORD	ESCORT	0.39	2.55	1.19	290.67	27.56	0.86	2.54	66580	75
9038	1994	SEDAN	PLYMOUTH	ACCLAIM	0.20	4.09	0.92	338.36	24.72	11.38		77000	76
9039	1996	SEDAN	INFINITI	I30	0.18	0.22	0.31	305.69	27.82			29000	78
9040	1982	SEDAN	HONDA	ACCORD	0.92	22.96	0.03	271.54	23.90	42.35	30.76	221000	78
9041	1990	SEDAN	EAGLE	SUMMIT	0.97	8.05	3.27	261.50	26.00	18.68		95000	79
9042	1986	PICKUP	FORD	F150	0.71	4.02	4.38	515.39	15.54	12.26		97000	80
9043	1995	SEDAN	CHEVY	LUMINA	0.26	2.47	0.47	300.66	27.51	5.50		53000	80
9044	1993	SUV	FORD	EXPLORER	0.10	3.74	1.05	404.51	21.25	4.87		79000	80
9045	1993	SEDAN	MITS	ECLIPSE	0.40	10.28	0.66	370.03	21.42	15.51		67000	81
9046	1992	SEDAN	NISSAN	SENTRA	0.22	2.41	1.09	261.57	31.57	2.34		38000	82
9047*	1986	SEDAN	BUICK	CENTURY	0.51	6.95	3.69	331.23	23.62	4.08		198000	83
9049	1993	SEDAN	HONDA	ACCORD	0.07	0.98	1.19	318.11	27.35			107000	83
9050	1995	PICKUP	FORD	RANGER	0.12	6.74	1.48	377.62	22.38	4.65	1.71	42000	83
9051	1997	SEDAN	OLDS	ACHIEVA	0.03	0.68	0.67	331.45	26.49	3.57		53000	84
9052	1986	SEDAN	ACURA	LEGEND	0.27	4.53	1.57	352.27	23.47	4.64		146000	75
9053	1985	SEDAN	HONDA	ACCORD	1.02	54.00	1.01	194.38	25.37	0.83		115000	76
9054	1989	SEDAN	SUBARU	GL	0.25	3.16	0.79	264.10	30.95	2.77	3.25	59900	77
9055	1984	SEDAN	CHYRSLER	LEBARON	1.69	54.30	3.31	319.90	16.99	60.91		179000	76
9056	1986	SEDAN	HONDA	ACCORD	0.45	4.83	0.93	324.04	24.45	5.88	2.13	127400	75
9057	1990	SEDAN	BMW	525I	0.06	0.81	1.60	346.52	25.18	1.92		130000	77
9058	1977	PICKUP	CHEVY	EL CAMINO	1.59	67.92	2.52	569.96	11.27	8.50		257000	78
9059	1987	SEDAN	CHEVY	CELEBRITY	0.43	2.94	0.82	349.88	23.07	2.55		157000	79
9060	1991	SEDAN	VOLVO	740.00	0.15	0.77	0.80	339.73	25.26	3.51		77000	81
9061	1994	PICKUP	FORD	F150	0.44	3.34	1.69	436.36	18.78	7.66		63000	82
9062	1997	SEDAN	FORD	ESCORT	0.17	2.52	0.80	280.51	29.93	0.84		17000	82
9063*	1987	PICKUP	TOYOTA	PICKUP	0.31	0.48	0.91	299.78	22.576	3.75		40000	82
9065	1985	SEDAN	BUICK	RIVIERA	0.98	21.98	0.83	435.66	16.48	10.21		152798	84
9066	1995	SEDAN	CHRYSLER	CIRRUS	0.05	0.35	0.26	387.82	22.65	2.78		51000	77
9067	1991	WAGON	OLDS	CRUISER	0.74	23.84	0.67	389.59	18.55	12.15		142000	77

APPENDIX A

Table A-1. Summer Phase, Gasoline Vehicles

RUN	YEAR	STYLE	MAKE	MODEL	HC	CO	NOX	CO2	FE	PM10	PM2.5	Odometer	Temp.
					g/mile	g/mile	g/mile	g/mile	mi/gal	mg/mile	mg/mile	mile	°F
9068	1994	SEDAN	HONDA	ACCORD	0.13	2.25	0.27	354.18	24.18	5.58		69000	78
9069	1988	SEDAN	FORD	TEMPO	0.11	1.79	1.73	250.43	33.97	1.99		152000	78
9070*	1992	SUV	CHEV	S10 BLAZER	0.34	6.14	1.49	359.66	22.58	3.70		125000	78
9072	1992	SEDAN	CHRYSLER	NEW YORKER	0.29	3.81	2.68	435.60	19.21	0.43		58000	80
9073	1997	SEDAN	MERC	SABLE	0.21	1.97	1.09	438.95	19.41	2.57		32973	79
9074	1989	SEDAN	HONDA	ACCORD	0.06	0.37	2.66	324.89	26.91	2.52		145000	80
9075	1990	PICKUP	NISSAN	PICKUP	0.63	10.98	2.24	336.62	22.32	9.49	1.07	182000	81
9076	1991	SEDAN	ACURA	LEDGEND	0.14	1.97	1.69	414.99	20.73	0.43		92000	82
9078	1987	SEDAN	NISSAN	SENTRA	0.27	9.54	1.37	315.72	25.38	6.04		76337	85
9079	1995	SEDAN	CHEV	CORSICA	0.19	3.55	0.88	364.17	23.15	1.71		63000	86
9081	1985	SEDAN	PONTIAC	6000.00	0.38	7.41	4.73	243.87	31.43	8.54		188000	79
9082	1992	SEDAN	CHRYSLER	LE BARON	0.28	4.99	3.25	392.12	21.15	3.46	1.47	130000	79
9083	1986	SEDAN	MAZDA	626.00	0.54	6.55	2.25	358.58	21.82	9.62		189000	80
9084	1987	SEDAN	HONDA	ACCORD	0.32	8.57	2.06	295.14	26.83	0.85		215000	80
9086	1997	SEDAN	TOYOTA	CAMRY	0.21	1.97	0.47	445.92	19.12	4.44		19000	82
9087	1988	PICKUP	FORD	RANGER	0.74	12.89	1.97	409.32	18.44	4.56		137000	82
9088	1988	SEDAN	HONDA	ACCORD	0.25	4.23	2.21	345.80	24.00	1.48		180000	87
9089	1995	SEDAN	BUICK	LE SABRE	0.16	0.47	0.19	423.49	20.37	2.02		51203	88
9090	1994	VAN	DODGE	CARAVAN	0.16	2.48	0.60	423.41	20.25	1.26		115000	88
9091*	1987	PICKUP	CHEVY	EL CAMINO	1.18	64.31	3.150	503.68	12.94	15.39		295000	89
9093	1996	SEDAN	HONDA	ACCORD	0.15	0.98	0.41	413.05	20.86			53000	90
9094	1988	VAN	PLYMOUTH	VOYAGER	5.76	320.18	0.96	288.76	7.45	0.64		135000	91
9095	1985	PICKUP	CHEVY	C10	3.92	170.96	1.70	485.97	8.65	96.95		95780	77
9096	1980	SEDAN	PONTIAC	GRAND PRIX	2.28	11.09	3.53	522.06	12.73	22.80		190228	77
9097	1991	PICKUP	CHEVY	S10	0.79	15.06	1.59	390.43	18.91	1.09	4.43	132000	76
9098	1988	SEDAN	CHRYSLER	LE BARON	0.36	8.72	3.81	403.50	20.05	3.60		147000	77
9099	1984	SEDAN	NISSAN	STANZA	0.27	3.01	1.42	340.33	24.40	3.27	2.22	165000	77
9100	1996	SEDAN	DODGE	STRATUS	0.24	14.04	1.55	419.40	19.36	0.43		69000	77
9101	1994	SEDAN	MAZDA	626.00	0.37	6.06	3.07	373.20	21.71	2.12		105000	78
9102	1994	VAN	DODGE	RAM350	0.87	16.10	2.48	540.44	14.17	6.88	4.11	100883	78
9103	1990	VAN	DODGE	CARAVAN	0.53	8.57	5.66	498.72	16.16	9.16		156000	78
9104	1992	SEDAN	TOYOTA	CAMRY	0.30	3.71	1.05	396.50	20.97	2.16		140000	78
9105	1994	SEDAN	TOYOTA	CAMRY	0.05	4.55	0.57	368.74	23.38		0.70	65000	79

APPENDIX A

Table A-1. Summer Phase, Gasoline Vehicles

RUN	YEAR	STYLE	MAKE	MODEL	HC	CO	NOX	CO2	FE	PM10	PM2.5	Odometer	Temp.
					g/mile	g/mile	g/mile	g/mile	mi/gal	mg/mile	mg/mile	mile	°F
9106	1988	SEDAN	TOYOTA	CAMRY	0.51	3.00	1.72	358.22	22.26	17.20		189000	80
9107	1988	SEDAN	NISSAN	MAXIMA	0.26	5.32	2.44	449.55	18.64			160000	80
9108	1985	SEDAN	MERC	MARQUIS	0.48	4.17	2.00	397.60	20.29	13.34		91000	80
9109	1988	SUV	ISUZU	TROOPER	0.73	19.08	7.76	442.24	16.97	3.47		136000	80
9110	1978	WAGON	FORD	LTD	1.98	78.86	1.24	546.67	10.98	3.18		110000	80
9111	1997	SEDAN	FORD	PROBE	0.16	0.88	0.27	407.71	21.10			22000	80
9112	1995	SEDAN	CHEVY	CAPRICE	0.13	3.49	1.61	531.02	16.26			80000	81
9113	1993	PICKUP	GMC	SONOMA	0.85	11.64	1.11	391.33	18.92	1.47		93600	81
9115	1978	PICKUP	FORD	COURIER	4.80	51.98	2.66	372.94	11.28	6.32		178000	79
9116	1985	PICKUP	FORD	F150	7.11	161.74	1.10	344.55	8.13	19.61		75469	80
9117	1990	SUV	TOYOTA	4RUNNER	0.38	4.61	1.62	498.77	16.65	11.07		137000	80
9118	1996	SEDAN	DODGE	NEON	0.22	0.62	0.75	346.00	24.50	0.66		24000	80
9119	1992	SEDAN	BUICK	LESABRE	0.35	10.73	1.11	428.43	18.89			76583	80
9120	1985	PICKUP	FORD	RANGER	1.60	17.43	8.23	455.11	14.95	31.39		87000	80
9121	1997	SEDAN	BUICK	LESABRE	0.17	0.18	0.65	442.61	19.49	2.77		45000	78
9122	1991	SEDAN	HONDA	ACCORD	0.35	3.27	2.46	365.48	22.45	1.95		138123	79
9123	1981	PICKUP	FORD	F150	1.37	32.83	6.41	333.47	18.50	5.54	1.08	175000	79
9124	1987	SEDAN	VOLVO	240.00	0.44	6.80	6.43	460.68	17.67	2.13		137000	83
9126	1989	SEDAN	HONDA	ACCORD	0.14	10.45	1.59	236.60	33.78	0.42		141000	83
9127	1997	SEDAN	FORD	CONTOUR	0.20	5.37	0.47	408.77	20.56	3.52		19000	83
9128	1994	SEDAN	BUICK	PARK AVENUE	0.04	0.95	0.20	443.55	19.79	0.82		39500	83
9129	1995	SEDAN	ACURA	INTEGRA	0.28	2.61	0.63	418.17	20.09			33000	82
9130	1991	SEDAN	HONDA	ACCORD	0.12	2.40	2.10	338.58	25.29	1.25		185000	83

* Average of two runs

APPENDIX A

Table A-1. Winter Phase, Gasoline Vehicles

RUN	YEAR	STYLE	MAKE	MODEL	HC g/mile	CO g/mile	NOX g/mile	CO2 g/mile	FE mi/gal	PM10 mg/mile	PM2.5 mg/mile	Odometer mile	Temp. °F
33041	1977	SEDAN	CHEVY	CAPRICE	3.19	49.02	4.36	440.24	16.33	23.38		170274	35
33043	1987	PICKUP	CHEVY	C10 DELUX	1.57	7.55	3.23	465.37	17.86	0.98		97196	35
33045	1984	SEDAN	CHRYSLER	LEBARON	1.87	32.04	2.61	330.95	22.24	20.29		165385	35
33047	1979	PICKUP	FORD	F100 EXPLORER	5.11	77.34	2.03	309.47	19.27	32.46		168723	35
33049	1985	PICKUP	FORD	RANGER	3.85	30.88	1.61	315.98	22.87	18.08		47710	35
33051	1992	PICKUP	DODGE	DAKOTA	1.70	25.98	5.95	576.99	13.82	8.65		88389	35
33052	1995	SEDAN	OLDS	ACHIEVA	0.35	5.82	0.76	375.81	22.30	5.27		70024	35
33053	1991	SEDAN	ACURA	INTEGRA	0.28	7.55	1.00	314.20	26.33	33.88		170000	35
33054	1989	SEDAN	NISSAN	MAXIMA	0.18	3.56	0.76	347.05	24.37	9.54		135411	35
33055	1985	SEDAN	SAAB	900S	0.41	8.92	2.29	354.37	23.29	2.26		205743	35
33056	1996	SEDAN	NISSAN	MAXIMA	0.09	0.95	0.23	363.46	23.56	3.29		84862	35
33057	1992	SUV	CHEVY	S10 BLAZER	0.69	12.84	0.65	369.40	21.98	48.01		119626	35
33058	1982	SEDAN	CHEVY	CAPRICE	1.67	37.23	4.70	460.63	16.42	11.41		80522	35
33059	1994	PICKUP	MAZDA	B3000	0.50	7.78	1.65	417.30	19.97	4.28		52823	35
99001	1993	MINIVAN	PLYMOUTH	VOYAGER	0.36	5.62	1.61	510.46	16.30	38.44		78777	69
99002	1995	SEDAN	BMW	318I	0.06	2.11	0.09	412.86	21.08	11.22		102048	68
99003	1982	PICKUP	FORD	F150	2.80	69.05	3.24	594.51	9.89	451.87		127341	71
99004	1982	SEDAN	TOYOTA	CRESSIDA	0.81	10.25	3.56	406.23	18.54	8.06		165385	72
99005	1992	SEDAN	BUICK	SKYLARK	2.36	91.10	0.71	290.35	14.87	25.77		125289	71
99006*	1996	SUV	FORD	EXPLORER	0.05	0.98	0.98	526.25	16.70	36.23		41278	73
99008	1982	PICKUP	CHEVY	S10	1.93	37.74	4.25	341.65	16.59	25.86		263756	72
99009	1979	SUV	JEEP	CJ5	2.98	18.91	4.40	470.07	12.57	104.09		35470	72
99025	1995	SEDAN	MAZDA	PROTEGE	0.19	4.61	0.90	259.85	31.64		1.91	72803	67
99026	1995	SEDAN	NISSAN	MAXIMA	0.39	6.34	1.35	367.95	21.89	2.67		86878	63
99027	1984	SEDAN	NISSAN	PULSAR	1.35	13.82	3.16	310.58	20.85	26.77		139799	64
99028	1974	SUV	TOYOTA	LANDCRUISER	5.75	29.06	3.65	447.98	9.95	55.78		117848	64
99029*	1988	SEDAN	PONTIAC	FIREBIRD	0.87	7.92	0.92	413.68	18.23	3.73		179529	62
99030	1993	PICKUP	FORD	RANGER	0.11	2.18	0.61	446.71	19.36	4.03		55042	64
99031	1984	SEDAN	OLDSMOBILE	CUTLASS	1.36	20.92	2.76	443.03	15.56	3.24	4.84	125332	66
99032	1991	MINIVAN	DODGE	CARAVAN	2.49	17.36	8.39	497.27	12.74	9.21		121293	68
99033	1995	SEDAN	FORD	ESCORT	0.15	5.44	1.32	343.87	24.45	4.33		58179	70
99034*	1996	PICKUP	CHEVY	1500	0.17	1.26	0.31	501.24	17.35	2.12		79081	71

APPENDIX A

Table A-1. Winter Phase, Gasoline Vehicles

RUN	YEAR	STYLE	MAKE	MODEL	HC	CO	NOX	CO2	FE	PM10	PM2.5	Odometer	Temp.
					g/mile	g/mile	g/mile	g/mile	mi/gal	mg/mile	mg/mile	mile	°F
99035*	1975	SUV	FORD	BRONCO	9.84	173.07	3.88	480.66	6.19	75.61		123612	70
99036	1997	SEDAN	SATURN	GL	0.27	2.03	0.27	319.45	25.99	3.39		25332	71
99037	1986	SEDAN	FORD	MUSTANG	0.88	4.41	1.25	373.62	20.10	2.77	5.01	14480	71
99038	1988	SEDAN	PONTIAC	GRANDAM	0.50	6.73	6.12	351.64	22.35	3.90		165705	71
99039	1989	SEDAN	HONDA	ACCORD	0.74	5.82	1.45	314.03	23.70	2.15	6.30	146935	71
99040*	1990	PICKUP	FORD	F150	0.87	5.11	1.51	461.89	16.77	18.71		86724	72
99041	1992	SEDAN	OLDS	CUTLASS CIERA	0.22	1.64	1.89	419.91	20.25	3.54	4.43	57938	70
99042	1979	SEDAN	OLDS	NINETY-EIGHT	3.25	20.43	4.53	563.63	10.81	3.55	3.49	84085	69
99043	1994	SEDAN	FORD	ESCORT	0.55	4.23	1.10	319.21	24.35	7.23		62580	50
99044	1994	SEDAN	FORD	TAURUS	0.26	2.29	0.48	409.77	20.56	6.28	2.99	49545	53
99045*	1987	SEDAN	HONDA	PRELUDE	0.29	2.50	2.75	308.22	26.70	1.37		106074	53
99046*	1985	PICKUP	CHEVY	SILVERADO 10	0.74	2.23	2.01	663.48	12.35	150.13		100545	55
99047	1989	MINIVAN	FORD	AEROSTAR	0.89	13.56	1.62	420.94	17.59	5.44		104171	55
99048	1996	SEDAN	TOYOTA	AVALON	0.31	1.00	0.60	412.20	20.37	3.68	14.75	41633	56
99049	1987	SEDAN	CHEVY	CAPRICE	0.47	7.40	1.30	441.39	18.27	5.88		80765	57
99050	1989	SEDAN	CADILLAC	DEVILLE	0.45	10.57	2.18	456.36	17.59	7.40	9.57	110803	58
99051*	1991	SEDAN	ACURA	LEGEND	0.33	2.41	0.11	409.94	20.35	1.9		58738	59
99052	1993	SUV	JEEP	CHEROKEE	0.61	5.47	1.70	421.77	18.76	6.19	7.87	89786	60
99053	1987	SEDAN	TOYOTA	CELICA	0.39	3.30	1.02	288.10	27.67	2.84		119301	62
99054	1995	SEDAN	SATURN	GL	0.89	9.78	0.68	301.83	23.43	15.20	23.15	68316	63
99055*	1990	SEDAN	OLDS	NINETY-EIGHT	0.31	6.38	1.80	492.45	16.94	3.1		69940	62
99056*	1986	SEDAN	TOYOTA	CELICA	0.72	7.73	0.81	334.71	22.39	2.44		187611	61
99057	1993	SEDAN	FORD	MUSTANG	0.60	4.26	1.89	401.50	19.71	10.55		66958	68
99058	1997	SEDAN	DODGE	INTREPID	0.30	2.80	0.81	432.35	19.38	1.19	0.34	60656	67
99059	1989	SEDAN	MAZDA	626	0.30	2.95	0.59	322.98	25.43	2.55		104657	66
99060*	1990	SEDAN	TOYOTA	CAMRY	0.23	5.57	0.93	330.26	24.99			162674	67
99061	1988	SEDAN	VW	JETTA	0.64	6.83	1.59	278.07	26.63	3.88		111662	65
99062	1994	MINIVAN	DODGE	CARAVAN	0.14	2.82	0.36	427.30	20.09	1.18	2.79	22319	68
99063*	1987	SEDAN	DODGE	OMNI	0.06	0.46	5.02	397.92	22.05	78.26	89.57	54815	60
99064	1997	SEDAN	TOYOTA	CAMRY	0.32	2.51	0.33	409.48	20.36	2.71		31345	60
99065	1993	SEDAN	ACURA	INTEGRA	0.58	6.98	0.71	330.59	23.24	4.70	10.28	40725	61
99066*	1993	SUV	ISUZU	RODEO	0.36	8.22	2.90	508.78	16.23	5.88		77114	61

APPENDIX A

Table A-1. Winter Phase, Gasoline Vehicles

RUN	YEAR	STYLE	MAKE	MODEL	HC	CO	NOX	CO2	FE	PM10	PM2.5	Odometer	Temp.
					g/mile	g/mile	g/mile	g/mile	mi/gal	mg/mile	mg/mile	mile	°F
99067	1985	SEDAN	OLDS	CUTLASS SUPREME	3.65	129.27	1.15	473.79	9.54	60.20	64.98	88255	61
99068	1996	PICKUP	FORD	RANGER	0.28	0.80	0.78	425.48	19.87	4.96		40653	62
99069	1979	PICKUP	CHEVY	LUV	1.65	25.59	3.47	373.08	16.82	11.44	15.19	189124	63
99070*	1984	PICKUP	CHEVY	CD20	5.48	105.25	2.61	620.73	7.62	32.23		210635	62
99071*	1993	SEDAN	CHEVY	CAVALIER	0.25	3.82	0.96	313.56	26.32	2.13	3.77	147650	64
99072	1993	SEDAN	FORD	TAURUS	0.24	2.80	1.29	427.75	19.76	5.07		72166	64
99073	1986	SEDAN	OLDS	CUTLASS CIERA	0.54	7.21	1.50	403.25	19.63	181.91	202.28	90000	66
99074	1991	SEDAN	FORD	ESCORT	1.11	6.45	4.60	306.45	22.53	9.83		158368	65
99075	1997	SEDAN	FORD	TAURUS	0.17	1.77	0.83	459.26	18.73	1.13	3.18	60000	65
99076*	1985	SEDAN	FORD	ESCORT	2.34	15.89	0.58	141.58	27.02	17.11		97034	64
99077	1988	SEDAN	HONDA	CIVIC	1.87	9.80	5.12	295.65	20.13	122.81	147.09	213395	65
99078	1997	SEDAN	FORD	MUSTANG	0.38	3.61	0.39	331.40	24.41	3.06		20956	66
99079	1996	PICKUP	GMC	SONOMA	0.25	2.98	0.66	322.23	25.76	3.98	2.89	24413	67
99080	1991	MINIVAN	DODGE	CARAVAN	1.44	7.92	3.32	420.72	16.64	245.68		134760	32
99081*	1994	SEDAN	BUICK	LESABRE	0.03	1.10	0.57	497.48	17.70	21.52	20.6	51420	58
99082*	1993	SUV	FORD	EXPLORER	0.23	4.43	1.25	489.13	17.35	23.78	24.89	88387	60
99083	1980	SEDAN	BMW	320I	0.77	4.86	1.60	316.30	23.53	38.00		160078	60
99084	1985	SEDAN	BUICK	LESABRE	0.63	18.99	2.96	566.15	13.86	21.13	19.41	207864	65
99085	1984	SEDAN	NISSAN	300ZX	0.67	5.55	2.90	315.63	23.92	5.81		273395	67
99086*	1995	SUV	FORD	EXPLORER	0.30	5.18	1.25	401.69	20.60	2.18	1.34	54693	68
99087	1993	PICKUP	NISSAN	0	0.40	4.47	0.97	335.06	24.00	1.17		54502	72
99088	1991	PICKUP	CHEVY	1500	1.80	21.09	2.31	489.76	13.71	2.84	3.21	76622	70
99089	1992	SEDAN	HONDA	CIVIC	0.36	13.03	0.77	253.44	29.68	2.12		122933	74
99090*	1985	PICKUP	FORD	F150	5.85	77.47	3.87	525.20	8.44	29.03	26.62	123952	75
99091*	1989	SEDAN	FORD	PROBE	0.21	2.99	0.49	378.75	22.29	5.95		85653	75
99092	1996	PICKUP	TOYOTA	T100	0.19	0.94	1.10	442.07	19.42	3.45	7.46	62825	75
99093	1984	SEDAN	VW	RABBIT	1.10	8.61	2.82	304.05	22.51	5.05		139000	78
99094	1987	SEDAN	FORD	MUSTANG	0.90	1.25	2.17	425.85	18.09	5.42	7.28	26807	61
99095	1990	VAN	FORD	ECONOLINE	2.40	14.91	6.10	485.07	13.15	34.93		162580	63
99096*	1987	SEDAN	TOYOTA	CELICA	1.68	8.42	3.74	254.78	23.08	25.68	24.73	174000	64
99097	1993	MINIVAN	DODGE	CARAVAN	0.31	4.97	4.00	459.43	18.15	7.51		89571	65
99098	1984	PICKUP	FORD	RANGER	2.28	12.13	2.04	305.29	18.39	17.59	22.52	86478	65

APPENDIX A

Table A-1. Winter Phase, Gasoline Vehicles

RUN	YEAR	STYLE	MAKE	MODEL	HC	CO	NOX	CO2	FE	PM10	PM2.5	Odometer	Temp.
					g/mile	g/mile	g/mile	g/mile	mi/gal	mg/mile	mg/mile	mile	°F
99099	1995	SEDAN	FORD	CONTOUR	0.08	2.23	0.77	421.83	20.58	10.47	13.47	106226	67
99100*	1993	PICKUP	FORD	F150	0.34	0.79	1.35	547.56	15.50	16.87		75596	68
99101*	1992	SEDAN	FORD	TEMPO	0.17	1.34	2.06	395.08	21.70	15.92	17.06	105068	70
99102	1995	MINIVAN	FORD	WINDSTAR	0.15	1.03	0.53	455.38	18.96	2.99		49395	70
99103	1988	MINIVAN	PLYMOUTH	VOYAGER	0.77	9.52	4.15	451.77	17.05	13.33	12.96	174174	71
99104	1990	SEDAN	BMW	535I	0.13	2.08	0.34	480.13	18.01	3.20		90304	73
99105	1992	SEDAN	OLDS	CUTLASS CIERA	0.62	7.08	1.75	467.36	17.00	5.96	8.84	113205	73
99106*	1986	PICKUP	FORD	RANGER	1.22	7.82	4.13	371.85	18.99	6.37		60803	73
99107	1991	PICKUP	FORD	RANGER	0.83	6.15	1.40	391.14	19.34	2.59	2.83	55509	74
99108	1989	SEDAN	TOYOTA	CAMRY	0.25	2.82	0.74	284.58	28.98	3.64		104938	74
99109	1988	SEDAN	TOYOTA	CELICA	0.80	7.24	2.95	352.38	21.17	19.64	23.04	178882	73
99110*	1987	SEDAN	PLYMOUTH	HORIZON	1.25	23.43	0.95	330.39	19.61	53.72		135898	60
99111*	1987	VAN	CHEVY	20	0.28	3.49	1.35	400.30	20.87	3.25	3.5	64189	66
99112	1996	MINIVAN	PLYMOUTH	VOYAGER	0.31	2.61	0.73	431.90	19.39	2.74		62838	64
99113	1991	MINIVAN	DODGE	CARAVAN	0.37	6.71	1.70	431.29	18.97	6.61	5.09	128173	66
99114	1965	SEDAN	PLYMOUTH	BARRACUDA	4.90	75.31	3.44	372.81	10.69	48.01		54293	73
99115	1984	SEDAN	HONDA	CIVIC	0.80	4.53	3.82	262.71	27.25	279.70	289.45	214959	71
99116*	1995	MINIVAN	FORD	WINDSTAR	0.08	1.93	0.66	430.57	20.23	15.44	1.5	62249	70
99117	1985	SEDAN	CHEVY	MONTE CARLO	0.83	7.13	4.66	399.48	18.95	13.78	15.04	149569	79
99118	1986	SEDAN	TOYOTA	TERCEL	0.50	5.44	3.49	253.82	29.84	22.13		167000	79
99119	1983	SEDAN	HONDA	CIVIC	0.78	0.86	5.49	243.46	29.69	246.38	269.68	95088	79
99120*	1996	SEDAN	FORD	MUSTANG	0.18	2.66	0.72	357.09	23.74	2.98		51602	80
99121*	1992	SEDAN	BUICK	LESABRE	0.63	19.48	1.52	414.55	18.18	2.85	3.84	0	80

* Average of two runs

APPENDIX A

Table A-2. Diesel Model Year, Style, Make,, and Regulated PM Data

RUN	YEAR	STYLE	MAKE	MODEL	HC	CO	NOX	CO2	FE	PM10	PM2.5	Odometer	Temp.
					g/mile	g/mile	g/mile	g/mile	mi/gal	mg/mile	mg/mile	mile	°F
					Winter Phase								
33060	1983	PICKUP	Chevy	Scottsdale	0.16	1.27	1.77	501.79	19.80	228.48		118862	35
33061	1977	SEDAN	Mercedes	240D	0.17	1.32	1.67	422.41	23.49	450.20		173963	35
33062	1980	WAGON	VW	Dasher	0.45	2.06	0.98	275.63	35.62	448.47		168398	35
					Summer Phase								
9077	1983	SEDAN	Mercedes	300D	0.18	1.44	1.72	400.69	24.00	895.60	580.18	217000	83
9080	1985	WAGON	Mercedes	300SD	0.23	1.11	1.92	414.41	23.29	253.92		187000	86
9085	1981	PICKUP	VW	PICKUP	0.48	2.39	1.00	318.38	30.44	429.86		104317	81
9114	1989	SEDAN	VW	JETTA	0.06	1.00	0.98	266.49	36.40	135.12		147000	79
9125	1982	SEDAN	AUDI	4000	0.26	5.18	2.04	286.34	33.51	720.96		160000	83

APPENDIX A

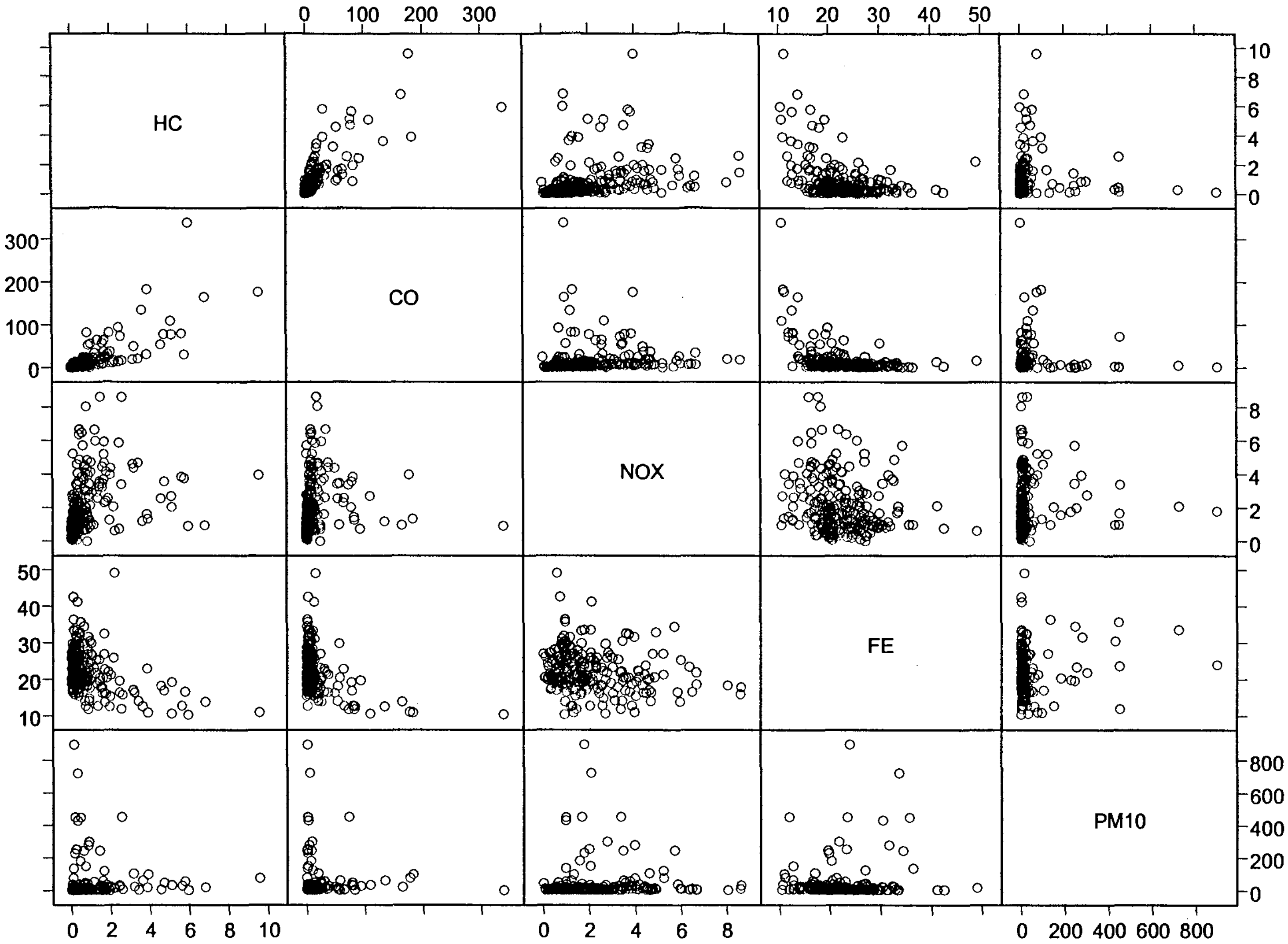


Figure A-1. Scatter Plot Correlation of Regulated and PM10 Emissions and Fuel Economy

APPENDIX A

Table A-3. Winter Phase Aldehyde and Ketone Emission Data

Table A-3. Winter Phase Aldehyde and Ketone Emission Data

	99001	99002	99003	99004	99005	99006	99007	99008	99009	99010	99011	99012	99013	99014	99015
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	2.66	2.43	52.82	11.67	4.2	4.49	2.67	78.43	56.57	1.8	24.66	23.92	4.38	13.97	2.84
Acetaldehyde	0.86	0	7.41	1.08	4.58	0.01	0.01	7.99	4.44	0.27	1.36	1.35	0.47	5.32	0.03
Acrolein	0	0	0.88	0.01	0.06	0	0	1.62	0.83	0.1	0.18	0.15	0	0.64	0.1
x-Acrolein	0.17	0.01	1.84	0.21	0.6	0	0	1.37	1	0.03	0.18	0.18	0.04	0.59	0
Benzaldehyde	0.19	0.17	1.45	0.33	0.72	0.04	0.01	1.45	1.04	0.05	0.23	0.22	0.18	0.99	0.1
Tolualdehydes	0.26	0.24	1.58	0.47	0.81	0.09	0.01	2.02	1.59	0.07	0.35	0.23	0.24	1.23	0.17
2-Butanone	0.13	0.01	0.33	0.1	0.24	0	0	0.45	0.21	0.02	0.02	0.02	0.02	0.22	0.03
Methacrolein	0.06	0.01	0.77	0.11	0.4	0	0	0.85	0.68	0.02	0.08	0.08	0.04	0.59	0
Acetone	0.27	0.04	1.74	0.63	1.35	0.06	0.06	2.02	1.38	0.17	0.36	0.26	0.36	1.36	0.01

	99016	99017	99018	99019	99020	99021	99022	99023	99024	99025	99026	99027	99028	99029	99030
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	1.52	8.49	6.29	4.4	0.4	3.44	4.1	1.14	11.03	1.97	2.43	9.34	90.84	17.51	6.83
Acetaldehyde	0.36	0.4	0.87	1.33	0.07	1.25	0.16	0	0.21	0.26	0.94	3.29	9.74	1.93	0.28
Acrolein	0.12	0.09	0	0	0	0	0.13	0.16	0.16	0.15	0.16	0.2	2.99	0.09	0
x-Acrolein	0.03	0.01	0.09	0.04	0	0.2	0.01	0	0	0.01	0.15	0.51	1.51	0.17	0
Benzaldehyde	0.1	0.04	0.25	0.17	0.04	0.41	0.11	0.04	0.02	0.08	0.16	0.56	2.7	0.37	0.15
Tolualdehydes	0.14	0.07	0.36	0.24	0.06	0.63	0.19	0.08	0.02	0.1	0.2	0.66	3.06	0.59	0.22
2-Butanone	0	0	0.05	0.03	0.03	0.12	0.04	0.05	0.03	0.04	0.05	0.13	0.37	0.12	0.12
Methacrolein	0	0	0.04	0	0	0.1	0	0	0	0.01	0.05	0.31	1.06	0.13	0
Acetone	0.23	0.15	0.46	0.5	0.13	0.58	0.13	0.13	0.14	0.2	0.5	1.07	2.81	0.85	0.24

	99031	99032	99033	99034	99035	99036	99037	99038	99039	99040	99041	99042	99043	99044	99045
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	11.13	80.9	2.21	6.01	152.14	8.74	2.78	13.05	3.42	21.09	8.88	59.05	3.36	1.29	17.03
Acetaldehyde	3.65	8.42	0.09	0.35	12.43	0.09	1.22	2.49	2.43	4.82	0.29	12.24	0.61	0.02	0.68
Acrolein	0.17	2.51	0	0	4.11	0	0	0.11	0	0.42	0.14	2.43	0	0	0.06
x-Acrolein	0.36	1.23	0.03	0	1.49	0	0.07	0.27	0.16	0.37	0.02	1.39	0.1	0	0.05
Benzaldehyde	0.51	2.9	0.1	0.12	4.18	0.17	0.23	0.62	0.29	0.46	0.09	1.56	0.21	0.02	0.06
Tolualdehydes	0.65	3.62	0.15	0.18	5	0.31	0.3	0.76	0.33	0.58	0.14	1.87	0.27	0.06	0.09
2-Butanone	0.18	0.44	0.05	0.13	0.55	0.05	0.16	0.19	0.2	0.43	0.05	0.87	0.03	0	0.04
Methacrolein	0.24	1.16	0.02	0.01	1.53	0	0.04	0.16	0.12	0.31	0	1.15	0.03	0	0.02

Table A-3. Winter Phase Aldehyde and Ketone Emission Data

Acetone	1.76	3.13	0.15	0.24	4.19	0.19	0.78	1.13	0.9	2.24	0.19	4.55	0.13	0	0.28
	99046	99047	99048	99049	99050	99051	99052	99053	99054	99055	99056	99057	99058	99059	99060
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	69.44	9.79	6.17	6.37	6.1	3.2	7.71	1.92	2.15	14.96	3.4	3.35	1.15	1.41	0.88
Acetaldehyde	10.19	1.52	0.69	0.56	0.7	0.13	1.22	0.4	1.87	0.75	0.58	0.64	0.13	0.05	0.2
Acrolein	0.22	0	0	0	0	0.06	0	0	0	0.05	0.05	0	0	0	0.05
x-Acrolein	0.3	0.09	0.08	0	0.07	0.01	0.13	0.12	0.12	0	0.08	0.08	0.02	0	0.06
Benzaldehyde	0.22	0.17	0.19	0.04	0.09	0.13	0.19	0.23	0.35	0.07	0.1	0.04	0.04	0.03	0.09
Tolualdehydes	0.29	0.23	0.23	0.02	0.1	0.21	0.26	0.28	0.5	0.1	0.12	0.04	0.04	0.02	0.1
2-Butanone	0.73	0.07	0.08	0.02	0.03	0.02	0.13	0	0.03	0.08	0.03	0.06	0.13	0.03	0.03
Methacrolein	0.27	0.08	0.05	0	0	0	0.09	0.06	0.1	0.03	0.02	0.04	0.05	0	0.02
Acetone	4.36	0.63	0.42	0.45	0.57	0.21	0.54	0.24	0.66	0.2	0.27	0.56	0.14	0.11	0.17
	99061	99062	99063	99064	99065	99066	99067	99068	99069	99070	99071	99072	99073	99074	99075
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	0.94	2.14	23.61	2.61	0.99	8.93	49.07	5.48	98.55	210.92	7.94	4.69	24.05	39.69	2.67
Acetaldehyde	0.91	0.19	0.76	0.09	0.22	0.86	7.18	0.15	22.33	21.43	0.88	0.43	2.17	5	0.38
Acrolein	0	0	0.08	0	0	0.04	0.64	0	2.06	4.22	0.03	0	0.34	0.58	0
x-Acrolein	0.16	0.01	0.17	0.03	0.03	0.09	0.95	0.04	1.91	3.1	0.11	0.05	0.28	1.06	0
Benzaldehyde	0.14	0.13	0.03	0.04	0.09	0.2	1.06	0.09	1.9	4.48	0.21	0.2	0.38	1.01	0.06
Tolualdehydes	0.18	0.17	0.04	0.04	0.13	0.27	1.36	0.11	2.03	5.36	0.33	0.27	0.52	1.16	0.1
2-Butanone	0.03	0.05	0.04	0.03	0.02	0.04	0.48	0.04	0.41	1.03	0.09	0.16	0.16	0.25	0.03
Methacrolein	0.14	0	0.02	0	0	0.02	0.66	0	0.85	1.88	0.08	0.08	0.22	0.48	0.01
Acetone	0.44	0.21	0.22	0.15	0.24	0.37	2.26	0.15	3.88	6.06	0.39	0.23	0.62	1.26	0.1
	99076	99077	99078	99079	99080	99081	99082	99083	99084	99085	99086	99087	99088	99089	99090
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	27.23	70.44	4.65	0.73	12.77	13.04	8.52	14.25	16.14	12.52	1.72	0.691	29.52	1.533	141.11
Acetaldehyde	4.04	8.46	0.2	0.54	4.8	0.14	0.02	1.37	2.196	2.028	0.12	0.125	8.838	0.566	16.27
Acrolein	0.31	1.3	0.11	0.12	0.14	0	0	0.02	0.08	0.07	0.01	0	0.6	0	3.46
x-Acrolein	0.63	1.6	0.04	0.01	0.95	0.01	0.01	0.23	0.21	0.28	0.01	0.03	1.56	0.16	2.32
Benzaldehyde	0.63	1.52	0.13	0.04	0.78	0.02	0.03	0.35	0.32	0.37	0.01	0.03	1.4	0.19	2.59
Tolualdehydes	0.82	1.92	0.19	0.07	1.13	0.05	0.06	0.38	0.43	0.49	0.04	0.08	1.57	0.28	3.48
2-Butanone	0.2	0.42	0.04	0.04	0.29	0	0.02	0.1	0.05	0.13	0.01	0	0.47	0	0.77
Methacrolein	0.33	0.88	0	0	0.52	0	0	0.13	0.06	0.2	0	0.02	0.96	0.05	1.55

APPENDIX A

Table A-3. Winter Phase Aldehyde and Ketone Emission Data

Acetone	1.15	2.66	0.29	0.17	1.57	0	0	0.72	1.07	1.28	0.01	0.05	3.19	0.21	3.8
	99091	99092	99093	99094	99095	99096	99097	99098	99099	99100	99101	99102	99103	99104	99105
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	2.76	5.99	3.45	22.37	81.18	64.34	7.92	53.2	6.747	32	5.84	1.92	9.6	2.5	8.37
Acetaldehyde	0.15	0.06	1.65	1.75	9.86	7.74	0.46	9.39	0	0.8	0.14	0	1.5	0.03	0.65
Acrolein	0	0	0.03	0.02	1.53	0.96	0	0.68	0	0	0	0	0.08	0	0.04
x-Acrolein	0.06	0	0.17	0.2	2.26	1.74	0.06	1.3	0	0.03	0.01	0	0.27	0	0.05
Benzaldehyde	0.07	0.09	0.21	0.14	1.76	1.42	0.15	0.75	0.02	0.02	0.02	0	0.31	0	0.12
Tolualdehydes	0.13	0.13	0.28	0.21	2.47	2.07	0.25	1.22	0.06	0.05	0.04	0.01	0.41	0.01	0.21
2-Butanone	0	0.01	0.11	0.2	0.52	0.44	0.01	0.7	0.02	0.05	0.04	0.01	0.12	0	0.05
Methacrolein	0.01	0	0.07	0.16	1.01	0.79	0.03	0.59	0	0.02	0	0	0.18	0	0.07
Acetone	0.01	0.02	0.33	2.13	2.45	2.39	0.19	3.04	0	0.27	0.11	0	0.53	0	0.23
	99106	99107	99108	99109	99110	99111	99112	99113	99114	99115	99116	99117	99118	99119	99120
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	42.49	12.6	0.91	12.89	35.35	7.52	3.14	2.69	51.78	16.04	4.99	16.44	1.62	36.24	2.38
Acetaldehyde	4.56	2.31	0.16	1.98	2.94	1.25	0.47	0.35	6.7	3.04	0.08	2.5	0.36	5.16	0.04
Acrolein	0.39	0.07	0	0.17	0.32	0.03	0	0.03	0.92	0.14	0	0.19	0	0.51	0
x-Acrolein	0.79	0.27	0.06	0.45	0.71	0.28	0.08	0.05	1.21	0.46	0.01	0.28	0.04	1.1	0.01
Benzaldehyde	0.52	0.19	0.05	0.35	0.68	0.16	0.15	0.11	1.27	0.32	0.01	0.28	0.03	0.52	0.01
Tolualdehydes	0.77	0.18	0.09	0.56	0.87	0.21	0.19	0.19	1.48	0.39	0.03	0.38	0.05	0.72	0.04
2-Butanone	0.14	0.08	0.05	0.04	0.11	0.06	0	0	0	0.13	0	0.19	0	0.26	0
Methacrolein	0.34	0.13	0.05	0.21	0.41	0.13	0.03	0.03	0.67	0.2	0	0.13	0.01	0.46	0
Acetone	1.2	0.95	0.01	0.55	1.12	0.31	0.07	0	1.44	0.87	0	1.15	0.05	1.64	0
	99121	33041	33043	33045	33047	33049	33051	33052	33053	33054	33055	33056	33057	33058	33059
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	1.31	0.01	0	12.04	11	5.74	0	0.95	0.61	7.06	2.32	1.03	3.15	0	3.68
Acetaldehyde	0.63	0	0.09	2.65	3.65	3.82	0	0.17	0.25	2.59	0.34	0	1.9	0	0.36
Acrolein	0.05	0.02	0.01	0.47	0.66	0.52	0	0	0	0.23	0	0	0.04	0	0
x-Acrolein	0.04	0	0	0.52	0.75	0.55	0	0	0	0.26	0.07	0	0.12	0	0
Benzaldehyde	0.06	0	0.01	0.55	0.95	0.59	0	0.02	0.05	0.33	0.07	0.03	0.2	0	0.04
Tolualdehydes	0.06	0.03	0.01	0.58	1.34	0.96	0	0.01	0.07	0.45	0.08	0.02	0.27	0	0
2-Butanone	0	0.06	0.03	0	0.21	0.33	0	0	0	0.12	0	0	0	0	0

APPENDIX A

Table A-3. Winter Phase Aldehyde and Ketone Emission Data

Methacrolein	0.02	0	0	0	0.51	0.36	0	0	0	0.18	0	0	0.07	0	0
Acetone	0.12	0.01	0	0.03	0.05	0.65	0	0.04	0.11	0.83	0.07	0	0.6	0	0.08

Table A-4. Summer Phase Aldehyde and Ketone Emission Data

Table A-4. Summer Phase Aldehyde and Ketone Emission Data

	9000	9001	9002	9003	9004	9005	9006	9007	9008	9009	9010	9011	9012	9013
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	0.58	0.45	16.05	10.3	6.32	7.94	6.15	35.37	21.87	2.61	6.01	2.25	0	0.62
Acetaldehyde	1.25	0.47	6.05	0.65	2.05	0.47	0.43	9.98	5.64	1.01	0.55	0.93	0	0.32
Acrolein	0	0	0.08	0	0	0	0	0.47	0.38	0	0	0	0	0
x-Acrolein	0	0	0.49	0	0	0	0	0.45	0.49	0.08	0	0	0	0
Benzaldehyde	0	0.02	0.79	0.11	0.34	0.33	0.12	1.37	0.83	0.28	0.11	0.05	0	0
Tolualdehydes	0	0.04	1.14	0.26	0.41	0.42	0.2	1.42	1.07	0.28	0.18	0.07	0	0.01
2-Butanone	0.06	0	0.41	0.03	0.07	0.03	0.03	0.59	0.34	0.05	0	0	0.02	0
Methacrolein	0.02	0	0.7	0.02	0.14	0.01	0.04	0.75	0.66	0.09	0.04	0.12	0.02	0
Acetone	0.13	0.06	1.74	0.37	0.91	0.12	0.16	3.7	2	0.51	0.35	0.58	0	0.05
	9014	9015	9016	9017	9018	9020	9021	9022	9023	9024	9025	9026	9027	9029
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	10.49	2.81	4.99	4.38	0.9	0.42	3.81	1.65	6.13	3.67	5.09	6.04	4.98	7.08
Acetaldehyde	3.82	0.4	0.89	0	0	0	2.43	0	2.42	0.04	0.31	3.14	0.57	0.49
Acrolein	0.21	0.05	0.05	0	0	0	0.14	0	0.15	0	0	0.29	0	0
x-Acrolein	0.27	0	0	0	0	0	0.16	0	0.09	0	0	0.22	0	0
Benzaldehyde	0.66	0.12	0.07	0	0	0	0.29	0	0.35	0	0.08	0.35	0.07	0.07
Tolualdehydes	0.85	0.21	0.14	0	0	0.01	0.47	0.03	0.37	0.01	0.17	0.61	0.12	0.13
2-Butanone	0.19	0.03	0.03	0	0	0	0.16	0	0.13	0	0	0.14	0.01	0
Methacrolein	0.39	0.1	0.07	0.02	0.02	0.01	0.3	0.01	0.2	0.01	0.04	0.34	0.04	0.04
Acetone	0.94	0.11	0.34	0	0	0	0.97	0	0.84	0	0.11	0.9	0.13	0.13
	9030	9031	9032	9033	9034	9035	9036	9037	9038	9039	9040	9041	9042	9043
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	67.63	11.08	4.55	4.25	5.61	5.28	1.78	6.45	1.39	2.66	2.58	12.32	18.88	3.85
Acetaldehyde	8.27	0.13	0.06	0.46	0.09	0	0	0.24	0.2	0	1.53	4.24	3.29	0

APPENDIX A

Table A-4. Summer Phase Aldehyde and Ketone Emission Data

Acrolein	2.43	0	0	0	0	0.05	0	0.06	0.02	0	0.08	0.7	0.11	0
x-Acrolein	0.45	0	0	0	0	0	0	0	0	0	0	0.32	0.05	0
Benzaldehyde	2.18	0.15	0	0.01	0.03	0.1	0	0.14	0.02	0	0.11	0.63	0.12	0
Tolualdehydes	2.8	0.27	0.04	0.05	0.04	0.16	0.03	0.21	0.06	0	0.18	0.88	0.19	0.02
2-Butanone	0.13	0	0	0	0	0	0	0	0	0.02	0.06	0.29	0.19	0
Methacrolein	0.91	0.06	0.01	0.02	0.03	0.05	0.02	0.05	0.04	0.03	0.09	0.46	0.14	0
Acetone	2.4	0.05	0	0.19	0	0.21	0	0.01	0	0	0.5	1.26	1.55	0
	9044	9045	9046	9047	9049	9050	9051	9052	9053	9054	9055	9056	9057	9058
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	4.25	4.19	1.81	12.67	5.01	2.05	2.53	3.21	2.54	1.78	5.97	0.62	1.85	21.15
Acetaldehyde	0	0.8	0.15	2.17	0.03	0.01	0	0.87	1.75	0	3.28	0.18	0.13	3.61
Acrolein	0	0.06	0	0.26	0	0	0	0.02	0.09	0	0.64	0.04	0.01	0.81
x-Acrolein	0	0.01	0	0.08	0	0	0	0.01	0.1	0	0.28	0	0	0.44
Benzaldehyde	0	0.18	0	0.31	0.04	0	0	0.11	0.29	0	0.67	0.04	0.01	1.03
Tolualdehydes	0.05	0.3	0.03	0.48	0.06	0.03	0.03	0.1	0.38	0.02	0.7	0.07	0.04	0.94
2-Butanone	0	0.02	0	0.09	0	0	0	0.04	0.01	0	0.15	0	0	0.14
Methacrolein	0.02	0.09	0.03	0.22	0.02	0.01	0.01	0.08	0.15	0.01	0.45	0.04	0.03	0.41
Acetone	0	0.17	0.02	0.63	0	0	0	0.23	0.44	0	0.74	0	0	0.89
	9059	9060	9061	9062	9063	9065	9066	9067	9068	9069	9070	9072	9073	9074
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	11.75	5.91	6.3	1.41	6.84	16.45	2.66	1.87	1.39	2.33	1.92	2.82	1.01	0.61
Acetaldehyde	0.68	0.05	0.72	0	0.37	2.71	0.54	2.01	0.51	0.58	0.7	1.14	0.05	0.13
Acrolein	0.02	0	0	0	0	0.13	0	0.08	0	0	0.06	0.11	0	0
x-Acrolein	0	0	0	0	0.07	0.1	0	0.06	0	0	0.01	0.04	0	0
Benzaldehyde	0.15	0	0	0	0.08	0.59	0.03	0.16	0.06	0.04	0.07	0.15	0	0
Tolualdehydes	0.25	0.06	0.02	0.01	0.07	0.66	0	0.2	0.03	0.02	0.07	0.14	0.01	0.01
2-Butanone	0	0.01	0	0	0.14	0.25	0.1	0.19	0.16	0.15	0.1	0.11	0	0
Methacrolein	0.08	0.02	0	0	0.02	0.16	0.01	0.13	0.02	0.01	0.02	0.06	0	0
Acetone	0.38	0.07	0.45	0	0.31	3.48	0.4	0.87	0.4	0.42	0.47	0.69	0.03	0.06
	9075	9076	9077	9078	9079	9080	9081	9082	9083	9084	9085	9086	9087	9088
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	3.81	0.51	2.77	1.15	5.43	1.9	1.61	0.26	2.15	2.97	2.07	1.76	0.6	6.6
Acetaldehyde	0.76	0.09	0.27	0.07	1.37	0.55	0.86	0.32	0.29	0.97	0.38	0.22	0.2	2.74

APPENDIX A

Table A-4. Summer Phase Aldehyde and Ketone Emission Data

Acrolein	0.03	0	0	0	0.09	0	0.1	0	0	0.04	0	0	0	0.18
x-Acrolein	0.01	0	0	0	0.15	0.03	0.1	0	0	0.06	0	0	0	0.2
Benzaldehyde	0.22	0	0.02	0	0.18	0.1	0.13	0.05	0.02	0.07	0.02	0	0	0.3
Tolualdehydes	0.23	0.01	0.03	0.01	0.29	0.17	0.17	0.05	0.05	0.14	0.05	0.01	0.01	0.38
2-Butanone	0	0	0	0	0.02	0.06	0.06	0	0	0	0.03	0	0	0.06
Methacrolein	0.05	0	0.01	0	0.13	0.07	0.12	0.03	0.02	0.07	0.04	0	0.01	0.18
Acetone	0.51	0.06	0.1	0.05	0.54	0.19	0.37	0.09	0.1	1.06	0.3	0.06	0.13	0.96
	9089	9090	9091	9092	9093	9094	9095	9096	9097	9098	9099	9100	9101	9102
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	1.76	0.6	6.43	6.76	6.56	51.11	123.19	87.65	7.37	1.66	1.98	2.2	0.21	3.18
Acetaldehyde	0.22	0.2	2.63	2.85	0.36	10.14	15.33	18.91	1.65	0.6	0.46	0.59	0.49	2.45
Acrolein	0	0	0.13	0.23	0	1.89	4.91	5.98	0.03	0.04	0	0	0	0.07
x-Acrolein	0	0	0.17	0.23	0.02	1.06	1.74	2.16	0.06	0.04	0.02	0	0	0.09
Benzaldehyde	0	0	0.32	0.27	0.11	1.67	4.49	2.83	0.14	0.08	0.07	0.06	0.03	0.2
Tolualdehydes	0.01	0.01	0.4	0.36	0.01	2	4.97	2.92	0.15	0.1	0.1	0.08	0.08	0.23
2-Butanone	0	0	0.08	0.04	0.05	0.11	0.68	0.48	0.1	0	0	0	0	0.09
Methacrolein	0	0.01	0.16	0.21	0.03	0.76	1.91	1.57	0.08	0.05	0.03	0.03	0.03	0.14
Acetone	0.06	0.13	1.03	0.89	0.15	1.81	5.86	4.13	0.71	0.25	0.25	0.3	0.29	0.92
	9103	9104	9105	9106	9107	9108	9109	9110	9111	9112	9113	9115	9116	9117
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	2.6	1.55	0.35	3.23	1.27	3.57	5	4.2	0.84	0.14	1.76	131.63	75.37	13.59
Acetaldehyde	1.35	0.38	0.24	1.27	0.57	2	2.83	3.28	0.17	0.25	1.21	20.63	9.34	0.53
Acrolein	0.08	0	0.04	0.08	0	0.03	0.4	0.18	0	0.02	0	7.99	2.76	0
x-Acrolein	0.14	0	0	0.15	0	0.03	0.5	0.12	0	0	0	1.73	0.95	0
Benzaldehyde	0.21	0.09	0	0.36	0.05	0.05	0.55	0.4	0	0.04	0.07	3.15	2.06	0.15
Tolualdehydes	0.29	0.14	0.03	0.35	0.08	0.06	0.62	0.37	0	0.01	0.12	4.04	2.35	0.23
2-Butanone	0.08	0	0	0.1	0.12	0.09	0.17	0.27	0	0.09	0.14	1.08	0.54	0
Methacrolein	0.13	0.03	0.02	0.1	0.04	0.05	0.3	0.23	0	0.02	0.04	2.62	0.96	0.03
one	0.65	0.21	0.14	0.6	0.37	1.61	0.76	2.04	0.11	0.13	0.66	5.06	2.09	0.28
	9118	9119	9120	9121	9122	9123	9124	9126	9127	9128	9129	9130		
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile		
Formaldehyde	4.55	1.72	30.33	12.61	3.85	13.46	4.87	2.5	1.29	1.89	1.05	3.16		

APPENDIX A

Table A-4. Summer Phase Aldehyde and Ketone Emission Data

Acetaldehyde	0.23	0.34	7.04	0.24	0.42	4.41	1.3	0.4	0.17	0.19	0.29	0.32		
Acrolein	0	0	1.03	0	0	0.64	0.17	0.02	0	0	0	0		
x-Acrolein	0	0	0.68	0	0	0.44	0.05	0	0	0	0	0.06		
Benzaldehyde	0.08	0	1.13	0.17	0.09	0.56	0.19	0.01	0	0.09	0.01	0.09		
Tolualdehydes	0.02	0.01	1.45	0.05	0.04	0.77	0.28	0.01	0	0.03	0.02	0.05		
2-Butanone	0.11	0	0.44	0	0.12	0.08	0.01	0	0.01	0	0	0.06		
Methacrolein	0	0.04	0.79	0.03	0.06	0.38	0.12	0.02	0	0.02	0.02	0.02		
Acetone	0.14	0.18	3.85	0.2	0.25	1.1	0.68	0.19	0.21	0.17	0.2	0.38		

APPENDIX A

Table A-5. Duplicate Runs Average

Table A-5. Duplicate Runs Average, Winter

	99029	99529	avg	99034	99534	avg	99035	99535	avg	99040	99540	avg
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	27.05	7.98	17.51	4.16	7.87	6.01	160.61	143.67	152.14	27.38	14.79	21.09
Acetaldehyde	2.29	1.57	1.93	0.65	0.05	0.35	13.82	11.03	12.43	7.99	1.65	4.82
Acrolein	0.17	0	0.09	0	0	0	4.77	3.44	4.11	0.85	0	0.42
x-Acrolein	0.22	0.12	0.17	0	0	0	1.61	1.37	1.49	0.7	0.04	0.37
Benzaldehyde	0.52	0.22	0.37	0.19	0.04	0.12	4.59	3.77	4.18	0.84	0.09	0.46
Tolualdehydes	0.78	0.4	0.59	0.29	0.08	0.18	5.52	4.48	5	1.03	0.13	0.58
2-Butanone	0.16	0.07	0.12	0.12	0.14	0.13	0.6	0.51	0.55	0.65	0.21	0.43
Methacrolein	0.16	0.09	0.13	0.03	0	0.01	1.67	1.39	1.53	0.55	0.08	0.31
Acetone	1.1	0.6	0.85	0.3	0.17	0.24	4.62	3.77	4.19	3.17	1.3	2.24
	99045	99545	avg	99051	99551	avg	99055	99555	avg	99056	99556	avg
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	10.2	23.86	17.03	4.91	1.48	3.2	7.63	22.29	14.96	2.77	4.04	3.4
Acetaldehyde	0.74	0.62	0.68	0.24	0.02	0.13	1.26	0.24	0.75	0.8	0.35	0.58
Acrolein	0	0.11	0.06	0	0.12	0.06	0	0.11	0.05	0	0.1	0.05
x-Acrolein	0.05	0.04	0.05	0.02	0.01	0.01	0	0	0	0.12	0.04	0.08
Benzaldehyde	0.06	0.06	0.06	0.18	0.08	0.13	0.09	0.04	0.07	0.12	0.08	0.1
Tolualdehydes	0.08	0.09	0.09	0.28	0.15	0.21	0.14	0.06	0.1	0.16	0.09	0.12
2-Butanone	0.04	0.03	0.04	0.01	0.03	0.02	0.03	0.14	0.08	0.03	0.03	0.03
Methacrolein	0	0.03	0.02	0	0	0	0	0.05	0.03	0.04	0	0.02
Acetone	0.29	0.27	0.28	0.25	0.17	0.21	0.2	0.2	0.2	0.38	0.16	0.27
	99060	99560	avg	99563	99063	avg	99066	99566	avg	99070	99570	avg
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	0.92	0.85	0.88	26.54	20.69	23.61	9.6	8.25	8.93	205.61	216.23	210.92
Acetaldehyde	0.17	0.23	0.2	0.86	0.66	0.76	1.6	0.13	0.86	20.8	22.06	21.43
Acrolein	0	0.09	0.05	0.09	0.07	0.08	0	0.08	0.04	4.48	3.95	4.22
x-Acrolein	0.08	0.03	0.06	0.15	0.2	0.17	0.18	0	0.09	3.09	3.1	3.1
Benzaldehyde	0.11	0.08	0.09	0.08	0.09	0.08	0.32	0.09	0.2	4.27	4.68	4.48
Tolualdehydes	0.15	0.05	0.1	0.02	0.03	0.03	0.42	0.12	0.27	5.34	5.37	5.36
2-Butanone	0.02	0.05	0.03	0.05	0.03	0.04	0.04	0.04	0.04	0.96	1.09	1.03

APPENDIX A

Table A-5. Duplicate Runs Average, Winter

Methacrolein	0.05	0	0.02	0	0.04	0.02	0.03	0	0.02	1.97	1.8	1.88
Acetone	0.15	0.18	0.17	0.23	0.21	0.22	0.61	0.14	0.37	5.76	6.37	6.06
	99571	99071	avg	99076	99576	avg	99081	99581	avg	99082	99582	avg
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	2.57	13.31	7.94	27.07	27.39	27.23	8.39	17.7	13.04	6.04	11	8.52
Acetaldehyde	0.07	1.7	0.88	4.09	3.98	4.04	0.06	0.21	0.14	0	0.03	0.02
Acrolein	0	0.06	0.03	0.31	0.31	0.31	0	0	0	0	0	0
x-Acrolein	0.01	0.22	0.11	0.58	0.68	0.63	0.02	0	0.01	0	0.01	0.01
Benzaldehyde	0.09	0.34	0.21	0.62	0.64	0.63	0.03	0.01	0.02	0.03	0.02	0.03
Tolualdehydes	0.18	0.48	0.33	0.84	0.79	0.82	0.05	0.05	0.05	0.06	0.06	0.06
2-Butanone	0.04	0.13	0.09	0.18	0.23	0.2	0	0	0	0.03	0.01	0.02
Methacrolein	0	0.16	0.08	0.37	0.29	0.33	0	0	0	0	0	0
Acetone	0.15	0.64	0.39	1.1	1.2	1.15	0	0	0	0	0	0
	99086	99586	avg	99090	99590	avg	99091	99591	avg	99096	99596	avg
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	1.77	1.66	1.72	137.89	144.33	141.11	2.32	3.2	2.76	54.49	74.19	64.34
Acetaldehyde	0.24	0	0.12	15.96	16.58	16.27	0.05	0.25	0.15	7.33	8.14	7.74
Acrolein	0	0.02	0.01	3.63	3.3	3.46	0	0	0	0.96	0.96	0.96
x-Acrolein	0.01	0	0	2.28	2.36	2.32	0.03	0.09	0.06	1.67	1.82	1.74
Benzaldehyde	0.02	0.01	0.01	2.62	2.56	2.59	0.07	0.07	0.07	1.32	1.51	1.42
Tolualdehydes	0.06	0.03	0.04	3.51	3.45	3.48	0.13	0.12	0.13	1.91	2.23	2.07
2-Butanone	0.03	0	0.01	0.74	0.8	0.77	0.01	0	0	0.4	0.48	0.44
Methacrolein	0	0	0	1.61	1.5	1.55	0.01	0.01	0.01	0.78	0.81	0.79
Acetone	0.01	0	0.01	3.73	3.88	3.8	0.01	0.01	0.01	2.22	2.47	2.35
	99100	99600	avg	99101	99601	avg	99106	99606	avg	99110	99610	avg
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	24.83	39.17	32	5.36	6.32	5.84	34.92	50.07	42.49	27.86	42.83	35.35
Acetaldehyde	0.81	0.8	0.8	0.17	0.11	0.14	3.82	5.3	4.56	2.93	2.94	2.94
Acrolein	0	0	0	0	0	0	0.27	0.52	0.39	0.26	0.38	0.32
x-Acrolein	0.02	0.03	0.03	0.02	0.01	0.01	0.61	0.98	0.79	0.62	0.79	0.71
Benzaldehyde	0.01	0.03	0.02	0.03	0.02	0.02	0.37	0.68	0.52	0.71	0.65	0.68
Tolualdehydes	0.04	0.07	0.05	0.02	0.05	0.04	0.51	1.03	0.77	0.96	0.78	0.87
2-Butanone	0.09	0.02	0.05	0.07	0.02	0.04	0.12	0.16	0.14	0.12	0.1	0.11

APPENDIX A

Table A-5. Duplicate Runs Average, Winter

Methacrolein	0.02	0.02	0.02	0	0	0	0.25	0.43	0.34	0.42	0.41	0.41
Acetone	0.27	0.26	0.27	0.15	0.08	0.11	1.17	1.22	1.2	1.17	1.06	1.12
	99116	99616	avg	99120	99620	avg	99121	99621	avg			
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile			
Formaldehyde	2.39	7.6	4.99	3.19	1.57	2.38	1.08	1.53	1.31			
Acetaldehyde	0.16	0	0.08	0	0.09	0.04	0.37	0.9	0.63			
Acrolein	0	0	0	0	0	0	0.03	0.07	0.05			
x-Acrolein	0.01	0.01	0.01	0.02	0	0.01	0.03	0.06	0.04			
Benzaldehyde	0.02	0.01	0.01	0.02	0	0.01	0.03	0.08	0.06			
Tolualdehydes	0.04	0.02	0.03	0.07	0.01	0.04	0.03	0.08	0.06			
2-Butanone	0	0	0	0	0	0	0	0	0			
Methacrolein	0	0	0	0	0	0	0.01	0.03	0.02			
Acetone	0	0	0	0	0	0	0.02	0.21	0.12			

Table A-5. Duplicate Runs Average, Summer

	9018	9019	avg	9027	9028	avg	9027	9028	avg	9063	9064	avg
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile
Formaldehyde	1.49	0.32	0.9	4.08	5.89	4.98	15.41	9.92	12.67	4.23	9.46	6.84
Acetaldehyde	0	0	0	0.73	0.42	0.57	3.15	1.2	2.17	0.11	0.62	0.37
Acrolein	0	0	0	0	0	0	0.39	0.13	0.26	0	0	0
x-Acrolein	0	0	0	0	0	0	0.13	0.03	0.08	0	0.14	0.07
Benzaldehyde	0	0	0	0.09	0.05	0.07	0.48	0.15	0.31	0.01	0.15	0.08
Tolualdehydes	0	0	0	0.09	0.14	0.12	0.71	0.26	0.48	0.07	0.07	0.07
2-Butanone	0	0	0	0.03	0	0.01	0.14	0.04	0.09	0	0.28	0.14
Methacrolein	0.02	0.02	0.02	0.06	0.03	0.04	0.3	0.15	0.22	0.01	0.03	0.02
Acetone	0	0	0	0.22	0.05	0.13	0.96	0.31	0.63	0.1	0.52	0.31
	9070	9071	avg	9091	9092	avg						
Compound	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile	mg/mile						
Formaldehyde	1.78	2.05	1.92	6.43	6.76	6.6						
Acetaldehyde	0.63	0.77	0.7	2.63	2.85	2.74						
Acrolein	0	0.12	0.06	0.13	0.23	0.18						
x-Acrolein	0	0.03	0.01	0.17	0.23	0.2						
Benzaldehyde	0.05	0.09	0.07	0.32	0.27	0.3						

APPENDIX A

Tolualdehydes	0.04	0.1	0.07	0.4	0.36	0.38						
2-Butanone	0.1	0.1	0.1	0.08	0.04	0.06						
Methacrolein	0.02	0.03	0.02	0.16	0.21	0.18						
Acetone	0.46	0.48	0.47	1.03	0.89	0.96						

APPENDIX A

Table A-6. Duplicate Runs of Regulated Emissions

Winter Phase													
		HC			CO			NOx			CO2		
		gm/mile			gm/mile			gm/mile			gm/mile		
YR	MAKE	#1	#2	ave	#1	#2	ave	#1	#2	ave	#1	#2	ave
75	FORD	9.64	10.04	9.84	165.39	180.75	173.07	4.41	3.35	3.88	492.96	468.36	480.66
84	CHEVY	5.05	5.92	5.48	99.70	110.80	105.25	2.63	2.58	2.61	631.81	609.65	620.73
85	FORD	2.43	2.26	2.34	15.45	16.34	15.89	0.58	0.59	0.58	145.56	137.60	141.58
85	CHEVY	0.59	0.90	0.74	2.68	1.78	2.23	2.16	1.86	2.01	662.44	664.52	663.48
85	FORD	5.76	5.93	5.85	75.66	79.28	77.47	3.66	4.09	3.87	526.64	523.77	525.20
86	FORD	1.05	1.38	1.22	6.32	9.32	7.82	4.21	4.06	4.13	363.15	380.55	371.85
86	TOYOTA	0.88	0.57	0.72	8.30	7.16	7.73	0.99	0.64	0.81	341.21	328.22	334.71
87	HONDA	0.31	0.27	0.29	2.09	2.90	2.50	2.85	2.64	2.75	304.08	312.36	308.22
87	CHEVY	0.34	0.21	0.28	4.60	2.38	3.49	1.58	1.13	1.35	400.71	399.89	400.30
87	PLYMOUTH	1.47	1.03	1.25	25.44	21.41	23.43	1.05	0.84	0.95	338.07	322.71	330.39
87	TOYOTA	1.73	1.64	1.68	8.22	8.63	8.42	3.68	3.81	3.74	248.68	260.88	254.78
87	DODGE	0.06	0.06	0.06	0.54	0.38	0.46	5.42	4.62	5.02	410.58	385.27	397.92
88	PONTIAC	0.91	0.84	0.87	6.56	9.27	7.92	0.98	0.86	0.92	419.39	407.97	413.68
89	FORD	0.31	0.11	0.21	2.96	3.02	2.99	0.43	0.54	0.49	374.50	383.01	378.75
90	TOYOTA	0.35	0.12	0.23	7.83	3.31	5.57	0.92	0.95	0.93	331.30	329.22	330.26
90	FORD	1.22	0.53	0.87	8.74	1.47	5.11	1.60	1.43	1.51	462.01	461.77	461.89
90	OLDS	0.29	0.32	0.31	5.60	7.17	6.38	1.95	1.64	1.80	491.58	493.33	492.45
91	ACURA	0.36	0.29	0.33	2.56	2.27	2.41	0.12	0.09	0.11	423.46	396.42	409.94
92	FORD	0.15	0.19	0.17	1.52	1.16	1.34	2.09	2.03	2.06	399.09	391.07	395.08
92	BUICK	0.37	0.89	0.63	12.88	26.08	19.48	1.22	1.82	1.52	420.11	408.99	414.55
93	FORD	0.40	0.28	0.34	1.04	0.55	0.79	1.25	1.45	1.35	544.89	550.23	547.56
93	ISUZU	0.51	0.21	0.36	7.94	8.51	8.22	3.08	2.72	2.90	501.54	516.03	508.78
93	FORD	0.30	0.16	0.23	5.52	3.34	4.43	1.42	1.08	1.25	502.42	475.83	489.13
93	CHEVY	0.33	0.18	0.25	4.59	3.04	3.82	1.18	0.75	0.96	311.24	315.88	313.56
94	BUICK	0.03	0.03	0.03	1.34	0.85	1.10	0.62	0.53	0.57	503.73	491.24	497.48
95	FORD	0.37	0.23	0.30	5.42	4.93	5.18	1.05	1.44	1.25	398.20	405.18	401.69
95	FORD	0.14	0.02	0.08	2.10	1.75	1.93	0.75	0.56	0.66	443.09	418.06	430.57
96	CHEVY	0.18	0.15	0.17	1.52	0.99	1.26	0.26	0.37	0.31	456.26	546.21	501.24
96	FORD	0.16	0.20	0.18	1.54	3.78	2.66	0.75	0.68	0.72	353.41	360.76	357.09
Summer Phase													
		HC			CO			NOx			CO2		
		gm/mile			gm/mile			gm/mile			gm/mile		
YR	MAKE	#1	#2	ave	#1	#2	ave	#1	#2	ave	#1	#2	ave
86	BUICK	0.78	0.24	0.51	7.65	6.25	6.95	4.22	3.17	3.69	339.46	323.00	331.23
87	CHEV	0.38	0.53	0.46	5.02	9.54	7.28	1.99	1.98	1.98	318.92	313.05	315.98
87	TOYOTA	0.33	0.28	0.31	0.65	0.31	0.48	0.92	0.89	0.91	296.95	302.60	299.78
87	CHEVY	1.04	1.31	1.18	50.43	78.19	64.31	3.29	3.01	3.15	511.88	495.49	503.68
88	FORD	0.12	0.20	0.16	4.00	3.46	3.73	0.52	0.42	0.47	339.64	347.27	343.46
92	CHEV	0.36	0.32	0.34	5.29	6.99	6.14	1.49	1.49	1.49	363.39	355.93	359.66

APPENDIX A

Table A-7. Duplicate PM10 Runs, Winter Phase

PM10, mg/mile		
run #1	run #2	Ave
2.12	6.69	4.40
3.10	5.41	4.26
3.75	3.65	3.70
32.23	58.97	45.60
21.52	25.47	23.49
29.03	25.09	27.06
16.87	34.72	25.80
53.72	54.46	54.09
2.98	1.51	2.24

Table A-8. Comparison of Cars PM10 to Truck PM10

Category	Season	# Cars	# Trucks	PM10 cars, mg/mi	PM10 trucks, mg/mi
93-97	Summer	22	14	4.11	5.37
93-97	Winter	21	19	6.10	9.65
90-92	Summer	16	9	4.21	7.35
90-92	Winter	11	9	9.82	41.91
85-89	Summer	24	14	6.20	9.22*
85-89	Winter	27	8	25.26	28.33
Pre-85	Summer	6	4	28.73	5.88
Pre-85	Winter	13	9	55.36	89.66

* two high emitters (96.95 and 300.05 mg/mile) excluded from the average

NERL-RTP-O-659

TECHNICAL REPORT DATA

1. REPORT NO. EPA/600/R-99/090	2.	3.

4. TITLE AND SUBTITLE Central Carolina Vehicle Particulate Emission Study	5. REPORT DATE 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Kenneth T. Knapp, Silvestre Tejada, Steven H. Cadle, Douglas R. Lawson , and Richard Snow	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS US EPA, RTP, NC 27711, CAVTC, RTP, NC 27711, GM R&D, Warren MI 48090, NREL, Golden CO 80401, and Coordinating Research Council, Atlanta GA 30346	10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS same as 9	13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

A vehicle emission study was carried out in the Research Triangle Park area of North Carolina to determine the PM emission rates and emissions profiles of the fleet of in-use vehicles in central Carolina. The NERL transportable dynamometer was set-up in the parking lot of Home Depot in Cary, NC. Vehicles from the general area were recruited and tested for their particulate and gaseous emissions. The study was divided into two phase, a winter phase and a summer phase. In the winter phase, 121 gasoline fueled vehicles were tested in Cary and 14 gasoline fueled and three diesel fueled vehicles were tested at the NERL, cold cell dynamometer located in the ERC annex at 35°F. In the summer phase all vehicles were tested on the transportable dynamometer in Cary. A total of 120 gasoline fueled and five diesel fueled vehicles were tested in the summer. Samples were collected for all tests for PM 10 [both for mass, and carbon analyses (elemental and organic)], regulated gaseous emissions [carbon monoxide (CO), total hydrocarbons (HC), and oxides of nitrogen (NOx)] and aldehydes. On some vehicle, tests for PM2.5, organic speciation, and samples for semi- and non-volatile organics were collected. The PM emissions rate was very close to that found in the Denver NFRAQS at 32 mg/mile in the winter and 34 mg/mi in the summer. The Denver study had a PM emission rate of 33.7 mg/mi. In the winter study the PM10 and 2.5 were almost identical at 32.8 and 32.5 mg/mi. The eight diesel fueled vehicles had a much higher emission rate at 1781 mg/mi.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/ OPEN ENDED TERMS	c. COSATI
18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES
	20. SECURITY CLASS *(This Page)* UNCL;ASSIFIED	22. PRICE