STUDY TO DEFINE COLD AND HOT START EMISSIONS FINAL INVESTIGATIVE REPORT

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EXECUTIVE SUMMARY

The objective of this study is to collect emissions test data and other vehicle related parameters that can be utilized to improve the capability of the California Air Resources Board's emission inventory model, EMFAC. Specifically, the data will enhance the model's ability to estimate start emissions under real-world conditions which are not included in the current methodology. Data collected in this study will be analyzed in depth by the ARB staff to determine the effect of engine cranking, catalyst light-off and cool-down times, engine-off duration, driving mode, and fuel type on start emissions at different ambient temperatures.

Until recently, emissions data for estimating start emissions were collected by testing vehicles over the Federal Test Procedure (FTP). Start emissions were calculated using the three bags of the FTP, i.e., bag 1 (cold start), bag 2 (stabilized), and bag 3 (hot start). However, this method has since been reevaluated by the ARB and found inadequate for modeling starts.

The FTP, developed over two decades ago, includes a series of accelerations, decelerations, idles, and cruises originally intended to simulate a typical trip. However, contemporary driving patterns involve conditions not encountered during the FTP. In ARB's previous methodology, cold start emissions of a catalyst-equipped vehicle were calculated using bag 1 (performed after an overnight soak), and were applied to all cold soaks greater than 60 minutes. Similarly, hot start emissions, calculated using bag 3 (performed after a 10 minute soak), were applied to all hot starts less than 60 minutes. Recent studies by the ARB instead indicate that start emissions are best modeled as a continuous function of soak time. The ARB has since revised the start emissions calculations methodology in an attempt to address these inadequacies.

The purpose of this project is to supplement data used for the revised methodology by testing vehicles of various ages and technologies at various engine-off times and driving modes. In addition, this project required testing vehicles with different fuels and under different ambient temperatures not required by the FTP. The results will be used to estimate what effects various fuel formulations and temperature combinations may have on start emissions. Overall, the shortcomings of the current methodology will be addressed and will thus improve the ARB's capability for modeling emission factors related to starts.

Ten in-use California certified vehicles were procured by the contracting laboratory for the test program. These vehicles were selected to represent various technologies including engine size, emission control systems, and fuel delivery systems. The vehicles were tested on four fuels (Summer Pre 1992, Winter Pre 1992, Summer Phase II, Winter Phase II), at three different ambient temperatures (50°F, 75°F, 100°F), and for 15 scenarios (cycle/soak period combinations). All ten vehicles were tested over three cycles - the FTP, Unified Cycle, and a Special Start Cycle.

HC, CO, NO_x, and CO_2 emissions data, as well as catalyst skin and coolant temperatures, were recorded at a one second sampling rate for each test sequence. Bag specific mass data was provided for all test cycles, in addition to the second by second modal data. Speciation of exhaust hydrocarbons, air toxins, aldehydes and oxygenates was performed for two vehicles, tested on one fuel/temperature combination and two soak periods. In addition to the complete set of tests, the contractor performed ten replicate tests to verify the validity of the data.

In general, analyses of the data indicates that start emissions increase with increasing soak time. There appears to be no fuel effect; however, there is evidence of an effect with respect to ambient temperature. Catalyst type and fuel delivery system can also effect start emissions, especially for HC. In addition, there is a clear correlation between coolant temperature and start emissions for HC and CO. NOx emissions also have a similar trend, but are better characterized by the temperature of the catalyst. These effects of catalyst and coolant temperatures are strongest for fuel-injected vehicles. Finally, the driving events taking place immediately after start-up can influence the emissions associated with that start. For this reason, a test cycle which is representative of real world driving conditions occurring upon start-up procedures should be developed.

I. INTRODUCTION

As an on-going effort to improve the capability of the state of California's emission inventory model, EMFAC, the Air Resources Board continues to investigate the methodology used to calculate start emissions. Motor vehicle emission factor models such as EMFAC have been developed around the FTP. The FTP is a driving cycle of approximately 11.0 miles in length with an average speed of 19.6 miles per hour. During the test, the vehicle is exercised over a series of accelerations, decelerations, idles, and cruises designed to simulate a typical trip in an urban area. The cycle consists of three parts: cold start (bag 1), stabilized or running portion (bag 2), and hot start (bag 3).

While the cycle was designed to represent typical vehicle operating conditions, recent studies[1] have shown its inadequacies in modeling present driving conditions. The FTP driving cycle was developed over 20 years ago and was modified to accommodate the limitations of the dynamometers used at the time. The Unified Cycle (UC) was recently developed in an attempt to more accurately represent today's real-world driving patterns. The cycle includes harder acceleration/deceleration rates as well as higher speed excursions. Its use in this program provided a more contemporary account of driving events occurring during start-up procedures. In addition, comparing the results of different cycles tested in the program will provide data showing the effects that driving modes may have on start emissions.

Until recently, start emissions were calculated by the ARB as the difference in emissions between bag 1 and bag 2 of the FTP for cold starts, and between bag 3 and bag 2 for hot starts. It was previously assumed that the only difference between these modes were start emissions and speed. Therefore, bag 2 was speed corrected to the same speed as bags 1 and 3. A cold start was defined as a start that occurred after one hour or more since the engine was last turned off for a catalyst-equipped vehicle, and after four hours or more for a non-catalyst vehicle. A hot start was defined as a start occurring after a soak time (non-operating time) of less than one hour for a catalyst-equipped vehicle and less than four hours for a non-catalyst vehicle.

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[1] Robert Gammariello and Jeffrey Long, *An Emissions Comparison Between the Unified Cycle and the Federal Test Procedure*, AWMA Technical Paper, 1993.

After conducting extensive studies and test programs, staff of the ARB determined that the methodology and definitions for start emissions used in previous versions of EMFAC were inadequate. For example, cold start emissions of a catalyst-equipped vehicle were calculated using bag 1 (performed after an overnight soak), and were applied to all cold soaks greater than 60 minutes. Similarly, hot start emissions, calculated using bag 3 (performed after a 10 minute soak), were applied to all hot starts less than 60 minutes. The studies performed by the ARB, however, indicate that start emissions are a continuous function of soak time. This study will supply data for various soak periods between 0 minutes and 12 hours which will not only supplement data previously collected to create these soak functions; but will also assist in characterizing the soak functions with respect to ambient temperature, fuel type, and cycle.

Furthermore, by collecting second-by-second emissions and catalyst temperature data, the results of this study will help determine the effect that engine cranking, catalyst light-off and cool-down times, and engine-off duration have on start emissions.

II. PROJECT DESCRIPTION

A. Test Vehicles

Specifications for the test fleet were provided by the ARB in the Request for Proposal (RFP) entitled, "Study to Redefine Cold- and Hot-Start Emissions". The vehicles were described in terms of specific vehicle configuration requirements defined by certain technology types. The technology types specified by ARB included minimum requirements for the catalytic converter type and location, the fuel control system and the number of cylinders. The RFP required that the vehicles be representative of the categories listed in Table II-1.

Table II-1. Vehicle Technologies required by RFP

QUANTITY	CATALYST TYPE	NO. CYLINDERS	FUEL SYSTEM
1	none	*not specified*	*not specified*
1	oxidation	6 or 8	*not specified*
1	twc	4	carb
1	twc	4	fuel inj
1	twc	6 or 8	carb
1	twc	6 or 8	fuel inj
1	twc (cc or wu)	4	carb
1	twc (cc or wu)	4	fuel inj
1	twc (cc or wu)	6 or 8	carb
1	twc (cc or wu)	6 or 8	fuel inj

* twc - Three-way catalyst
cc or wu - Close-coupled or Warm-up catalyst equipped
carb - carbureted
fuel inj - fuel injected

The vehicles were selected for procurement by a subcontractor using the appropriate selection criteria. The criteria were based on both the requirements of the RFP and the contractor's procurement qualification and repair plan.

The criteria used for test vehicle selection was as follows:

- Representative of specified technology type
- Must be in-use and CA-certified
- Exhibits reasonable maintenance efforts
- Odometer reading between 8,000 - 12,000 miles/year
- Vehicle must be within 2x applicable emissions standards for HC, CO, and NO_x

Vehicle accrual rates and maximum baseline emissions criteria were used to ensure that the vehicle test fleet for the project was representative of the vehicle test fleet included in EMFAC. In addition, emissions criteria was used to ensure that all vehicles being procured (excluding the non-catalyst vehicle) were equipped with normal working catalysts.

In order to meet the requirements of the various technology types, the procurement subcontractor performed a literature search, utilized personal contacts with vehicle manufacturers and conducted field inspections to develop a list of candidate vehicles. In some instances, the ARB staff provided names of engine families which identified specific vehicles meeting the criteria. Upon approval by ARB staff, an effort was initiated to locate candidate vehicles. If a vehicle type satisfying the criteria was identified during the search, ARB was contacted for approval.

Once final approval was obtained, the procurement subcontractor would then provide an appropriate monetary incentive to the owner for use of the vehicle in the screening process. The vehicle was then inspected by the Vehicle Emission Laboratory (VEL) program mechanic for safety and emission systems integrity. A hot start (Bag 1 of the FTP), and a modified FTP test were performed on the vehicle to provide an indication that the vehicle was likely to meet the 2x base certification standard criterion. This screening test was performed, as received, with no fuel drain/fill or formal prep procedure. If the screening test produced results that were close to the 2x standard, the ARB staff was notified and approval was obtained, by phone, for the vehicle's inclusion into the program.

Upon procurement, a complete mechanical inspection was performed which included checking the condition of the components, maintenance records (if available), and inspecting the vehicle for signs of possible tampering. In addition, the air cleaner, spark plugs, vehicle timing, and coolant level were checked. Non-emission related components were replaced as necessary, with ARB approval. A safety check was also performed that included tires, transmission, engine function, and brakes. A copy of the mechanical inspection for each vehicle was submitted to ARB, as requested, along with initial test results for each vehicle (Appendix A). No restorative maintenance to the emission control system was allowed by the ARB as it would directly effect the exhaust emissions of the vehicle; thereby invalidating it as representative of a typical in-use vehicle.

A formal qualification test was then performed which included fuel drain and 40% fill with test fuel, preconditioning using the Urban Dynamometer Driving Schedule (UDDS), and a minimum 12 hour cold soak. An FTP was then performed to determine if the vehicle would qualify for acceptance into the program with an emission test result of $\leq$ 2x the base certification standard.

If the emission results were within tolerances, ARB staff was notified by phone of these results and then made the final determination for acceptance into the program. A total of ten vehicles were obtained; six procured by the contractor, and four provided by the ARB. A description of the resulting test fleet is included in Table II-2.

Table II-2. Vehicle Test Fleet

VEH NO.	MODEL YR	MAKE / MODEL	FUEL SYSTEM	NO. CYLINDERS	CATALYST TYPE	ODOMETER
1	1987	Ford Tempo	fuel inj	4	twc	102,500
2	1996	Honda Accord	fuel inj	4	twc (wu)	18,189
3	1972	GM Chevrolet Impala	carb	8	none	168,065
4	1978	GM Chevrolet Nova	carb	6	oxi	133,483
5	1987	GM Chevrolet Nova	carb	4	twc	106,006
6	1992	Ford Taurus	fuel inj	6	twc	39,128
7	1991	Toyota Camry	fuel inj	4	twc (wu)	44,777
8	1985	Oldsmobile Toronado	carb	8	twc	72,313
9	1990	Honda CRX	fuel inj	4	twc (wu)	52,312
10	1996	Nissan Maxima	fuel inj	6	twc (wu)	11,143

* twc - Three-way catalyst
cc or wu - Close-coupled or Warm-up catalyst equipped
carb - carbureted
fuel inj - fuel injected

While efforts were made to obtain vehicles matching the requirements set in the RFP, not all vehicle types were satisfied. Procurement of the carbureted, close-coupled or warm-up catalyst-equipped vehicles were difficult due to the fact that carburetor technology was being phased out as close-coupled technology was being introduced. For this reason, the ARB decided to replace these vehicles with those of other technology types. In the initial process of procurement, a 4-cylinder, carbureted, three-way catalyst equipped vehicle was procured to increase the number of carbureted vehicles in the test fleet. However, the vehicle was subsequently disqualified in the middle of testing due to mechanical problems. The ARB opted to procure two newer technology vehicles equipped with a close-coupled or warm-up catalyst. These changes resulted in the vehicle breakdown listed in Table II-2.

In order to successfully complete the program, it was necessary to perform repairs on some of the vehicles during the testing sequence. ARB personnel were notified and approval was obtained prior to any vehicle repair. A list of repairs is summarized in Table II-3, and is further explained in Appendix B.

Table II-3. Vehicle Repairs

VEHICLE NO.	VEHICLE	REPAIR
01	1987 Ford Tempo	Radiator replaced Muffler replaced Water pump belt replaced Water pump replaced
03	1972 Chevrolet Impala	Transmission detent cable replaced
04	1978 Chevrolet Nova	Rear brakes adjusted and linings sanded
10	1996 Nissan Maxima	"Service Engine" light "vent control valve" code detected, codes cleared

The vehicles' batteries, tires and fluid levels were periodically checked throughout the program and serviced as necessary. VEL personnel accompanied any vehicle that needed to be taken off of GM property to ensure that the integrity of the vehicle remained intact.

B. Test Fuels

The project required procurement of four test fuels consisting of winter and summer grades of both Pre-1992 (CA average) fuel and current Phase II oxygenated fuel. VEL worked with ARB personnel to determine the desired characteristics of the fuels. The fuels were to be representative of actual in-use commercial fuels, as opposed to specialized emission test fuels.

The Pre-92 average fuels were blended by Phillips Petroleum per the ARB supplied specifications. The oxygenated Phase II fuels were supplied out of stock from a batch blended by Phillips for ARB field trials.

The fuels were supplied in 55 gallon drums which were stored throughout the project in a temperature controlled enclosure at the contractor's facility.

Significant attention was given to fuel handling procedures to ensure the proper fuel was used at the proper time. Upon receipt, all barrels were clearly labeled with painted identification of the fuel type and barrel number. A key factor in the nested randomization scheme was to require the utilization of only one fuel type at a time. This minimized fuel handling and the potential for error during each test block in that only one fuel type was available in the fueling area at any given time. The fuel barrels were kept in the temperature controlled fuel shed and brought into the test facility one barrel at a time on an as needed basis.

Vehicle run sheets included instructions for fuel drain/fill, preconditioning, and test procedures. These run sheets clearly identified the fuel type to be used. The operator was required to enter the fuel type and barrel used on the form. Due to the extensive number of tests required for a vehicle in a given block, the fuel tank was filled to 75% capacity in order to eliminate the need for refueling during the test sequence.

Fuel analyses were performed at the beginning, mid-point, and at the completion of testing to ensure that the fuel had not degraded during the project. These analyses were performed by a combination of facilities including a testing laboratory affiliated with the contractor, a local independent facility, and the ARB at their Haagen Smit laboratory in El Monte. Initial fuel analysis data and actual samples of each fuel were supplied to ARB for review and approval prior to the initiation of testing. Fuel samples were also provided to ARB at the mid-point and at the completion of testing. Fuel analysis results for the entire project is included in Table II-4.

The following fuel sampling procedures were followed in order to standardize the conditions and minimize the possibilities of tainting the results.

- Barrels opened only at room temperature or cooler
- Designated or new sampling hoses used
- Sample taken from midpoint of drum
- Sample dispensed to the bottom of the sample container to minimize splashing
- Recapping the drum and sample container as soon as possible

During the course of the project some variability was encountered in fuel analysis results at different facilities and between techniques used to determine various fuel parameters. To provide consistency with the ARB laboratory, gas chromatography (GC) results for olefins, aromatics, benzene and MTBE were used by the contractor laboratory during the project.

Initial tests performed by the contractor on the Winter Phase II fuel showed sulfur levels which were inconsistent with the other laboratories. These levels did not comply with the fuel specifications required by ARB as a valid Phase II fuel. However, based on initial specifications given by the supplier, and the results of the fuel analysis performed at ARB, the fuel was deemed valid and was subsequently accepted for the program. Using the GC method in analyzing olefins, aromatics, benzene and MTBE provided consistent results throughout the program for those parameters. However, the contractor could not determine the reason for the consistently higher sulfur results.

During the initial analysis, trace levels of MTBE near the level of detection were reported in one of the samples of pre-92 fuel. Subsequent analysis of the same fuel showed no MTBE detected. Sulfur results from the contractor laboratory for the summer Phase II fuel showed a large increase from initial levels to the mid-point. However, analysis at the final test point confirmed the initial results, and analyses conducted at the ARB's laboratory showed no significant variability in sulfur for the same fuel. In general, the fuel analyses performed by the laboratories throughout the entire test program verified the stability of all fuels.

Table II-4. Fuel Specifications and Analyses

	Specifications	WINTER PH II							Specifications	SUMMER PH II							
	PH II Winter	Phillips cert	GM_1	ARB_1	GM_2	ARB_2	GM_3	ARB_3	**PH II Summer**	Phillips	GM_1	Saybolt	ARB_1	GM_2	ARB_2	GM_3	ARB_3
RVP (psi)	11 - 12	11.2	11.3	11.2	11.0	10.7	11.4	10.7	6.7 - 7.0	7.0	7.0		6.9	7.4	6.8	7.4	6.8
T50 (deg F)	190 - 210	190	182	189	184	189	173	189	190 - 210	189	184		190	182	188	186	190
T90 (deg F)	280 - 300	300	299	301	302	303	298	304	290 - 300	297	294		298	292	293	295	295
sulfur (ppm)	15 - 25	16	60	17	60	20	50	19	30 - 40	45	40	50	42	70	44	38	44
olefins (vol%)	3.0 - 5.0	4.7	5.5	5.2	5.5	5.9	5.5	6.1	4.0 - 5.0	4.4	5.5	7.5	5.9	5.7	5.9	5.5	6.0
aromatics (vol%)	18 - 20	18.7	17.8	20.6	18.3	19.6	18.2	19.7	22 - 25	22.3	16.4	19.9	18.1	16.1	17.9	16.4	16.8
benzene (vol%)	0.5 - 1.0	0.67	0.61	0.6	0.61	0.59	0.61	0.59	0.8 - 1.0	0.95	0.96		0.94	0.95	0.93	0.96	0.87
MTBE (vol%)	10.8 - 11.2	11.1	10.6		10.4	11.18	10.5		10.8 - 11.2	11.2	11.27		11.88	11.4	12.07	11.4	
or oxygen (wt%)	1.8 - 2.2		1.97	2.04		2.09		1.94					2.16		2.24		2.07

	Specifications	WINTER CA AVG							SUMMER CA AVG							
	Pre-1992 (CA Avg)	Phillips cert	GM_1	ARB_1	GM_2	ARB_2	GM_3	ARB_3	Phillips cert	GM_1	Saybolt	ARB_1	GM_2	ARB_2	GM_3	ARB_3
RVP (psi)	S 8.7 - 9.0 (W 11-12)	11.0	10.6	10.5	11.2	10.4	10.6	10.5	9.0	8.5		8.4	8.7	8.2	8.6	8.3
T50 (deg F)	200 - 230	224	218	223	220	219	211	220	226	218		225	220	221	221	224
T90 (deg F)	300 - 325	324	331	317	335	317	325	316	322	326		323	321	322	329	324
sulfur (ppm)	125 - 175	138	170	145	170	129	180	126	131	160	110	103	160	112	160	105
olefins (vol%)	9.0 - 11.0	10.0	10.2	11.5	10.2	10.9	10.3	9.7	10.7	10.3	12.8	12.3	10.5	9.3	9.9	10.1
aromatics (vol%)	29 - 35	33.4	30.1	33.2	30.6	33.6	32.6	31.7	34.8	32.5	34.6	33.9	32.6	35.2	31.3	33.4
benzene (vol%)	1.4 - 2.0	1.54	1.35	1.36	1.39	1.35	1.41	1.25	1.47	1.4		1.39	1.416	1.37	1.34	1.32
MTBE (vol%)	0	0	ND	< 0.1	ND	< LOD	ND		0	0.14		< 0.1	ND	< LOD	ND	
or oxygen (wt%)	0			< 0.02		< LOD		0				< 0.02		< LOD		0

C. Test Procedures

Emissions testing was conducted on 10 vehicles representing several different emission control technologies. A series of 15 tests were performed under various conditions in order to quantify the emission effects of different fuels, soak periods, and ambient temperatures on the various emission control technologies. Each test is defined by a soak time and driving cycle. The fifteen tests specified by the ARB's RFP to be performed on the ten vehicles are listed in Table II-5.

Table II-5. Tests Specified by the ARB

TEST	CYCLE	SOAK TIME (min)	APPROXIMATE RUN TIME (min)
1	FTP	Overnight	42
2	UCnite	Overnight	5
3	UC300	300	5
4	UC180	180	5
5	UC120	120	5
6	UC60	60	5
7	UC50	50	5
8	UC30	30	5
9	UC20	20	5
10	UC10	10	5
11	STAB UC	0	5
12	start60	60	9
13	start10	10	9
14	STAB start	0	14
15	STAB FTP bag1	0	14

* "UC" test includes only bag 1 of the Unified Cycle

The three cycles used in this test program were the FTP, bag 1 of the Unified Cycle, and a special start test cycle. Speed traces of each cycle may be found in Appendix C. These cycles were run after the various soak periods that are outlined in Table II-5. The two cycles supplied by ARB (UC and start) were programmed into the custom test feature of the Corporate Emission Test System (CETS) computer for consistent execution during the testing process. The FTP was already a part of the CETS software package.

The no start hot stabilized, STAB, tests consisted of driving the vehicle for five minutes at 50 mph, followed by the respective FTP bag1, UC, and start cycles.

In addition to the exhaust emissions data, catalyst and coolant temperature data were collected. The vehicle was instrumented with thermocouples to monitor the pre-converter (if equipped), main converter (if equipped), and engine coolant temperature. Details of the equipment and procedures used are further described in Appendix D.

Randomization Sequence. The sequence of tests using the different soak, temperature, fuel type and vehicle technology type combinations utilized a "nested randomization" plan to randomize the 900 individual tests (four fuels*three temperatures*10 vehicles*15 test combinations). The two winter fuels were only used for testing at 50 degrees, while the two summer fuels were used for testing at both 75 and 100 degrees. The nested randomization was arranged in such a way that the number of fuel changes made during the testing sequence was minimized. This was necessary because of the additional vehicle preparation required when switching fuels. A special vehicle preconditioning sequence was required when changing fuels to permit the "adaptive learn" vehicles to become conditioned to the new fuel.

The final randomization plan used the following 4-step procedure:

(1) randomize the sequence of the four fuels
(2) within each fuel, randomize the three temperatures
(3) within each temperature regime, randomize the ten test vehicles
(4) randomize the 15 test cycles

Table II-6 outlines the randomization sequence test plan.

Table II-6. Randomization Plan

FUEL (4)	TEMPERATURE (3)	VEHICLE (10)	TEST (15)
WF2 (Winter Phase II)	T3 (50 °F)	8,4,7,1,5,3,2,9,6,10	C1,C2,...C15
SF1 (Summer Pre '92)	T2 (100 °F)	8,4,7,1,5,3,2,9,6,10	C1,C2,...C15
SF1 (Summer Pre '92)	T1 (75 °F)	8,4,7,1,5,3,2,9,6,10	C1,C2,...C15
SF2 (Summer Phase II)	T2 (100 °F)	8,4,7,1,5,3,2,9,6,10	C1,C2,...C15
SF2 (Summer Phase II)	T1 (75 °F)	8,4,7,1,5,3,2,9,6,10	C1,C2,...C15
WF1 (Winter Avg)	T3 (50 °F)	8,4,7,1,5,3,2,9,6,10	C1,C2,...C15

The overnight FTP and Unified Cycle bag1 tests were performed first for each vehicle, and the remaining 13 tests were randomized. This process resulted in the randomized test sequence in Table II-7. Details of the actual testing sequence, preparation, and scheduling performed at VEL may be found in Appendix E.

Table II-7. Randomized Tests

TEST	CYCLE	SOAK TIME (min)
1	FTP	Overnight
2	UCnite	Overnight
3	UC50	50
4	STAB UC	0
5	UC30	30
6	UC120	120
7	start10	10
8	STAB FTP bag 1	0
9	UC10	10
10	start60	60
11	STAB start	0
12	UC20	20
13	UC60	60
14	UC300	300
15	UC180	180

Changes to the randomization sequence for a number of vehicles were made on a case by case basis with the approval of ARB. The following is a summary of the changes.

- V10 (Nissan Maxima) - moved to the end of the program and tested in its entirety due to the high costs involved in renting this type of vehicle.
- V07 (Toyota Camry) - removed from the randomization sequence and tested in its entirety per ARB request.
- V03 (Chev Impala) - tested out of sequence due to vehicle repair work.
- V02 (Honda Accord) - original vehicle procured was released in the middle of testing due to a broken timing belt. This vehicle was replaced by a 1996 Honda Accord and subsequently tested at the end of the program in its entirety.
- V01 (Ford Tempo) - required to be completely re-tested at the end of the program due to an exhaust system muffler change.

Replicate Tests. Ten replicate tests were also performed as part of the fulfillment of the contract. The ten tests were requested by ARB after their review of the original test data. These tests were performed as requested by ARB and are not part of the primary randomization plan. A list of the replicate tests is shown in Table II-8.

Table II-8. Replicate Tests

VEH NO.	VEHICLE	FUEL	TEMP	TEST
07	Toyota Camry	Summer Ph II	75	FTP
09	Honda CRX	Summer Pre '92	100	UC 50 min. soak
09	Honda CRX	Summer Pre '92	100	UC 0 min. soak
03	Chevrolet Impala	Summer Ph II	75	FTP
04	Chevrolet Nova	Summer Ph II	75	FTP
05	Toyota Nova	Summer Ph II	75	FTP
08	Olds Toronado	Summer Ph II	75	FTP
01	Ford Tempo	Summer Ph II	75	FTP
06	Ford Taurus	Summer Ph II	75	FTP
06	Ford Taurus	Summer Ph II	75	UC overnight soak

Vehicle Preconditioning. Prior to performing the baseline FTP, the vehicles were preconditioned before being placed in cold soak. In cases where there were special concerns, such as excessive canister loading or special fuel considerations, special preconditioning procedures were used.

ARB requested that VEL utilize a special preconditioning procedure for the adaptive learn vehicles, involving multiple fuelings, an extended 50 mph cruise, and start-stop and key on-key off sequences. VEL agreed to perform this preconditioning sequence on the computer-controlled vehicles. This preconditioning sequence, as well as the procedure used for non-adaptive learn vehicles are outlined in Appendix F.

Speciation. In addition to the testing as outlined previously, speciation tests were performed on the exhaust emissions of the 1985 Oldsmobile Toronado (08) and the 1991 Toyota Camry (07). These tests were performed within each vehicle's randomization schedule on Summer Phase II fuel at 75 degrees, for the overnight and 10 minute soak of the UC.

Speciation testing consists of filling a separate container (Summa® canister) with diluted exhaust sample and analyzing the sample on a gas chromatograph (GC) for the different hydrocarbon compounds that may be present. The VEL speciation process consists of analyzing the sample for 160 different hydrocarbon compounds and determining the mass of each compound. Data generated in the chemical analysis of the sample is then processed by a separate non-methane organic gas (NMOG) spreadsheet program that provides a summary of the results along with a detailed list of the masses of all the compounds that were determined from the analysis.

A parallel sample of diluted exhaust is also taken and passed through a dinitrophenylhydrazine (DNPH) cartridge for the purpose of analyzing the exhaust sample for carbonyls. The sample is then eluded using acetonitrile and analyzed on a liquid chromatograph (LC) for the presence of any carbonyl compounds. Data generated is then processed along with the GC data that was determined from the gaseous sample.

D. Data Collection and Deliverables

For each test, HC, CO, NO_x and CO_2 emissions were measured from the tailpipe and sampled on a second-by-second basis. Along with this data, second-by-second temperature readings were taken of the engine coolant, catalytic converter and warm-up catalytic converter (if present).

Sample bags were also filled for each of these tests. A separate file was provided that included the bag analysis data. The exhaust bag analysis is provided in a gram per mile format.

Upon the conclusion of a 15-cycle test for each vehicle, data validation was performed using Federal Register guidelines, as well as good engineering judgment. Details explaining the data collection procedures and the subsequent validation efforts are summarized in Appendix G.

All data was transferred from the site computer to a PC post processor for final storage on a floppy diskette. The original files from the site were processed to provide the relevant data and were converted into an Excel 4.0 format. The compilation of all tests for all vehicles was transferred to a CD (compact disc) for final delivery to ARB. The final CD includes the following:

- second by second emissions data (900 primary tests + 10 replicates)
- second by second catalyst and coolant temperatures (900 primary tests + 10 replicates)
- bag emissions data (900 primary tests + 10 replicates)
- speciated exhaust data

III. RESULTS AND DISCUSSION

The following graph (Figure III-1) gives an example of the modal, second-by-second, HC emissions performance of a vehicle tested on bag 1 of the Unified Cycle. The graph shows the initial peak of emissions occurring with the start of the vehicle, and the eventual stabilizing of emissions as the engine heats up. There is also an overall trend of increasing emissions with increasing soak time.

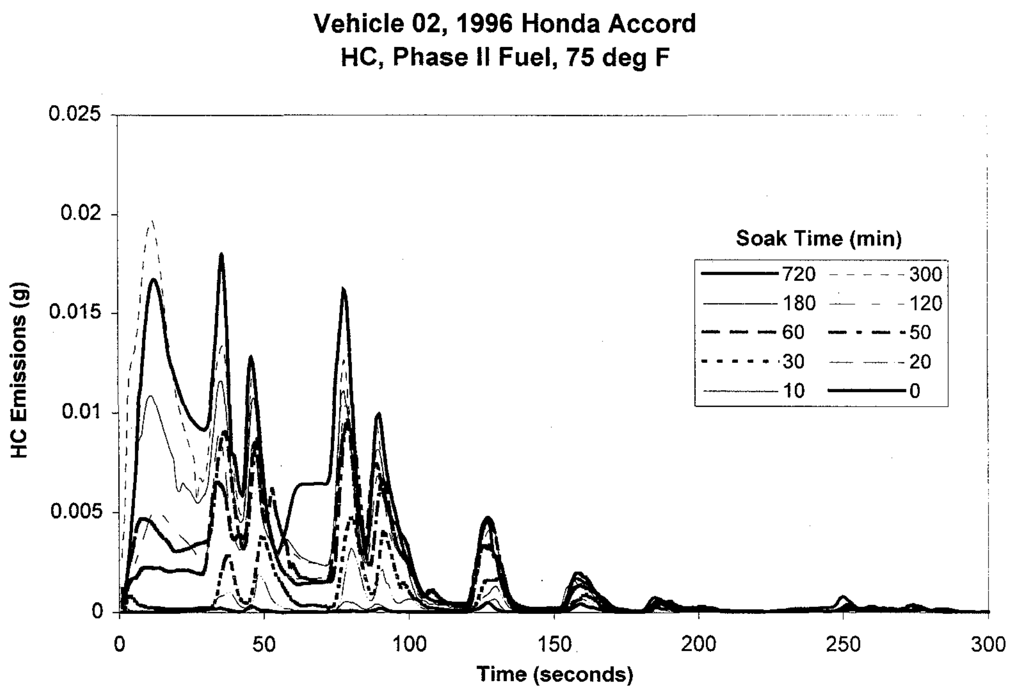


Figure III-1. Modal, second by second, HC Emissions for Various Soak Periods

Previous studies of modal data on various vehicles indicated that all emissions attributable to the start of the vehicle occurred within the first 100 seconds of start-up procedures, regardless of vehicle technology type or pollutant. After this time, the start event is over, and the vehicle is assumed to be producing only running emissions. An illustration of the cumulative HC emissions for the same vehicle shown in Figure III-1 is shown in Figure III-2. The point of inflection of each curve indicates the time at which the emissions stabilize for the individual soak periods. The graph shows all emissions stabilizing within the first 100 seconds regardless of soak time. It was this concept that led to the start interval being defined as 100 seconds for all pollutants and vehicles.

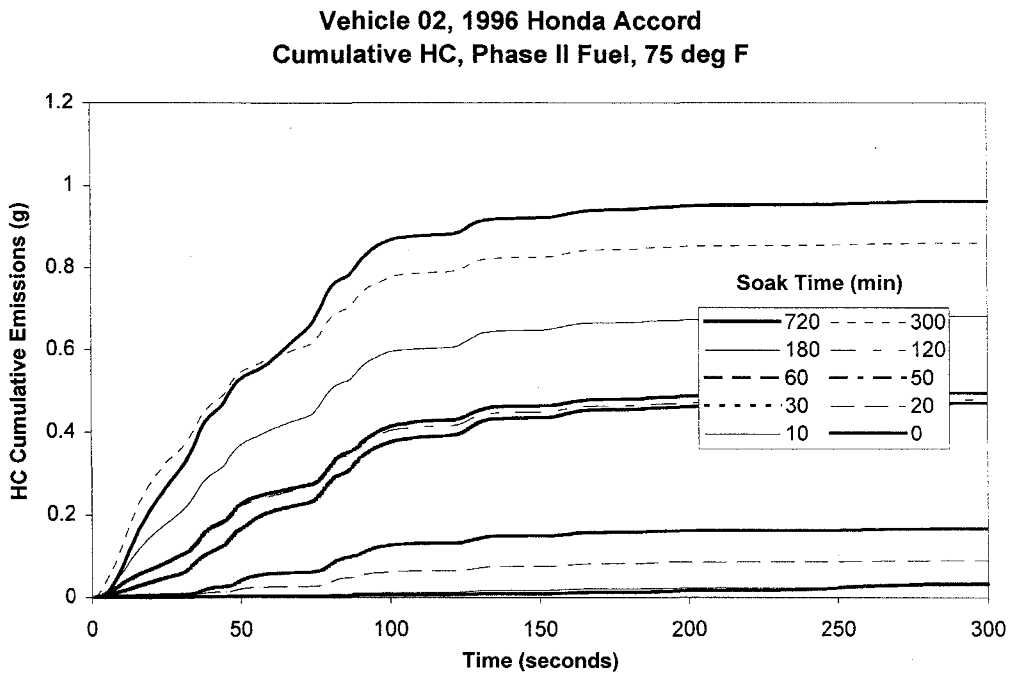


Figure III-2. Cumulative HC Emissions for Various Soak Periods

Start emissions are calculated as the difference between the cumulative emissions collected after a certain soak and the cumulative running emissions (estimated from the no soak test) for this interval. Numerically, the amount of start emissions for each vehicle/pollutant/soak combination can be expressed by the following equation:

$$z_i = CE_i - RE \quad (1)$$

where z_i = start emissions in grams for soak time i,

CE_i = cumulative emissions produced during the start interval for soak time i,

RE = cumulative running emissions produced by the vehicle during the start interval.

These values were calculated for each vehicle/fuel/temperature combination for tests conducted over the Unified Cycle. Table III-1 gives the HC start emissions for vehicle 02, including each temperature and fuel combination. The table shows that in general, higher start emissions are produced when the vehicle is tested on CA average fuel, and that higher emissions are also associated with lower ambient temperatures.

Table III-1. HC Start Emissions for Vehicle 02, 1996 Honda Accord (g)

Soak Time (min)	Temperature / Fuel					
	50		75		100	
	CA avg	PhII	CA avg	PhII	CA avg	PhII
10	0.018	0.016	0.001	0.006	0.010	0.009
20	0.071	0.074	0.062	0.055	0.065	0.048
30	0.201	0.169	0.177	0.120	0.120	0.110
50	0.608	0.477	0.494	0.406	0.389	0.374
60	0.401	0.536	0.391	0.369	0.411	0.351
120	0.609	0.504	0.472	0.397	0.381	0.371
180	1.048	0.853	0.707	0.588	0.605	0.434
300	1.160	0.968	0.806	0.768	0.529	0.518
720	2.076	1.632	1.080	0.859	0.635	0.583

Once the total grams per start calculations were completed for all soak times, the start emissions for all soaks were then normalized to the overnight soak. This allows all soaks to be expressed as a function of the overnight soak start emissions. Table III-2 shows the HC normalized factors for vehicle 02. It shows that with Phase II fuel, HC start emissions between the overnight and 180 minute soaks decrease by approximately 50% at 50 deg F, 30% at 75 deg F, and by 25% at 100 deg F. These trends are further illustrated in Figure III-3.

Table III-2. HC Normalized Start Emissions for Vehicle 02, 1996 Honda Accord

Soak Time (min)	Temperature / Fuel					
	50		75		100	
	CA avg	PhII	CA avg	PhII	CA avg	PhII
10	0.009	0.010	0.001	0.007	0.015	0.016
20	0.034	0.045	0.057	0.064	0.102	0.083
30	0.097	0.104	0.164	0.140	0.190	0.188
50	0.293	0.292	0.457	0.473	0.613	0.642
60	0.193	0.328	0.362	0.429	0.647	0.602
120	0.293	0.309	0.437	0.462	0.600	0.637
180	0.505	0.522	0.654	0.684	0.953	0.745
300	0.559	0.593	0.746	0.894	0.834	0.889
720	1	1	1	1	1	1

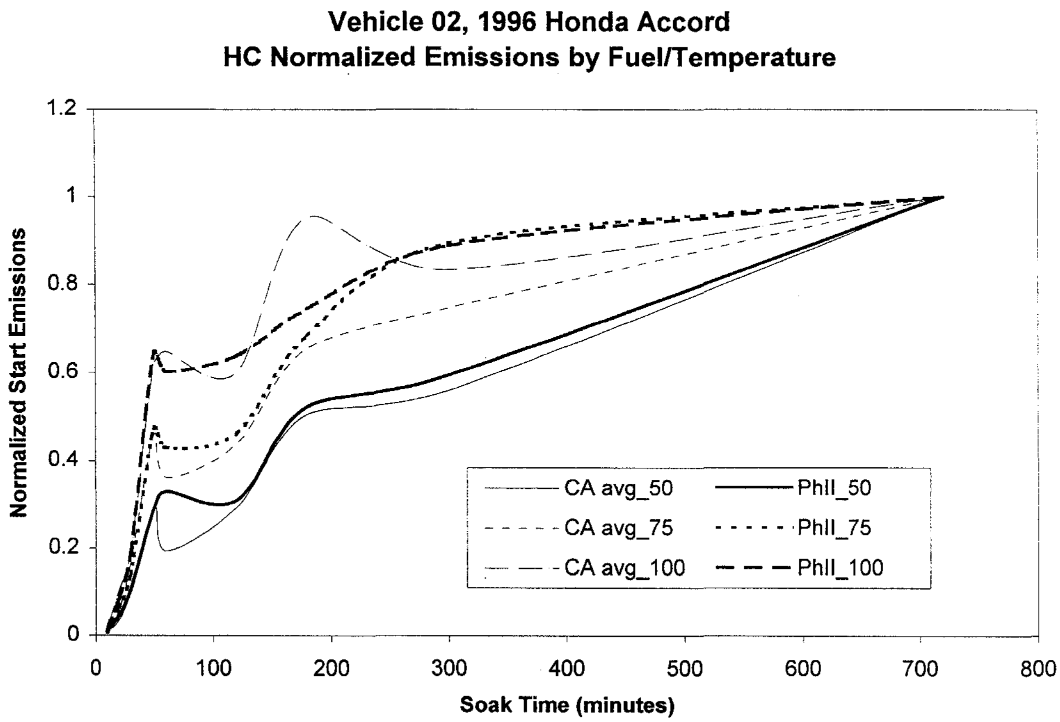


Figure III-3. Normalized HC Emissions by Fuel/Temperature for Vehicle 02

The graph illustrates that start emissions for this vehicle tend to increase as the soak time increases and the vehicle sits for longer periods of time. The graph also suggests that ambient temperature affects the relationship of start emissions as a function of soak time; however, there seems to be little difference between fuels. This difference in emissions seems to be less significant for the shortest soaks of less than 30 minutes where the vehicle is still very warm.

In general, all fuel-injected vehicles exhibited similar trends for HC and CO while trends for the carbureted vehicles were inconsistent. Non-catalyst and oxidation catalyst vehicles showed no clear trend for either of the three pollutants. The three-way catalyst carbureted vehicles displayed similar trends to the fuel-injected vehicles except with more variability. The trend for NOx was similar; however, at times the emissions increase with increasing soak time beyond a factor of one, then decrease. Also, for some of the vehicles, the soak factors at 50 degF increased to higher values then for those at 75 or 100 degF. To give an example of these trends, Figure III-4 shows the normalized NOx emissions for vehicle 07. The graph shows that the 50 degF curves for NOx are higher than those of the 75 and 100 degF. In many instances, the slopes of the 50 degF curves for HC and CO are much more modest (See Figure III-3).

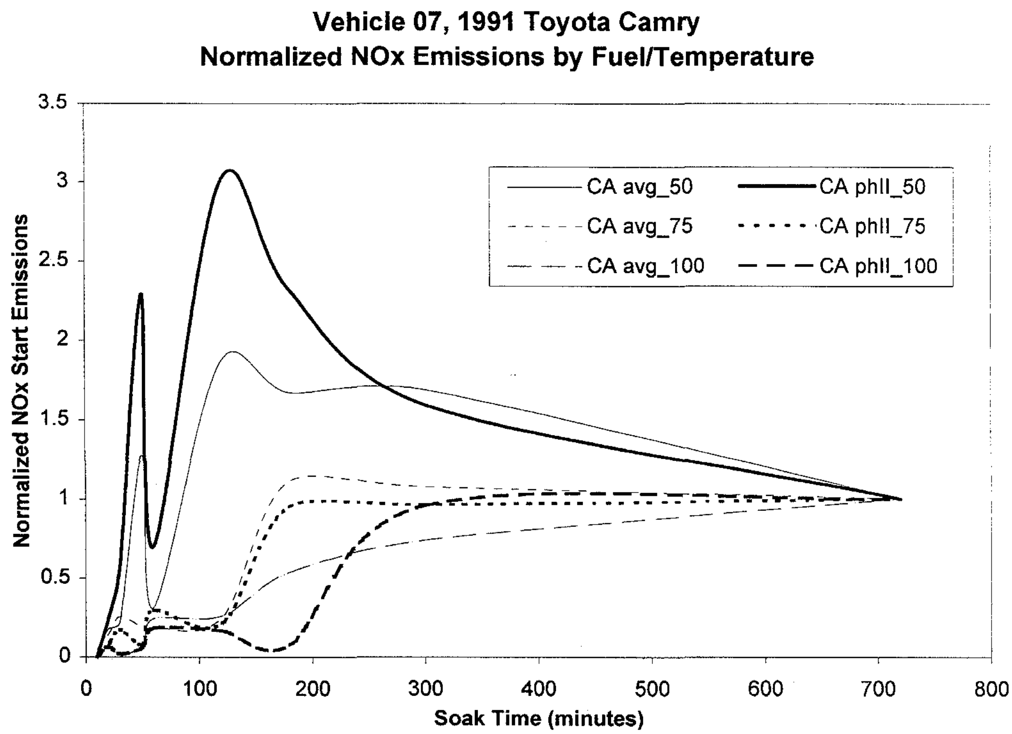


Figure III-4. Normalized NOx Emissions by Fuel/Temperature for Vehicle 07

A comprehensive statistical analysis was performed on all start emissions to establish the effects of fuel, temperature, and technology type including catalyst and fuel delivery systems. This was done for HC, CO, and NOx, and was conducted at each distinct soak time.

The statistical analysis showed that there was virtually no fuel effect on start emissions for either pollutant. However, an analysis performed on HC start emissions showed a significant difference with respect to the three ambient temperatures. A more detailed analysis within each temperature showed that there are also significant differences with respect to technology type, including catalyst and fuel delivery system. This was clearly evident at the shorter soak times of less than 60 minutes. While there were clear trends associated with start emissions for HC, the trends for CO and NOx were less obvious. There was an ambient temperature effect for CO only up through 120 minutes of soak. Within each temperature, there was little significance with respect to technology type. The only temperature significance for NOx occurred at the longer soak times of greater than 120 minutes. In addition, there was virtually no discernable difference associated with technology type for NOx.

Further investigation of the data revealed an interesting trend with respect to the normalized emissions for each vehicle. For a number of vehicles a peak in emissions occurs at 50 minutes of soak (See Figure III-3). Normalized emissions increase from 0-50 minutes of soak, peak at this point, then decline before increasing again towards its convergence value of one at 720 minutes. This occurred across various vehicles and pollutants, and for different fuel and temperature combinations.

Analyses of coolant and catalyst temperatures were performed on vehicle 02 to explain what might cause this anomaly. Figure III-5 is a plot of initial catalyst and coolant temperatures for each soak period, showing the temperatures of each at start-up. The temperatures for both the catalyst and close-couple catalyst exhibit a general trend of decreasing temperature as the soak period increases. Up until approximately 50-60 minutes of soak, the initial catalyst temperatures are equal, regardless of ambient temperature. For soaks greater than 50 minutes, the curves for each ambient temperature diverge from each other and eventually plateau at their respective temperatures.

The trend of initial coolant temperature by soak period, however, seems to be more unique. The curves show similar characteristics to the catalyst except for a drop in temperature occurring at 50 minutes of soak. Initial coolant temperature decreases with increasing soak time until 50 minutes, then rises and peaks at 60 minutes, and eventually continues decreasing until it levels off at its ambient temperature. This is basically an inverse of the normalized emissions' curve (See Figure III-6). The vehicle experiences a lower initial temperature at 50 minutes, which results in a peak of emissions. Conversely, the higher temperature at 60 minutes of soak produces lower start emissions because the engine is warmer. This suggests that for this vehicle, there is a clear relationship between initial engine temperature and start emissions; and that the temperature of the coolant has a greater effect on start emissions than the temperature of the catalyst.

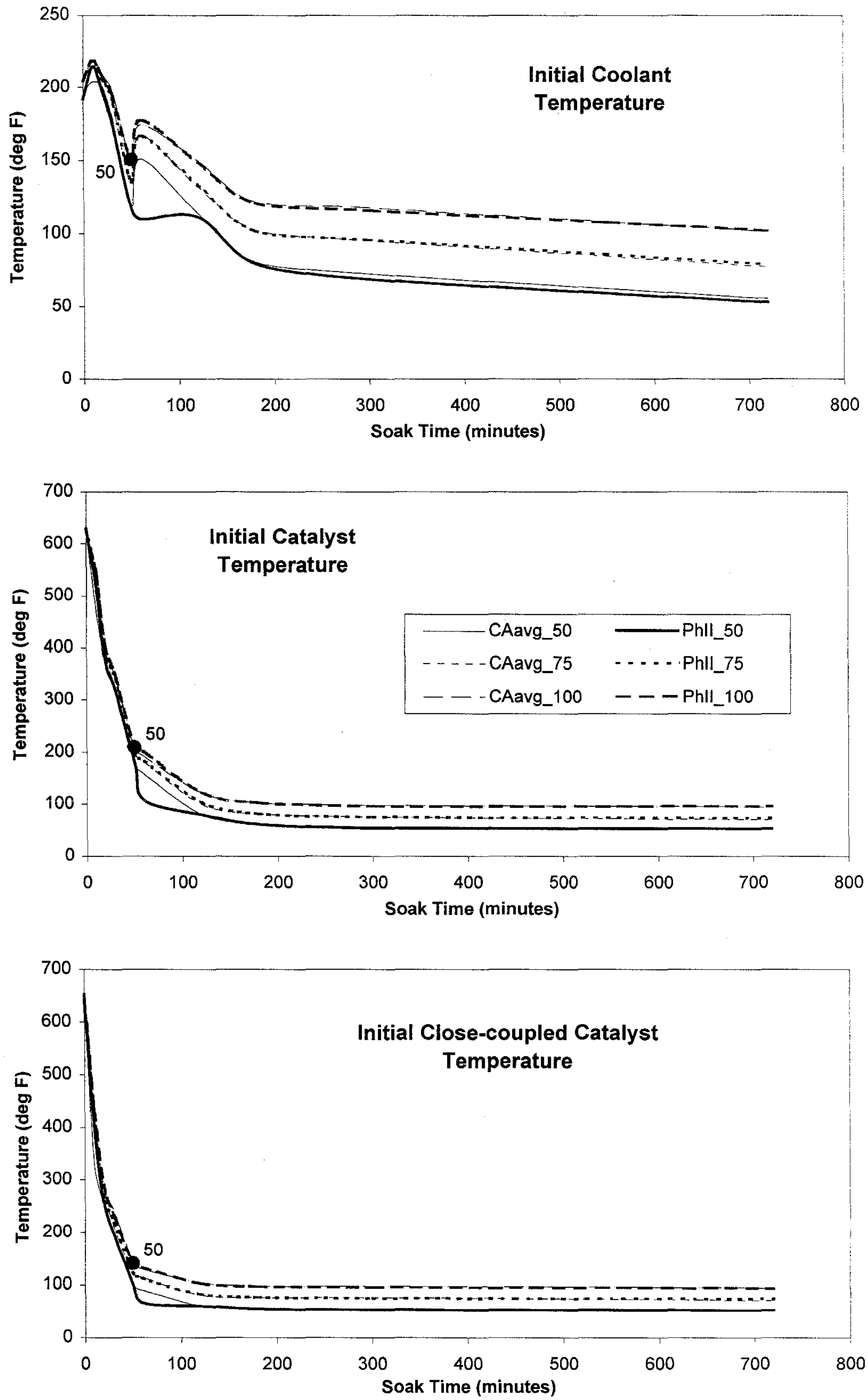


Figure III-5. Initial Catalyst and Coolant Temperature by Soak Time for Vehicle 02

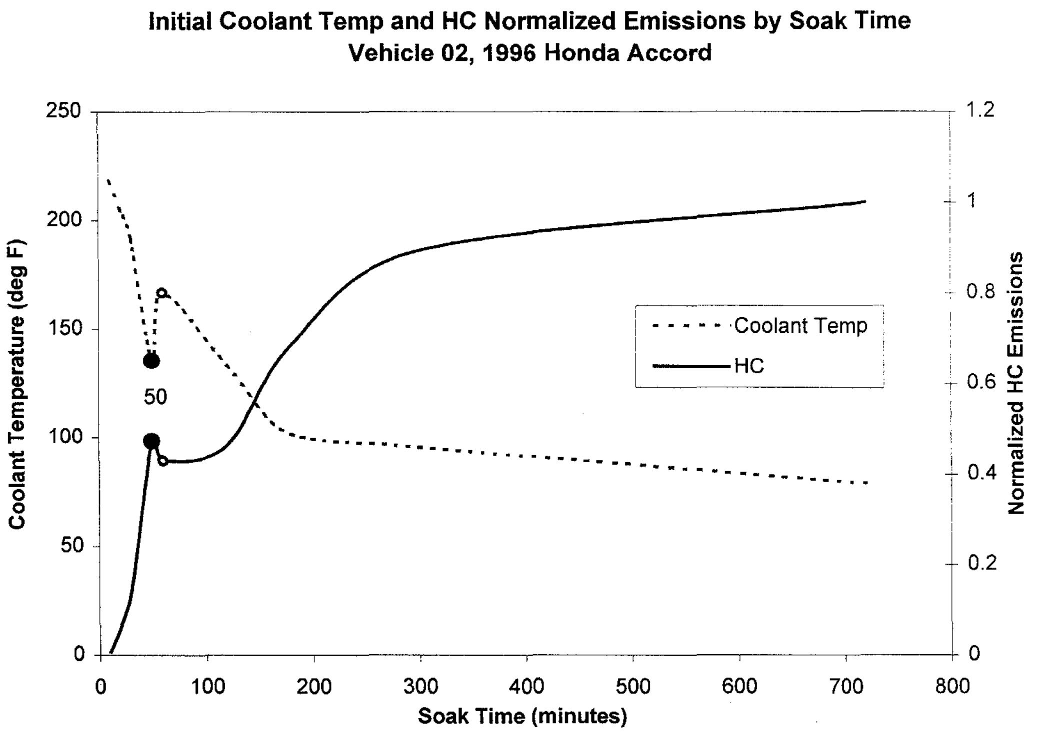


Figure III-6. Initial Coolant Temperature and HC Normalized Emissions for Veh 02

To further evaluate this relationship, initial temperature was plotted as a function of HC normalized emissions. Figure III-7 shows the correlation between emissions and temperature of the coolant, catalyst, and close-couple catalyst for vehicle 02. Since an earlier analysis established virtually no fuel difference, CA average and Phase II fuel data were combined for each vehicle and ambient temperature to enhance the data set. The graphs show strong correlations for each, with the greatest being with respect to coolant temperature. CO showed similar trends, with R-squared values all greater than 0.9. Figure III-8 shows the NOx emissions for the same vehicle. The correlation is still strong for this pollutant; however, NOx is different from HC and CO in the sense that catalyst temperature has a more significant effect than coolant temperature.

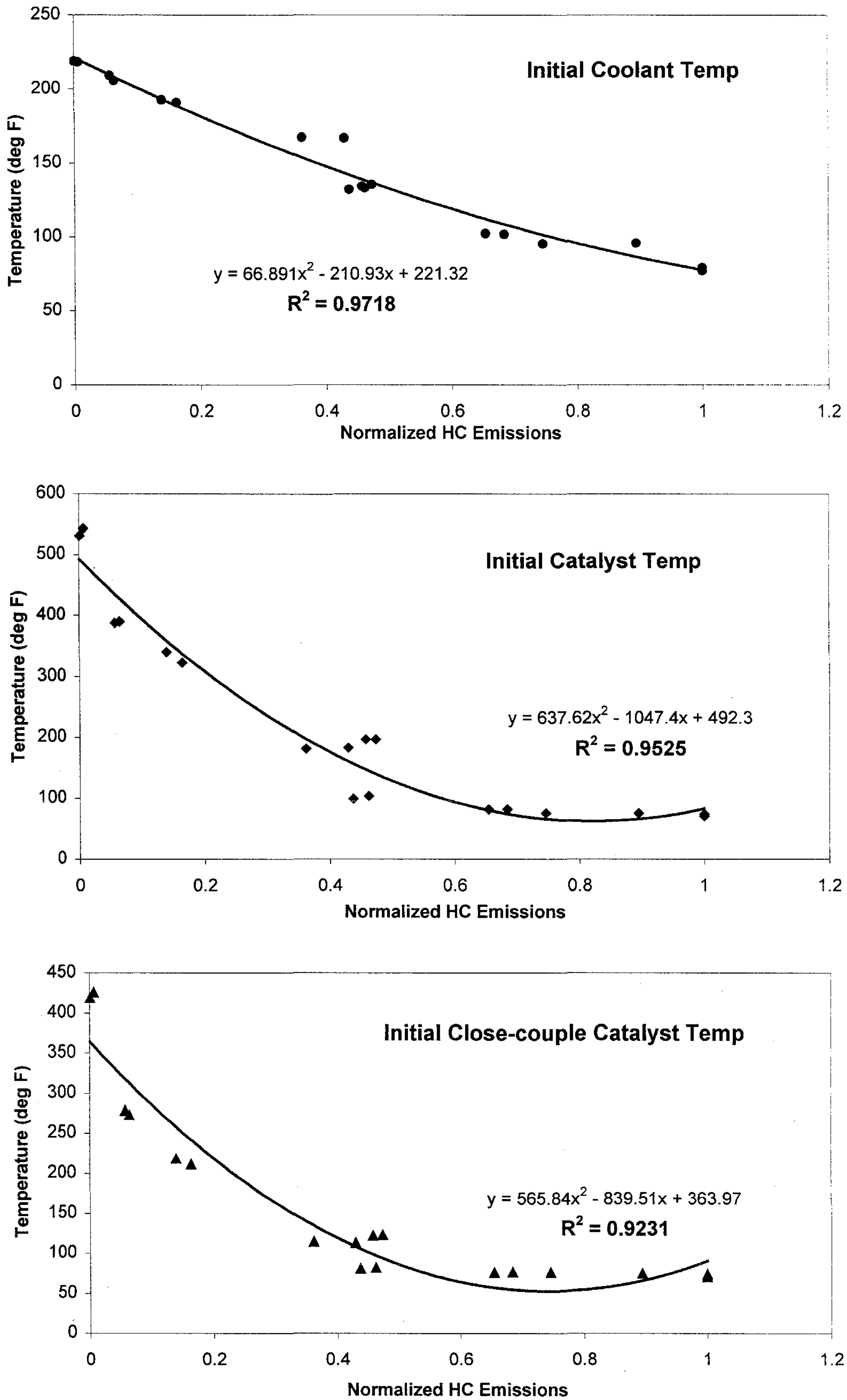


Figure III-7. Normalized HC Emissions vs Initial Temperature for Vehicle 02

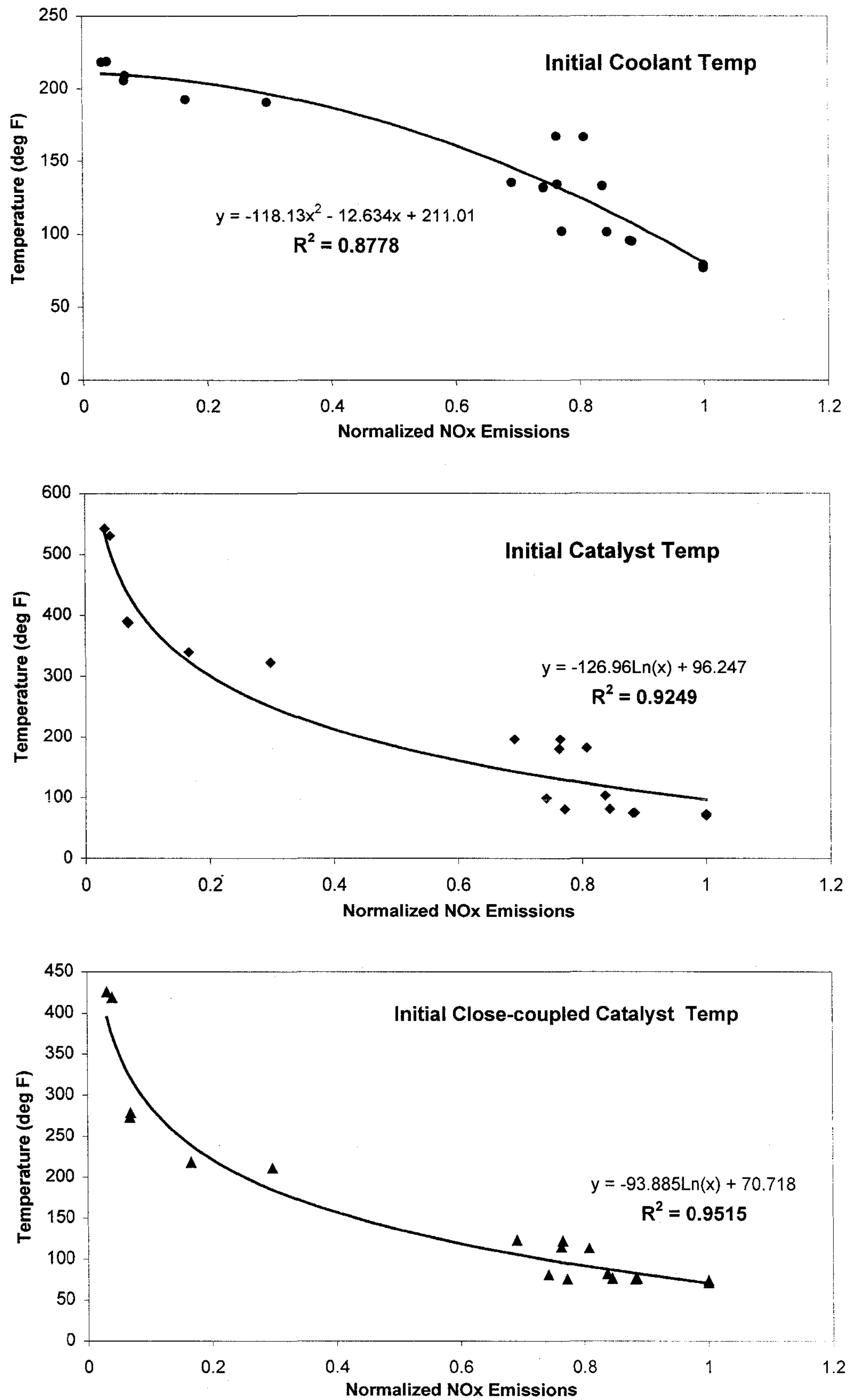


Figure III-8. Normalized NOx Emissions vs. Initial Temperature for Vehicle 02

Best fit polynomial, logarithmic, power, and exponential curves were used in this same way to establish the relationship for all other vehicles. It was found that most fuel-injected vehicles exhibited similar characteristics; however, the carbureted vehicles displayed greater variances in the data with no clear correlation.

Analysis of emissions as a function of temperature may explain the peak in emissions experienced by some of the vehicles. At this point, emissions are higher because there is a dip in the initial temperature at 50 minutes of soak (Figure III-6). However, without a comprehensive investigation, it is difficult to explain why this anomaly would occur consistently. It is possible that the system is being affected by a calibration strategy programmed by the automobile manufacturer. However, another reason that was discovered through this analysis may be that the vehicles are being inadvertently influenced by the test sequence. The initial temperatures of each test could be affected by prior tests. This would be evident for all vehicles involved in the program.

Figure III-9 shows the second-by-second coolant temperature for each test in the order in which they were performed. The graph illustrates that while a vehicle should cool to a lower temperature given 60 minutes of soak, the test run after the 50 minute soak instead begins with a lower engine temperature. By looking at the tests run prior to both of these soak times, one may be able to infer why this is happening. The 60 minute soak follows tests run after short soaks of 0 and 20 minutes. These tests do not allow the vehicle a sufficient time to cool down. The graph also shows that during these tests, the vehicle reaches higher temperatures for longer periods of time. On the other hand, the 50 minute test follows a completely cold overnight soak. The coolant reaches a high temperature, but does not maintain that level. This allows the coolant to cool down quicker, even though the soak is only 50 minutes. The analysis presented here suggests that the start emissions for these tests may have been inadvertently affected by the order in which the tests were performed. However, further testing is needed in order to draw definite conclusions.

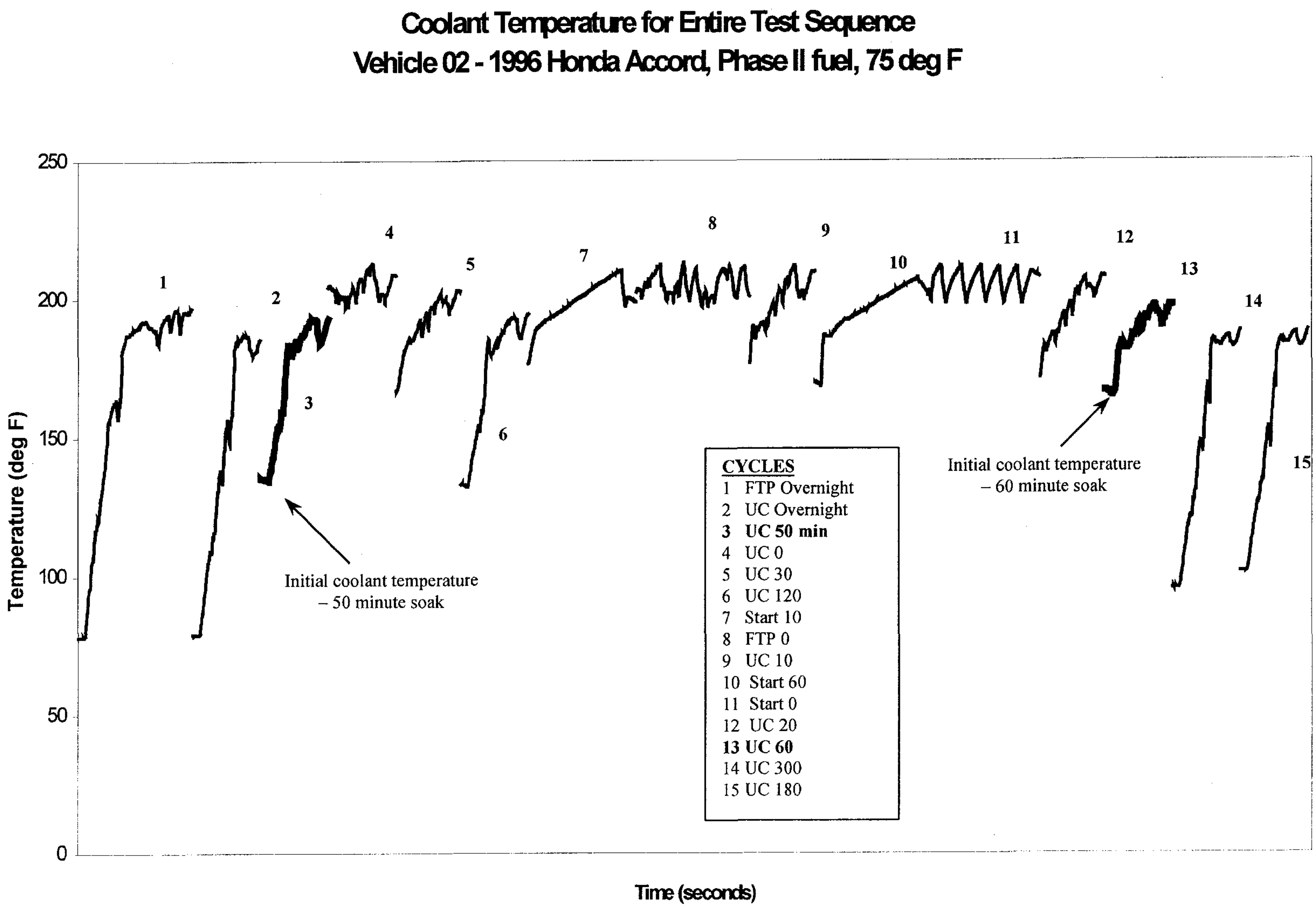
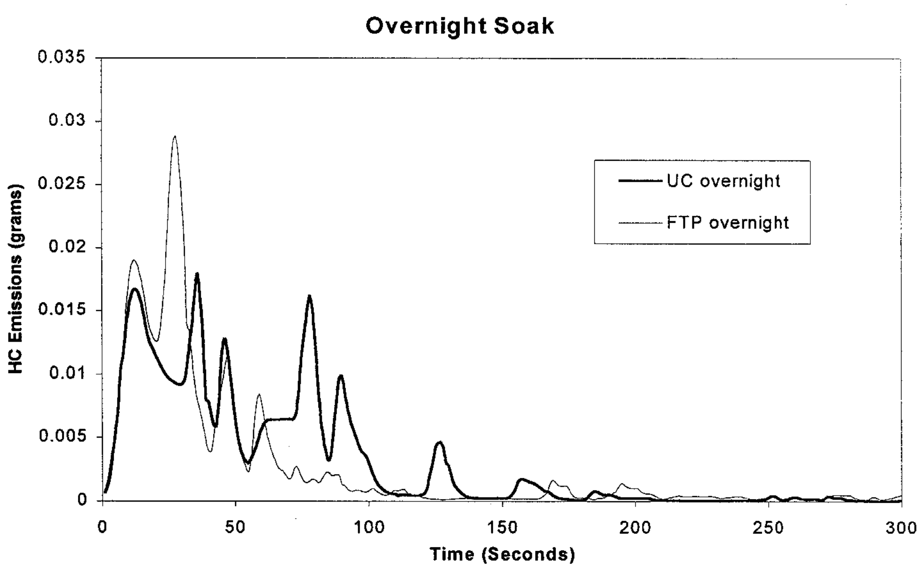


Figure III-9. Second-by Second Coolant Temperature for Entire Test Sequence of Vehicle 02

Three different cycles were tested in this program – the Unified Cycle, the FTP, and the special start test cycle. The cycles were performed following different soak periods in order to see how a vehicle's activity immediately after start-up affected emissions. Figure III-10 illustrates the second-by second emissions for the different cycles performed on vehicle 02. The data represents the tests performed after the overnight soak and 60 minutes soak. The graphs show some difference between the FTP and UC; and a substantial difference when comparing the UC and special start test cycle. Start emissions were calculated for the overnight and 60 minute soaks for all vehicles and a statistical analysis was performed.



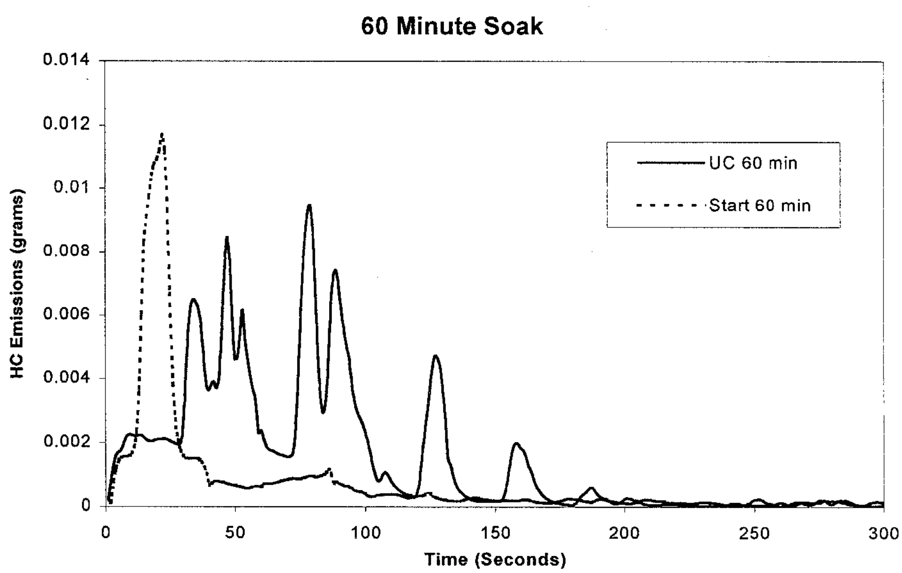


Figure III-10. Second-by-second HC Emissions of Cycles tested on Vehicle 02

The analysis revealed no significant difference between start emissions from the UC and start emissions from the FTP for the overnight soak. However, there was a significant difference in HC and NOx start emissions when comparing the UC and the start test cycle following the 60 minute soak. This is somewhat expected when comparing the speed traces of the three cycles (Refer to Appendix C). While the FTP and UC both have a series of accelerations and decelerations, the start cycle has only an initial acceleration up to 35 mph, and maintains this speed throughout the duration of the start interval (100 seconds). Therefore, in order to accurately estimate start emissions, it is important to use a cycle that is most representative of the driving events occurring after start-up in the real world.

APPENDICES

A. Baseline FTP Emissions Results

B. Vehicle Repairs

C. Cycles

D. Test System and Equipment Specifications

E. Test Procedures at VEL

F. Vehicle Preconditioning

G. Data Collection and Validation

H. Quality Assurance

Appendix A. Baseline FTP Emission Results

Table A-1. Baseline FTP Composite (g/mi)

VEHICLE #	VEHICLE	(NM)HC	CO	NOx
01	1987 Ford Tempo	0.247	2.416	1.84
02	1996 Honda Accord	0.053	0.920	0.110
03	1972 GM Chev Impala	1.76	54.32	1.68
04	1978 GM Chev Nova	0.957	18.5	1.48
05	1987 GM Chev Nova	0.32	9.4	0.88
06	1992 Ford Taurus	0.244	3.03	0.194
07	1991 Toyota Camry	0.122	1.87	0.16
08	1985 Olds Toronado	0.581	10.17	0.637
09	1990 Honda CRX	0.246	3.27	0.43
10	1996 Nissan Maxima	0.08	0.646	0.26

Appendix B. Summary of Vehicle Repairs

The coolant tank on the 1987 Ford Tempo (Veh 01) ruptured midway through the program requiring radiator replacement. Due to holes observed in the muffler of the Tempo, a decision was made by ARB to have the muffler replaced. This repair resulted in the retesting of this vehicle in it's entirety. Prior to complete retesting of the Tempo the water pump belt broke and was replaced. A few weeks later the water pump itself was replaced.

The 1972 Chevrolet Impala (Veh 03) required replacement of a broken transmission detent cable. This required the vehicle to be tested out of the assigned random sequence order due to the search for parts.

The 1978 Chevrolet Nova (Veh 04) required rear brake adjustment and the linings sanded during the course of testing, as well as replacement of the upper radiator hose.

The 1996 Nissan Maxima (Veh 10) displayed a "service engine" light which was diagnosed and cleared at a dealership. A VEL employee accompanied the vehicle to the dealership where the failure code was reported as a "vent control valve." The dealer suggested that this may have happened as a result of the gas cap not being closed tightly; and implied that they had seen similar cases in the past. ARB staff familiar with on-board diagnostic systems were also consulted. They explained that this particular vehicle should have an evaporative system leak check and that a loose or missing gas cap could cause the light to illuminate. The vehicle was cleared of stored codes and returned to the contractor's laboratory where all hose and wire connections at the evaporative canister were checked, as well as the vent solenoid. No problems were found and testing continued with no further occurrences.

Appendix C. Speed Traces of FTP, Unified Cycle, and Special Start Cycle

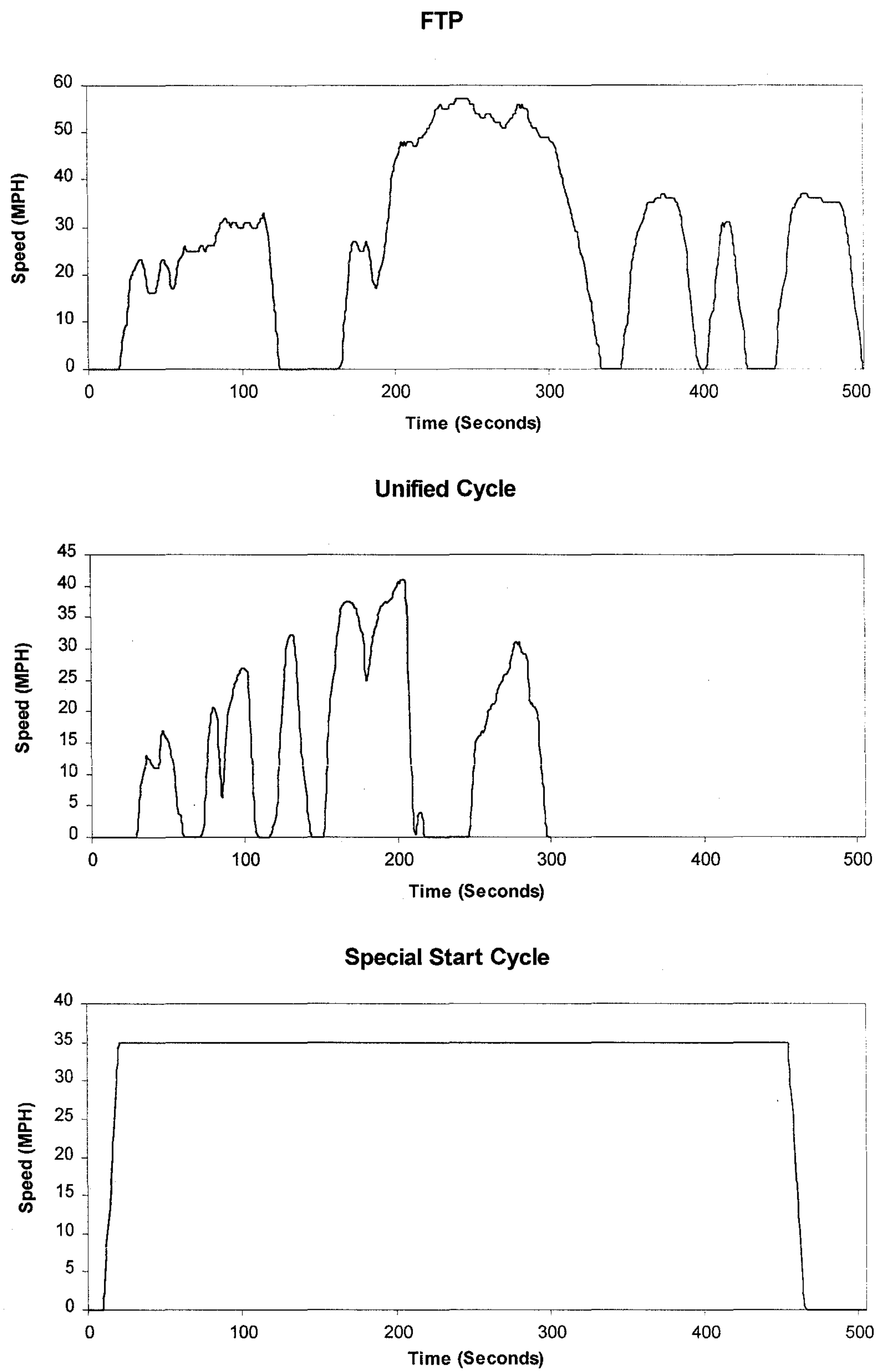


Figure C-1. Speed vs Time Traces of FTP, Unified Cycle, and Special Start Cycle

Appendix D. Test System

VEL utilized Test Site 1 which has the capability of maintaining the 50 to 100 °F temperature requirements for this test program. Vehicles were preconditioned, soaked and tested in the test cell at the 50, 75 or 100 °F settings. Test Site I is capable of maintaining the cell temperature to ± 5 °F of the set point. The cell is equipped with a complete bag and modal emission test system capable of second by second data acquisition for HC, CO, NO_x, CO_2, and additional channels, including catalyst and coolant temperatures. Site support equipment included a General Eastern dew point hygrometer unit model Hygro-M1 and a Texas Electronics model Electric 2012 for barometric measurements. Environmental reports were generated for each day through the host computer system.

The speciation bench uses a PC and Modicon control logic for the control of sample flows and solenoids. The bench is also interfaced with the test site Corporate Emission Test System (CETS) computer to ensure the proper sequencing of events. The bench is designed to collect hydrocarbon and carbonyl samples through a heated line which is connected from the Critical Flow Venturi (CFV) sample bulkstream to the speciation bench. Bench flows are controlled by mass flow controllers which pass the sample to Summa® canisters and DNPH cartridges. The DNPH cartridges are processed on site, and along with the Summa® canisters, sent to a chemistry laboratory for analysis.

The Horiba bag bench is one of a three bench system that allow engine, tailpipe and bag samples to be analyzed by one test site. Each bench is modular in design and is interconnected to the others in order to allow the flexibility to perform converter efficiency tests, modal and/or bag testing. The bag bench has a built in Modicon logic control system which controls solenoids, pumps and other bench functions. Sample bags filled during an FTP are analyzed by the bag emission test bench for HC, CO, NO_x, and CO_2. Reports are generated by the real-time (CETS) computer system. Analyzer zero/spans are performed before and after each bag read sequence. Virtual zero/span (individual analyzer correction for a deviation from data table specified span values) is used to guarantee a high level of accuracy in analyzing the bag exhaust samples. The bag bench has a built-in automated gas divider, CFO kit and NO_x generator. The following table lists analyzers and support equipment on the bag bench.

Table D-1. Bag Bench
Analyzers and Support Equipment

GAS	ANALYZER	RANGES
THC	BECKMAN 400A	25 / 100
CH_4	BENDIX 8205	25
CO	HORIBA AIA-23AS	100 / 500 / 2000
O_X	BECKMAN 951A	50 / 150
CO_2	HORIBA AIA-23	1.5% / 3%

SUPPORT EQUIPMENT

CFO KIT	HORIBA MODEL CFO 202
GAS DIVIDER	STEC MODEL SGD-78-SP9
NO_X GENERATOR	THERMO ELECTRON MODEL 100

The Horiba tailpipe bench is another of the three bench combination which collects tailpipe samples. A modal sample is collected at the tailpipe with a heated (250 °F) sample line and conditioned by an electronic ice bath before being analyzed by the tailpipe test bench for HC, CO, NO_X, and CO_2. Analyzer zero/span reference is performed before and after each test sequence. Virtual zero/span is used to guarantee a high level of accuracy in analyzing the modal exhaust samples. Reports are generated by the real-time (CETS) computer system. The tailpipe bench is equipped with a built-in automated gas divider. The following is a table of analyzers and support equipment on the tailpipe bench.

Table D-2. Tailpipe Bench
Analyzers and Support Equipment

GAS	ANALYZER	RANGES
THC	HORIBA FIA-23A	100 / 1000 /10000
CO	HORIBA AIA-23	2000 / 5000
CO	HORIBA AIA-23	3% / 10%
NO_X	HORIBA CLA-22A	500 / 2500
CO_2	HORIBA AIA-23	16%
$CO_{2\ dilute}$	HORIBA AIA-23	3% / 8%

SUPPORT EQUIPMENT

GAS DIVIDER	STEC MODEL SGD-78-SP9

Testing was performed on a Horiba Model #DMA-86-106-100HP electric twin roll dynamometer. The dynamometer was warmed up to stabilize frictional losses when not operated within the last two hours. The dynamometer has the capability to be warmed up with the vehicle in place.

Exhaust emissions are collected using a Horiba Model CVS-46/GM CFV type Constant Volume Sampler (CVS), and utilizing a VEL developed tailpipe pressure control system to maintain the pressure at the tailpipe to ± .25″ H_2O at idle and ± 1.0″ H_2O off idle.

The coolant temperature was measured with a type "J" thermocouple that was placed about 6″ from the radiator by inserting the thermocouple wire into the upper radiator hose and sealing it with silicone prior to reinstalling the hose clamp.

The converter temperature was measured with a type "K" thermocouple that was placed as close to the middle of the converter as possible, under any heat shield around the converter, so that the thermocouple would be in direct contact with the actual converter skin. The thermocouples were typically secured by placing a 1″ square piece of 16 gauge aluminum along with a high temperature cloth insulation patch over the end of the thermocouple and securing it with a hose clamp. Insulation was placed over the end of the thermocouple to keep direct air flow from influencing the measured temperature during soak periods for cases in which there was no insulating cover over the converter.

Thermocouple signals were monitored by the computer on a second by second basis for each period of vehicle testing. The second by second data for all temperatures is included in electronic format along with the emission data for all tests performed. Temperatures were also monitored throughout testing and soak periods by a strip chart recorder.

Appendix E. Test Procedures at VEL

The test process necessitated the implementation of a third shift at the VEL and 24 hour laboratory operation, as each 15 cycle test sequence required approximately 42 hours to complete.

The project coordinator initiated the test sequence by issuing a folder containing the prep and test runsheets for each vehicle/temperature/fuel combination as specified by the random test plan. The vehicle was then brought in to begin the canister purge and fuel drain/fill process. The prep procedure initiated was dependent upon whether a fuel change was necessary, and/or the vehicle was computer controlled. In addition, all vehicles in the program went through the canister purge process prior to the start of any formal testing.

In order to complete two consecutive test sequences each week it was necessary to begin the first prep procedure at approximately 12:00 AM on Monday. Typically, the canister was purged and the initial drain/fill was performed on the previous working day before the actual prep sequence was started.

The preconditioning was completed at approximately 2:30 AM and the vehicle left to soak on the site at the required temperature. The FTP and subsequent test sequence began at approximately 2:30 PM that same day. With this starting time, a complete test ended at approximately 8:00 PM of day two. If all went well, the second test sequence was completed at approximately 8:00 PM on Thursday. Friday was utilized for any retests, if necessary.

The 15 individual tests specified by ARB were grouped together to form nine individual custom tests and then programmed into the CETS computer system for ease and consistency of operation during the entire testing process. The computer system controlled the timing within a custom test. Each custom test is comprised of one to three of the individual tests.

In addition to the programming of the fifteen tests into nine different custom tests, a "soak timer" control box was designed especially for this program. This unit signaled the test operators five minutes before the test was to begin, after a soak, by activating a buzzer and light. When it was time to start the test, the tone of the buzzer would change indicating to the driver to begin the test.

Table E-1 describes the 15 cycle custom test sequence.

Table E-1. 15 Cycle Custom Test Sequence

Custom Test #	Cycle(s)	Soak Length After Block (prior to next block)
1	FTP	12 hours
2	UC bag 1 Overnight	50 minutes
3	UC 50 min STAB UC UC 30 min	2 hours
4	UC 120 min Special Start 10 min	None Specified
5	STAB FTP bag 1 UC 10 min	60 minutes
6	Special Start 60 min STAB Special Start UC 20 min	60 minutes
7	UC 60 min	5 hour soak
8	UC 300 min	3 hour soak
9	UC 180 min	Test End

Appendix F. Vehicle Preconditioning

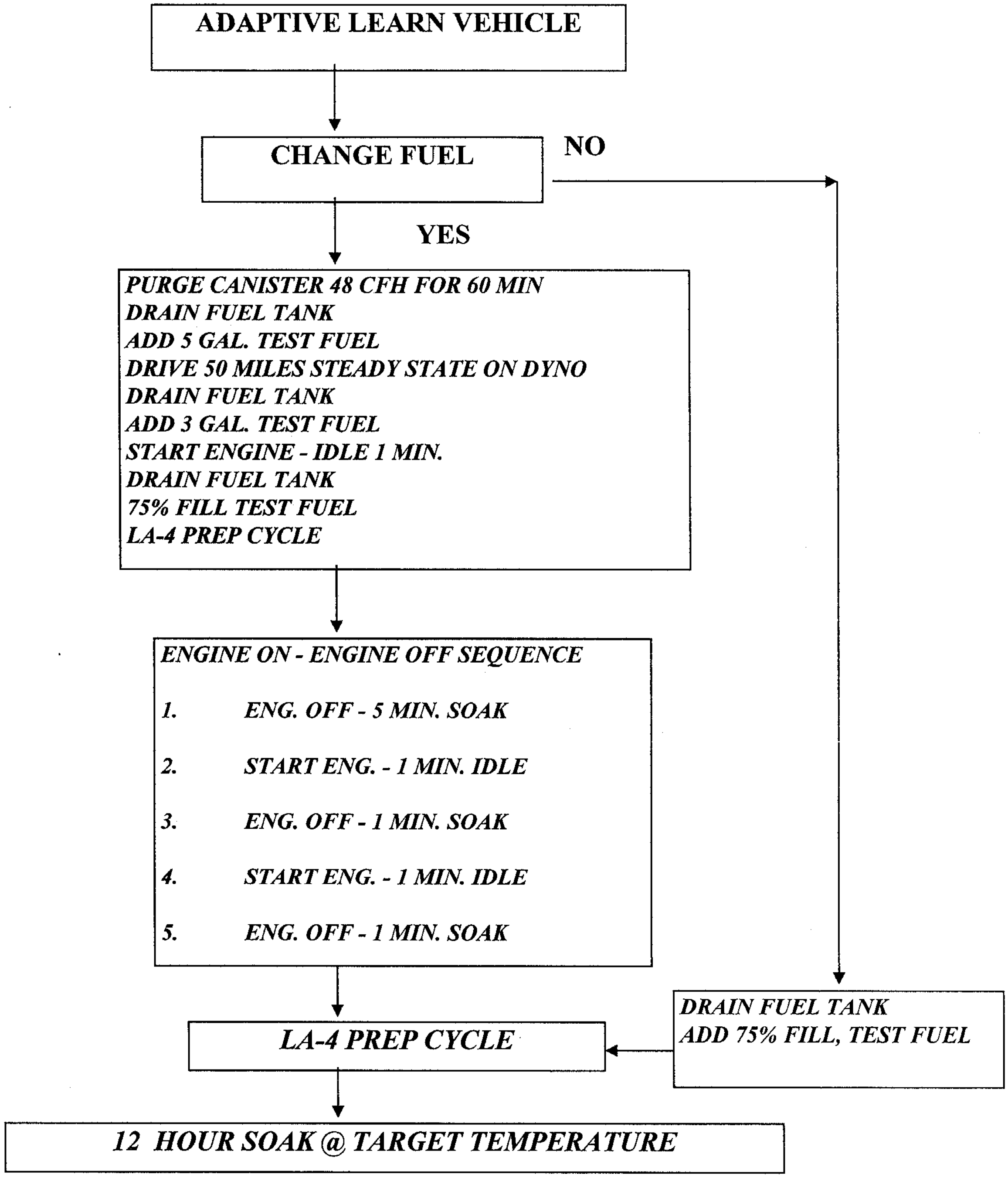


Figure F-1. Preconditioning Sequence for Adaptive Learn Vehicles

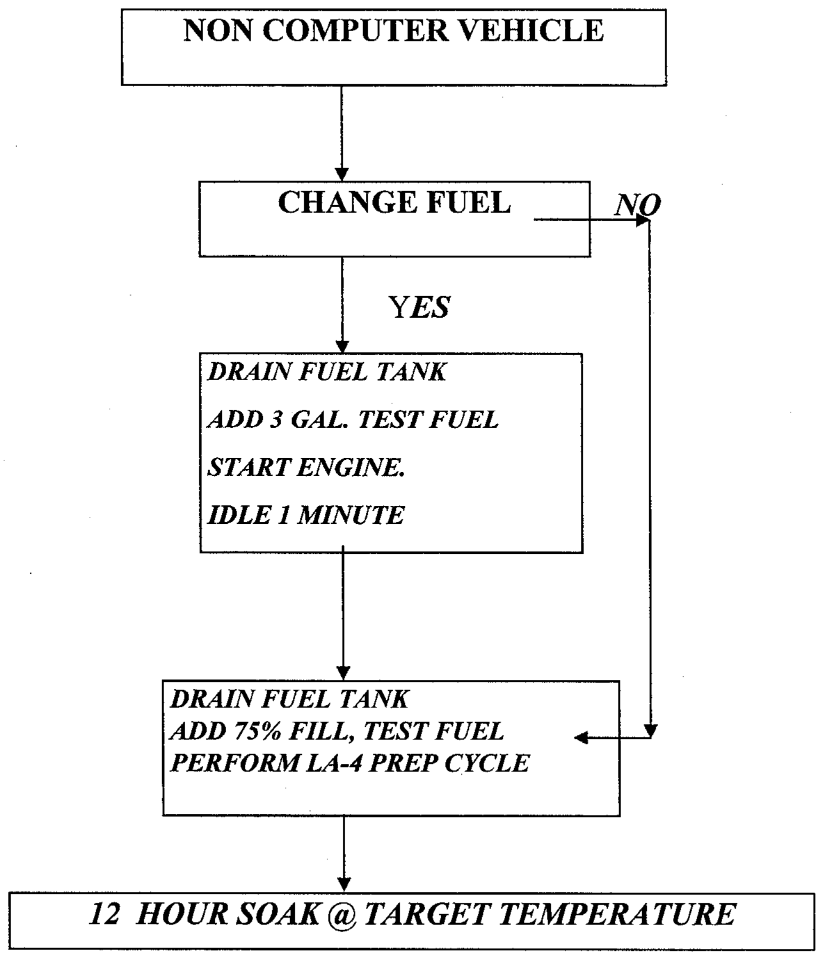


Figure F-2. Preconditioning for Non-Adaptive Learn Vehicles

Appendix G. Data Collection and Validation

Data Collection

Data collected and reported during this program included bag and second by second tailpipe modal data. The bag sample collection was performed using a CFV type CVS. A diluted sample of the exhaust was collected during the entire testing process and stored in Tedlar® bags for analysis after test completion. The concentrations of the sample bags were analyzed and appropriate calculations performed to determine gram-per-mile emission levels for HC, CO, NO_X and CO_2.

The tailpipe modal sample was removed during the entire testing process and analyzed by the tailpipe bench after conditioning (water removal and filtering). The mass calculation was performed using a CO_2 tracer method. CO_2 was measured in the tailpipe exhaust sample, as well as in the CVS diluted exhaust sample. The ratio of the two CO_2 measurements was used to determine exhaust flow on a second by second basis. From the exhaust flow, the modal mass can be determined. The emission levels were continuously sampled (ten times per second), accumulated on a second by second basis and stored on the site computer along with the bag emission data.

After collection on the site computer system, all data was transferred to a networked data concentrator and then to a PC for post processing and storage on floppy diskette. The second by second data required post processing and storage in Microsoft Excel format to facilitate further analysis by ARB personnel. The data supplied to ARB included the second by second vehicle speed, tailpipe concentrations, tailpipe grams, coolant and converter temperatures along with individual vehicle test information. An example of the data format is supplied in Table G-1.

A file naming convention was developed to keep track of the 2,160 individual test files that were generated during the course of the contract testing. The files that were generated included nine bag files, nine raw one second files, and nine processed one second files for each fuel, temperature and vehicle combination. An example of the file naming convention is supplied in Figure G-1.

Table G-1. Sample of Second-by-Second Modal Data

Vehicle Number 1
Test Date 12/10/96
Test Time 3:39:27 VN04005375

Test Temperature 100° F
Fuel Type S1

TESTTIME	RRMPH	TFID	TCO	TNOX	TCO2	TFIDM	TCOM	TNOXM	TCO2M	CONVT	CCCONVT	COOLANT	AMB.TEMP
0	0.0	458.88	13289.50	74.43	10406.10	1.51E-03	2.93E-02	2.59E-04	3.61E-02	96.41	95.37	102.28	102.08
1	0.0	1131.96	28360.90	214.50	30494.10	3.71E-03	6.26E-02	7.47E-04	1.06E-01	96.71	95.38	102.33	102.08
2	0.0	1267.56	35520.40	245.72	46636.90	1.89E-03	3.56E-02	3.88E-04	7.34E-02	96.17	95.92	102.64	102.09
2	0.0	1415.67	38230.70	218.01	61389.60	4.64E-03	8.44E-02	7.59E-04	2.13E-01	96.28	95.38	103.20	102.10
3	0.0	1616.11	37690.90	166.09	79286.40	5.30E-03	8.32E-02	5.78E-04	2.75E-01	96.60	95.25	103.68	102.10
4	0.0	1874.13	35737.30	144.79	91460.70	6.15E-03	7.89E-02	5.04E-04	3.17E-01	96.17	95.59	103.77	102.10
5	0.0	2206.27	33689.80	140.42	99213.10	9.97E-03	1.02E-01	6.74E-04	4.74E-01	96.22	95.52	103.79	102.11
6	0.0	2478.64	30929.70	139.31	104600.00	1.58E-02	1.32E-01	9.40E-04	7.03E-01	96.41	95.59	103.80	102.11
7	0.0	2550.45	28061.30	140.70	108917.00	2.04E-02	1.51E-01	1.20E-03	9.23E-01	96.37	95.53	103.69	102.12
8	0.0	2449.13	25213.10	143.65	112111.00	2.28E-02	1.58E-01	1.42E-03	1.10E+00	96.30	95.27	103.39	102.12
9	0.0	2269.07	22084.00	154.44	114900.00	2.31E-02	1.51E-01	1.67E-03	1.24E+00	96.28	95.37	103.09	102.14

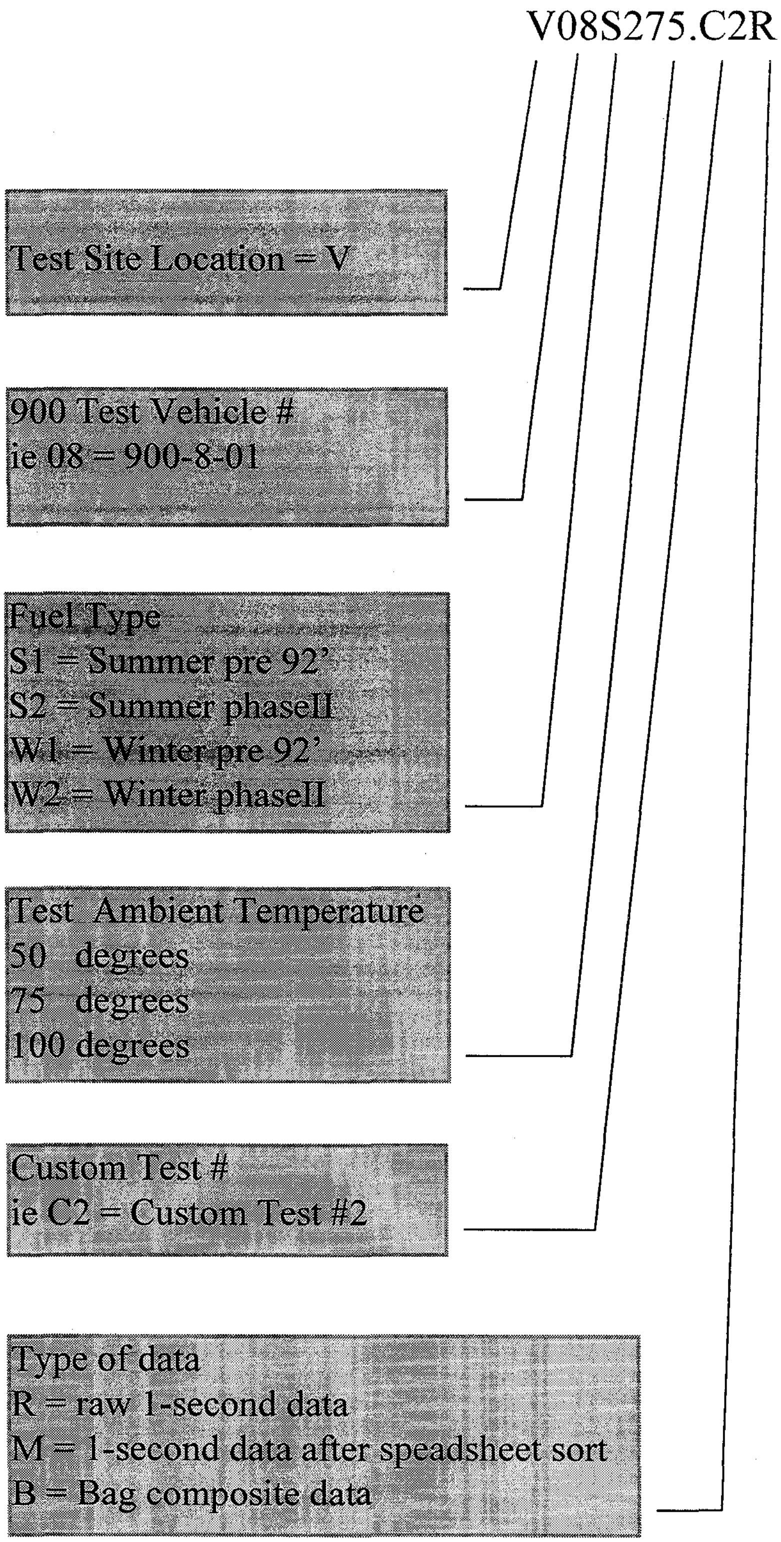


Figure G-1. File Naming Convention

Data Validation

Upon the conclusion of a 15-cycle test for each vehicle, data validation was performed using Federal Register guidelines, as well as good engineering judgment. Validation items reviewed included the following:

- End of Prep to Soak Start Time for Initial FTP
- Soak Times - Prep, Test, Within Custom Tests
- Engine Crank & Start Times
- Test Times
- Prep and Test Cell Temperatures
- Soak Temperatures
- NO_X Correction Factor
- Dewpoint Temperature
- Relative Humidity
- CFV Inlet Temperatures
- Actual Distance Miles
- Background Bag Concentrations
- Bag to Modal Agreement
- Analyzer Zero/Span Checks
- Bag Read Times
- Driver Monitoring Limits

In addition to the foregoing, the tests were checked to ensure:

- Vehicle Sequencing Order
- Fuel Used
- Preconditioning Cycle Performed
- Test Header Information
- Inertia Weight
- Horsepower
- Custom Test Sequencing
- Odometer

ARB staff was consulted for direction when out of limit conditions in testing were observed for approval or direction to retest. All tests significantly out of limits, or not in accordance with Federal Register or program guidelines, were automatically repeated.

Appendix H. Quality Assurance

The test validation process assures that all tests are conducted per the requirements of the Code of Federal Regulations (CFR), California Air Resources Board (ARB) and/or special test program criteria. All test data was validated prior to release. All testing was performed per existing established quality assurance processes currently used for California audit testing plus any unique criteria required to control engineering or custom test programs.

The established quality assurance program utilized a quality control coordinator responsible for correlation, diagnostic vehicle programs, and monitoring of all diagnostic test data. Daily and weekly diagnostic test results are analyzed using individual moving range calculations as flag limits. Decisions are made daily on the stability and state of calibration of the test equipment. Figure H-1 is an example of a moving range plot of dynamometer coast down checks. Additional quality assurance is provided by participation in correlation vehicle test programs. An internal operational review program also checks test equipment and calibrations annually against standards maintained by a separate corporate group.

Test equipment is calibrated or verified on a 30 day interval. Routine daily, weekly, monthly, quarterly, and annual procedures are in place, along with contingent procedures to ensure equipment operation meets or exceeds regulatory requirements and good engineering practices. Daily quality checks over and above CFR requirements include analyzer mid-master checks and CFV propane injections. The dynamometer parasitic losses are checked as a part of the computer controlled automated dyno warm-up program.

In the event of an unsatisfactory calibration condition, maintenance and calibration personnel evaluate the situation and utilize good engineering judgment to determine if any previous test data should be invalidated and tests rerun. The site is not operated until any necessary corrective action has been completed. A summary of the Maintenance Schedule is included here.

MAINTENANCE SCHEDULE

	Daily	Week	Month	Quarter	Semi-Ann.	Annual
Analyzer mid-range check	X		X			
CFO propane injections	X		X			
Bag leak check	X		X			
Bench leek cheeks	X		X			
Environmental monitor verifications						
Barometer		X	X			
Cell temperatures		X	X		X	
Soak area temperatures		X	X		X	
Dew point indicators		X	X		X	
NO_x converter efficiency		X	X			
Diagnostic vehicle test		X				
Zero air generator check		X				
Dilution air controller calibration			X			
Dyno calibration			X			
Analyzer calibration			X			
Analyzer span check			X			
SHED analyzer calibration			X			
SHED CFO propane injection			X			
SHED retention check			X			
SHED temperature calibration checks			X			
Data table verify			X			
C02 interference				X		
NDIR tune check			X			
Analyzer range to range			X			
NO_x flow balance			X			
SCU filter			X			
Methane relative response			X			
CFV filter			X			
CFV sample flow and alarm checks			X			
CFV temperature/pressure verify			X			
CH4 repeatability/retention			X			
CFV sampler PM				X		
Dilution air controller PM				X		
Sample conditioning unit PM				X		
Dyno PM				X		
Zero air generator PM					X	
Gas divider verify						X
Analyzer PM						X
CFO kit calibration						X

The ARB Quality Control and Special Testing (QCST) team scheduled visits to the VEL to inspect for ARB and Code of Federal Regulations (CFR) laboratory specifications conformity. On these visits unknown gases (cylinders provided by ARB) were analyzed on bag and tailpipe ranges with strip chart documentation. Test site calibrations and assurance checks were observed and/or documentation was provided to ARB when requested. The inspection conducted by the QCST team showed that the VEL was in compliance with ARB and CFR specifications and thus approved the site for testing.

The quality assurance checks are listed below.

ARB Quality Assurance Checks

⇒ Analysis of unknown cylinder concentrations on bag and tailpipe ranges with strip chart documentation

⇒ Observed and/or requested documentation on the following:

- Propane injection
- Converter efficiency
- Dyno roll speeds
- Dyno calibration
- Dyno coastdowns
- Environmental checks - dew point, barometer, cell temperature
- Analyzer curves
- CFV pressure and temperature checks

Laboratory correlation is monitored by participation in a facility to facility correlation vehicle test program which includes among others, VEL, ARB El Monte and the contractor's Michigan certification laboratory. This program has been in place since 1978. The VEL facility has recently completed a correlation round employing two correlation vehicles. Tests were run, on one site, at each of the above noted laboratories. Plots of correlation vehicle test data for CO are included as Figure H-3.

A hot start site diagnostic vehicle is tested weekly at the VEL, on each site, to monitor the stability of the sites. Control limits are established utilizing Statistical Process Control (SPC) individual moving range limit calculations. When hot start vehicle results exceed a control limit, the problem is investigated prior to further testing. Site diagnostic data, run during the testing period is shown below in Figure H-2. The upper plot shows actual vehicle data and the lower plot shows the moving range over the entire testing period.

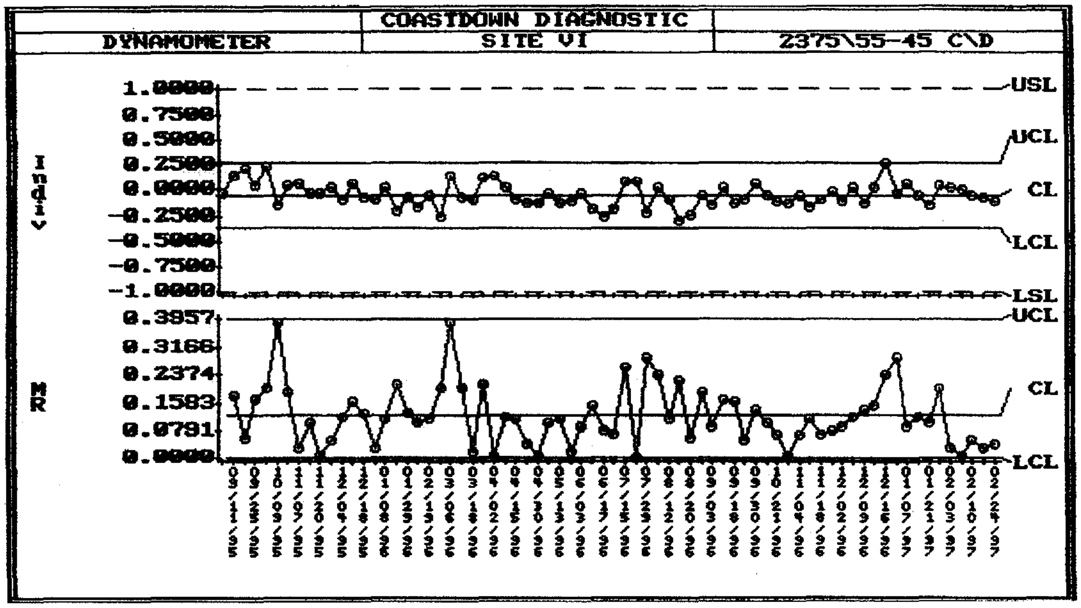


Figure H-1. Dynamometer Coast Down Checks

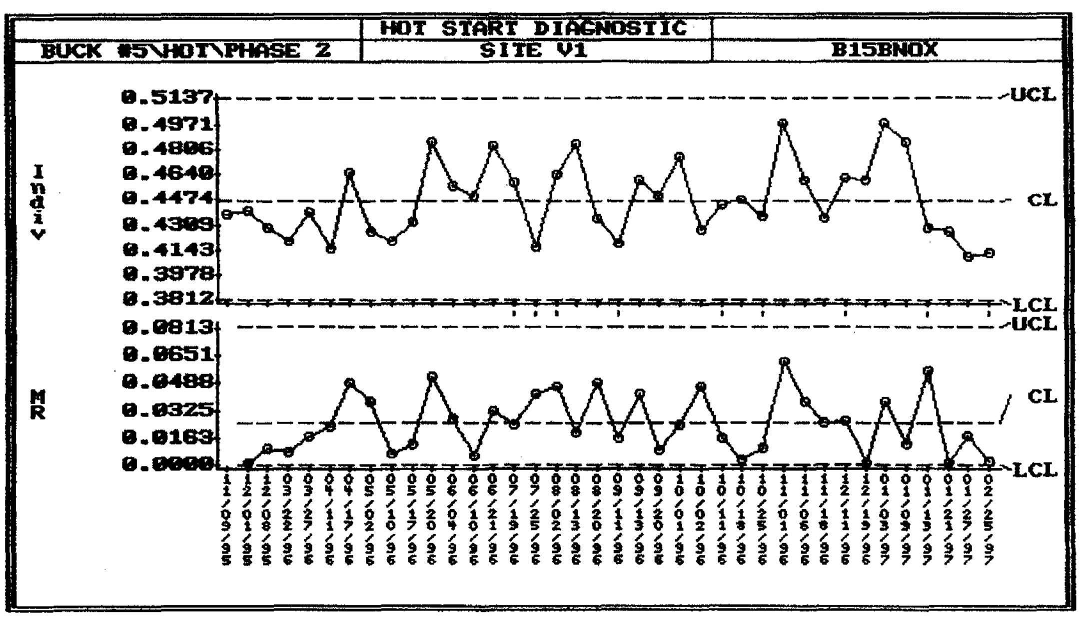
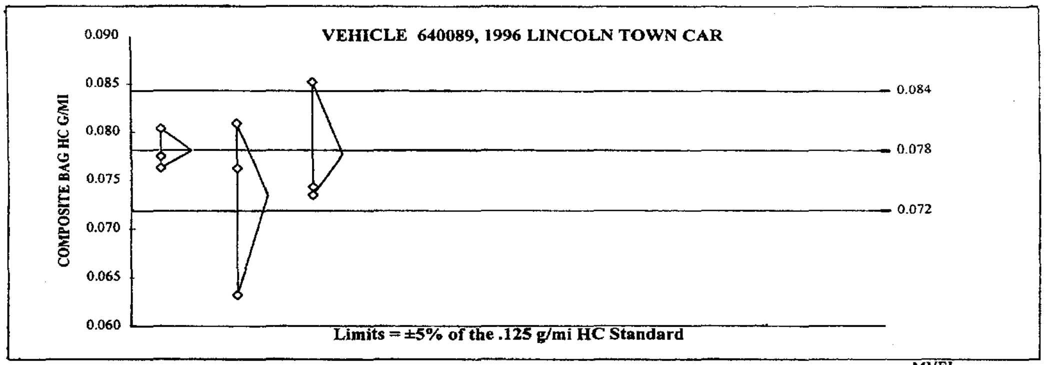
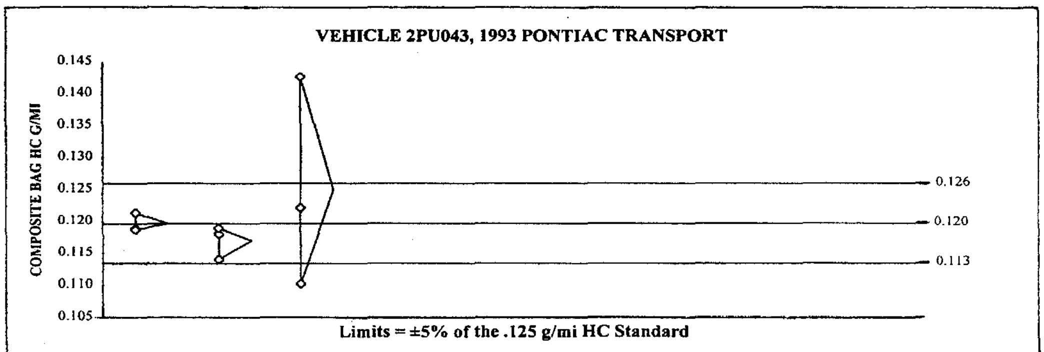


Figure H-2. Hot Start Vehicle Diagnostic Data



	FACILITY DATA											MVEL GRAND
	MVEL 8	CARB 2	GMPT-LA 1	.	.	.	.	.	.	.	.	MEAN
MEAN	0.078	0.073	0.078 .		.	.	.	.	.	.		0.078
STD DEV	0.002	0.009	0.007 .		.	.	.	.	.	.		0.002
% VARIABILITY	2.71%	12.49%	8.47% .		.	.	.	.	.	.		2.71%
% DIFFERENCE	0.00%	-5.91%	-0.48% .		.	.	.	.	.	.		
% STANDARD	0.00%	-3.69%	-0.30% .		.	.	.	.	.	.		



	FACILITY DATA											MVEL GRAND
	MVEL 8	CARB 2	GMPT-LA 1	.	.	.	.	.	.	.	.	MEAN
MEAN	0.120	0.117	0.125 .		.	.	.	.	.	.		0.120
STD DEV	0.001	0.003	0.016 .		.	.	.	.	.	.		0.001
% VARIABILITY	1.25%	2.23%	13.14% .		.	.	.	.	.	.		1.25%
% DIFFERENCE	0.00%	-2.24%	4.43% .		.	.	.	.	.	.		
% STANDARD	0.00%	-2.14%	4.24% .		.	.	.	.	.	.		

2/27/97 BAGPLOT.XLS

Figure H-3. Correlation Vehicle Test Data - CO

GLOSSARY

Canister	Emission control device used to collect hydrocarbon vapors for evaporative emission control.
CARB	California Air Resources Board
CD	Compact Disc
CFO Kit	Critical flow orifice injection kit
CFR	Code of Federal Regulations
CFV	Critical flow venturi
CO	Carbon monoxide
CO2	Carbon dioxide
CVS	Constant volume sampler
DNPH	Dinitrophenylhydrazine
ECM	Electronic Control Module
FTP	Federal Test Procedure
Gas Divider	Device for diluting calibration gases for analyzer curve calibration points.
GC	Gas chromatograph
HC	Hydrocarbons
Hot 505	Hot start test over the first bag of the FTP
NMOG	Non-methane organic gas
NOx	Oxides of Nitrogen
NOx Generator	Device for checking efficiency of NOx converter in a Nox Analyzer
PC	Personal Computer
Prep	Vehicle preconditioning prior to test; typically a UDDS
SPC	statistical process control
THC	Total hydrocarbon value (methane not removed)
UC	Unified Cycle
UDDS	Urban dynamometer driving schedule (Bags 1 & 2 of FTP)
VSZ	Virtual span and zero; computer correction of sample readings for nominal zero & span values.