FORMALDEHYDE EMISSION CONTROL TECHNOLOGY FOR METHANOL-FUELED VEHICLES

Final Report

Contract No. A732-148

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FOREWORD

This project was conducted for the State of California Air Resources Board (ARB) and the South Coast Air Quality Management District (SCAQMD) by the Department of Emissions Research, Southwest Research Institute (SwRI). The program, authorized by ARB Contract No's. A732-148, A996-204, and A166-135, was initiated July 11, 1988 and completed on July 7, 1993. It was identified within Southwest Research Institute as Project No's. 08-2346, 08-3734, and 08-5102. The ARB Contract Manager for the program was Mr. Manjit Ahuja of the Research Division, Sacramento, California. The ARB Project Technical Monitor was Ms. Sarah Santoro of the Mobile Source Division, El Monte, California. The SwRI Project Manager was Dr. Lawrence R. Smith. SwRI Principal Researchers for the project were Dr. Lawrence R. Smith and Mr. Matthew S. Newkirk. At the direction of the ARB Contract Manager, a portion of the funds from Contract No. A996-204 were used in support of work being conducted under Contract No. A6-204-32, "Control of Benzene Emissions from Light-Duty Motor Vehicles."

Several catalyst manufacturers were contacted and asked to supply prototype emission control technologies for study in this program. Manufacturers who supplied catalysts include Degussa Corporation, Johnson Matthey, Nippon Shokubai, Allied Signal, and Camet. Technical support with respect to test vehicles was provided by General Motors, Ford, Toyota, and Volkswagen. SwRI, ARB, and SCAQMD recognize and appreciate the support and cooperation that these companies gave throughout this study.

This report is submitted in fulfillment of ARB Contract No's. A732-148, A996-204, and A166-135, "Formaldehyde Emission Control Technology for Methanol-Fueled Vehicles" by Southwest Research Institute, 6220 Culebra Road, San Antonio, Texas, under the sponsorship of the California Air Resources Board and South Coast Air Quality Management District. Work completed under Contract No. A996-204 in support of Contract No. A6-204-32 has been reported in the report entitled, "Control of Benzene Emissions from Light-Duty Motor Vehicles."

ABSTRACT

This program involved screening and evaluation of catalyst systems from manufacturers throughout the world for control of formaldehyde emissions from methanol-fueled vehicles. Initially, catalyst samples were screened using a vehicle operating on M90. Three catalyst systems were selected from the screened samples for evaluation on methanol-fueled vehicles. One catalyst system from the three evaluated was selected for permanent application and short-term durability testing on five methanol-fueled vehicles. The vehicles were tested using a chassis dynamometer and a constant volume sampler. Exhaust emissions were evaluated using methanol fuel blends and included regulated emissions (total hydrocarbons, carbon monoxide, and oxides of nitrogen) and a number of unregulated emissions including: methane, methanol, formaldehyde, and other aldehydes/ketones. Additional evaluations included determination of fuel economy by carbon balance method and calculation of non-methane organic gas emissions.

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SUMMARY

The objective of this project was to identify and demonstrate durable emission control systems capable of reducing formaldehyde emissions from methanol-fueled vehicles to a level comparable to those from gasoline-fueled vehicles, without adversely affecting control of other criteria pollutants. In order to meet the project objective a multi-task program was conducted.

The objective of Task 1 was to identify catalysts which, based on research results, exhibited the most promising formulations for improved formaldehyde control for dedicated methanol-fueled and flexible-fueled vehicles. The objective of Task 2 was to select three catalyst systems from Task 1 screening for evaluation on a dedicated M85 vehicle, two flexible fueled vehicles, and a dual-fueled vehicle. The objective of Task 3 was to select a catalyst system from Task 2 for permanent installation on each of the Task 2 vehicles plus one additional flexible fueled vehicle, and conduct 4000-mile short-term durability testing.

For Task 1, catalyst manufacturers throughout the world were contacted and asked to supply catalyst samples for screening. A total of 18 catalyst formulations were screened using a Ford Escort vehicle operating on M90 (90% methanol/10% gasoline) as an exhaust generator to determine the best performing catalyst systems. Catalyst systems were screened using cold-start Urban Dynamometer Driving Schedule (UDDS), hot-start UDDS, 30 mile/hour steady-state, and 55 mile/hour steady-state emission test cycles. Average emissions of formaldehyde, methanol, gasoline-derived hydrocarbons (GDHC), carbon monoxide (CO), and oxides of nitrogen (NOx), along with average fuel economies for each of the test cycles and catalyst systems, were measured.

Results of Task 1 testing indicated that a major factor which appeared to most greatly influence the reduction of both regulated and unregulated exhaust emissions for the non-electrically-heated catalyst systems was catalyst proximity to the engine. Although catalyst light-off tests were not conducted as a part of this program, it appears that the shorter heating times associated with manifold and close-coupled systems had a significant impact on emission reductions. Overall, underbody catalyst systems were not as effective at controlling FTP formaldehyde and methanol emissions as the close-coupled and combination catalyst systems which were located in closer proximity to the engine. However, CO and NO_x control appeared to be more independent of catalyst location.

Noble metal composition also appeared to play a role in formaldehyde and methanol emission performance. Given approximately equivalent catalyst volumes in the close-coupled position, a catalyst system with only Palladium (Pd) showed better reduction of both formaldehyde and methanol than a catalyst system with Platinum (Pt) only. However, emission rates of formaldehyde and methanol for the Palladium catalyst were relatively similar to combination close-coupled and manifold catalysts systems with Platinum/Rhodium (Pt/Rh). Additional research is still needed to establish any definite metal composition effects.

The Task 1 FTP emission rate of formaldehyde for the Degussa close-coupled catalyst system (Pd/Rh) was similar to other close-coupled Pt/Rh systems. However, the methanol emission rate for the Degussa system was the lowest of any close-coupled system. This suggests that the use of Pd in a formulation may potentially minimize emissions of unburned methanol.

A loose trend is also apparent when formaldehyde emissions are considered with respect to catalyst volume. In general, as catalyst volume increased from 0.7 liters to 1.8 liters, formaldehyde emissions decreased. A similar decrease in methanol emissions is only observed from 0.7 liter to 1.0 liter catalyst volumes. Above the 1.0 liter catalyst volume other factors seem to be more dominant for close-coupled systems.

Some additional observations and findings which were noted for Task 1 are as follows.

- Fifteen (15) of the 18 catalyst systems evaluated gave formaldehyde emission levels below the California standard of 15 mg/mi. Eight systems gave formaldehyde levels of less than 5 mg/mi.

- The Camet electrically-heated catalyst system showed the best FTP reduction of methanol emissions for "underbody" catalysts.

- The Degussa close-coupled catalyst system showed good control of all regulated emissions, methanol, and formaldehyde.

- The Johnson Matthey manifold/close-coupled catalyst system showed the best control of regulated emissions, methanol, formaldehyde, and gasoline-derived hydrocarbons, of any multi-location system.

The Camet, Degussa, and Johnson Matthey catalyst systems were selected for Task 2 detailed evaluations on a dedicated M85 Toyota Camry, a Chevrolet Corsica, variable-fuel vehicle (VFV), a Ford Crown Victoria flexible-fuel vehicle (FFV) (#1), and a VW Jetta dual-fuel vehicle because they showed good emission performance and represented a variety of emission control technologies. The manufacturer of each of the selected catalyst systems was asked to prepare systems sized appropriately for each of the four vehicles mentioned above. Each catalyst system was installed on each vehicle and duplicate (at minimum) Federal Test Procedure (FTP), Highway Fuel Economy Test (HFET), and New York City Cycle (NYCC) emission tests were conducted using M85 fuel (and gasoline if the vehicles were capable of operating on this fuel). Based on Task 2 emission data, catalyst systems were to be selected for permanent installation on the four vehicles used in the Task 2 evaluations plus one additional Ford Crown Victoria (#2). Crown Victoria #2 was added to the fleet for Task 3 short-term durability testing to allow an additional catalyst system to be evaluated.

The Degussa close-coupled catalyst system was selected for permanent application on the Toyota Camry for the Task 3 durability phase primarily because of its formaldehyde emission performance. Although non-methane organic gas (NMOG) emissions were lower for the Camet plus OEM system than for the Degussa system, the Degussa system was selected because the emission control strategy was much less complicated and represented a more developed technology at the time of testing. In addition, the Degussa system provided the lowest FTP carbon monoxide emissions of any

catalyst system evaluated on this vehicle. It was felt at the time of selection that the heavier precious metal loading may lead to increased durability of the system.

The underbody Camet electrically-heated catalyst system in conjunction with the OEM catalyst and air injection at a rate of 5.2 ft^3/min (during vehicle start-up) was selected for the Chevrolet Corsica. The Camet system gave the lowest FTP NMOG emission rates of any of the catalyst systems evaluated on the Corsica with M85 and gasoline. The Camet system also provided the lowest carbon monoxide emissions of any of the systems evaluated. In addition, FTP oxides of nitrogen emissions were less than the 0.2 g/mi Ultra-Low Emission Vehicle (ULEV) California standard.

Both the Camet electrically-heated catalyst system and the Degussa catalyst system were selected for permanent application on the two Ford Crown Victorias during the Task 3 short-term durability testing. Originally, only one catalyst system was to be selected for application on one Crown Victoria. However, a second Crown Victoria was obtained for use during Task 3 evaluations because both the Degussa and Camet systems showed promising Task 2 emission test results. Consequently, the Camet system was permanently installed on Crown Victoria #1 and the Degussa system was installed on Crown Victoria #2.

The Camet system was selected for Crown Victoria #1 because it provided extremely low FTP NMOG emissions when operating on M85. In addition, FTP formaldehyde emissions were between 1-2 mg/mi when operating on either M85 or Howell EEE. The Camet system also gave the lowest FTP carbon monoxide emissions of the systems evaluated. It was also desired to evaluate the Camet system in the most current technology vehicle in the program. The Degussa system was selected for permanent application on Crown Victoria #2 because it gave the lowest FTP formaldehyde emissions for both gasoline and M85 fuels. In addition, the Degussa system provided good control of NMOG emissions.

The Camet electrically-heated catalyst in conjunction with the Degussa catalyst was the system chosen for permanent application and Task 3 durability testing on the VW Jetta. Although this combination of the two manufacturer-supplied systems was not originally investigated within the scope of Task 2, good emission performance of each system individually led ARB to request that they be evaluated in combination. Emission tests showed that combining the Degussa and the Camet systems was successful for the VW Jetta. Specifically, average FTP formaldehyde and NMOG were the lowest of any system for the Camet plus Degussa system. In addition, FTP carbon monoxide emissions for gasoline and M85 are also well controlled with this system.

Following permanent installation of the selected catalyst systems on each of the five vehicles, they were subjected to 4000 miles of on-road Alternate Mileage Accumulation (AMA) driving using M85 fuel. Task 3, emission tests were conducted using M85 at zero, 2000, and 4000 miles to determine short-term durability of the catalyst systems. On several occasions, the Camet electrically-heated catalyst controller systems had to be repaired by the manufacturer during visits to SwRI.

Although formaldehyde emissions remained low for the Toyota Camry (4.6 to 7.7 mg/mi) throughout the 4000 miles of vehicle operation, there was a continued increase in NMOG, and carbon monoxide emissions, with increased mileage. Fuel injectors also required replacement at the 4000-mile point. Once the injectors were replaced, emission levels decreased substantially.

In general, the Chevrolet Corsica equipped with the Camet EHC system was able to maintain low average FTP emission levels throughout the entire 4000-mile durability testing. However, at the 4000-mile test point NMOG emissions did exceed 0.040 g/mi.

Average FTP emissions of formaldehyde, NMOG, and NO_x remained constant or decreased slightly throughout the 4,000 miles of AMA driving on Crown Victoria #1 equipped with the Camet System. However, from the 2000- to 4000-mile point, average FTP CO emissions more than doubled.

The Degussa catalyst system on Crown Victoria #2 showed a general deterioration trend throughout the 4000 miles of accumulation. Specifically, formaldehyde, NMOG, and CO emissions all increased slightly from the zero- to 2000-mile point and more rapidly from the 2000- to 4000-mile point. NO_x emissions increased slightly from the zero- to 2000-mile test points, but remained relatively stable from 2000 to 4000 miles. Formaldehyde emissions only increased to roughly 8 mg/mile by the 4000-mile point.

Average FTP formaldehyde, NMOG, and NO_x emissions remained relatively constant throughout the entire 4000 miles of mileage accumulation for the Camet plus Degussa system on the VW Jetta. However, like Crown Victoria #1, CO emissions for the VW Jetta showed a continuous increase from the zero- to 4000-mile point. It should be noted that average 4000-mile FTP formaldehyde, NMOG, CO, and NOx emissions from the VW Jetta remained less than the ARB Ultra-Low Emission Vehicle standards.

It is important to also note that Task 3 durability and emission testing was only conducted for 4000 miles. Although several of the vehicles subjected to Task 3 short-term durability testing showed ULEV levels of some emissions, long-term (100,000-mile) durability is still unknown. Of all of the vehicles tested, the VW Jetta equipped with the Camet electrically-heated catalyst in conjunction with the Degussa system showed the best emission performance with mileage accumulation to date.

I. INTRODUCTION

The use of methanol and methanol blended fuels as an alternative to gasoline is one of the strategies available to achieve further reductions in air polluting emissions from motor vehicles. However, concern has been expressed over the potential for increased formaldehyde emissions compared to conventional fuels. This program attempts to identify and investigate possible formaldehyde emission control technologies and provide information which may be useful in developing overall formaldehyde control strategies.

A. Project Objective

The overall objective of this program was to identify and demonstrate durable emission control systems capable of reducing formaldehyde emissions from methanol-fueled vehicles to a level comparable to those from gasoline-fueled vehicles, without adversely affecting control of other criteria pollutants. In order to meet the program objective, a four-task program was conducted.

B. Scope of Work

The objective of Task 1 was to identify catalysts which, based on research results, exhibited the most promising formulations for improved formaldehyde control for dedicated methanol-fueled and flexible fueled vehicles. Next, the selected formulations were screened using a dedicated M90 vehicle (operated on 90% methanol/10% gasoline fuel) as an exhaust generator to determine the best performing catalyst systems.

For Task 2, three catalyst systems which performed the best and represented a variety of emission control technologies were selected from Task 1 evaluations. Each catalyst system was installed on a dedicated M85 vehicle, two flexible fueled vehicles, and a dual-fuel vehicle. Duplicate (at minimum) emission tests were conducted on each catalyst system for each vehicle.

Task 3 consisted of 4000-mile short-term durability emission testing of a catalyst system selected for each of five vehicles. Final catalyst systems were selected for 4000-mile short-term durability testing on each vehicle based on Task 2 emission test results. Because ARB desired a variety of catalyst technologies to be evaluated for durability, catalysts systems selected for Task 3 did not necessarily provide the lowest emissions during Task 2 tests. Rather, the systems tested included a variety of emission control technologies that had the potential to maintain good emission performance and durability.

In addition to the first three tasks mentioned above, ARB also directed SwRI to conduct several emission tests with hydrocarbon speciation using two of the test vehicles, in order to estimate reactivity adjustment factors (RAFs). These tests were conducted during Task 2 of the program.

This report was prepared as a Draft Report for Task 4. ARB then reviewed the document and returned it to SwRI for changes and final printing.

C. Test Vehicles

The vehicle used for Task 1 screening of catalyst samples was a 1981 Ford Escort equipped with a 1983 1.6 liter M90 (90% methanol/10% unleaded gasoline) engine. The vehicles that were used for both Task 2 and Task 3 evaluations were as follows: 1986 dedicated M85 Toyota Camry; 1989 VW Jetta dual-fuel vehicle (either M85 or gasoline); 1988 Chevrolet Corsica Variable Fuel Vehicle; and 1989 Ford Crown Victoria Flexible Fuel Vehicle. For Task 3 durability evaluations, a second 1989 Ford Crown Victoria was included in testing along with all Task 2 vehicles for a total of five vehicles. More detailed descriptions of test vehicles are given in Section III. A.

D. Catalyst Systems

A total of 18 catalyst systems were from manufacturers throughout the world for Task 1 screening tests. Task 1 catalyst systems were selected for evaluation on four methanol-fueled vehicles for Task 2 testing. Task 2 catalyst systems were supplied by Camet, Degussa, and Johnson Matthey. One Task 2 catalyst system was selected for permanent application on each of the five methanol-fueled vehicles used for Task 3 short-term durability testing. More detailed descriptions of the catalyst systems used for each task are given in Section III.

E. Test Procedures

The catalyst samples were screened during Task 1 on the Ford Escort operating on a chassis dynamometer over the Federal Test Procedure (FTP) as well as 30 mi/hr and 55 mi/hr steady-states. Task 2 and Task 3 emission tests were conducted using the remaining vehicles mentioned above following the Federal Test Procedure (FTP), the Highway Fuel Economy Test (HFET), and the New York City Cycle (NYCC). A more detailed description of the test procedures is given in Section III. E.

F. Emission Measurement Procedures

Total hydrocarbons (THC), carbon monoxide (CO), oxides of nitrogen (NO_x), and carbon dioxide (CO_2) were evaluated according to procedures established in the *Code of Federal Regulations*.(1)* Sampling methods used to evaluate regulated emissions (HC, CO, NO_x, CO_2) as well as methanol, aldehydes, and C_1-C_{10} speciated hydrocarbons are shown in Table 1. The detailed analytical procedures used to evaluate the emissions are discussed in a following section of this report.

TABLE 1. SAMPLING METHODS

Sampling Method	Compound(s) Evaluated
Bag	Regulated Emissions: HC, CO, NO_x, CO_2
Impinger	Methanol
Impinger	Aldehydes and Ketones
Bag	Methane
Bag	C_1-C_{10} Hydrocarbon Speciation

*Numbers in parentheses designate references at the end of the report.

II. GENERAL EQUIPMENT, INSTRUMENTS, PREPARATIONS AND PROCEDURES

This section describes the test vehicles, the test facilities, and general instrumentation and procedures used throughout this project. The sampling systems for unregulated emissions (methanol, aldehydes and ketones, methane, and hydrocarbon speciation) are also discussed.

A. Test Vehicles

The vehicle used for all Task 1 screening evaluations of catalyst samples supplied for the program was a 1981 Ford Escort equipped with a 1983 M90 (90% methanol/10% unleaded gasoline) engine. The engine was a 1.6 liter, high output, 4-cylinder, and was operated on a 9:1 mixture of reagent grade methanol and unleaded emission grade test fuel. The chassis dynamometer settings used for the vehicle when evaluating catalyst samples were as follows: 2500 pounds inertia weight, and 6.5 horsepower road load. It should be noted that this vehicle was used solely as an exhaust generator and not as a representative test vehicle for current technology.

The vehicle engine was equipped with an air pump. During the cold start, this system provided supplemental air to the exhaust manifold, and in the original configuration, air between a three-way catalyst segment and an oxidation catalyst segment. The air line to the catalyst position was disconnected for all testing in this study. A photograph of the test vehicle is shown in Figure 1. A summary of selected engine-out emissions at idle speed and 60 miles/hour is given in Table 2. Exhaust temperatures at idle and at 60 miles/hour were provided to catalyst suppliers, and are given in Table 3.

FIGURE 1. PHOTOGRAPH OF M90 FORD ESCORT

TABLE 2. M90 FORD ESCORT EMISSIONS AT IDLE AND 60 MPH

THC (ppmC)		CO (ppm)		NO_x (ppm)		CO_2(%)	
Idle	60 mph	Idle	60 mph	Idle	60 mph	Idle	60 mph
870	1800	38,000	21,000	20	270	11	12

TABLE 3. M90 FORD ESCORT EXHAUST TEMPERATURES

Location	Temperature (°C)	
	Idle	60 mph
Manifold	339	540
Underbody	186	420

The test vehicles used for evaluating each of three catalyst systems during Task 2 of the program were a 1986 dedicated M85 Toyota Camry, a 1989 VW Jetta dual-fuel vehicle (either M85 or gasoline), a 1988 Chevrolet Corsica Variable Fuel Vehicle, and a 1989 Ford Crown Victoria Flexible Fuel Vehicle. An additional 1989 Ford Crown Victoria Flexible Fuel Vehicle (obtained by ARB from the South Coast Air Quality Management District) was used along with the other four Task 2 vehicles for the Task 3 work. A description of all Task 2 and Task 3 vehicles is given in Table 4, and photographs are shown in Figures 2, 3, 4, 5, and 6. In order to provide the catalyst suppliers with information necessary to prepare catalysts for the Toyota Camry and Chevrolet Corsica, engine-out emissions and maximum exhaust temperatures were measured using the Federal Test Procedure. The vehicles were operated on M85 fuel (and 100 percent gasoline if possible). A summary of the information provided to the catalyst manufacturers is given in Table 5.

TABLE 4. DESCRIPTION OF TEST VEHICLES

Make	Model	Year	Fuel Type	Engine		Dynamometer Settings	
				Type	Size (liters)	Inertia (lbs.)	Power (hp)
Toyota	Camry	1986	M85	L4	2.0	3000	7.4
Chevrolet	Corsica	1988	Variable	V6	2.8	3125	5.9
Volkswagen	Jetta	1989	Dual Fuel	L4	1.8	2750	7.0
Ford (#1)	Crown Vic	1989	Flexible	V8	5.0	4250	12.6
Ford (#2)	Crown Vic	1989	Flexible	V8	5.0	4250	12.6

FIGURE 2. 1986 DEDICATED M85 TOYOTA CAMRY

FIGURE 3. 1988 CHEVROLET CORSICA VARIABLE FUEL VEHICLE

FIGURE 4. 1989 VW JETTA DUAL FUEL VEHICLE (M85 OR GASOLINE)

FIGURE 5. 1989 FORD CROWN VICTORIA FLEXIBLE FUEL VEHICLE #1

FIGURE 6. 1989 FORD CROWN VICTORIA FLEXIBLE FUEL VEHICLE #2

TABLE 5. SUMMARY OF TOYOTA CAMRY AND CHEVROLET CORSICA ENGINE-OUT FTP EMISSIONS

Vehicle	Fuel	Exhaust Temp., Maximum (°C)		FTP Emissions, grams/mile (except as noted)				
		Underbody	Manifold	THC	CO	NO_x	CO_2	Form. (mg/mi)
Toyota Camry	M85	490	565	2.51	9.55	2.11	260.9	189
Chevrolet Corsica	M85	520	575	1.99	10.59	1.31	349.2	198
Chevrolet Corsica	gasoline	540	600	2.44	11.70	1.56	383.8	83

B. Test Fuels

Task 1 catalyst screening tests were conducted using M90 (a splash blend of 90% volume reagent grade methanol and 10% volume Howell EEE unleaded emission test fuel). Task 2 and 3 emission tests were conducted using both M85 (a splash blend of 85% volume reagent grade methanol and 15% volume Howell EEE unleaded emission test fuel) and 100% unleaded gasoline (if vehicles were flexible fuel, variable fuel, or dual fuel). A mixture of "industry average" (RF-A) fuel from the CRC Auto/Oil Program was also used to blend M85 for one FTP test in the Chevrolet Corsica. A summary of the density, percent carbon, percent hydrogen, and percent oxygen for each fuel (or blend) as used for emission testing is given in Table 6. Note that values given in Table 6 were used to calculate fuel economy by carbon balance.

TABLE 6. FUEL DENSITIES, % CARBON, % HYDROGEN, AND % OXYGEN

Fuel	Density (lb/gal)	Carbon (%)	Hydrogen (%)	Oxygen (%)
Howell EEE	6.163	86.6	13.4	0.0
M90	6.742	41.0	13.0	46.0
M85	6.570	43.6	12.8	43.6

C. Dynamometer and CVS Systems

Throughout the entire program all vehicles were operated on two Clayton Model ECE-50 passenger car dynamometers (SwRI Dynamometers Nos. 1 and 2) with direct drive variable inertia systems. These inertia systems simulate equivalent weight of vehicles from 1,000 lb to 8,875 lb in 125 lb increments. For Task 1 and 2 work, the constant volume sampler (CVS) used for the evaluations was SwRI CVS No. 2. An 18-inch diameter by 16-ft long stainless steel dilution tunnel was used in conjunction with the CVS, which was run at a nominal 315 scfm. The dimensional details of the dilution tunnel are provided in Figure 7 along with a schematic of the entire system in Figure 8. Task 3 work was conducted using CVS No. 8 system with a nominal 550 scfm flow rate. A schematic of the CVS system used for Task 3 work is shown in Figure 9.

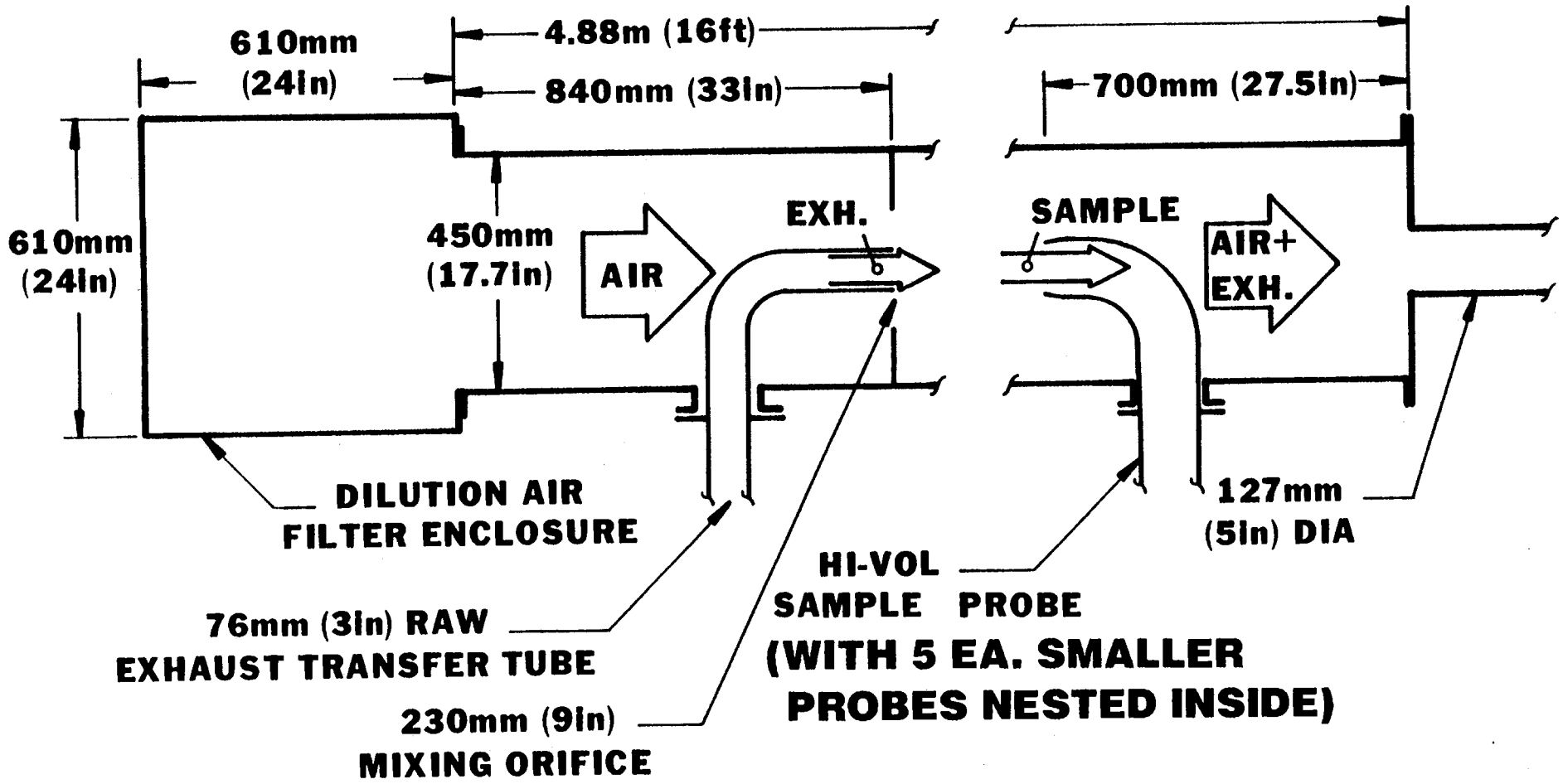

FIGURE 7. DIMENSIONAL DETAILS OF DILUTION TUNNEL

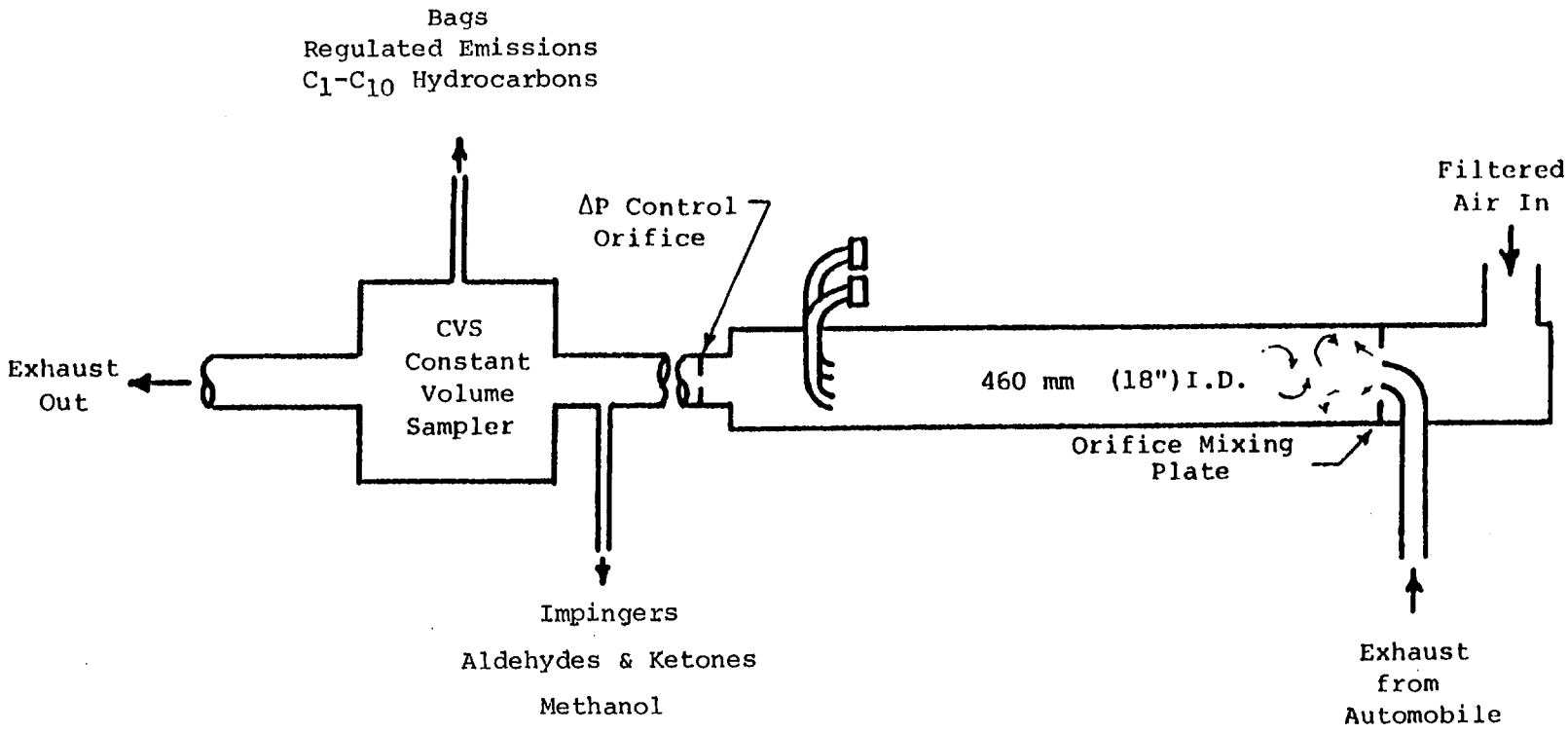

FIGURE 8. SCHEMATIC OF CVS SYSTEM USED FOR TASK 1 AND 2 TESTING

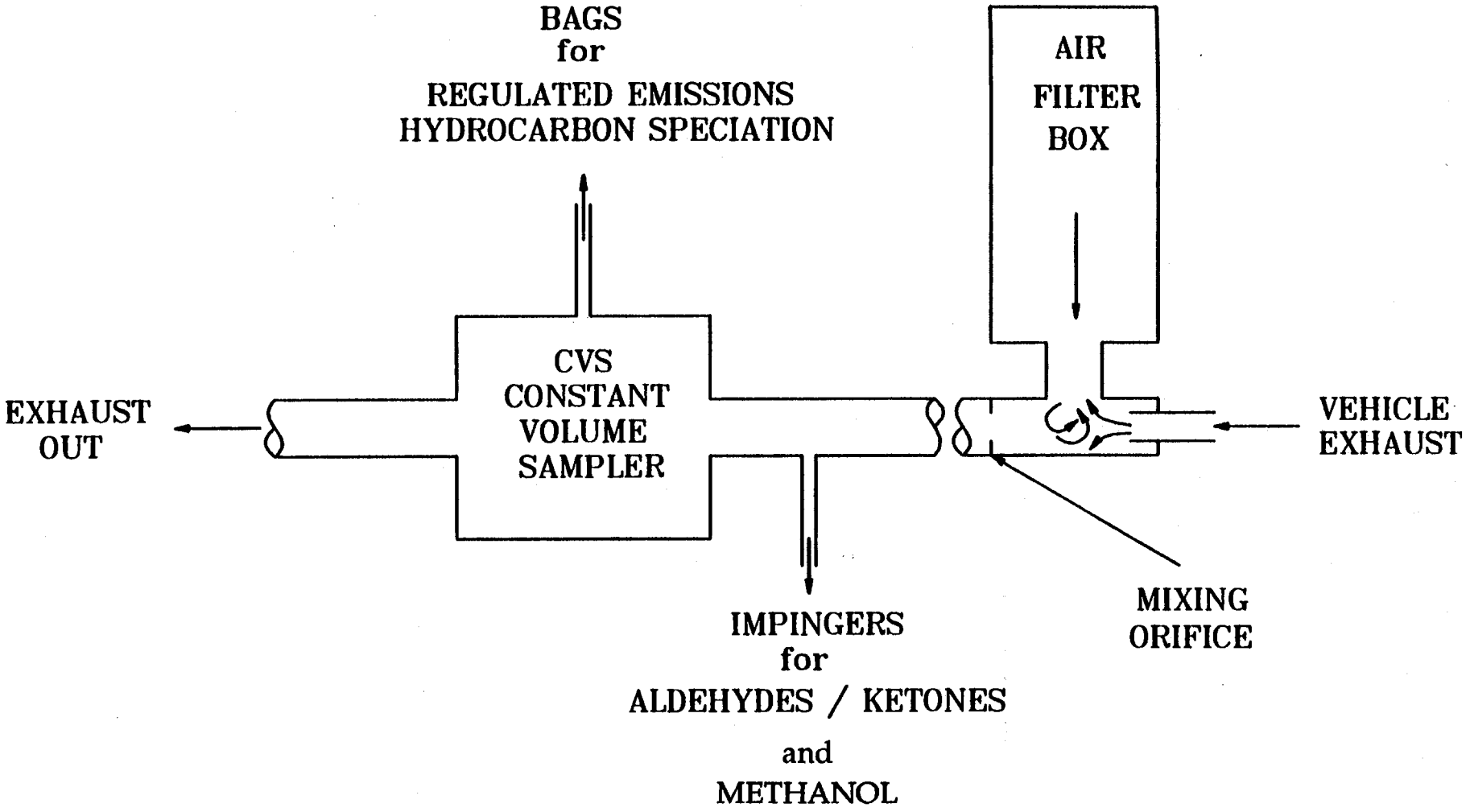

FIGURE 9. SCHEMATIC OF CVS USED FOR TASK 3 TESTING

A cooling fan of 5000 cfm capacity was used in front of the vehicles during all emission tests and test cycles. The hood was maintained fully open during all cycles and was closed during the soak periods. A partial view of a test vehicle, dynamometer, cooling fan, and CVS can be seen in Figure 10.

D. Instrumentation for Regulated Emissions

Bagged gaseous emission samples obtained at the CVS were analyzed for total hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), and carbon dioxide (CO_2). The emissions were evaluated using SwRI Bag Carts Nos. 1 and 2. Both are designed, calibrated, and operated in accordance with appropriate sections of the *Code of Federal Regulations* for light-duty vehicles.[1] A photograph of one of the two bag carts used for regulated emissions analysis is shown in Figure 11.

E. Emissions Test and Sampling Procedures

The test cycles that were used in Tasks 1, 2, and 3 of the program were the Federal Test Procedure (FTP)[1], the Highway Fuel Economy Test[2], and the New York City Cycle.[3] In addition to these variable speed driving cycles, 30 mile/hour and 55 mile/hour steady-state or constant speed tests were used for Task 1 catalyst screening to provide additional emissions information for catalyst evaluations.

The FTP cycle uses the Urban Dynamometer Driving Schedule (UDDS) which is 1372 seconds in duration. The UDDS, in turn, is divided into two segments; the first having 505 seconds (Bags 1 and 3 of the FTP) and the second having 867 seconds (Bags 2 and 4 of the FTP). The FTP consists of a cold-start 505 (Bag 1) and a stabilized 867 (Bag 2) followed by a ten minute soak and then a hot-start 505 (Bag 3). In this project, the hot-start 505 was followed by another 867 segment (Bag 4). The FTP, HFET, and NYCC schedules are summarized in Table 7 and illustrated in Figure 12.

TABLE 7. SUMMARY OF DRIVING SCHEDULE PARAMETERS

	Duration, Seconds	Distance, Miles	Average Speed	
			km/hr	mph
FTP:				
505	505	3.60	41.3	25.7
867	867	3.85	25.8	16.2
UDDS	1372	7.45	31.4	19.5
HFET	765	10.25	77.6	48.2
NYCC	599	1.19	11.5	7.1

For all emission tests conducted throughout this program, regulated emissions (HC, CO, NO_x, and CO_2) were sampled using Tedlar® Bags on a bag-by-bag basis (ie. one sample for Bag 1, one sample for Bag 2, etc.). During Task 1, impinger samples (aldehydes/ketones and methanol) were taken throughout the entire UDDS (ie. one sample for Bags 1 and 2 combined and one sample for Bags 3 and 4 combined). For Tasks 2 and 3 emission testing, impinger samples were taken and analyzed on a bag-by-bag basis. A photograph of the impinger sampling cart used for collecting aldehyde/ketone and methanol samples in Task 3 is shown in Figure 13.

FIGURE 10. PARTIAL VIEWS OF TEST VEHICLE, DYNAMOMETER, COOLING FAN, AND CVS

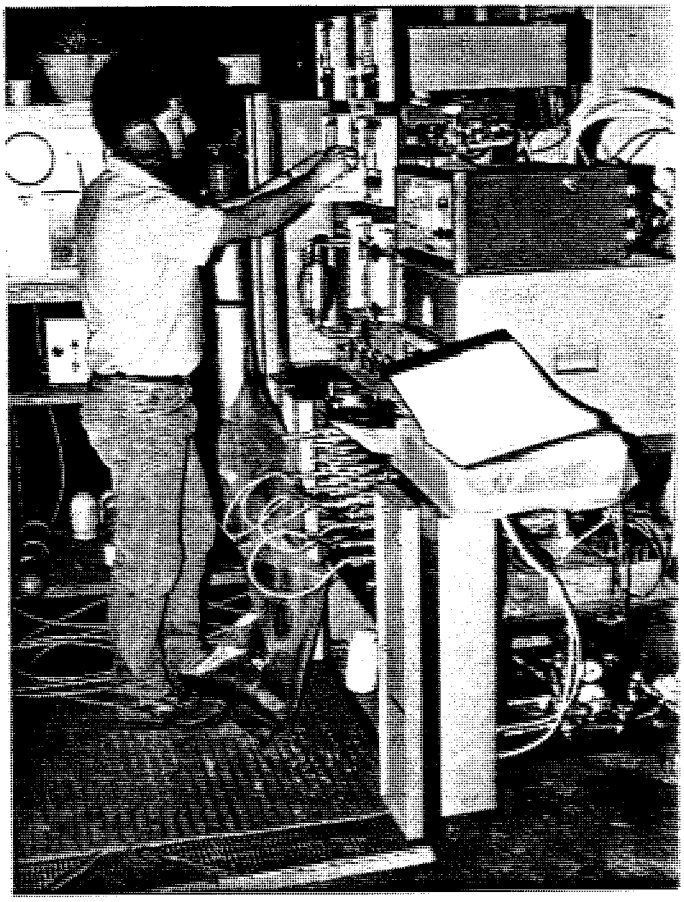

FIGURE 11. BAG CART USED FOR REGULATED EMISSIONS ANALYSIS

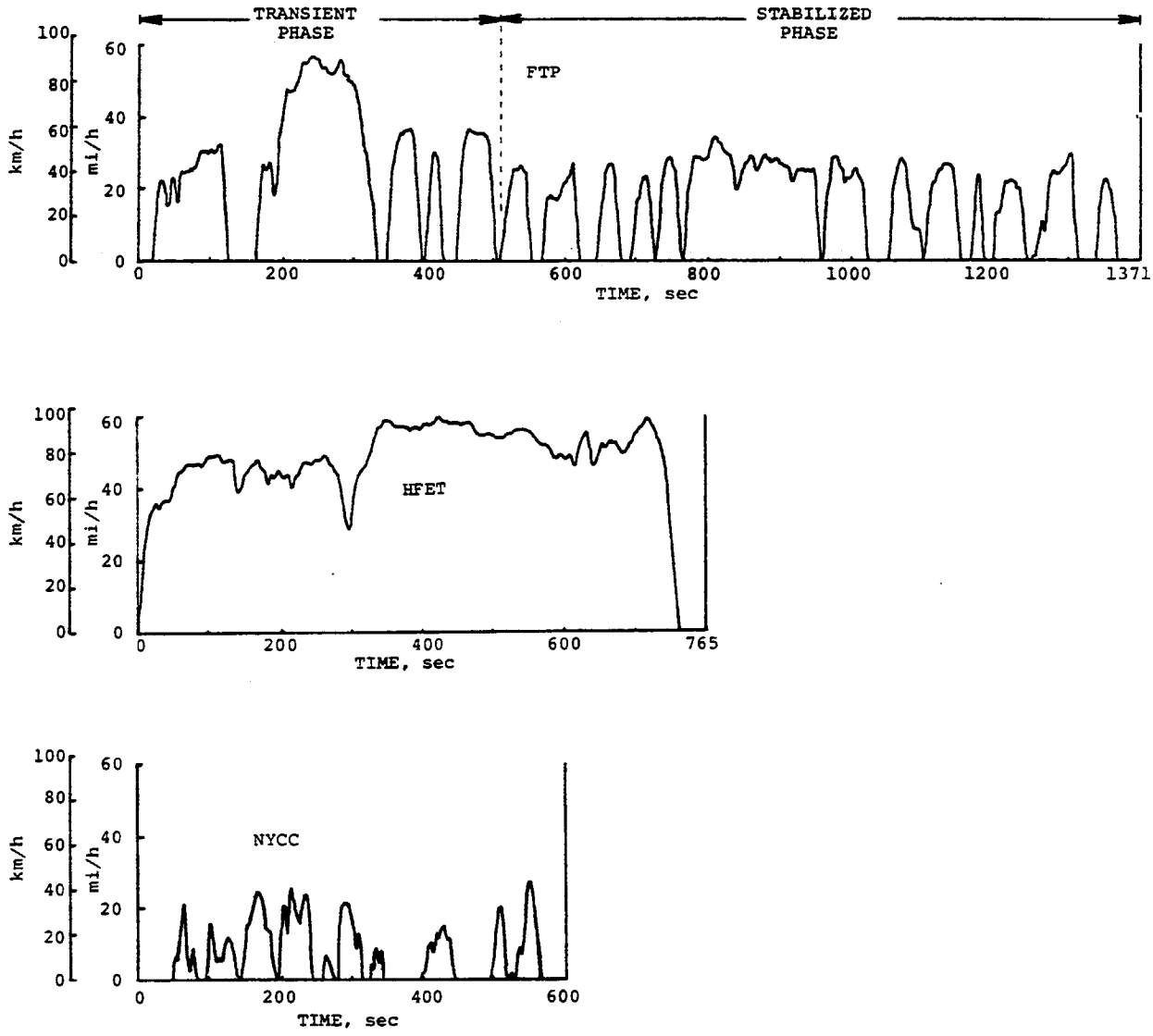

FIGURE 12. ILLUSTRATION OF FTP, HFET, AND NYCC SCHEDULES

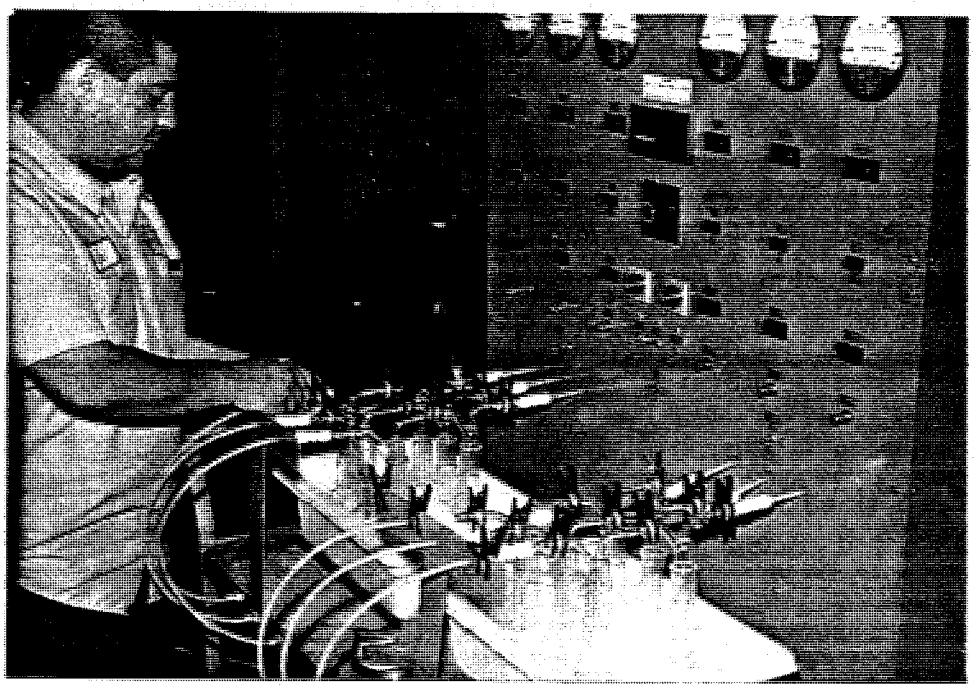

FIGURE 13. PHOTOGRAPH OF IMPINGER SAMPLING CART

Sampling and analysis were conducted on a bag-by-bag basis for all Task 2 and 3 methane analyses and for requested Task 2 hydrocarbon speciation. A summary of test cycles and emission sampling schedules used for Task 1 emission tests is given in Table 8. A summary of the Task 2 and 3 test cycles and emission sampling schedule is given in Table 9.

In order to explain the rationale used to compare composite values (in mass per distance) for the three-cycle, three-sample FTP to the four-cycle, two-sample FTP composite values (needed for Task 1 aldehyde/ketone and methanol sampling and analysis), the following emission calculation derivation has been provided:

$$\frac{MASS}{DISTANCE} = \frac{0.43 \times (MASS\ 1 + MASS\ 2)}{(DIST.\ 1 + DIST.\ 2)} + \frac{0.57 \times (MASS\ 3 + MASS\ 2)}{(DIST.\ 3 + DIST.\ 2)}$$

Assuming Distance 3 is equal to Distance 1, this equation can be reduced to:

$$3\text{-}FTP\ M/D = \frac{0.43 \times (M1 + M2) + 0.57 \times (M3 + M2)}{D1 + D2}$$

For the four cycle, two sample FTP composite values determined in this project, the following formula was used:

$$\frac{MASS}{DISTANCE} = \frac{0.43 \times M(1 + 2)}{(D1 + D2)} + \frac{0.57 \times M(3 + 4)}{(D3 + D4)}$$

TABLE 8. SUMMARY OF TASK 1 TEST CYCLES AND EMISSION SAMPLING SCHEDULES

	Four-Cycle FTP				30 mph SS	55 mph SS
	Cold-Start UDDS		Hot-Start UDDS			
Duration (seconds)	505	867	505	867	300	300
Regulated Emissions, 4-bag	X	X	X	X	X	X
Methanol (Impinger)	<----X---->		<----X---->		X	X
Aldehyde/Ketone (Impinger)	<----X---->		<----X---->		X	X
Note: "X" denotes a sample taken.						

TABLE 9. SUMMARY OF TASK 2 and 3 TEST CYCLES AND EMISSION SAMPLING SCHEDULES

	Four-Cycle FTP			
	Cold-Start UDDS		Hot-Start UDDS	
Duration (seconds)	505	867	505	867
HC, CO, NO_X, and CO_2 (bag)	X	X	X	X
Methane (bag)	X	X	X	X
Methanol (Impinger)	X	X	X	X
Aldehyde/Ketone (Impinger)	X	X	X	X
Note: "X" denotes a sample taken.				

Assuming distance 3 is equal to Distance 1 and Distance 4 is equal to Distance 2, then this equation can be reduced to:

$$4\text{-}FTP\ M/D = \frac{0.43 \times M(1 + 2) + 0.57 \times M(3 + 4)}{D1 + D2}$$

Therefore, with the assumption that the changes in distance traveled are negligible, the composite results with the four-cycle FTP relative to results with the three-cycle FTP will differ only as the mass emissions emitted during Cycle 4 differ from those emitted during Cycle 2.

III. CATALYST SYSTEMS

Upon initiation of Task 1 of the project, catalyst manufacturers throughout the world were contacted and asked if they were interested in participating in this program. A total of 11 catalyst companies were contacted. A list of individuals contacted along with their respective companies is given in Table 10. Of the 11 companies contacted, five provided catalyst samples for evaluation in this program.

TABLE 10. EXHAUST AFTERTREATMENT TECHNOLOGY CONTACTS

Name	Company	Comments
Dr. Hartmut Kurtzke Dr. Dimitrios Psaras	Degussa Corporation	Supplied close-coupled catalyst systems
Dr. Hassan Windawi	Johnson Matthey	Supplied a variety of catalyst systems
Mr. William Whittenberger	Camet	Supplied electrically-heated catalyst systems (EHCs)
Mr. Shoichi Ichihara	Nippon Shokubai	Supplied a variety of catalyst systems
Dr. Burton Williamson	Allied Signal	Supplied underfloor and manifold/close-coupled catalyst systems
Mr. Marty Morril	Prototech	No catalysts supplied
Dr. Patricia A. Tooley	Phillips	No catalysts supplied
Mr. Mike Evans	W.R. Grace	No catalysts supplied
Mr. Kent Wiberg	EKA Nobel	No catalysts supplied
Dr. Ken Voss	Engelhard	No catalysts supplied
Mr. Koichi Matsuo	Mitsui Mining and Smelting	No catalysts supplied

The remainder of this section will be used to describe the catalyst systems for each of the three tasks of the project.

A. Task 1 Catalyst Systems

A total of 18 catalyst systems were screened using the M90 Ford Escort during Task 1 of the program. Systems tested included underbody, close-coupled, and combinations of manifold plus either close-coupled or underbody. Underbody catalyst systems were located in the OEM underfloor location. Close-coupled catalyst systems were located approximately 12 inches from the exhaust manifold. Manifold catalysts were located as closely as possible to the exhaust manifold. Descriptions of catalyst location(s) and type are given in Table 11. Note that only the catalyst size, location, and metal type were required for this initial screen phase of testing. For comparative purposes, a new (unaged) Ford Escort gasoline catalyst (catalyst system "A") as well as a "no catalyst" or "NC" configuration were also evaluated within the test matrix.

TABLE 11. DESCRIPTION OF SIZE, LOCATION, AND TYPE OF CATALYSTS SCREENED

Catalyst System	Supplier	Location	Shape	Volume (liters)	Metal(s)
NC	--	--	--	--	--
A	Ford/OEM	U	Racetrack	unknown	unknown
B	Nippon Shokubai	U	Racetrack	1.7	Pt/Rh
C	Degussa	U	Round	1.0	Pt/Rh
D[a]	Johnson Matthey	U U	Racetrack Racetrack	1.8 0.9	Pt/Rh Pt
E[b]	Camet	U	Rectangle	1.8	Pt/Rh
F	SwRI	U	Round	1.2	Pt
G	Allied Signal	C	Round	1.0	Pd
H	Nippon Shokubai	C	Round	0.7	Pt/Rh
I	Degussa	C	Round	1.0	Pt/Rh
J	Johnson Matthey	C	Racetrack	1.8	Pt/Rh
K	Nippon Shokubai	C	Racetrack	1.7	Pt/Rh
L	SwRI	C	Round	1.2	Pt
M	Allied Signal	C	Round	1.0	Pt/Rh
N	Allied Signal	C	Round	1.0	Pt/Rh
O	Nippon Shokubai	C U	Round Racetrack	0.7 1.7	Pt/Rh Pt/Rh
P	Johnson Matthey	M C	Racetrack Racetrack	0.4 1.8	Pt/Rh Pt/Rh
Q	Johnson Matthey	M C	Racetrack Racetrack	0.4 1.8	Pd Pt/Rh
R	Johnson Matthey	M U	Racetrack Racetrack	0.4 1.7	Pt/Rh Pt/Rh

[a]Air injected between two catalyst bricks.
[b]Metal substrate.

Locations:
U - Underbody
C - Close-coupled (approx. 12" from exhaust manifold)
M - Manifold (approx. 5" from exhaust manifold)

"NC" - No Catalyst
"A" - New OEM gasoline catalyst
"B"-"R" - Test catalysts

B. Task 2 Catalyst Systems

Upon completion of Task 1 screening of the 18 catalyst systems, three catalyst systems were selected by the State of California Air Resources Board (ARB) for detailed testing using the Toyota Camry, the Chevrolet Corsica, the VW Jetta, and the Ford Crown Victoria #1 (as described in Section II. A.). The three catalyst systems selected were the combination close-coupled and manifold Johnson-Matthey System ("P"), the close-coupled Degussa System ("I"), and the Camet electrically-heated catalyst in conjunction with the OEM catalyst ("E"). Manufacturers of the selected catalyst systems were asked to produce one catalyst system for each of the aforementioned vehicles. Descriptions of the catalyst systems provided in response to this request are given below in Table 12.

TABLE 12. DESCRIPTION OF TASK 2 CATALYST SYSTEMS

Vehicle	Catalyst Supplier	Location	Shape	Volume (liters)	Metal(s)	Ratio	Loading (g/ft^3)
Toyota Camry	Johnson Matthey	C M	Racetrack Racetrack	1.80 0.36	Pt/Rh Pt/Rh	5:1 5:1	40 40
Toyota Camry	Degussa	C	Round	1.40	Pd/Rh	10:1	70
Toyota Camry	Camet	U	Round	0.20	Pt/Rh	6.7:1	40
Chevrolet Corsica	Johnson Matthey	C M	Racetrack Racetrack	2.70 0.36	Pt/Rh Pt/Rh	5:1 5:1	40 40
Chevrolet Corsica	Degussa	C	Round	2.80	Pd/Rh	10:1	70
Chevrolet Corsica	Camet	U	Round	0.30	Pt/Rh	6.7:1	40
Ford Crown Vic #1	Johnson Matthey	C M	Racetrack Racetrack	0.90 0.90	Pt/Rh Pt/Rh	5:1 5:1	40 40
Ford Crown Vic #1	Degussa	C	Round	2.80	Pd/Rh	10:1	70
Ford Crown Vic #1	Camet	U	Round	0.17	Pt/Rh	6.7:1	40
VW Jetta	Johnson Matthey	C M	Racetrack Racetrack	1.80 0.36	Pt/Rh Pt/Rh	5:1 5:1	40 40
VW Jetta	Degussa	C	Round	1.67	Pd/Rh	10:1	70
VW Jetta	Camet	U	Round	0.20	Pt/Rh	6.7:1	40

Locations:
- U - Underbody
- C - Close-coupled (located approximately 12" from the exhaust manifold)
- M - Manifold (located as close as possible to exhaust manifold)

Notes: All Camet EHC systems were used in conjunction with the OEM catalyst. Each vehicle was optimized with supplemental air injection.

Description of catalyst systems for the Ford Crown Victoria is for a single exhaust bank. Actual number of catalysts is twice the number given above.

C. Task 3 Catalyst Systems

Based on Task 2 emission test results of the three optimized catalyst systems for each of the four vehicles, one catalyst system was selected by ARB for permanent application and 4000-mile short-term durability testing on each vehicle. Systems selected did not necessarily produce the lowest levels of all regulated emissions and formaldehyde for each vehicles. Some systems were chosen because they represented a variety of emission control technologies that had the potential for sustained durability. Because ARB desired to test both the Degussa and the Camet EHC systems on the Ford Crown Victoria, ARB furnished a second Ford Crown Victoria through SCAQMD (Crown Victoria #2) to SwRI so that one system could be installed on each vehicle. Also, because both the Degussa system and the Camet EHC (plus OEM) system yielded low emission levels on the VW Jetta, ARB decided to combine the two systems. Specifically, the OEM catalyst in the Camet plus OEM system was replaced by the Degussa catalyst system. A more detailed description of the catalyst systems used for Task 3 short-term durability testing is given below in Table 13.

TABLE 13. DESCRIPTION OF TASK 3 CATALYST SYSTEMS

Vehicle	Catalyst Supplier	Location	Shape	Volume (liters)	Metal(s)	Ratio	Loading (g/ft^3)
Toyota Camry	Degussa	C	Round	1.40	Pd/Rh	10:1	70
Chevrolet Corsica	Camet	U	Round	0.30	Pt/Rh	6.7:1	40
Ford Crown Vic #1	Camet	U	Round	0.17	Pt/Rh	6.7:1	40
Ford Crown Vic #2	Degussa	C	Round	2.80	Pd/Rh	10:1	70
VW Jetta	Camet Degussa	U U	Round Round	0.20 1.67	Pt/Rh Pd/Rh	6.7:1 10:1	40 70

Locations:
U - Underbody
C - Close-coupled
M - Manifold (located as closely as possible to exhaust manifold)

Notes: Description of catalyst systems for Ford Crown Victorias are for a single exhaust bank. Actual number of catalysts is twice the number given above.

Camet systems on the Chevrolet Corsica and Ford Crown Victoria #1 were used in conjunction with the OEM catalysts.

IV. ANALYTICAL PROCEDURES FOR UNREGULATED EMISSIONS

Analytical procedures used to measure unregulated emissions (aldehydes/ketones, methanol, methane and speciated hydrocarbons) are summarized in this section. Detailed descriptions of some of the procedures including aldehydes/ketones, methanol, and hydrocarbon speciation along with discussions of their development, validation, and qualification are available in the following EPA and Coordinating Research Council reports: "Analytical Procedures for Characterizing Unregulated Emissions from Vehicles Using Middle-Distillate Fuels," EPA Report EPA-600/2-80-068[4]; CRC Final Report for Project CAPE-30-81[5]; "Advanced Emissions Speciation Methodologies for the Auto/Oil Air Quality Improvement Research Program - II. Aldehydes, Ketones, and Alcohols," SAE Technical Paper No. 920321[6]; and "Butadiene Measurement Technology," EPA Report EPA 460/3-88-005[7].

Unregulated emissions evaluated in this program, along with the methods of sampling and the procedures used in analysis, are listed in Table 14.

TABLE 14. SAMPLING AND ANALYSIS METHODOLOGY FOR UNREGULATED EMISSIONS

Compound(s)	Sampling	Method of Analysis
Aldehydes and Ketones	Impinger	2,4-Dinitrophenylhydrazone derivative. Liquid chromatograph with UV detector.
Methanol	Impinger	Gas chromatograph with flame ionization detector.
Methane	Bag	Gas chromatograph with flame ionization detector.
Hydrocarbon Speciation:		
C_1-C_3 + benzene, toluene	Bag	Gas chromatograph with flame ionization detector.
C_4	Bag	Gas chromatograph with flame ionization detector.
C_5-C_{10}	Bag	Gas chromatograph with flame ionization detector.

Analytical procedures used in this project are briefly described below.

A. Aldehydes/Ketones

The aldehydes and ketones that were included in this analysis are: formaldehyde, acetaldehyde, acrolein, acetone, propionaldehyde, crotonaldehyde, isobutyraldehyde/methylethylketone (not resolved from each other under normal operating conditions and so reported together), benzaldehyde, and hexanaldehyde. The measurement of the aldehydes and ketones in exhaust is accomplished by bubbling dilute exhaust at 4 L/min through chilled glass impingers containing an acetonitrile solution of 2,4-dinitrophenylhydrazine (DNPH), and perchloric acid. The exhaust sample is collected continuously during the test cycle. For analysis, a portion of the acetonitrile solution is injected into a liquid chromatograph equipped with a UV detector. External standards

of the aldehyde and ketone DNPH derivatives are used to quantify the results. Detection limits for this procedure are on the order of 0.005 ppm aldehyde or ketone in dilute exhaust. A photograph of one of the HPLCs used to conduct aldehyde/ketone analysis is given in Figure 14.

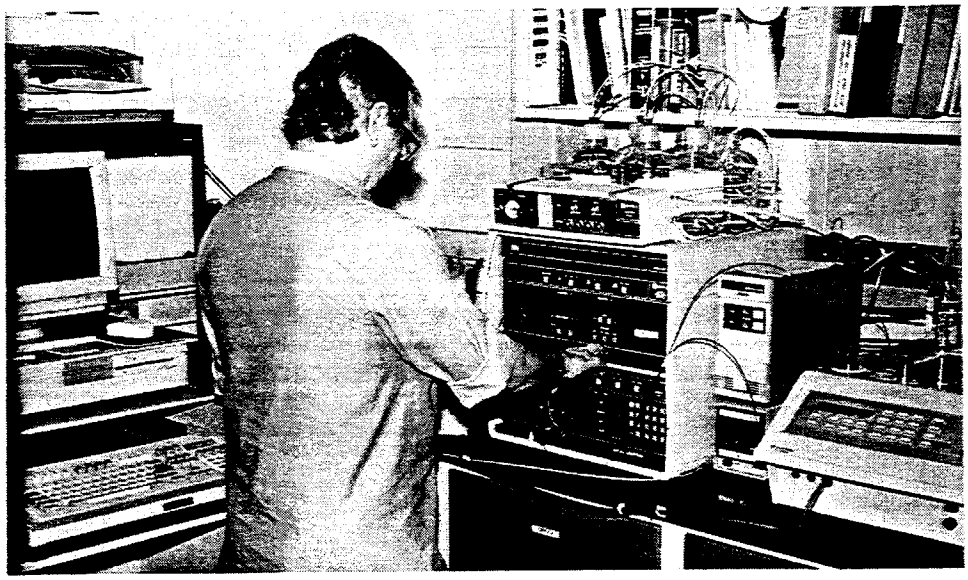

FIGURE 14. PHOTOGRAPH OF HPLC USED FOR ALDEHYDE/KETONE ANALYSIS

B. Methanol

The measurement of methanol in dilute exhaust is accomplished by bubbling the exhaust through glass impingers containing deionized water. The exhaust sample is collected continuously during the test cycle. For analysis, a portion of the aqueous solution is injected into a gas chromatograph equipped with a flame ionization detector (FID). External methanol standards in deionized water are used to quantify the results. Detection limits for this procedure are on the order of 0.06 ppm in exhaust for methanol. A photograph of the GC used to conduct methanol analysis is given in Figure 15.

C. Methane

The measurement of methane in exhaust is accomplished by collecting dilute gaseous exhaust samples in Tedlar bags with subsequent analysis by a gas chromatograph (GC) with a flame ionization detector. The GC used for this analysis has been configured according to SAE Method J1151, "Methane Measurement Using Gas Chromatography." The gas chromatograph is equipped with a 10-port gas sampling/backflush valve. The columns used are a 2-ft x 1/8-inch Porapak N and a 4-ft x 1/8-inch Molecular Sieve 13X. As soon as the methane passes into the molecular sieve column, the carrier gas (helium) flow is reversed through the Porapak N column to vent. A second carrier flow carries the methane through the molecular sieve column to the detector. The detection limit is less than 0.1 ppmC for methane. A photograph of the instrument used to conduct methane analysis is given in Figure 16.

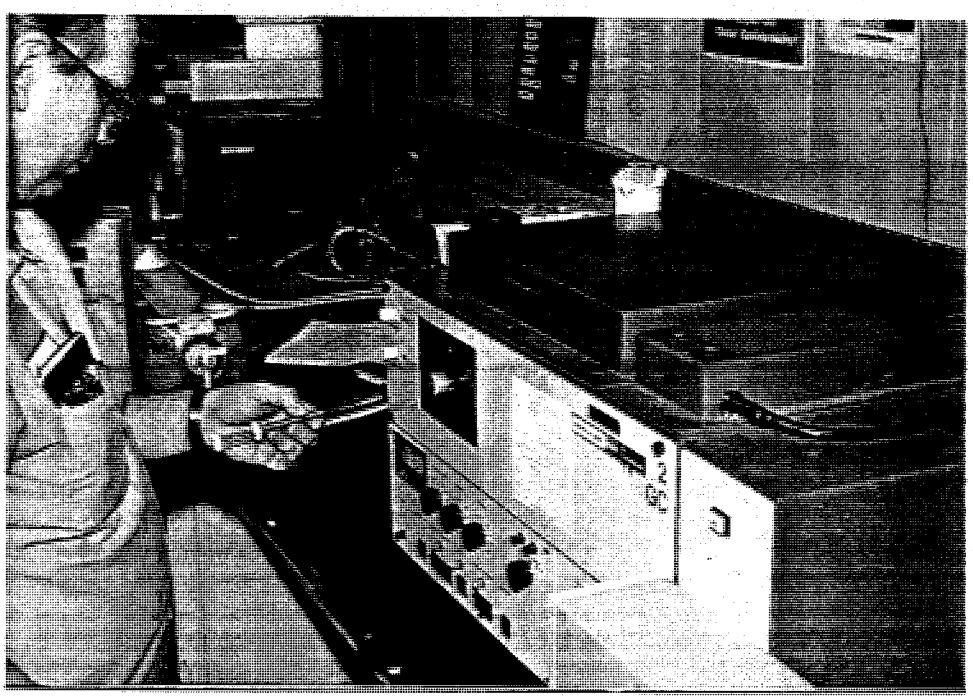

FIGURE 15. PHOTOGRAPH OF GC USED FOR METHANOL ANALYSIS

FIGURE 16. PHOTOGRAPH OF GC USED FOR METHANE ANALYSIS

D. Hydrocarbon Speciation

For this program, three GCs were used to conduct requested C_1-C_{10} hydrocarbon speciation. Summaries of each of these methods are given in this section.

1. C_1-C_3 plus Benzene and Toluene

Dilute exhaust emissions were sampled in Tedlar bags and analyzed by gas chromatography (GC) with a flame ionization detector. The compounds that were analyzed are methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), propane (C_3H_8), propylene (C_3H_6), benzene (C_6H_6), and toluene (C_7H_8). The GC system is equipped with four separate packed columns which are used to resolve the individual compounds. A system of timers, solenoid valves, and gas sampling valves directs the flow of sample through the system. The carrier gas is helium. Peak areas are compared to an external calibration blend, and the hydrocarbon concentrations are obtained.

2. C_4 Compounds

The procedure was developed to measure 1,3-butadiene in dilute vehicle exhaust. In addition to 1,3-butadiene, the procedure provides separation and concentrations for six of the C_4 hydrocarbons including: isobutane, butane, 1-butene, isobutylene, cis-2-butene, and trans-2-butene. Standard CVS bag samples and evaporative emission bag samples were analyzed for the C_4 compounds using a gas chromatograph equipped with a flame ionization detector (FID). The gas chromatograph system utilized a Perkin-Elmer Model 3920B gas chromatograph with an FID, two pneumatically-operated and electrically-controlled Seiscor valves, and an analytical column. The analytical column is a 9-ft x 1/8-inch stainless steel column containing 80/100 Carbopack C with 0.19% picric acid. The carrier gas is helium, which flows through the column at a rate of 17mL/min. The column temperature is maintained at 40°C for analysis. External standards in zero air are used to quantify the results. Detection limits for the procedure are on the order of 0.03 ppmC.

3. C_5-C_{10} Compounds

This procedure permits the quantitative determination of more than 90 individual species in automotive emissions. The gas chromatograph system utilizes a Perkin-Elmer F-50 Versilube, 150-ft x 0.02-inch WCOT stainless steel column. The column is initially cooled to -139°F (-95°C) for sample injection. Upon injection, the temperature is programmed at a 7°F (4°C) increase per minute to (85°C). The column temperature is held at 185°F for approximately 15 minutes to complete column flushing. A flow controller is used to maintain a 1.5 mL/min helium carrier flow rate. The 10 mL sample volume permits determination of 0.1 ppmC with the flame ionization detector.

V. TASK 1 AND 2 EMISSIONS TESTING

This section of the report describes research efforts conducted throughout Tasks 1 and 2 of the program. Task 1 involved screening 18 catalyst samples on the M90 Ford Escort using cold-start Urban Dynamometer Driving Schedule (UDDS), hot-start UDDS, 30 mph steady-state, and 55 mph steady-state tests. Task 2 consisted of evaluating three catalyst systems selected from Task 1 on a Toyota Camry, a Chevrolet Corsica, a VW Jetta, and Ford Crown Victoria #1 using the Federal Test Procedure (FTP), the Highway Fuel Economy Test (HFET), and the New York City Cycle (NYCC). Regulated emissions of total hydrocarbons, carbon monoxide, oxides of nitrogen, as well as formaldehyde and methanol were measured for each test conducted. In addition, the calculated values of gasoline-derived hydrocarbons (GDHC) were used during Task 1 and 2 testing to provide a further basis for comparison of catalyst systems. Methane emissions were measured and total non-methane organic gases (NMOG) were calculated to provide a basis for comparison of Task 2 emission test data.

The gasoline-derived fraction of the unburned fuel hydrocarbons was calculated using the total hydrocarbon (THC) emission rate (based on fuel density and fuel weight fractions of carbon, hydrogen, and oxygen) and the measured methanol emission rate. Additional factors in the calculation include the methanol flame ionization detector (FID) response factor (0.79), measured carbon weight percentage of M90 or M85 (41.0% or 43.6% respectively), and the fuel carbon weight percentage of gasoline from the *Code of Federal Regulations* (86.6%). The equation for determining GDHC is written:

$$GDHC = \frac{\%C}{86.6}\left[THC - \left(0.79\left(\frac{37.5}{\%C}\right)Methanol\right)\right]$$

Where % C = Measured carbon weight percentage of M90 or M85.

The value for NMOG was calculated for each test cycle in Task 2 using the following equation:

$$NMOG = GDHC + METHANOL + FORMALDEHYDE - METHANE$$

A. Task 1 Emission Testing

Task 1 catalyst screening was conducted on 18 catalyst samples supplied by manufacturers throughout the world (as described earlier in this report). A summary of two-test average formaldehyde, methanol, GDHC, CO, and NO_x emissions as well as fuel economies for cold-start UDDS, hot-start UDDS, 30 mph steady-state, and 55 mph steady-state tests are presented in Tables 15, 16, 17, and 18, respectively. Please refer to Table 13 to relate the letter for each catalyst system to the manufacturer and to determine specific properties. Computer printouts of emission test data for each test conducted during Task 1 are given in Appendix A.

TABLE 15. SUMMARY OF AVERAGE COLD-START UDDS EMISSIONS

Catalyst System	Form. (mg/mi)	Methanol (g/mi)	GDHC (g/mi)	CO (g/mi)	NO_x (g/mi)	Fuel Eco. (mi/gal)
NC	332	8.02	1.14	46.85	0.88	12.5
A	62.6	1.30	0.33	7.87	0.50	13.4
B	14.7	0.99	0.15	4.67	0.44	13.3
C	13.0	0.59	0.23	5.06	0.39	13.5
D	17.3	0.89	0.15	4.45	0.47	13.4
E	9.9	0.08	0.17	3.38	0.50	13.0
F[a]	98.3	2.68	0.14	5.76	0.43	13.2
G	6.1	0.17	0.16	6.76	0.39	13.0
H	41.6	0.43	0.17	8.85	0.51	12.3
I	5.2	0.09	0.09	5.32	0.46	13.1
J	5.1	0.22	0.12	5.73	0.42	13.1
K	5.2	0.28	0.12	4.85	0.45	13.5
L[a]	14.7	0.47	0.21	13.86	0.49	13.2
M	6.5	0.23	0.16	6.56	0.45	13.1
N[a]	5.9	0.15	0.18	6.13	0.38	13.4
O[a]	17.5	0.80	0.19	7.12	0.35	13.0
P	4.1	0.25	0.08	4.53	0.36	13.4
Q	7.6	0.50	0.10	5.76	0.43	13.2
R[a]	17.8	0.34	0.29	7.81	0.39	14.1

[a]Only one test conducted.

TABLE 16. SUMMARY OF AVERAGE HOT-START UDDS EMISSIONS

Catalyst System	Form. (mg/mi)	Methanol (g/mi)	GDHC (g/mi)	CO (g/mi)	NO_x (g/mi)	Fuel Eco. (mi/gal)
NC	244	3.36	0.61	27.77	0.74	15.3
A	9.4	0.03	0.09	2.65	0.44	15.4
B	2.7	<0.01	0.03	0.43	0.41	15.4
C	1.7	<0.01	0.03	0.50	0.39	15.8
D	3.2	<0.01	0.05	0.37	0.35	15.6
E	5.7	<0.01	0.04	0.53	0.42	15.7
F	19.9	0.22	0.08	4.19	0.51	15.9
G	2.1	<0.01	0.02	0.85	0.46	15.4
H	19.1	0.05	0.04	1.50	0.58	15.0
I	2.3	<0.01	0.02	0.76	0.54	15.6
J	1.3	<0.01	0.01	0.60	0.56	15.7
K	0.3	<0.01	0.01	0.43	0.54	16.2
L	2.5	<0.01	0.03	3.46	0.56	16.0
M	1.7	<0.01	0.04	0.98	0.57	15.7
N	1.4	<0.01	0.03	0.47	0.52	15.9
O	1.6	<0.01	0.04	1.30	0.43	15.6
P	0.7	<0.01	0.01	0.53	0.41	15.8
Q	0.5	<0.01	0.01	0.68	0.49	15.5
R	2.1	0.05	0.07	0.92	0.46	16.4

TABLE 17. SUMMARY OF AVERAGE 30 MPH EMISSIONS

Catalyst System	Form. (mg/ml)	Methanol (g/ml)	GDHC (g/ml)	CO (g/ml)	NO_x (g/ml)	Fuel Eco. (ml/gal)
NC	27.8	1.25	0.27	5.02	1.12	27.8
A	9.5	0.01	0.03	0.03	0.96	27.9
B	2.3	<0.01	0.02	0.01	0.90	27.2
C	1.7	<0.01	0.01	0.00	0.70	28.2
D	2.5	<0.01	0.01	0.01	0.77	27.6
E	3.3	0.01	0.01	0.01	0.87	28.1
F	30.5	0.16	0.01	0.33	0.70	28.0
G	2.1	<0.01	0.01	0.02	1.09	27.7
H	16.7	0.01	0.02	0.03	0.53	27.0
I	1.5	<0.01	0.01	0.01	0.75	27.3
J[a]	1.2	<0.01	0.01	0.02	0.65	27.9
K	<0.1	<0.01	0.01	0.02	0.80	28.0
L	2.2	<0.01	0.01	0.00	1.08	27.9
M	1.4	<0.01	0.01	0.03	0.85	27.4
N	1.3	<0.01	0.01	0.10	0.47	26.7
O	0.6	<0.01	0.01	0.00	1.08	27.7
P	1.0	<0.01	0.01	0.01	0.36	27.5
Q	0.7	<0.01	0.01	0.01	0.31	27.3
R	1.0	<0.01	0.03	0.00	0.58	27.8

[a]Only one test conducted.

TABLE 18. SUMMARY OF AVERAGE 55 MPH EMISSIONS

Catalyst System	Form. (mg/mi)	Methanol (g/mi)	GDHC (g/mi)	CO (g/mi)	NO_x (g/mi)	Fuel Eco. (mi/gal)
NC	285	1.88	0.42	4.69	1.04	22.2
A	11.3	<0.01	0.03	0.00	0.55	22.9
B	1.7	<0.01	0.01	0.01	0.54	22.2
C	1.6	<0.01	0.01	0.00	0.51	23.0
D	2.3	<0.01	0.01	0.00	0.53	22.6
E	6.4	0.01	0.01	0.01	0.63	22.1
F	8.5	<0.01	0.01	0.00	0.84	22.6
G	1.4	<0.01	0.01	0.02	1.03	22.2
H	29.2	0.03	0.04	0.07	1.27	21.2
I	1.8	<0.01	0.01	0.01	1.04	20.8
J	1.3	<0.01	0.01	0.01	1.08	21.1
K	0.5	<0.01	0.01	0.01	0.97	21.9
L	3.0	<0.01	0.01	0.01	0.98	21.3
M	1.9	<0.01	0.01	0.01	1.18	21.8
N	1.2	<0.01	0.01	0.00	0.99	22.1
O	1.3	<0.01	0.01	0.00	0.75	21.4
P	0.6	<0.01	0.01	0.00	0.90	22.1
Q	0.7	<0.01	0.01	0.01	0.81	21.7
R	1.4	<0.01	0.01	0.00	0.84	21.8

It should be noted that all catalyst systems screened in Task 1 of the program were evaluated without aging. It is understood that unaged catalyst systems may not provide a definite indication of long-term performance; however, this mode of preliminary evaluation was a feasible means of controlled initial screening. In addition, all catalyst systems were tested under the same conditions to allow relative comparisons of effectiveness to be determined.

A major factor which appeared to most greatly influence the reduction of both regulated and unregulated exhaust emissions for the non-electrically-heated catalyst systems was catalyst proximity to the engine. Although light-off tests were not conducted as a part of this program, it appears that the shorter heating times associated with manifold and close-coupled systems had a significant impact on emission reductions. This observation is highlighted for formaldehyde and methanol emission in Table 19 as well as Tables 15, 16, 17, and 18 given previously. Formaldehyde and methanol emission values given in Table 19 represent combined cold-start and hot-start UDDS emissions - Federal Test Procedure (FTP) emissions. Overall, underbody catalyst systems "A"-"F" were not as effective at controlling FTP formaldehyde and methanol emissions as the close-coupled and combination catalyst systems which were located more proximally to the engine. However, as can be seen in Tables 15, 16, 17, and 18, CO and NO_x control appeared to be more independent of catalyst location.

TABLE 19. EFFECT OF CONVERTER LOCATION, CATALYST COMPOSITION, AND CATALYST VOLUME ON FTP FORMALDEHYDE AND METHANOL EMISSIONS

Catalyst	Location	Metal(s)	Catalyst Volume (L)	Formaldehyde (mg/mi)	Methanol (g/mi)
NC	--	--	--	272.0	5.36
C	U	Pt/Rh	1.0	6.6	0.25
B	U	Pt/Rh	1.7	7.0	0.43
E	U	Pt/Rh (metal-heated)	1.8	7.5	0.03
F	U	Pt	1.2	53.6	1.28
D	U	Pt/Rh + Pt	1.8 + 0.9	9.3	0.38
H	C	Pt/Rh	0.7	28.8	0.21
M	C	Pt/Rh	1.0	3.8	0.10
N	C	Pt/Rh	1.0	3.3	0.06
K	C	Pt/Rh	1.7	2.4	0.12
J	C	Pt/Rh	1.8	2.9	0.09
I	C	Pd/Rh	1.0	3.6	0.04
G	C	Pd	1.0	3.8	0.07
L	C	Pt	1.2	7.8	0.20
O	C + U	Pt/Rh + Rh	0.7 + 1.7	8.4	0.34
P	M + C	Pt/Rh + Pt/Rh	0.4 + 1.8	2.1	0.11
Q	M + C	Pd + Rh	0.4 + 1.8	3.6	0.22
R	M + U	Pt/Rh + Pt/Rh	0.4 + 1.7	8.9	0.17

Noble metal composition also appeared to play a role in formaldehyde and methanol emission performance. For example, given approximately equivalent catalyst volumes in the close-coupled position, catalyst G (Pd only) showed better reduction of both formaldehyde and methanol than catalyst L (Pt only). However, emission rates of formaldehye and methanol for catalyst G were relatively similar to catalysts M and N (Pt/Rh). Additional research is still needed to establish any definite metal composition effects.

Although the FTP emission rate of formaldehyde for catalyst system I (Pd/Rh) was similar to systems G, M, and N, the methanol emission rate for system I was the lowest of any close-coupled system. This suggests that the use of Pd in a formulation may potentially minimize emissions of unburned methanol

A loose trend is also apparent when formaldehyde emissions from catalyst systems H, J, K, M, and N are considered with respect to catalyst volume. In general, as catalyst volume increased from 0.7 liters to 1.8 liters, formaldehyde emissions decreased. A similar decrease in methanol emissions is only observed from 0.7 liter to 1.0 liter catalyst volumes. After 1.0 liter catalyst volume other factors seem to be more dominant for close-coupled systems.

Some additional observations and findings which were noted for this test series are as follows.

- Fifteen (15) of the 17 catalyst systems supplied for evaluation gave formaldehyde emission levels below the California standard of 15 mg/mi. Eight systems gave formaldehyde levels of less than 5 mg/mi.

- Heated catalyst system E showed the best FTP reduction of methanol emissions for "underbody" catalysts.

- Close-coupled catalyst system I showed good control of all regulated emissions, methanol, and formaldehyde.

- Manifold/close-coupled catalyst system P showed the best control of regulated emissions, methanol, formaldehyde, and GDHC, of any multi-location system.

B. Task 2 Emission Testing

Based on the results of Task 1 emission tests using the M90 Ford Escort, three catalyst system were selected for evaluation on a M85 Toyota Camry, a Chevrolet Corsica VFV, a dual-fuel VW Jetta (M85 or gasoline), and a Ford Crown Victoria FFV. The specific catalysts selected were the Camet electrically-heated catalyst ("E"), Degussa close-coupled system ("I"), and Johnson Matthey combination manifold and close-coupled system ("P"). These catalyst systems were selected based on emission test results, because they represent a variety of technologies, and for several qualitative reasons such as cost, metal loading, and ability to apply the technology. Each of the manufacturers was asked to supply one catalyst system sized appropriately for each of the four vehicles to be used throughout Task 2. The formulation, loading, etc. remained unchanged.

1. Toyota Camry

Upon receipt of the 1986 M85 Toyota Camry in August 1989, a Federal Test Procedure (FTP) emission test was conducted on it to determine engine-out exhaust emission rates and temperatures using M85 fuel. Based on emission test results, it was determined that the average raw exhaust concentrations were: THC, 1400 ppmC (uncorrected for methanol response factor); CO, 6000 ppm; and NO_x 850 ppm. Maximum FTP exhaust temperatures were 565°C at the manifold and 490°C at the underbody location. Engine-out FTP formaldehyde emissions were measured and determined to be 189 mg/mi. A detailed computer printout of regulated emission test results from the FTP test used to determine these temperatures and emissions data is given in Appendix B.

Following the initial determination of engine-out emissions on the Toyota Camry, FTP, Highway Fuel Economy Test (HFET), and New York City Cycle (NYCC) emission tests were conducted using the original equipment manufacturer's (OEM) catalyst system to provide a reference for comparison of the supplied catalysts systems. Emission results for the OEM tests as well as test results from the Camet, Degussa, and Johnson Matthey systems are given in Table 20. It should be noted that no supplemental air injection was used with any of the supplied catalyst systems for the Toyota Camry, including the Camet system. Detailed computer printouts of all Task 2 catalyst evaluation emission tests conducted on the Toyota Camry are found in Appendix C. In addition to formaldehyde, nine other aldehydes and ketones were determined as a part of the overall analysis described earlier in the report. A summary of all measured aldehyde/ketone data for emission tests conducted on the Toyota Camry is given in Appendix D.

2. Chevrolet Corsica

Upon receipt of the Chevrolet Corsica in June 1989, a FTP emission test was conducted on the Chevrolet Corsica to determine engine-out exhaust emission rates and temperatures using M85 and gasoline (Howell EEE). Based on emission test results, it was determined that the average FTP raw exhaust concentrations with gasoline were: THC, 2200 ppmC; CO, 6000 ppm; and NO_x 550 ppm. FTP raw exhaust concentrations with M85 fuel were: THC, 1000 ppmC (uncorrected for methanol response factor); CO, 5350 ppm; and NO_x 490 ppm. Average FTP exhaust temperatures were lower with M85 (520°C underbody; 575°C manifold) than with gasoline (540°C underbody; 600°C manifold). Engine-out FTP formaldehyde emissions were measured and determined to be 198 mg/mi for M85 and 83.2 mg/mi for gasoline. Detailed computer printouts of regulated emission test results from the FTP tests used to determine these temperatures and emissions data are given in Appendix E.

In November 1989, Southwest Research Institute (SwRI) was notified by General Motors that a new set of more durable fuel injectors needed to be installed in the Chevrolet Corsica. The Corsica was shipped to GM in November 1989 for installation of the new fuel injectors and returned to SwRI in December 1989 prior to the commencement of Task 2 evaluations on the manufacturer-supplied catalyst systems. In order to verify that the new injectors were operating correctly, the State of California Air Resources Board (ARB) directed SwRI to conduct duplicate FTP emission tests using the OEM catalyst system and M85 fuel. Based on results from these two emission tests (presented in Table 21), ARB approved continuation of project work using the Corsica.

TABLE 20. SUMMARY OF M85 TOYOTA CAMRY TASK 2 EMISSION TEST RESULTS

Date	Test No.	Fuel	Catalyst	Test Cycle	THC (g/mi)	GDHC (g/mi)	NMOG (g/mi)	CO (g/mi)	NO_x (g/mi)	Fuel Economy (mi\gal)	Methanol (g/mi)	Methane (mg/mi)	Form. (mg/mi)
3/13/90	B2TTCU-01	M85	OEM	FTP	0.340	0.098	0.307	1.81	0.45	17.7	0.213	22	17.5
3/13/90	B2TTCU-01	M85	OEM	HFET	0.040	0.016	0.026	0.07	0.19	26.5	0.013	7	4.2
3/13/90	B2TTCU-01	M85	OEM	NYCC	0.310	0.123	0.179	4.19	0.56	10.4	0.097	47	5.8
2/28/90	B2THCU-01	M85	Camet	FTP	0.270	0.087	0.224	1.62	0.17	17.6	0.143	16	10.5
2/28/90	B2THCU-01	M85	Camet	HFET	0.030	0.015	0.014	0.08	0.06	26.3	0.001	3	1.6
2/28/90	B2THCU-01	M85	Camet	NYCC	0.170	0.086	0.057	1.05	0.30	9.9	0.000	33	4.6
3/01/90	B2THCU-02	M85	Camet	FTP	0.260	0.076	0.226	1.65	0.19	17.6	0.159	18	8.5
3/01/90	B2THCU-02	M85	Camet	HFET	0.020	0.010	0.007	0.03	0.11	24.4	0.000	4	1.6
3/01/90	B2THCU-02	M85	Camet	NYCC	0.160	0.080	0.045	1.98	0.42	10.3	0.000	38	3.1
3/16/90	B2TDCC-01	M85	Degussa	FTP	0.350	0.093	0.327	1.45	0.37	17.6	0.243	20	10.8
3/16/90	B2TDCC-01	M85	Degussa	HFET	0.070	0.031	0.038	0.09	0.19	26.2	0.013	10	3.8
3/16/90	B2TDCC-01	M85	Degussa	NYCC	0.160	0.047	0.137	0.36	0.33	10.2	0.098	31	22.9
3/19/90	B2TDCC-02	M85	Degussa	FTP	0.340	0.097	0.310	1.09	0.27	17.6	0.218	14	9.5
3/19/90	B2TDCC-02	M85	Degussa	HFET	0.050	0.017	0.041	0.09	0.13	26.4	0.024	4	3.9
3/19/90	B2TDCC-02	M85	Degussa	NYCC	0.180	0.049	0.148	0.44	0.29	10.1	0.122	32	9.0
7/02/90	B2TJM2-01	M85	JM	FTP	0.980	0.171	1.121	1.50	0.17	17.6	0.942	9	16.3
7/02/90	B1TJM2-01	M85	JM	HFET	0.010	0.005	0.004	0.01	0.04	26.2	0.000	1	0.1
7/02/90	B1TJM2-01	M85	JM	NYCC	0.030	0.015	0.000	0.71	0.04	10.0	0.000	19	0.0
7/03/90	B2TJM2-02	M85	JM	FTP	0.870	0.142	1.016	1.55	0.17	17.2	0.865	12	20.5
7/03/90	B2TJM2-02	M85	JM	HFET	0.000	0.000	0.000	0.05	0.00	25.6	0.000	3	1.1
7/03/90	B2TJM2-02	M85	JM	NYCC	0.000	0.000	0.000	0.80	0.04	10.1	0.000	38	3.4

Computer printouts of emission test results from the two FTPs which followed the installation of the new fuel injectors are found in Appendix F.

TABLE 21. SUMMARY OF FTP EMISSION TEST RESULTS FOR NEW FUEL INJECTORS

Test No.	THC (g/mi)	CO (g/mi)	NO_X (g/mi)	Fuel Eco. (mi/gal)
C	0.28	1.75	0.25	13.18
D	0.28	1.43	0.24	13.06

The first catalyst system to be evaluated on the Chevrolet Corsica during Task 2 was the electrically-heated catalyst (EHC) system supplied by Camet in conjunction with the OEM catalyst. The EHC was located upstream from and as proximal to the OEM catalyst as possible to minimize heat loss. Duplicate FTP, HFET, and NYCC emission tests were conducted using both M85 and Howell EEE fuels. The Degussa and Johnson Matthey systems were also installed and tested individually (without the OEM catalyst) in the same manner. Emission test results for the OEM tests as well as test results from the Camet, Degussa, and Johnson Matthey systems operating on M85 are given in Table 22. Test results for the catalyst systems operating on Howell EEE are given in Table 23. Detailed computer printouts of all Task 2 catalyst evaluation emission tests conducted on the Chevrolet Corsica are found in Appendix G. A summary of all aldehydes/ketones data for Task 2 emission tests conducted on the Chevrolet Corsica is given in Appendix D.

Following completion of the planned Task 2 evaluations of the three catalyst systems, ARB directed SwRI to conduct air injection experiments on the Chevrolet Corsica using the Camet system in conjunction with the OEM catalyst (installed as described above) and the Degussa catalyst system. A summary of all air injection experiments conducted on the Chevrolet Corsica is given in Table 24. Detailed computer printouts of air injection emission tests results are found in Appendix H. The combination of air injection and the Camet system in conjunction with the OEM gave the lowest formaldehyde, total hydrocarbon, methanol, and carbon monoxide levels of all the catalyst systems when operating on M85. The optimized air and heating strategy for the Camet system in conjunction with the OEM was as follows: pre-heat catalyst to 600°C prior to both the cold-start 505 and hot-start 505 segments of the FTP; inject supplemental air immediately prior to the EHC at 5.2 ft^3/min.

At the direction of ARB, hydrocarbon speciation was also conducted on Corsica using the Camet system to determine the detailed chemical composition of the exhaust emissions for ARB to use in estimating ozone forming potential. A total of three hydrocarbon speciation FTP emission tests were conducted using M85 fuel. The first test, Test No. B2CHRF1, was conducted using a mixture of 15 percent "1989 industry average unleaded gasoline" (RF-A) and 85 percent "reagent grade methanol." The second and third tests, Test Nos. B2CHCC-05A and B2CHCC-08A, were conducted using M85 blended with 15 percent Howell EEE unleaded emissions test gasoline. Results of these

TABLE 22. SUMMARY OF M85 CHEVROLET CORSICA TASK 2 EMISSION TEST RESULTS

Date	Test No.	Fuel	Catalyst	Test Cycle	THC (g/mi)	GDHC (g/mi)	NMOG (g/mi)	CO (g/mi)	NO_x (g/mi)	Fuel Economy (mi/gal)	Methanol (g/mi)	Methane (mg/mi)	Form. (mg/mi)
1/11/92	B2COEM-1	M85	OEM	FTP	0.340	0.074	0.366	1.74	0.20	11.8	0.28	12	19.1
1/11/92	B2COEM-1	M85	OEM	HFET	0.040	0.016	0.022	0.77	0.08	17.6	0.01	6	0.2
1/11/92	B2COEM-1	M85	OEM	NYCC	0.130	0.064	0.036	3.81	0.03	6.3	0.00	31	0.5
3/02/90	B2CHCU-01	M85	Camet	FTP	0.140	0.046	0.109	1.51	0.13	13.5	0.072	13	4.8
3/02/90	B2CHCU-01	M85	Camet	HFET	0.030	0.015	0.009	0.47	0.04	20.1	0.000	7	0.5
3/02/90	B2CHCU-01	M85	Camet	NYCC	0.130	0.065	0.013	1.13	0.18	7.0	0.000	53	0.6
3/05/90	B2CHCU-02	M85	Camet	FTP	0.160	0.040	0.158	1.19	0.13	13.3	0.119	11	10.0
3/05/90	B2CHCU-02	M85	Camet	HFET	0.020	0.010	0.006	0.22	0.05	20.0	0.000	5	0.9
3/05/90	B2CHCU-02	M85	Camet	NYCC	0.190	0.096	0.036	3.16	0.18	7.0	0.000	63	3.8
3/26/90	B2CDCC-01	M85	Degussa	FTP	0.240	0.074	0.206	0.97	0.15	13.5	0.137	11	6.9
3/26/90	B2CDCC-01	M85	Degussa	HFET	0.030	0.015	0.012	0.09	0.06	19.9	0.000	5	1.7
3/26/90	B2CDCC-01	M85	Degussa	NYCC	0.100	0.050	0.029	1.13	0.00	7.3	0.000	31	9.2
3/27/90	B2CDCC-02	M85	Degussa	FTP	0.240	0.072	0.210	1.07	0.12	13.7	0.143	12	6.8
3/27/90	B2CDCC-02	M85	Degussa	HFET	0.030	0.015	0.008	0.19	0.07	20.1	0.000	8	0.5
3/27/90	B2CDCC-02	M85	Degussa	NYCC	0.120	0.060	0.008	1.91	0.00	7.2	0.000	56	3.2
5/29/90	B2CJM4-01	M85	JM	FTP	0.280	0.073	0.262	0.54	0.10	12.9	0.199	16	6.3
5/29/90	B2CJM4-01	M85	JM	HFET	0.030	0.015	0.013	0.20	0.01	19.3	0.000	3	1.2
5/29/90	B2CJM4-01	M85	JM	NYCC	0.140	0.070	0.029	0.62	0.00	7.1	0.000	45	4.3
5/30/90	B2CJM4-02	M85	JM	FTP	0.310	0.068	0.324	1.37	0.10	13.5	0.257	11	9.3
5/30/90	B2CJM4-02	M85	JM	HFET	0.030	0.015	0.012	0.20	0.03	20.2	0.000	3	0.5
5/39/90	B2CJM4-02	M85	JM	NYCC	0.170	0.086	0.080	0.60	0.04	7.3	0.000	8	2.1

TABLE 23. SUMMARY OF HOWELL EEE CHEVROLET CORSICA TASK 2 EMISSION TEST RESULTS

Date	Test No.	Fuel	Catalyst	Test Cycle	THC (g/mi)	GDHC (g/mi)	NMOG (g/mi)	CO (g/mi)	NO_x (g/mi)	Fuel Economy (mi/gal)	Methanol (g/mi)	Methane (mg/mi)	Form. (mg/mi)
1/12/92	B1OEM-01	Howell EEE	OEM	FTP	0.150	0.150	0.128	1.13	0.11	20.4	0.00	24	2.2
1/12/92	B10EM-01	Howell EEE	OEM	HFET	0.030	0.030	0.015	0.28	0.12	32.2	0.00	15	0.1
1/12/92	B1OEM-01	Howell EEE	OEM	NYCC	0.790	0.790	0.547	28.27	0.19	10.7	0.00	243	0.3
3/06/90	B1CHCU-01	Howell EEE	Camet	FTP	0.090	0.090	0.080	0.57	0.15	21.7	0.000	14	1.5
3/06/90	B1CHCU-01	Howell EEE	Camet	HFET	0.010	0.010	0.000	0.28	0.12	33.6	0.000	11	0.4
3/06/90	B1CHCU-01	Howell EEE	Camet	NYCC	0.940	0.940	0.750	19.24	0.17	11.5	0.000	194	0.0
3/07/90	B1CHCU-02	Howell EEE	Camet	FTP	0.130	0.130	0.120	0.92	0.13	21.8	0.002	18	1.8
3/07/90	B1CHCU-02	Howell EEE	Camet	HFET	0.020	0.020	0.010	0.32	0.13	33.6	0.000	10	0.0
3/07/90	C1CHCH-02	Howell EEE	Camet	NYCC	0.710	0.710	0.520	12.00	0.16	11.5	0.000	194	0.0
3/22/90	B1CDCC-01	Howell EEE	Degussa	FTP	0.160	0.160	0.150	0.84	0.25	21.6	0.000	12	3.1
3/22/90	B1CDCC-01	Howell EEE	Degussa	HFET	0.020	0.020	0.020	0.10	0.25	32.5	0.000	4	1.0
3/22/90	B1CDCC-01	Howell EEE	Degussa	NYCC	0.460	0.460	0.320	3.92	0.00	11.9	0.000	141	2.5
3/23/90	B1CDCC-02	Howell EEE	Degussa	FTP	0.160	0.160	0.150	0.91	0.17	22.1	0.000	17	3.6
3/23/90	B1CDCC-02	Howell EEE	Degussa	HFET	0.020	0.020	0.020	0.02	0.22	33.0	0.000	2	0.8
3/23/90	B1CDCC-02	Howell EEE	Degussa	NYCC	0.460	0.460	0.420	3.66	0.03	11.8	0.000	52	10.4
5/31/90	B1CJM4-01	Howell EEE	JM	FTP	0.210	0.210	0.200	0.58	0.18	22.3	0.000	16	2.5
5/31/90	B1CJM4-01	Howell EEE	JM	HFET	0.020	0.020	0.010	0.13	0.20	33.5	0.000	8	1.1
5/31/90	B1CJM4-01	Howell EEE	JM	NYCC	0.650	0.650	0.230	9.31	0.19	11.8	0.000	428	6.2
6/01/90	B1CJM4-02	Howell EEE	JM	FTP	0.240	0.240	0.230	0.80	0.10	22.4	0.000	12	2.0
6/01/90	B1CJM4-02	Howell EEE	JM	HFET	0.010	0.010	0.010	0.08	0.20	33.5	0.000	4	0.5
6/01/90	B1CJM4-02	Howell EEE	JM	NYCC	0.740	0.740	0.350	13.84	0.15	11.6	0.000	396	1.5

TABLE 24. SUMMARY OF CHEVROLET CORSICA AIR INJECTION EMISSION TEST RESULTS

Date	Test No.	Fuel	Catalyst	Test Cycle	NMOG[a] (g/mi)	CO (g/mi)	NO_x (g/mi)	Fuel Economy (mi/gal)	Methanol (g/mi)	Methane (mg/mi)	Form. (mg/mi)
3/02/90	B2CHCU-01	M85	Camet[b]	FTP	0.17	1.51	0.13	13.5	0.07	13.20	4.8
3/0590	B2CHCU-02	M85	Camet[b]	FTP	0.16	1.19	0.13	13.3	0.12	11.18	10.0
3/06/90	B1CHCU-01	Howell EEE	Camet[b]	FTP	0.09	0.57	0.15	21.7	0.00	13.63	1.5
3/07/90	B1CHCU-02	Howell EEE	Camet[b]	FTP	0.13	0.92	0.13	21.8	0.00	18.36	1.8
3/26/90	B2CDCC-01	M85	Degussa[c]	FTP	0.22	0.97	0.15	13.5	0.14	11.35	6.9
3/27/90	B2CDCC-02	M85	Degussa[c]	FTP	0.21	1.07	0.12	13.7	0.14	12.38	6.8
6/12/90	B2CDCC-01A	M85	Deg.+Air1[d]	FTP	0.18	0.48	0.23	13.4	0.14	12.27	7.8
6/13/90	B2CHCC-01A	M85	HC+Air1[e]	FTP	0.08	0.89	0.16	13.4	0.04	13.21	5.7
6/15/90	B2CHCC-03A	M85	HC+Air1/3[f]	FTP	0.03	0.40	0.17	13.7	0.01	12.48	3.6
7/13/90	B2CHCC-04A	M85	HC+Air1/3[f]	FTP	0.07	0.26	0.18	13.3	0.05	14.55	4.1
7/27/90	B1CHCU-01A	Howell EEE	HC+Air1/3[f]	FTP	0.16	0.84	0.20	22.1	0.00	25.37	1.2
8/03/90	HCA85/10	Howell EEE	HC+Air1[g]	FTP	0.08	0.50	0.16	22.2	--[h]	--[h]	--[h]
8/08/90	HCA100/10	Howell EEE	HC+Air1[e]	FTP	0.04	0.33	0.13	22.1	--[h]	--[h]	--[h]
8/31/90	B2CHCC-05A	M85	HC+Air1/3[f]	FTP	0.06	0.34	0.20	13.4	0.03	11.8	6.0
9/06/90	B2CHCC-07A	M85	HC+Air1/3[f]	FTP	0.04	0.25	0.21	13.4	0.02	13.9	4.5
10/02/90	B2CHCRF1	M85	HC+AIR1/3[f]	FTP	0.03[i]	0.52	0.24	13.3	0.00	13.9	2.3
10/10/90	B2CHCC-08A	M85	HC+AIR1/3[f]	FTP	0.03[i]	0.31	0.25	13.2	0.00	14.8	1.1

[a]NMOG = Gasoline Derived Hydrocarbons + Methanol + Formaldehyde
[b]Heated catalyst without air injection.
[c]Degussa catalyst without air injection.
[d]Degussa catalyst with air injection for first 100 seconds of Bag 1.
[e]Heated catalyst and OEM catalyst with air injection for first 100 seconds of Bag 1.
[f]Heated catalyst and OEM catalyst with air injection for first 100 seconds of Bags 1 and 3.
[g]Heated catalyst and OEM catalyst with air injection for first 85 seconds of Bag 1.
[h]Analysis not conducted for this test.
[i]Calculated using hydrocarbon speciation data.

hydrocarbon speciation tests indicate no significant differences in hydrocarbon species observed when using the RF-A as a blending fuel with the methanol as compared to the Howell EEE. For all three tests, methane accounted for the majority of Bag 2 and 3 mass emissions. Tabulated speciated hydrocarbon test results for these three tests are given in Appendix I.

Upon completion of Task 2 emission testing on the Corsica, ARB requested that SwRI allow General Motors (GM) to update the fuel system of the Corsica and make necessary modifications. GM sent a representative to SwRI and made their required modifications prior to commencement of Task 3 testing.

3. Ford Crown Victoria #1

Upon arrival at SwRI in August 1990, Ford Crown Victoria #1 was inspected for any potential mechanical problems and proper operation. Following the inspections, duplicate baseline emission tests were conducted with the OEM catalyst system using both M85 and Howell EEE. The emission test cycles run were the FTP, HFET, and NYCC. For the OEM configuration tested, supplemental air was supplied between the two OEM catalyst bricks (for each catalyst bank of the dual exhaust) by the OEM belt-driven air pump on the vehicle.

After the completion of baseline testing, catalyst cans and an exhaust system were fabricated for the catalysts supplied by Johnson Matthey. The Johnson Matthey system consisted of two catalyst bricks for each exhaust bank (four bricks total, as described earlier in the report). The first catalyst on each bank (0.4 liter volume) was located as close as possible to the exhaust manifold. The second catalyst on each bank was placed in the close-coupled position, approximately 12 to 16 inches from the exhaust manifold. Supplemental air injection was provided between the manifold and close-coupled bricks using the OEM air pump in a manner identical to the baseline configuration. Duplicate emission tests were then conducted with both M85 and Howell EEE using the FTP, HFET, and NYCC.

The next catalyst system evaluated on Crown Victoria #1 was that supplied by Degussa. This system also consists of two catalyst bricks per bank. However, unlike the other catalyst systems evaluated on this vehicle, Degussa directed SwRI not to use any supplemental air injection at the catalysts. For this testing, the air pump line to the catalyst was disconnected. Again, duplicate emission tests were then conducted with both M85 and Howell EEE using the FTP, HFET, and NYCC.

The third catalyst system tested on Crown Victoria #1 was the Camet EHC in conjunction with the OEM catalyst. One EHC was installed on each exhaust bank downstream of the first OEM brick. The EHC was located upstream and as proximal to the second OEM catalyst brick as possible (approximately two inches away). The OEM air pump was used to supply supplemental air between the two OEM catalyst bricks immediately prior to the EHC on each bank. Duplicate emission tests were then conducted with both M85 and Howell EEE using the FTP, HFET, and NYCC.

A summary of all Task 2 emission tests conducted on the Ford Crown Victoria #1 using M85 fuel is given in Table 25. A summary of Task 2 emission tests conducted on the Ford Crown Victoria #1 using Howell EEE is given in Table 26. A summary of all aldehyde and ketone emissions measured for Task 2 emission tests on

TABLE 25. SUMMARY OF M85 CROWN VICTORIA #1 TASK 2 EMISSION TEST RESULTS

Date	Test No.	Fuel	Catalyst	Test Cycle	THC (g/mi)	GDHC (g/mi)	NMOG (g/mi)	CO (g/mi)	NO_x (g/mi)	Fuel Economy (mi\gal)	Methanol (g/mi)	Methane (mg/mi)	Form. (mg/mi)
1/08/91	B2FBL-01	M85	OEM	FTP	0.160	0.037	0.140	0.72	0.53	10.4	0.126	33	9.0
1/08/91	B2FBL-01	M85	OEM	HFET	0.030	0.015	0.007	0.00	0.33	16.1	0.000	10	2.4
1/08/91	B2FBL-01	M85	OEM	NYCC	0.330	0.166	0.079	0.18	1.08	5.5	0.000	95	8.1
12/26/90	B2FJM1-02	M85	JM	FTP	0.150	0.044	0.114	0.79	0.47	10.4	0.093	26	3.6
12/26/90	B2FJM1-02	M85	JM	HFET	0.010	0.005	0.000	0.01	0.57	15.9	0.000	5	0.4
12/26/90	B2FJM1-02	M85	JM	NYCC	0.160	0.080	0.007	0.03	0.81	5.3	0.000	75	0.8
1/03/91	B2FJM1-03	M85	JM	FTP	0.140	0.041	0.104	0.90	0.49	10.5	0.087	27	3.3
1/03/91	B2FJM1-03	M85	JM	HFET	0.010	0.005	0.000	0.02	038	16.2	0.000	6	0.3
1/03/91	B2FJM1-03	M85	JM	NYCC	0.110	0.055	0.000	0.01	0.89	5.3	0.000	74	2.7
1/23/91	B2FD-01	M85	Degussa	FTP	0.140	0.046	0.099	0.62	0.39	10.4	0.071	18	0.5
1/23/91	B2FD-01	M85	Degussa	HFET	0.020	0.010	0.005	0.00	0.48	15.9	0.000	5	0.2
1/23/91	B2FD-01	M85	Degussa	NYC	0.060	0.029	0.001	0.06	0.85	5.4	0.004	32	0.4
1/24/91	B2FD-02	M85	Degussa	FTP	0.150	0.044	0.121	0.69	0.39	10.4	0.092	16	0.8
1/24/91	B2FD-02	M85	Degussa	HFET	0.010	0.005	0.000	0.00	0.76	16.1	0.001	7	0.2
1/24/91	B2FD-02	M85	Degussa	NYCC	0.070	0.030	0.019	0.00	0.86	5.4	0.017	28	0.2
5/0291	B2FHC-01	M85	Camet	FTP	0.100	0.050	0.011	0.30	0.53	9.7	0.000	40	1.2
5/02/91	B2FHC-01	M85	Camet	HFET	0.030	0.015	0.004	0.00	0.33	15.3	0.000	12	0.5
5/02/91	B2FHC-01	M85	Camet	NYCC	0.250	0.126	0.021	0.02	1.01	5.0	0.000	107	1.9
5/03/91	B2FHC-02	M85	Camet	FTP	0.100	0.050	0.011	0.23	0.52	9.8	0.002	42	1.2
5/03/91	B2FHC-02	M85	Camet	HFET	0.030	0.015	0.003	0.00	0.29	15.7	0.000	13	0.4
5/03/91	B2FHC-02	M85	Camet	NYCC	0.270	0.135	0.029	0.02	1.08	5.0	0.002	110	2.1

TABLE 26. SUMMARY OF HOWELL EEE CROWN VICTORIA #1 TASK 2 EMISSION TEST RESULTS

Date	Test No.	Fuel	Catalyst	Test Cycle	THC (g/mi)	GDHC (g/mi)	NMOG (g/mi)	CO (g/mi)	NO_x (g/mi)	Fuel Economy (mi\gal)	Methanol (g/mi)	Methane (mg/mi)	Form. (mg/mi)
1/09/91	B2FBL1-01	Howell EEE	OEM	FTP	0.200	0.200	0.133	0.40	0.65	17.4	0.000	69	2.2
1/09/91	B2FBL1-01	Howell EEE	OEM	HFET	0070	0.070	0.044	0.02	0.40	26.8	0.000	27	0.8
1/09/91	B2FBL1-01	Howell EEE	OEM	NYCC	0.410	0.410	0.164	0.57	1.21	8.7	0.000	248	1.7
12/27/90	B1FJM-01	Howell EEE	JM	FTP	0.090	0.090	0.053	0.19	0.49	17.4	0.000	37	0.8
12/27/90	B1FJM-01	Howell EEE	JM	HFET	0.020	0.020	0.005	0.00	0.25	27.3	0.000	15	0.2
12/27/90	B1FJM-01	Howell EEE	JM	NYCC	0.260	0.260	0.013	0.02	0.85	8.9	0.000	247	0.7
1/02/91	B1FJM1-03	Howell EEE	JM	FTP	0.080	0.080	0.041	0.22	0.52	17.3	0.000	40	1.1
1/02/91	B1FJM1-03	Howell EEE	JM	HFET	0.020	0.020	0.006	0.01	0.28	27.1	0.000	15	0.4
1/02/91	B1FJM1-03	Howell EEE	JM	NYCC	0.270	0.270	0.012	0.05	0.88	8.4	0.000	261	3.1
1/21/91	B1FD-01	Howell EEE	Degussa	FTP	0.070	0.070	0.052	0.22	0.28	17.3	0.000	18	0.1
1/21/91	B1FD-01	Howell EEE	Degussa	HFET	0.010	0.010	0.003	0.22	0.25	26.5	0.000	8	0.3
1/21/91	B1FD-01	Howell EEE	Degussa	NYCC	0.020	0.020	0.002	0.04	0.42	8.5	0.000	19	1.0
1/22/91	B1FD-02	Howell EEE	Degussa	FTP	0.100	0.100	0.090	0.38	0.23	17.3	0.000	15	0.1
1/22/91	B1FD-02	Howell EEE	Degussa	HFET	0.010	0.010	0.010	0.20	0.19	26.8	0.000	3	0.0
1/22/91	B1FD-02	Howell EEE	Degussa	NYCC	0.020	0.020	0.000	0.03	0.35	8.9	0.000	25	0.0
5/06/91	B1FHC-01	Howell EEE	Camet	FTP	0.140	0.140	0.070	0.12	0.62	17.1	0.000	74	1.5
5/06/91	B1FHC-01	Howell EEE	Camet	HFET	0.040	0.040	0.010	0.01	0.35	26.4	0.000	29	0.3
5/06/91	B1FHC-01	Howell EEE	Camet	NYC	0.360	0.360	0.000	0.06	1.15	8.5	0.000	271	0.5
5/07/91	B1FHC-02	Howell EEE	Camet	FTP	0.130	0.130	0.060	0.20	0.68	17.0	0.000	68	1.6
5/07/91	B1FHC-02	Howell EEE	Camet	HFET	0.040	0.040	0.010	0.00	0.36	26.4	0.000	26	0.3
5/07/91	B1FHC-02	Howell EEE	Camet	NYCC	0.310	0.310	0.070	0.08	1.19	8.4	0.000	240	0.9

Crown Victoria #1 is given in Appendix D. Detailed computer printouts of Task 2 emission test results for Crown Victoria #1 are found in Appendix J.

After completing all scheduled Task 2 emission testing, ARB's requested that SwRI removed the EHC system from Crown Victoria #1 and re-install the Degussa system for a complete hydrocarbon speciation emission test. A summary of regulated emission results from this hydrocarbon speciation test is given in Table 27. Note that NMOG results contained in Table 27 were calculated from hydrocarbon speciation data. A detailed computer printout of test results along with hydrocarbon speciation data can be found in Appendix K. Hydrocarbon speciation data indicated that the Degussa catalyst system was able to eliminate most Bag 2 and Bag 3 hydrocarbon species. The only species that were present at any significant mass emission rate in Bag 2 were butane (3.9 mg/mi) and toluene (2.7 mg/mi). Bag 3 speciated emissions results confirmed presence of methane (5.1 mg/mi), benzene (0.9 mg/mi), toluene (1.3 mg/mi), and isopentane (2.8 mg/mi). No other species was present in either Bag 2 or Bag 3 at an emission rate of greater than 1 mg/mi. In addition, no methanol emissions were measurable in either of these bags. The overall low 1.0 mg/mi FTP formaldehyde emission rates observed in previous tests were also confirmed.

TABLE 27. SUMMARY OF REGULATED EMISSION TEST RESULTS FOR CROWN VICTORIA #1 HYDROCARBON SPECIATION TEST WITH DEGUSSA CATALYST SYSTEM

NMOG (g/mi)	CO (g/mi)	NO_X (g/mi)	Fuel Eco. (mi/gal)	Methanol (g/mi)	Methane (mg/mi)	Formal. (mg/mi)
0.150	0.93	0.32	9.7	0.110	9	1.0

Following the completion of all Task 2 emission testing on Crown Victoria #1, Ford sent a representative to SwRI to make engine modifications and update the vehicle. Subsequently, the vehicle was tested and it was discovered that the modifications substantially increased hydrocarbon and carbon monoxide emissions. It was later determined by Ford that the engine control module (ECM) also needed to be replaced. A new ECM was supplied by Ford and installed by SwRI. The new ECM corrected the high hydrocarbon and carbon monoxide emission levels.

4. VW Jetta

Upon arrival at SwRI in November 1990, baseline emission tests were conducted with both M85 and gasoline using the OEM catalyst system. Subsequently, the Johnson Matthey system was installed and tested without supplemental air injection. Next, the Camet EHC system was installed upstream of the OEM catalyst without supplemental air injection. During heating for the NYCC of the first test series with Howell EEE fuel, the EHC controller failed and testing had to be stopped. However, results from the FTP and HFET were still valid and are presented in Table 28. Detailed computer printouts for these two tests are found in Appendix L.

TABLE 28. SUMMARY OF FORD CROWN VICTORIA #1 FTP AND HFET EMISSION TEST DATA PRIOR TO EHC CONTROLLER FAILURE

Test Cycle	NMOG (g/mi)	CO (g/mi)	NO_X (g/mi)	Fuel Eco. (mi/gal)	Methane (mg/mi)
FTP	0.11[a]	1.70	0.01	24.3	29
HFET	0.08[a]	1.28	0.01	34.0	27

[a]Value does not include formaldehyde contribution.

After SwRI obtained a new power controller from Camet, ARB directed SwRI to optimize air injection time and flowrate for M85 fuel on the VW Jetta. During this experimentation, it was determined that the optimal air injection flow rate was 5.2 ft^3/min for the first 65 seconds of Bag 1 of the FTP. At the conclusion of this optimization, a 3-bag FTP was run using M85 to determine the effects on regulated emissions. A summary of regulated emission test results is given in Table 29. Note that methanol, methane, and formaldehyde were not measured for this test because optimization was geared toward total hydrocarbons (THC). Consequently, THC is not corrected for methanol response. A detailed computer printout of regulated emission test results for this post-optimization 3-bag FTP is found in Appendix M.

TABLE 29. RESULTS OF VW JETTA POST-OPTIMIZATION FTP

THC (g/mi)	CO (g/mi)	NO_X (g/mi)	Fuel Econ. (mi/gal)
0.10	0.89	0.03	13.8

Following optimization of the Camet system, the VW Jetta was tested in duplicate with both M85 and Howell EEE using the FTP, HFET, and NYCC. The Degussa system was also installed and tested on the VW Jetta with M85 and Howell EEE using duplicate FTP, HFET, and NYCC tests. Again, the Degussa system required no supplemental air injection. A summary of all Task 2 emission tests conducted on the VW Jetta using M85 fuel is given in Table 30. A summary of Task 2 emission tests conducted on the VW Jetta using Howell EEE is given in Table 31. A summary of all aldehyde and ketone emissions for Task 2 emission tests on the Jetta is given in Appendix D. Detailed computer printouts of Task 2 emission test results for the Jetta are found in Appendix N.

Because the Camet EHC system demonstrated the ability to greatly reduce emissions when used in conjunction with the OEM catalyst and the Degussa demonstrated the ability to reduce formaldehyde emissions to extremely low levels, ARB instructed SwRI to evaluate the Camet system in conjunction with the Degussa system. The goal of combining the two catalyst systems was to marry the two best-performing technologies on the VW Jetta and determine if emissions were reduced below values that

TABLE 30. SUMMARY OF VW JETTA TASK 2 EMISSION TEST RESULTS

Date	Test No.	Fuel	Catalyst	Test Cycle	THC (g/mi)	GDHC (g/mi)	NMOG (g/mi)	CO (g/mi)	NO_x (g/mi)	Fuel Economy (mi\gal)	Methanol (g/mi)	Methane (mg/mi)	Form. (mg/mi)
12/19/90	B2VBL-01	M85	OEM	FTP	0.310	0.108	0.222	2.65	0.04	14.7	0.141	32	6.1
12/19/90	B2VBL-01	M85	OEM	HFET	0.130	0.062	0.050	1.45	0.02	20.8	0.009	22	1.0
12/19/90	B2VBL-01	M85	OEM	NYCC	0.150	0.054	0.069	0.42	0.01	8.3	0.062	56	9.3
5/09/91	B2VJM-01	M85	JM	FTP	0.100	0.017	0.113	1.15	0.05	15.0	0.099	4	2.4
5/09/91	B2VJM-01	M85	JM	HFET	0.000	0.000	0.002	0.58	0.01	21.2	0.003	0	0.2
5/09/91	B2VJM-01	M85	JM	NYCC	0.020	0.005	0.008	0.00	0.21	8.2	0.015	13	0.5
5/10/01	B2VJM-02	M85	JM	FTP	0.090	0.012	0.108	1.06	0.04	14.9	0.099	5	2.5
5/10/91	B2VJM-02	M85	JM	HFET	0.010	0.005	0.004	0.51	0.01	21.2	0.000	1	0.0
5/10/91	B2VJM-02	M85	JM	NYCC	0.040	0.020	0.009	0.03	0.15	8.3	0.000	12	0.0
7/23/91	B2VDC-01	M85	Degussa	FTP	0.160	0.046	0.124	1.36	0.02	14.2	0.100	25	2.5
7/23/91	B2VDC-01	M85	Degussa	HFET	0.120	0.059	0.045	0.53	0.01	20.2	0.003	17	0.0
7/23/91	B2VDC-01	M85	Degussa	NYCC	0.050	0.013	0.031	0.33	0.03	7.7	0.036	18	0.0
7/24/91	B2VDC-02	M85	Degussa	FTP	0.230	0.081	0.160	1.38	0.02	14.1	0.102	25	2.4
7/24/91	B2VDC-02	M85	Degussa	HFET	0.110	0.055	0038	0.50	0.01	20.2	0.002	19	0.0
7/24/91	B2VDC-02	M85	Degussa	NYCC	0.030	0.006	0.018	0.30	0.02	7.8	0.028	15	0.0
9/30/91	B2VHC-01A	M85	Camet	FTP	0.070	0.035	0.026	0.85	0.05	13.8	0.001	10	0.1
9/30/91	B2VHC-01A	M85	Camet	HFET	0.070	0.035	0.025	0.99	0.02	19.4	0.000	10	0.0
9/30/91	B2VHC-01A	M85	Camet	NYCC	0.050	0.025	0.015	0.49	0.00	7.6	0.000	10	0.0
10/01/91	B2VHC-02A	M85	Camet	FTP	0.060	0.030	0.017	0.68	0.04	14.0	0.000	14	0.3
10/01/91	B2VHC-02A	M85	Camet	HFET	0.060	0.030	0.017	0.87	0.01	19.7	0.000	13	0.0
10/01/91	B2VHC-02A	M85	Camet	NYCC	0.060	0.027	0.000	0.37	0.01	7.6	0.010	31	0.0

TABLE 31. SUMMARY OF HOWELL EEE VW JETTA TASK 2 EMISSION TEST RESULTS

Date	Test No.	Fuel	Catalyst	Test Cycle	THC (g/mi)	GDHC (g/mi)	NMOG (g/mi)	CO (g/mi)	NO_x (g/mi)	Fuel Economy (mi\gal)	Methanol (g/mi)	Methane (mg/mi)	Form. (mg/mi)
12/18/90	B1VBL-01	Howell EEE	OEM	FTP	0.230	0.230	0.190	2.43	0.06	24.9	0.000	42	1.8
12/18/90	B1VBL-01	Howell EEE	OEM	HFET	0.140	0.140	0.110	2.01	0.02	35.0	0.000	35	0.8
12/18/90	B1VBL-01	Howell EEE	OEM	NYCC	0.180	0.180	0.100	0.85	0.01	14.3	0.000	89	8.0
5/13/91	B1VJM-01	Howell EEE	JM	FTP	0.100	0.100	0.091	1.23	0.22	26.3	0.000	9	0.3
5/13/91	B1VJM-01	Howell EEE	JM	HFET	0.040	0.040	0.029	0.76	0.06	36.9	0.000	11	0.0
5/13/91	B1VJM-01	Howell EEE	JM	NYCC	0.020	0.020	0.001	0.21	0.36	15.2	0.000	19	0.0
5/14/91	B1VJM-02	Howell EEE	JM	FTP	0.080	0.080	0.070	1.13	0.21	26.5	0.000	10	0.5
5/14/91	B1VJM-02	Howell EEE	JM	HFET	0.060	0.060	0.050	0.87	0.03	37.3	0.000	13	0.1
5/14/91	B1VJM-02	Howell EEE	JM	NYCC	0.030	0.030	0.000	0.35	0.20	0.20	0.000	27	0.4
7/22/91	B1VDC-01	Howell EEE	Degussa	FTP	0.210	0.210	0.168	0.99	0.02	24.4	0.000	43	0.2
7/18/91	B1VDC-01	Howell EEE	Degussa	HFET	0.080	0.080	0.053	0.88	0.01	34.9	0.000	27	0.0
7/18/91	B1VDC-01	Howell EEE	Degussa	NYCC	0.040	0.040	0.011	0.37	0.04	13.3	0.000	29	0.0
7/19/91	B1VDC-02	Howell EEE	Degussa	FTP	0.230	0.230	0.187	1.11	0.03	24.6	0.000	43	0.1
7/19/91	B1VDC-02	Howell EEE	Degussa	HFET	0.130	0.130	0.092	0.76	0.02	34.4	0.000	38	0.0
7/19/91	B1VDC-02	Howell EEE	Degussa	NYCC	0.040	0.040	0.011	0.48	0.04	13.2	0.000	29	0.0
10/02/91	B1VHC-01A	Howell EEE	Camet	FTP	0.070	0.070	0.046	0.88	0.05	27.1	0.000	24	<0.1
10/02/91	B1VHC-01A	Howell EEE	Camet	HFET	0.070	0.070	0.046	1.12	0.04	39.8	0.000	24	<0.1
10/02/91	B1VHC-01A	Howell EEE	Camet	NYCC	0.140	0.140	0.000	3.75	0.04	15.3	0.000	181	<0.1
10/03/91	B1VHC-02A	Howell EEE	Camet	FTP	0.080	0.080	0.062	0.79	0.06	27.6	0.000	18	<0.1
10/03/91	B1VHC-02A	Howell EEE	Camet	HFET	0.070	0.070	0.047	1.15	0.04	40.1	0.000	23	<0.1
10/03/91	B1VHC-02A	Howell EEE	Camet	NYCC	0.190	0.190	0.015	4.49	0.07	15.1	0.000	175	<0.1

either system could achieve individually. Duplicate FTPs were run on the Jetta with the Camet plus OEM system (as described above) with M85. Next, duplicate FTPs were run with the Camet system in conjunction with the Degussa system on M85. In the Camet plus Degussa configuration, supplemental air was injected in exactly the same manner as the Camet plus OEM configuration. As can be seen in Table 32 from the results of this comparison testing, the EHC+Degussa catalyst system clearly performed better than the EHC+OEM system. Specifically, EHC+Degussa NMOG, CO, methanol, methane, and formaldehyde emissions were significantly lower than those with the EHC+OEM system. Computer printouts of these test results can be found in Appendix N.

TABLE 32. SUMMARY OF VW JETTA OEM/DEGUSSA + EHC TESTS

Date	Test No.	Fuel	Catalyst	Test Cycle	NMOG[a] (g/mi)	CO (g/mi)	NO_x (g/mi	Fuel Economy (mi/gal)	Methanol (g/mi)	Methane (mg/mi)	Form. (mg/mi)
11/3/91	J2HC/OEM-1	M85	EHC+OEM	FTP	0.045	0.76	0.06	13.5	0.034	13.8	0.7
11/4/91	J2HC/OEM-2	M85	EHC+OEM	FTP	0.069	0.86	0.05	13.3	0.063	13.8	1.3
11/5/92	J2HC-DC-1	M85	EHC+Degussa	FTP	0.012	0.33	0.06	13.5	0.004	8.5	0.1
11/6/92	J2HC/DC-2	M85	EHC+Degussa	FTP	0.011	0.40	0.05	13.3	0.006	8.8	<0.1

[a]NMOG - Gasoline Derived Hydrocarbons + Methanol + Formaldehyde - Methane

VI. CATALYST SELECTION AND TASK 3 EMISSIONS TESTING

This section of the report discusses the rationale that was used for choosing catalyst systems from Task 2 for permanent installation on each of the four test vehicles. In addition, this section also discusses the results of Task 3 short-term durability (4000-mile) tests for each of the selected catalyst systems on five vehicles. The four vehicles used for Task 2 were also used for Task 3 short-term durability. However, because two catalyst systems showed the potential for maintaining low emission levels on Crown Victoria #1 during Task 2 evaluations, a second Crown Victoria (Crown Victoria #2) was obtained from the South Coast Air Quality Management District (SQAMD) so that both systems could be subjected to short-term durability testing under Task 3.

One catalyst system for each vehicle was recommended to the State of California Air Resources Board (ARB) by Southwest Research Institute (SwRI) for permanent installation and Task 3 testing based on Task 2 emission tests results and conversations between ARB and SwRI. Following acceptance of SwRI recommendations by ARB, each catalyst system was installed and subjected to Task 3 short-term durability and periodic emissions tests.

A. Catalyst Recommendations

The objective of Task 1 and Task 2 screening and evaluation was to determine which catalyst systems showed the best potential for permanent application on current technology vehicles. The rationale used to determine the catalyst system that was applied to each of five vehicles for Task 3 short-term durability testing follows.

1. Toyota Camry

The Degussa close-coupled catalyst system was selected for permanent application on the Toyota Camry for the Task 3 durability phase primarily because of its formaldehyde emission performance. Bar chart comparisons of average FTP formaldehyde and NMOG emissions are shown in Figures 17 and 18, respectively. As can be seen, formaldehyde emission levels for both the Degussa and Camet plus OEM systems were similar. Although NMOG emissions were lower for the Camet plus OEM system than the Degussa system, the Degussa system was selected because the emission control strategy was much less complicated and represented a more developed technology at the time of testing. In addition, the Degussa system provided the lowest FTP carbon monoxide emissions of any catalyst system evaluated on this vehicle. It was also felt that the heavier precious metal loading may lead to increased durability of the system.

2. Chevrolet Corsica

The underbody Camet electrically-heated catalyst system in conjunction with the OEM catalyst and air injection at a rate of 5.2 ft^3/min (during vehicle start-up) was selected for the Chevrolet Corsica. As can be seen in Figures 19 and 20, the Camet system provided, by far, the lowest FTP NMOG emission rates of any of the catalyst systems evaluated on the Corsica with M85 and gasoline. The Camet system also provided low FTP formaldehyde emission rates and the lowest carbon monoxide emissions

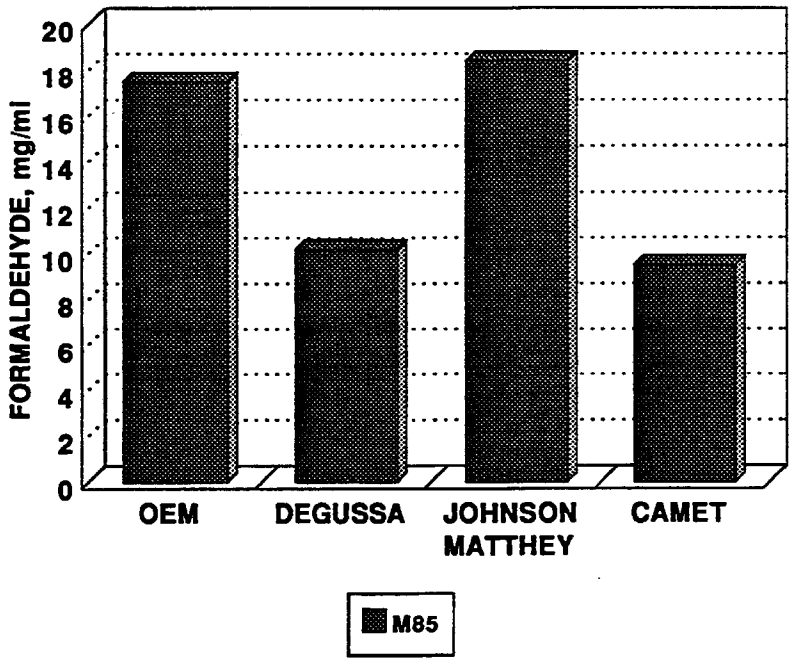

FIGURE 17. COMPARISON OF TOYOTA CAMRY AVERAGE FTP FORMALDEHYDE EMISSIONS

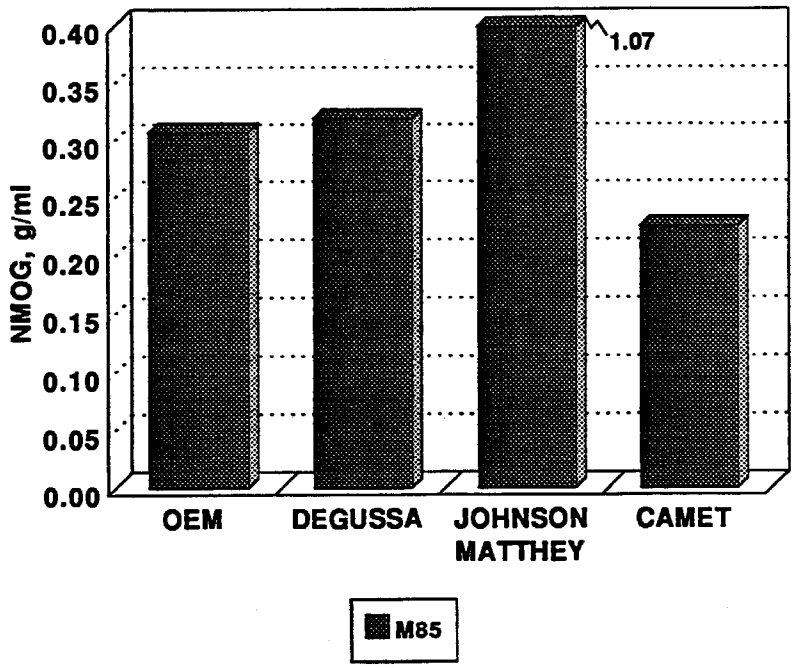

FIGURE 18. COMPARISON OF TOYOTA CAMRY AVERAGE FTP NMOG EMISSIONS

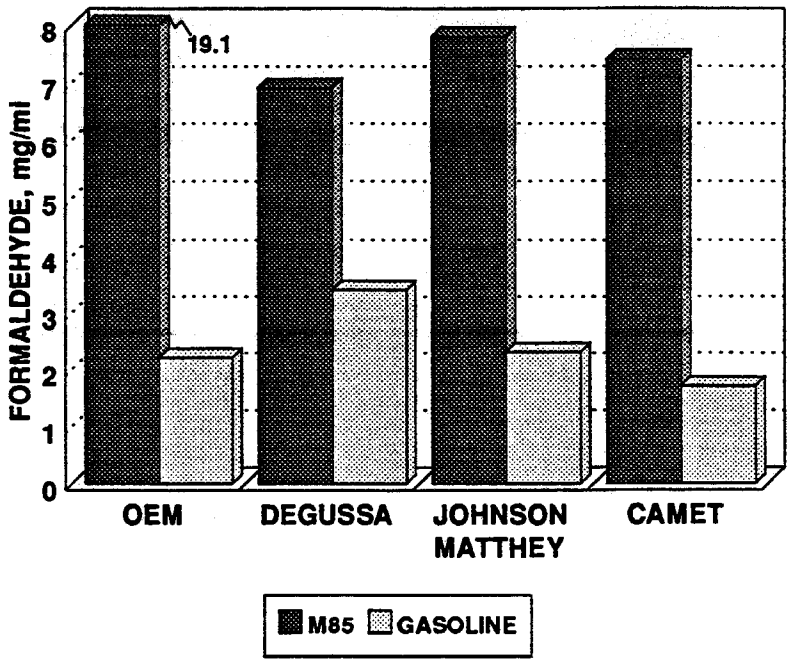

FIGURE 19. COMPARISON OF CHEVROLET CORSICA AVERAGE FTP FORMALDEHYDE EMISSIONS

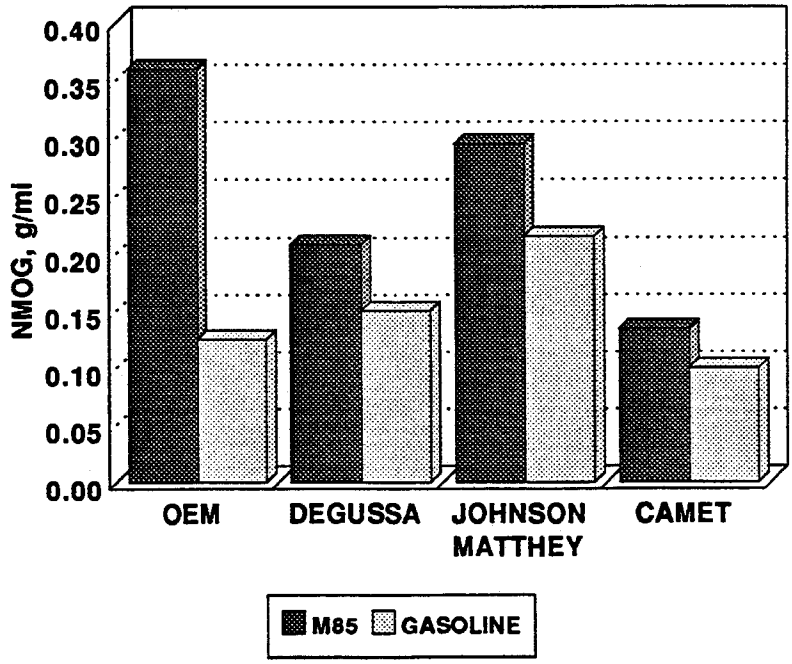

FIGURE 20. COMPARISON OF CHEVROLET CORSICA AVERAGE FTP NMOG EMISSIONS

of any of the systems evaluated. In addition, average FTP oxides of nitrogen emissions were less than the 0.2 g/mi Ultra-Low Emission Vehicle (ULEV) California standard.

3. Ford Crown Victoria #1 and Ford Crown Victoria #2

Both the Camet electrically-heated catalyst system and the Degussa catalyst system were selected for permanent application on two Ford Crown Victorias and Task 3 short-term durability testing. Originally, it was planned to only select one catalyst system for application on one Crown Victoria (#1). However, ARB obtained a second Crown Victoria (#2) for use during Task 3 evaluations because both the Degussa and Camet systems showed promising Task 2 emission test results. Consequently, the Camet system was permanently installed on Crown Victoria #1 and the Degussa system was installed on Crown Victoria #2.

The Camet system was selected because it provided extremely low FTP NMOG emissions when operating on M85. In addition, FTP formaldehyde emissions were between 1-2 mg/mi when operating on either M85 or Howell EEE. The Camet system also gave the lowest FTP carbon monoxide emissions of the systems evaluated. ARB also desired to evaluate the Camet system in the most current technology vehicle in the program.

The Degussa system was selected for permanent application on Crown Victoria #2 because it gave the lowest FTP formaldehyde emissions for both gasoline and M85 fuels. In addition, the Degussa system provided good control of NMOG emissions. Figures 21 and 22 are provided to show comparisons of average FTP formaldehyde and NMOG emissions respectively.

4. VW Jetta

The Camet EHC in conjunction with the Degussa catalyst was the system chosen by ARB for permanent application and Task 3 durability testing on the VW Jetta. As can be seen in Figures 23 and 24, average FTP formaldehyde and NMOG were the lowest for the Camet plus Degussa system. In addition, FTP carbon monoxide emissions were also well controlled with this system.

B. Short-Term Durability Test Results

This section of the report contains results from the Task 3 4000-mile short term durability testing on each of the five vehicles equipped with the selected catalyst system. Following installation of the selected catalyst system, each vehicle underwent duplicate zero-mile FTP, HFET, and NYCC emission tests using both M85 and Howell EEE (except for the dedicated M85 Toyota Camry which was not designed to operate on any fuel but M85). After the zero-mile testing was completed, the vehicles were subjected to 2000 miles of mileage accumulation using an on-road version of the Alternate Mileage Accumulation (AMA) cycle. A diagram of this cycle is presented in Figure 25. All mileage was accumulated using M85 fuel. Mileage accumulation took approximately 12 days for vehicles not equipped with EHCs and 13 days for vehicles equipped with EHCs.

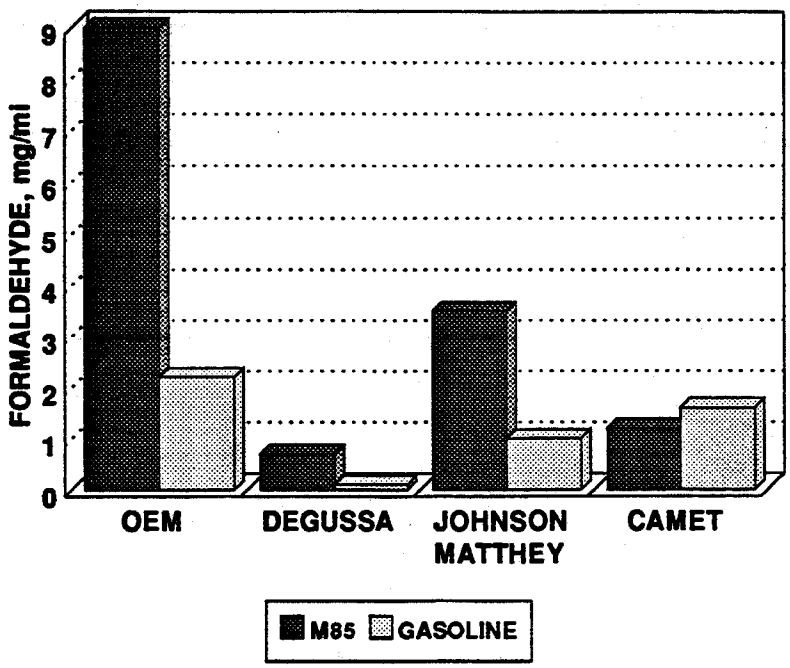

FIGURE 21. COMPARISON OF FORD CROWN VICTORIA #1 AVERAGE FTP FORMALDEHYDE EMISSIONS

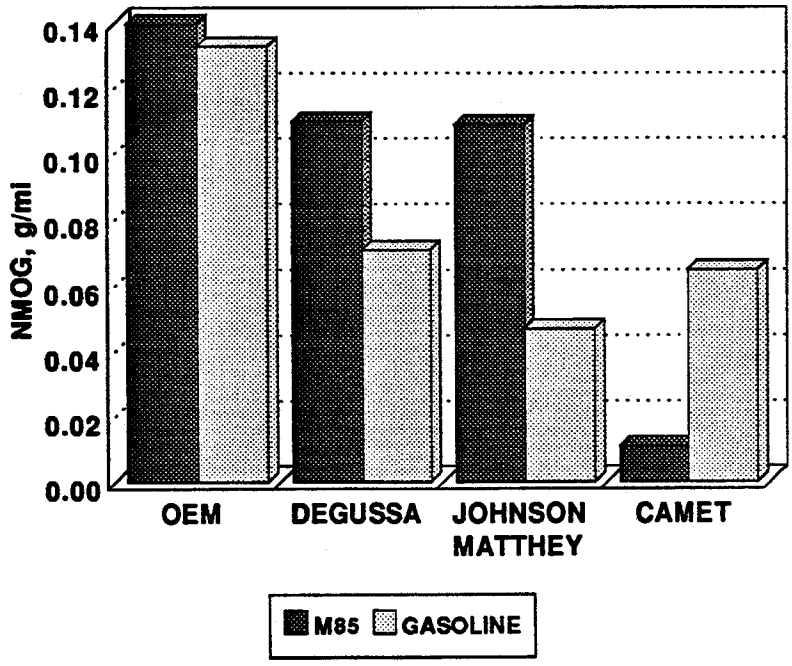

FIGURE 22. COMPARISON OF FORD CROWN VICTORIA #1 AVERAGE FTP NMOG EMISSIONS

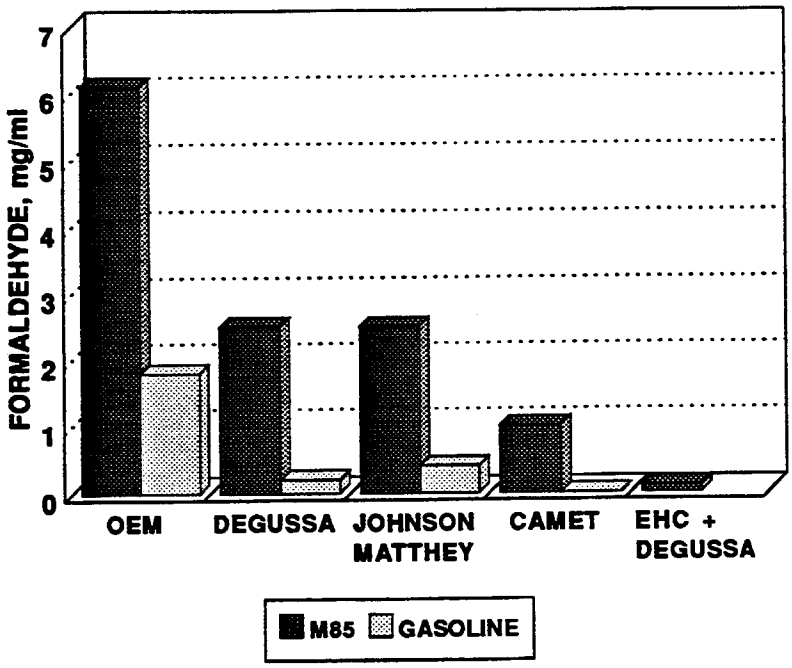

FIGURE 23. COMPARISON OF VW JETTA AVERAGE FTP FORMALDEHYDE EMISSIONS

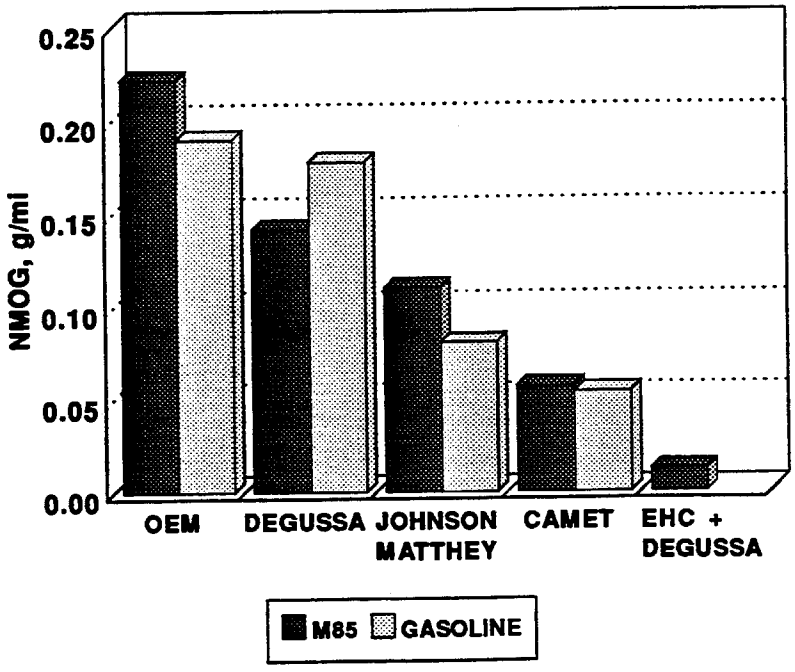

FIGURE 24. COMPARISON OF VW JETTA AVERAGE FTP NMOG EMISSIONS

6.3 MILE AMA ROUTE
(Average Lap Speed,30 miles/hour)

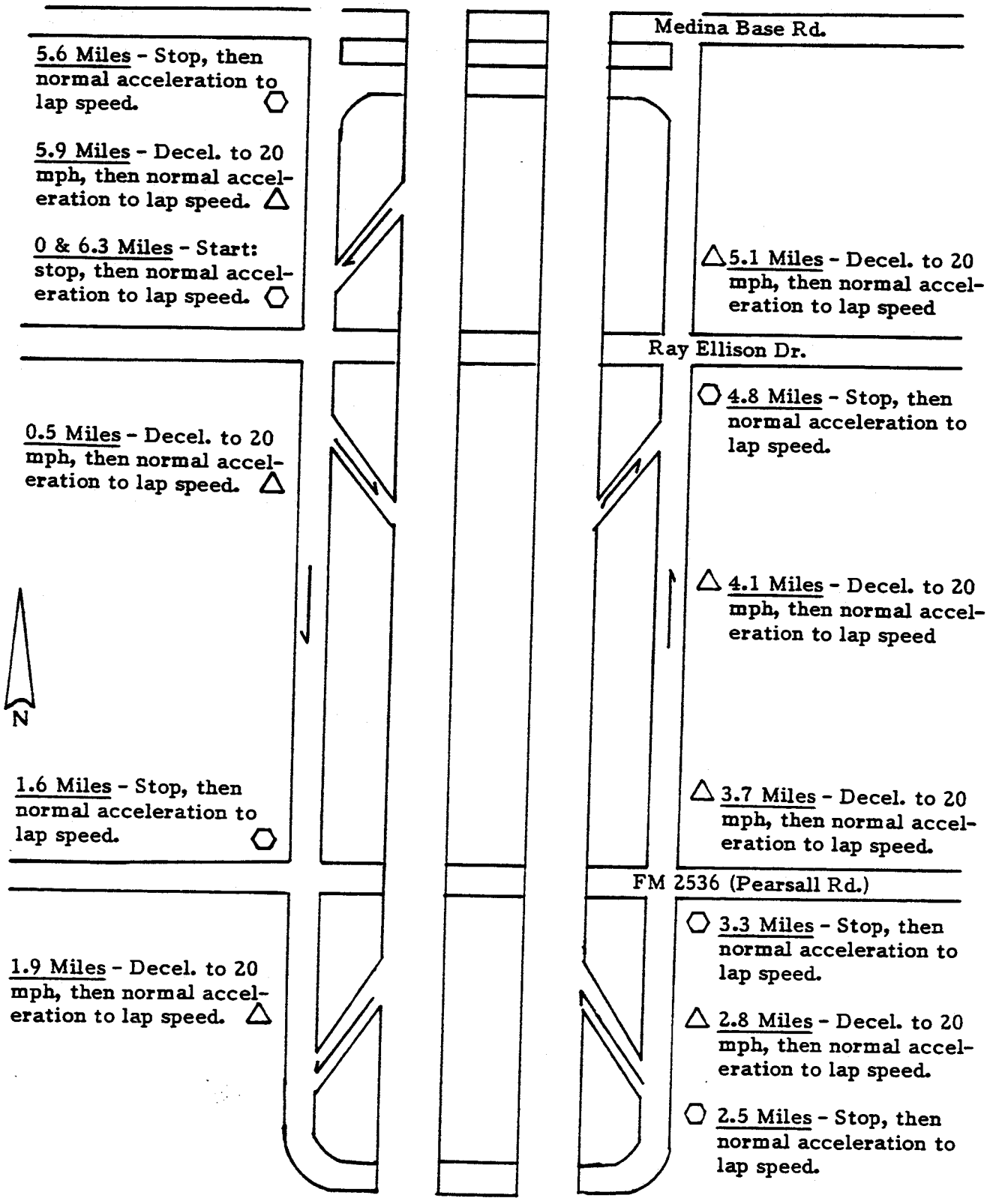

FIGURE 25. ALTERNATE MILEAGE ACCUMULATION (AMA) ROUTE

After 2000 miles were accumulated on each vehicle, they underwent duplicate FTP, HFET, and NYCC emission tests using M85. Following the 2000-mile emission tests, the vehicles accumulated 2000 additional miles (4000 miles total) and were re-tested in the same manner as the 2000-mile point. NMOG emission for Task 3 emission tests were calculated as described in Section V.

The EHC vehicles typically required one additional day to accumulate each 2000-mile segment to allow the EHC system to be fully exercised. For each day of mileage accumulation, the EHC vehicles were cold-started once after a 15 hour overnight soak. In addition, after every 25-30 minutes of mileage accumulation, each vehicle was stopped and soaked with the engine turned off for 15 minutes. After 15 minutes, the EHC was turned on and the vehicle was re-started. Typically the EHCs were subjected to at least 12 hot-starts per day.

1. Toyota Camry

Task 3 short-term durability testing of the Toyota Camry equipped with the Degussa catalyst system was initiated in May 1991 and was completed in June 1991. Because of a substantial increase in NMOG from the 2000-mile to the 4000-mile point. All of the fuel injectors were checked to ensure that they functioned correctly. After input from Toyota, it was decided that the fuel injectors should be replaced. Subsequently, the fuel injectors were replaced with those supplied by Toyota and the vehicle was retested at the 4000-mile point. A summary of zero-, 2000-, 4000-mile, and 4000-mile re-test results is given in Table 33. A summary of all Task 3 aldehyde and ketone emissions is given in Appendix O. Detailed computer printouts of all Task 3 emission tests on the Camry are found in Appendix P.

Although formaldehyde emissions remained low (4.6 to 7.7 mg/mi) throughout the 4000 miles of vehicle operation, there was a continued increase in NMOG, methanol, gasoline derived hydrocarbons, and carbon monoxide emissions, with increased mileage. Replacement of the fuel injectors substantially reversed this trend. This indicated that the catalyst system was still functioning correctly, but that the vehicle control system had changed during mileage accumulation. A plot of average FTP formaldehyde, NMOG, carbon monoxide, and oxides of nitrogen emissions versus mileage is shown in Figure 26. It should be noted that the values given in Figure 26 for the 4000-mile point are those from after the installation of the new fuel injectors (re-test results).

2. Chevrolet Corsica

In October 1991, SwRI began Task 3 zero-mile short-term durability testing on the Chevrolet Corsica. Task 3 work on the Chevrolet Corsica was completed in February 1992. A summary of zero-, 2000-, and 4000-mile results is given in Table 34. A summary of all aldehyde and ketone emissions is given in Appendix O. Detailed computer printouts of all Task 3 emission tests on the Corsica are found in Appendix Q. A plot of average FTP formaldehyde, NMOG, carbon monoxide, and oxides of nitrogen emissions versus mileage for M85 is shown in Figure 27.

In general, the Chevrolet Corsica equipped with the Camet EHC system was able to maintain low emission levels throughout the entire 4000-mile durability testing. However, at the 4000-mile test point NMOG emissions did exceed 0.040 g/mi.

TABLE 33. SUMMARY OF TOYOTA CAMRY TASK 3 SHORT-TERM DURABILITY EMISSION TEST RESULTS

Date	Test No.	Durability Mileage, mi	Catalyst	Test Cycle	NMOG[a] (g/mi)	CO (g/mi)	NO_x (g/mi)	Fuel Economy (mi/gal)	Methanol (g/mi)	Methane (mg/mi)	Form. (mg/mi)
5/1/91	TDC0K-01	0	Degussa	FTP	0.159	1.15	0.35	16.7	0.06	6	7.7
5/1/91	TDC0K-01	0	Degussa	HFET	0.007	0.00	0.11	26.1	0.00	4	0.6
5/1/91	TDC0K-01	0	Degussa	NYCC	0.005	0.01	0.55	9.4	0.00	14	1.4
5/2/91	TDC0K-02	0	Degussa	FTP	0.093	1.17	0.33	16.9	0.29	8	5.5
5/2/91	TDC0K-02	0	Degussa	HFET	0.006	0.02	0.06	25.7	0.00	5	0.7
5/2/91	TDC0K-02	0	Degussa	NYCC	0.000	0.02	0.36	9.9	0.00	11	1.0
5/10/91	TDC2K-01	2000	Degussa	FTP	0.273	1.53	0.05	16.3	0.25	9	4.6
5/10/91	TDC2K-01	2000	Degussa	HFET	0.022	0.17	0.02	24.7	0.00	9	0.3
5/10/91	TDC2K-01	2000	Degussa	NYCC	0.031	0.70	0.02	9.4	0.00	24	0.3
5/11/91	TDC2K-02	2000	Degussa	FTP	0.326	1.95	0.06	16.4	0.28	20	4.8
5/11/91	TDC2K-02	2000	Degussa	HFET	0.020	0.12	0.02	25.4	0.00	10	0.2
5/11/91	TDC2K-02	2000	Degussa	NYCC	0.024	0.58	0.02	9.3	0.00	28	1.2
5/20/91	TDC4K-01	4000	Degussa	FTP	0.354	2.34	0.08	16.6	0.25	23	4.6
5/20/91	TDC4K-01	4000	Degussa	HFET	0.026	0.24	0.02	24.8	0.00	10	0.5
5/20/91	TDC4K-01	4000	Degussa	NYCC	0.025	0.58	0.04	9.6	0.00	33	2.7
5/21/91	TDC4K-02	4000	Degussa	FTP	0.715	1.77	0.07	16.5	0.45	22	5.2
5/21/91	TDC4K-02	4000	Degussa	HFET	0.024	0.24	0.03	25.1	0.00	11	0.2
5/21/91	TDC4K-02	4000	Degussa	NYCC	0.039	0.99	0.06	9.6	0.00	38	0.5
10/8/91	TDC4K-1R[c]	4000	Degussa	FTP	0.242	1.83	0.12	16.6	0.17	21	5.4
10/8/91	TDC4K-1R[c]	4000	Degussa	HFET	0.022	0.21	0.02	25.5	0.00	10	<0.02
10/8/91	TDC4K-1R[c]	4000	Degussa	NYCC	0.067	1.65	0.01	9.7	0.00	14	<0.2
10/9/91	TDC4K-2R[c]	4000	Degussa	FTP	0.270	2.03	0.09	16.7	0.20	25	5.8
10/9/91	TDC4K-2R[c]	4000	Degussa	HFET	0.021	0.27	0.03	25.7	0.00	10	<0.02
10/9/91	TDC4K-2R[c]	4000	Degussa	NYCC	0.077	2.37	0.01	9.8	0.01	40	<0.2

[a]NMOG = Gasoline Derived Hydrocarbons + Methanol + Formaldehyde - Methane
[b]Total FID Hydrocarbons.
[c]Repeated 4000-mile test after installation of new fuel injectors.

TABLE 34. SUMMARY OF CHEVROLET CORSICA TASK 3 SHORT-TERM DURABILITY TEST RESULTS

Date	Test No.	Durability Mileage (mi)	Fuel	Catalyst	Test Cycle	NMOG[a] (g/mi)	CO (g/mi)	NO_x (g/mi)	Fuel Economy (mi/gal)	Methanol (g/mi)	Methane (mg/mi)	Form. (mg/mi)
10/29/91	C1HC0K-01	0	Howell EEE	Camet	FTP	0.030	0.35	0.12	19.2	0.00	20	<0.2
10/29/91	C1HC0K-01	0	Howell EEE	Camet	HFET	0.027	0.17	0.08	30.4	0.00	13	<0.02
10/29/91	C1HC0K-01	0	Howell EEE	Camet	NYCC	0.025	0.71	0.09	10.3	0.00	35	<0.2
11/08/91	C1HC0K-02	0	Howell EEE	Camet	FTP	0.017	0.07	0.18	19.4	0.00	13	<0.2
11/08/91	C1HC0K-02	0	Howell EEE	Camet	HFET	0.012	0.06	0.07	30.7	0.00	8	<0.02
11/08/91	C1HC0K-02	0	Howell EEE	Camet	NYCC	0.076	2.09	0.07	10.8	0.00	34	<0.2
11/11/91	C2HC0K-01	0	M85	Camet	FTP	0.014	0.52	0.10	11.8	0.00	8	<0.2
11/11/91	C2HC0K-01	0	M85	Camet	HFET	0.010	0.33	0.03	17.8	0.00	6	<0.02
11/11/91	C2HC0K-01	0	M85	Camet	NYCC	0.013	0.78	0.00	6.4	0.01	21	<0.2
11/12/91	C2HC0K-02	0	M85	Camet	FTP	0.012	0.37	0.12	11.9	0.00	7	0.9
11/12/91	C2HC0K-02	0	M85	Camet	HFET	0.004	0.34	0.03	17.8	0.00	6	0.3
11/12/91	C2HC0K-02	0	M85	Camet	NYCC	0.021	1.31	0.02	6.5	0.01	25	<0.2
1/9/92	C2HC2K-01	2000	M85	Camet	FTP	0.025	0.65	0.14	12.0	0.02	12	0.8
1/9/92	C2HC2K-01	2000	M85	Camet	HFET	0.008	0.48	0.08	18.0	0.00	6	0.1
1/9/92	C2HC2K-01	2000	M85	Camet	NYCC	0.024	2.36	0.02	6.2	0.00	32	<0.2
1/10/92	C2HC2K-02	2000	M85	Camet	FTP	0.022	0.56	0.16	11.9	0.01	11	1.2
1/10/92	C2HC2K-02	2000	M85	Camet	HFET	0.006	0.01	0.20	18.0	0.00	4	0.1
1/10/92	C2HC2K-02	2000	M85	Camet	NYCC	0.026	2.04	0.03	6.3	0.00	20	0.2
2/25/92	C2HC4K-01	4000	M85	Camet	FTP	0.035	0.66	0.14	12.1	0.02	13	1.4
2/25/92	C2HC4K-01	4000	M85	Camet	HFET	0.007	0.23	0.07	18.1	0.00	5	0.1
2/25/92	C2HC4K-01	4000	M85	Camet	NYCC	0.040	2.52	0.11	6.5	0.00	31	<0.2
2/26/92	C2HC4K-02	4000	M85	Camet	FTP	0.049	0.64	0.17	11.8	0.02	12	0.8
2/26/92	C2HC4K-02	4000	M85	Camet	HFET	0.007	0.11	0.10	17.8	0.00	5	0.2
2/26/92	C2HC4K-02	4000	M85	Camet	NYCC	0.022	2.55	0.11	6.4	0.00	30	<0.2

[a]NMOG = Gasoline Derived Hydrocarbons + Methanol + Formaldehyde - Methane

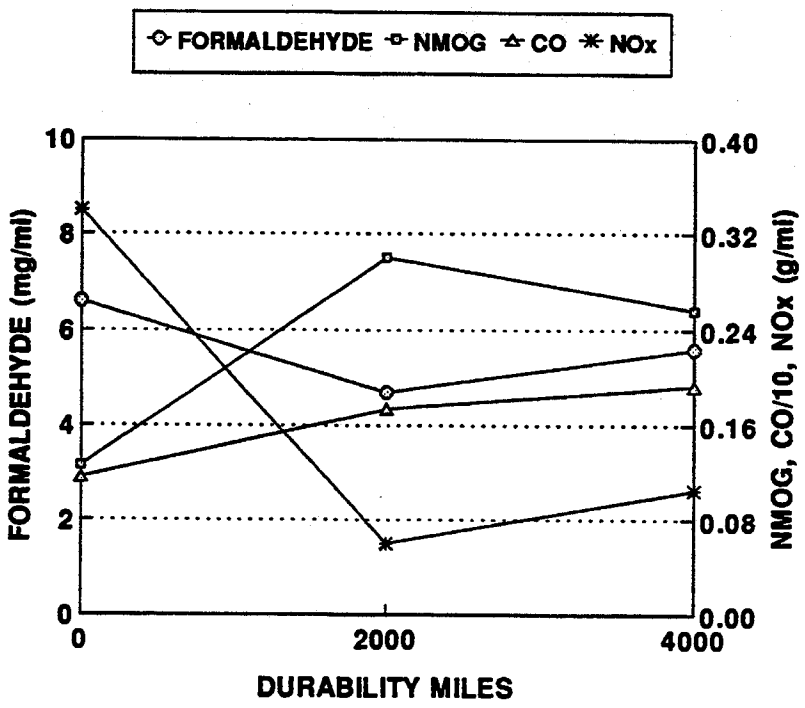

FIGURE 26. PLOT OF TOYOTA CAMRY FORMALDEHYDE, NMOG, CO, AND NO_x VERSUS ACCUMULATED MILEAGE

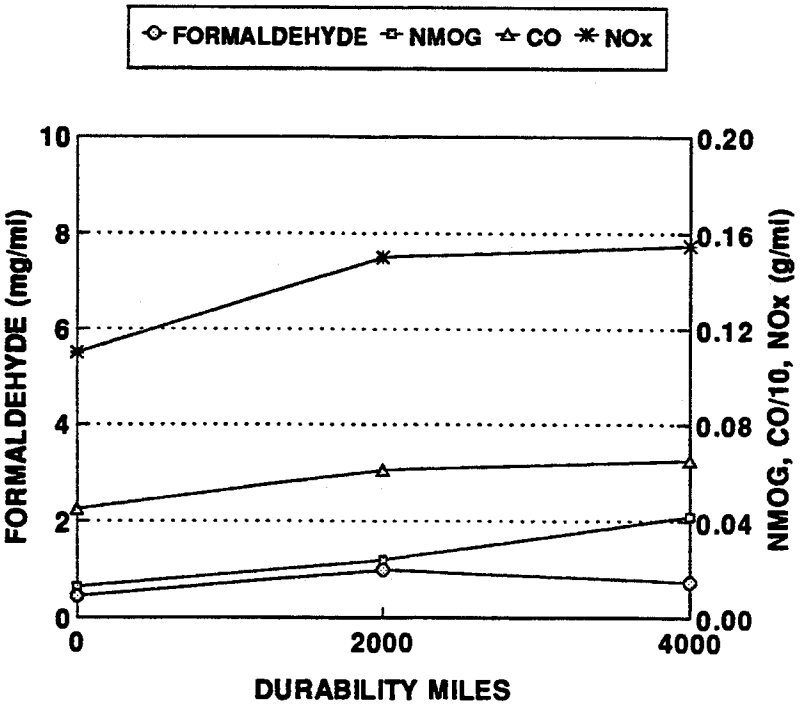

FIGURE 27. PLOT OF CHEVROLET CORSICA FORMALDEHYDE, NMOG, CO, AND NO_x VERSUS ACCUMULATED MILEAGE

3. Ford Crown Victoria #1

Installation of the newly designed Camet "extended durability" catalyst system with programmable control module and electric air pump on Crown Victoria #1 began in July 1992. On October 15, 1992, SwRI conducted an FTP emission test to determine if the new Camet system produced equivalent emission results to the system used during Task 2 testing. A comparison of average Task 2 emission test results to check-out emission test results for the "extended durability" catalyst system are given in Table 35. A detailed computer printout of the results from this emission test is found in Appendix R.

TABLE 35. RESULTS OF CROWN VICTORIA #1 FTP CHECK OUT TEST

Catalyst System	THC (g/mi)	CO (g/mi)	NO_x (g/mi)	Fuel Econ. (mi/gal)
Task 2 EHC	0.100	0.27	0.53	9.8
Task 3 "Extended Durability" EHC	0.082	0.05	0.77	9.2

Because the new programmable system allowed much greater flexibility in terms of controlling catalyst heating times/temperatures, it was decided that further optimization of emissions should be attempted. Detailed computer printouts of optimization test results are given in Appendix S. However, significant electronic complications with the Camet system created frequent intermittent failure of the Camet logic module for the EHC. Because of system difficulties, Mr. Stan Rolf of Camet traveled to SwRI to modify the installation. Following Mr. Rolf's visit, the vehicle operated correctly and an optimized strategy for air injection and EHC control was determined. A summary of the EHC logic module parameters can be found in Appendix T.

Following the completion of zero-mile emission testing, 2000 miles of mileage accumulation, and emission testing at the 2000-mile point, Crown Victoria #1 began to experience significant electronic problems. From the beginning of the zero-mile emission tests to the completion of the 2000 miles of mileage accumulation, two power control modules failed on Crown Victoria #1. In order to diagnose and eliminate the electronic problems, Camet sent Mr. Stan Rolf to SwRI again. Mr. Rolf made several electronic changes and Crown Victoria #1 was able to complete all 4000 miles of AMA mileage accumulation and required emission tests. A summary of zero-, 2000-, and 4000-mile emission test results is given in Table 36. A summary of aldehyde and ketone emissions is given in Appendix O. Detailed computer printouts of all Task 3 emission tests conducted on Crown Victoria #1 are found in Appendix U. A plot of average FTP formaldehyde, NMOG, carbon monoxide emissions, and oxides of nitrogen emissions versus mileage for M85 is shown in Figure 28.

In general, average FTP emissions of formaldehyde, NMOG, and NO_x remained constant or decreased slightly throughout the 4,000 miles of AMA driving on Crown Victoria #1 equipped with the Camet System. However, from the 2000- to 4000-mile point, average FTP CO emissions more than doubled. Average NMOG emissions at the 4000-mile test point were 0.035 g/mi.

TABLE 36. SUMMARY OF TASK 3 SHORT-TERM DURABILITY TEST RESULTS FOR CROWN VICTORIA #1

Date	Test No.	Durability Mileage (mi)	Fuel	Catalyst	Test Cycle	NMOG[a] (g/mi)	CO (g/mi)	NOx (g/mi)	Fuel Economy (mi/gal)	Methanol (g/mi)	Methane (mg/mi)	Form. (mg/mi)
11/10/92	F2HC0K-01	0	M85	CAMET	FTP	0.026	0.10	0.68	9.4	0.018	34	8.1
11/10/92	F2HC0K-01	0	M85	CAMET	HFET	0.005	0.01	0.47	14.6	0.005	11	0.1
11/10/92	F2HC0K-01	0	M85	CAMET	NYCC	0.064	0.02	1.47	4.7	0.061	100	3.5
11/11/92	F2HC0K-02	0	M85	CAMET	FTP	0.023	0.10	0.75	9.4	0.013	34	6.2
11/11/92	F2HC0K-02	0	M85	CAMET	HFET	0.005	0.01	0.43	14.6	0.004	10	0.8
11/11/92	F2HC0K-02	0	M85	CAMET	NYCC	0.083	0.00	1.25	4.8	0.071	103	0.0
11/12/92	F1HC0K-01	0	Howell EEE	CAMET	FTP	0.062	0.06	0.69	16.2	0.000	68	0.8
11/12/92	F1HC0K-01	0	Howell EEE	CAMET	HFET	0.009	0.00	0.35	25.6	0.000	29	0.2
11/12/92	F1HC0K-01	0	Howell EEE	CAMET	NYCC	0.041	0.00	1.41	8.1	0.000	212	0.2
11/13/92	F1HC0K-02	0	Howell EEE	CAMET	FTP	0.052	0.06	0.77	16.1	0.000	73	0.5
11/13/92	F1HC0K-02	0	Howell EEE	CAMET	HFET	0.016	0.01	0.47	27.0	0.000	28	0.1
11/13/92	F1HC0K-02	0	Howell EEE	CAMET	NYCC	0.093	0.03	1.53	6.7	0.000	221	0.0
2/9/92	F2HC2K-01	2000	M85	CAMET	FTP	0.052	0.12	0.64	9.7	0.030	33	5.9
2/9/93	F2HC2K-01	2000	M85	CAMET	HFET	0.010	0.00	0.41	14.8	0.001	8	0.6
2/9/93	F2HC2K-01	2000	M85	CAMET	NYCC	0.069	0.02	1.08	5.1	0.010	87	1.8
2/10/93	F2HC2K-02	2000	M85	CAMET	FTP	0.036	0.14	0.65	9.8	0.020	34	4.1
2/10/93	F2HC2K-02	2000	M85	CAMET	HFET	0.005	0.00	0.39	15.2	0.004	11	0.4
2/10/93	F2HC2K-02	2000	M85	CAMET	NYCC	0.031	0.01	1.21	4.9	0.020	103	1.4
5/10/93	F2HC4K-01	4000	M85	CAMET+OEM	FTP	0.039	0.12	0.66	10.1	0.026	33	5.6
5/7/93	F2HC4K-01	4000	M85	CAMET+OEM	HFET	0.001	0.06	0.34	15.6	0.000	11	0.5
5/7/93	F2HC4K-01	4000	M85	CAMET+OEM	NYCC	0.014	0.00	1.16	5.0	0.009	97	2.1
5/11/93	F2HC4K-02	4000	M85	CAMET+OEM	FTP	0.030	0.39	0.71	10.1	0.002	37	3.3
5/11/93	F1HC4K-02	4000	M85	CAMET+OEM	HFET	0.005	0.01	0.46	15.7	0.003	10	0.4
5/11/93	F2HC4K-02	4000	M85	CAMET+OEM	NYCC	0.015	0.03	1.34	4.9	0.000	293	2.9

[a]NMOG = Gasoline Derived Hydrocarbons + Methanol + Formaldehyde - Methane

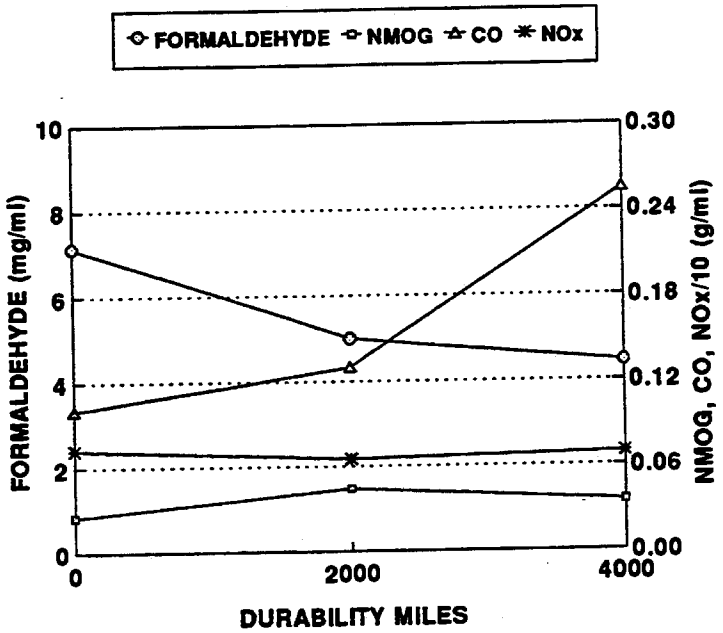

FIGURE 28. PLOT OF CROWN VICTORIA #1 FORMALDEHYDE, NMOG, CO, AND NO_x VERSUS ACCUMULATED MILEAGE

4. Crown Victoria #2

Upon arrival at SwRI in September 1992, SwRI conducted duplicate checkout emission tests on Crown Victoria #2 in the OEM configuration to verify that the baseline emission levels on the vehicle met with ARB expectations. Results of these checkout emission tests are given in Table 37. Detailed computer printouts of these emission test results are found in Appendix V. Results given in Table 37 were determined to be similar to those expected by ARB.

TABLE 37. SUMMARY OF CROWN VICTORIA #2 CHECKOUT TESTS

Date	Test No.	Fuel	Catalyst	Test Cycle	NMOG[a] (g/mi)	CO (g/mi)	NO_x (g/mi)	Fuel Economy (mi/gal)	Methanol (g/mi)	Methane (mg/mi)	Form. (mg/mi)
9/29/92	V2OEM-CK	M85	OEM	FTP	0.229	1.84	0.58	9.9	0.135	58.4	25.3
10/09/92	V2OEM-CK2	M85	OEM	FTP	0.244	1.27	0.79	10.0	0.142	56.5	22.1

[a]NMOG = Gasoline Derived Hydrocarbons + Methanol + Formaldehyde - Methane

Next, the Degussa catalyst system was installed on Crown Victoria #2 for Task 3 short-term durability testing. Duplicate FTP, HFET, and NYCC emission tests were conducted with both M85 and Howell EEE at the zero-mile point. The vehicle was then subjected to 2000 miles of AMA on-road mileage accumulation and duplicate FTP, HFET, and NYCC emission tests at the 2000-mile point using M85. Finally, Crown Victoria #2 was subjected to the final 2000 miles of AMA mileage accumulation (4000 miles total) and tested in duplicate for emissions at the 4000-mile point over the FTP, HFET, and NYCC using M85. A summary of zero-, 2000-, and 4000-mile emission test

results is given in Table 38. A summary of all aldehyde and ketone emissions is given in Appendix O. Detailed computer printouts of all Task 3 emission tests conducted on Crown Victoria #2 are found in Appendix W. A plot of average FTP formaldehyde, NMOG, carbon monoxide, and oxides of nitrogen emissions versus mileage for M85 is shown in Figure 29.

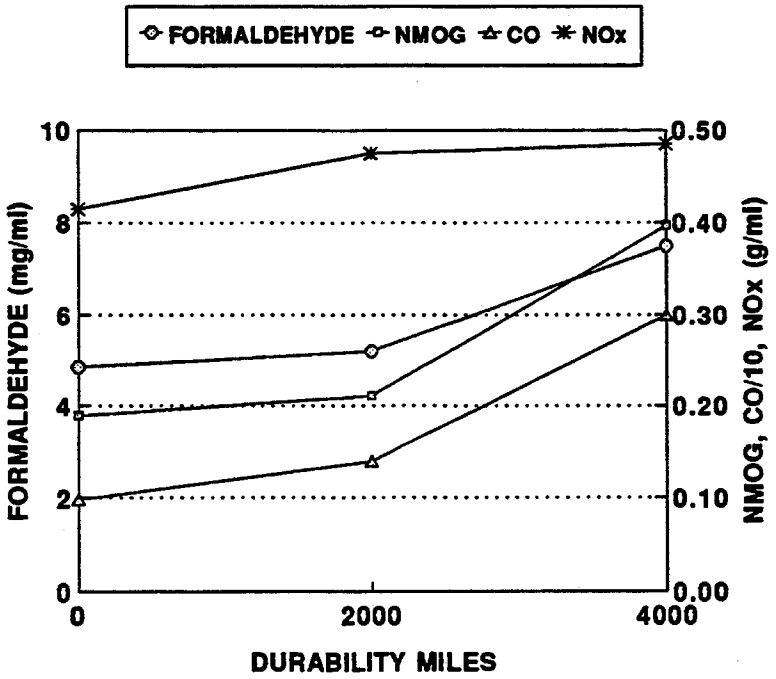

FIGURE 29. PLOT OF CROWN VICTORIA #2 FORMALDEHYDE, NMOG, CO, AND NO_X VERSUS ACCUMULATED MILEAGE

The Degussa catalyst system on Crown Victoria #2 showed a general deterioration trend throughout the 4000 miles of accumulation. Specifically, formaldehyde, NMOG, and CO emissions all increased slightly from the zero- to 2000-mile point and more rapidly from the 2000- to 4000-mile point. NO_X emissions increased slightly from the zero- to 2000-mile test points, but remained relatively stable from 2000 to 4000 miles. Average NO_X emissions were never less than 0.40 g/mile. Formaldehyde emissions only increased to roughly 8 mg/mile by the 4000-mile point.

5. VW Jetta

In September 1992, a Camet "extended durability" EHC system was permanently installed on the VW Jetta in conjunction with the Degussa catalyst for Task 3 short-term durability testing. Because the new programmable system allowed much greater flexibility in terms of controlling catalyst air injection rate/time as well as heating times/temperatures, it was decided that further optimization of emissions should be attempted. Detailed computer printouts of optimization test results are given in Appendix X. However, significant electronic complications with the Camet system created frequent intermittent failure of the Camet logic module for the EHC. Because of system

TABLE 38. SUMMARY OF TASK 3 SHORT-TERM DURABILITY TEST RESULTS FOR CROWN VICTORIA #2

Date	Test No.	Durability Mileage (mi)	Fuel	Catalyst	Test Cycle	NMOG[a] (g/mi)	CO (g/mi)	NOx (g/mi)	Fuel Economy (mi/gal)	Methanol (g/mi)	Methane (mg/mi)	Form. (mg/mi)
11/10/92	V2DC0K-01	0	M85	Degussa	FTP	0.204	1.05	0.44	10.0	0.169	23	5.8
11/10/92	V2DC0K-01	0	M85	Degussa	HFET	0.001	0.00	0.59	15.4	0.001	5	0.0
11/10/92	V2DC0K-01	0	M85	Degussa	NYCC	0.077	0.51	0.84	4.9	0.000	66	0.0
11/11/92	V2DC0K-02	0	M85	Degussa	FTP	0.173	0.91	0.39	10.1	0.152	22	3.9
11/11/92	V2DC0K-02	0	M85	Degussa	HFET	0.001	0.00	0.39	15.7	0.001	6	0.0
11/11/92	V2DC0K-02	0	M85	Degussa	NYCC	0.019	0.25	0.81	5.1	0.019	71	0.0
11/12/92	V1DC0K-01	0	Howell EEE	Degussa	FTP	0.210	1.68	0.29	19.4	0.000	47	0.3
11/12/92	V1DC0K-01	0	Howell EEE	Degussa	HFET	0.001	0.00	0.45	31.0	0.000	7	0.0
11/16/92	V1DC0K-01	0	Howell EEE	Degussa	NYCC	0.197	3.93	0.35	9.8	0.000	295	0.6
11/13/92	V1DC0K-02	0	Howell EEE	Degussa	FTP	0.184	1.41	0.26	19.4	0.000	51	0.4
11/13/92	V1DC0K-02	0	Howell EEE	Degussa	HFET	0.007	0.00	0.39	31.0	0.000	5	0.0
11/13/92	V1DC0K-02	0	Howell EEE	Degussa	NYCC	0.080	1.99	0.13	9.9	0.000	154	0.0
2/9/93	V2DC2K-01	2000	M85	Degussa	FTP	0.197	1.45	0.48	10.2	0.161	29	5.8
2/9/93	V2DC2K-01	2000	M85	Degussa	HFET	0.001	0.00	0.57	15.8	0.001	5	0.1
2/9/93	V2DC2K-01	2000	M85	Degussa	NYCC	0.184	0.06	0.91	5.6	0.016	47	0.3
2/10/93	V2DC2K-02	2000	M85	Degussa	FTP	0.224	1.33	0.47	10.2	0.194	14	4.6
2/10/93	V2DC2K-02	2000	M85	Degussa	HFET	0.015	0.00	0.52	15.9	0.002	3	0.0
2/10/93	V2DC2K-02	2000	M85	Degussa	NYCC	0.019	0.16	1.27	5.2	0.019	47	0.0
3/1/92	V2DC4K-01	4000	M85	Degussa	FTP	0.380	2.72	0.52	10.0	0.304	46	7.2
3/1/92	V2DC4K-01	4000	M85	Degussa	HFET	0.015	0.01	0.56	15,7	0.002	7	0.0
3/1/93	V2DC4K-01	4000	M85	Degussa	NYCC	0.011	1.06	0.90	5.5	0.011	137	0.0
3/2/93	V2DC4K-02	4000	M85	Degussa	FTP	0.414	3.28	0.45	10.0	0.321	46	7.8
3/2/93	V2DC4K-02	4000	M85	Degussa	HFET	0.002	0.00	0.56	15.8	0.001	5	0.0
3/2/93	V2DC4K-02	4000	M85	Degussa	NYCC	0.008	0.45	0.73	5.3	0.010	73	0.0

[a]NMOG = Gasoline Derived Hydrocarbons + Methanol + Formaldehyde - Methane

difficulties, Mr. Stan Rolf of Camet traveled to SwRI to modify the installation. Following Mr. Rolf's visit, the vehicle operated correctly and an optimized strategy for air injection and EHC control was determined. A summary of the EHC logic module parameters can be found in Appendix T.

After undergoing duplicate zero-mile FTP, HFET, and NYCC emission tests using both M85 and Howell EEE, the VW Jetta was subjected to 2000 miles of AMA on-road mileage accumulation. Immediately prior to emission testing at the 2000-mile point, the vehicle began to experience significant electronic problems. One power controller and one logic module failed. In order to diagnose and eliminate the electronic problems, Camet sent Mr. Stan Rolf to SwRI again. Mr. Rolf made several electronic changes, and the VW Jetta was able to complete all the 4000 miles of AMA mileage accumulation and required emission tests. A summary of zero-, 2000-, and 4000-mile emission test results is given in Table 39. A summary of aldehyde and ketone emissions is given in Appendix O. Detailed computer printouts of all Task 3 emission tests conducted on the VW Jetta are found in Appendix Y. A plot of average FTP formaldehyde, NMOG, carbon monoxide, and oxides of nitrogen emissions versus mileage for M85 is shown in Figure 30.

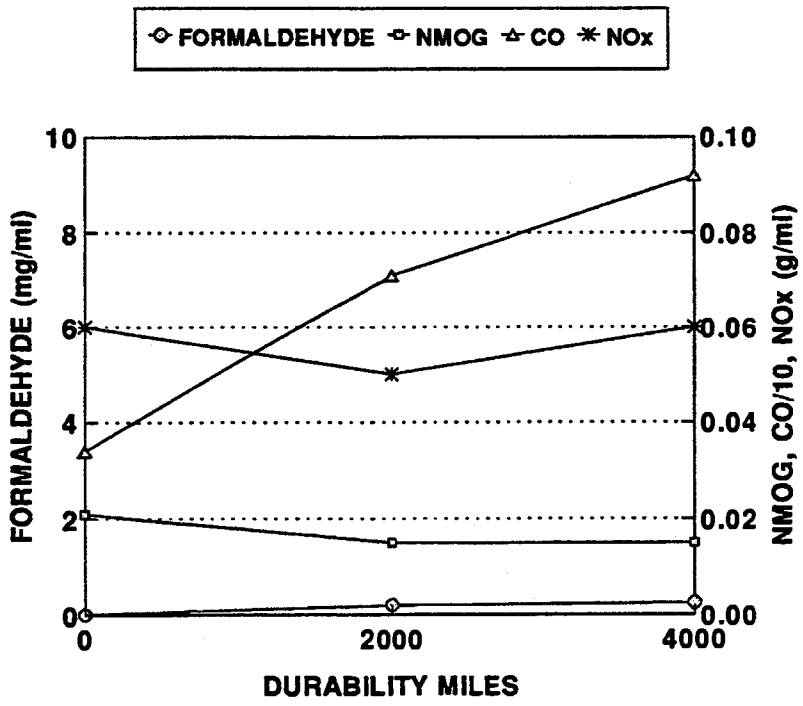

FIGURE 30. PLOT OF VW JETTA FORMALDEHYDE, NMOG, CO, AND NO_x VERSUS ACCUMULATED MILEAGE

Average FTP formaldehyde, NMOG, and NO_x emissions remained relatively constant throughout the entire 4000 miles of mileage accumulation for the Camet plus Degussa system on the VW Jetta. However, like Crown Victoria #1, CO emissions for the VW Jetta showed a continuous increase from the zero- to 4000-mile point. It should be noted that average 4000- mile FTP formaldehyde, NMOG, CO, and NOx emissions from the VW Jetta remained less than the ARB Ultra-Low Emission Vehicle standards.