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An Overview of Several EPA Misfueling Test Programs

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Abstract

A group of test programs were performed on current passenger cars to assess the rate of catalyst deterioration due to misfueling with leaded gasoline. These programs addressed both "casual" misfueling as well as intentional misfueling. Recovery of the catalyst upon return to unleaded fuel was also assessed. On the average, one tankful of leaded gasoline was found to triple hydrocarbon (HC) emissions while causing emissions of carbon monoxide (CO) to double. Continued use of leaded gasoline in vehicles designed to meet 1980 Federal Emission Standards resulted in HC and CO emissions increasing to levels which exceeded 1975 Federal Standards. Return to unleaded fuel resulted in recovery of some catalytic activity on slightly poisoned vehicles although continued use of leaded fuel resulted in a permanent loss of catalytic activity.

Background

Because there is a price differential between leaded and unleaded gasoline at the pump, there is a propensity for the consumer to consider using leaded gasoline in his catalyst equipped vehicle. This propensity is usually a result of a lack of knowledge on the part of the consumer concerning the true "costs" involved. These costs include the impact on the environment along with the fact that the perceived savings in operating costs may not actually be savings over the useful life of the vehicle.

Apart from the intentional misfueling described above, there are instances of "casual" misfueling which are a result of gasoline shortages. This type of misfueling is temporary with the consumer returning to unleaded gasoline when it becomes available.

This report presents an overview of a number of studies which were designed to address the environmental impact of fuel switching with respect to exhaust emissions. Although the operating cost impact is beyond the scope of these studies, it should be noted that the marginal savings associated with each fuel purchase is offset by increased maintenance and repair costs, e.g. decreased oil change intervals, reduced useful life of exhaust systems, and spark plug fouling with a possible adverse impact on fuel economy, etc.

The environmental impact of fuel switching addressed in these studies has been limited to the change in regulated exhaust emissions as determined by the 1975 Federal Test Procedure (without evaporative emission test). The emissions of interest are unburned hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NOx). No attempt has been made to assess the increase in elemental lead in the environment due to increased use of leaded gasoline although this may also result in costs to society.

A recent study performed for the National Commission on Air Quality (Reference 1)* indicated that price differential may not be the only motivation behind misfueling. Other reasons cited were better engine performance and better gas mileage. Motivation notwithstanding, the fact remains that misfueling is occurring (1,2).

Purpose

The purpose of these test programs was to obtain information that could be used to adjust the Emission Factor data base. These correction factors would be needed to calculate the impact on air quality for a given area in the event that a misfueling rate could be established. Additional tests were performed on the vehicles in support of Inspection/ Maintenance issues. The purpose of conducting the additional short cycle tests was to obtain data that could be used to assess the effectiveness of I/M tests in identifying misfueled vehicles.

*Numbers in parentheses refer to references at end of paper.

Test Program Design

A number of programs were designed to assess two types of misfueling. These two types are intentional misfueling and casual misfueling. The first type addresses the individual who decided to switch to leaded fuel on a regular basis. This individual would have modified the tank filler neck restrictor to allow the use of leaded nozzles. The second type addresses those vehicles which used leaded fuel only on an emergency basis. This would address those instances where unleaded gasoline was temporarily unavailable. A summary of these programs is presented in Table 1.

To obtain information on intentional misfueling, two test programs were implemented. One program, performed by the California Air Resources Board (CARB) under EPA contract, consisted of controlled mileage accumulation by professional drivers over a pre-determined course utilizing a controlled fuel source. A complete description of the program is provided as Attachment A. While this program provided data concerning deterioration rates for a given set of conditions, it was realized that consumer-operated vehicles may experience different deterioration rates due to a random mileage accumulation and the random lead content of in-use gasolines. Therefore, a second program was developed to address this problem. This project was performed by Automotive Testing Laboratories, Inc. (ATL) under another EPA contract. The test vehicles in this program were part of the "loan vehicle" fleet that was used in Emission Factor testing at ATL's test facility in St. Louis. Individuals who brought their personal vehicles to the ATL facility to participate in the Emission Factors program received a loan vehicle for their use while their vehicle was being tested. Each participant drove the loan vehicle for a period of approximately one week. Therefore, each vehicle received random mileage accumulation due to the driving patterns of the different drivers. The lead content of the fuel in this program varied somewhat because the fuel was a mixture of the in-use fuel drained from the non-catalyst vehicles prior to testing in the Emission Factors program. This project is described in Attachment B.

The two programs described above provided information on intentional misfueling. It was assumed that the vehicles would experience emission control deterioration. It was the rate and magnitude which was to be quantified. In the case of casual misfueling, these two factors were of interest along with the question of possible rejuvenation of catalytic activity due to a return to unleaded fuel.

Two test programs were performed to assess casual misfueling. One program was performed by the California Air Resources Board under EPA contract in conjunction with the program mentioned previously. This program involved mileage accumulation on one tankful of leaded gasoline. The vehicles were subsequently operated on unleaded fuel until HC emissions returned to within approximately 10% of the original baseline value. The details of this project are contained in Attachment C. The second program was performed by the EPA at its Motor Vehicle Emission Laboratory in Ann Arbor, MI. This program was substantially the same as the CARB test program. However, the vehicles were operated on a second tankful of leaded fuel after the first rejuvenation sequence was completed. This secondary poisoning was then followed by a second rejuvenation series as described in Attachment D. Since some of the catalyst activity returned after these rejuvenation sequences, an attempt was made to rejuvenate the grossly poisoned vehicles at the ATL test facility in St. Louis.

Table 1

Significant Elements of Test Programs

Organization	Test Dates	Type of Program	Number of Vehicles	Types of Control Systems	Lead Level	Type of Mileage Accumulation	Test Cycles Performed
Calif. Air Resources Board	July 1979 to October 1979	Casual poisoning/ recovery	5	5 Oxidation Catalysts	2.50 gm/gal.	controlled	1975 FTP, HFET
EPA in-house test program	July 1979 to September 1979	Casual poisoning/ recovery	5	5 Oxidation Catalysts	3.09 gm/gal.	controlled	1975 FTP, HFET 3-speed idle, Loaded 2-mode
Calif. Air Resources Board	July 1979 to October 1979	Intentional poisoning	10	4 Oxidation Catalysts 6 Three-Way Catalysts	2.50 gm/gal.	controlled	1975 FTP, HFET Hot 72 FTP. Federal 3-mode, Loaded 2-mode Two speed idle
Automotive Testing Labs. (St. Louis, Mo.)	May 1979 to December 1979	Intentional poisoning	7	4 Oxidation Catalysts 3 Three-Way Catalysts	random 0.43-1.49 gm/gal.	random	1975 FTP, HFET Federal Short Cycle, Federal 3-mode, Two Speed Idle, Raw Exhaust before and after catalyst at idle and 50 mph.
Automotive Testing Labs. (TRC, OH)	January 1980 to June 1980	Recovery	7	4 Oxidation Catalysts 3 Three-Way Catalysts	unleaded	random	1975 FTP, HFET Federal 3-mode, Two Speed Idle, Raw Exhaust before and

All four of the programs described above employed vehicles which were tuned to manufacturer's specifications. Each vehicle underwent a functional check of all emission-related components to assure that the systems were operating correctly. The programs were also designed to assure that all of the vehicles returned to proper emission control before being returned to their owners. This was accomplished by rejuvenation where confirmed by testing and by catalyst replacement where they had been permanently damaged. The vehicles were operated on unleaded gasoline for a period of time prior to installation of the new catalyst to assure that lead residue was purged and thereby reduce the likelihood of future degradation of the emission control system.

Discussion of Results

The data generated from the various test program taken as a whole indicate a substantial increase in emissions after only one tankful. When compared to the baseline values, the 27 vehicles exhibited a mean increase for HC of 193% while for CO the increase was 111% (see Appendix E). The data obtained concerning intentional misfueling (3,4) revealed that the emission levels rose rapidly for the first tank of fuel and then increased to approach "engine-out" emissions with continued use of leaded fuel (Figures 1 and 2). Recovery of catalytic activity upon return to use of unleaded fuel was observed in some cases (4,5). The CO emissions of casually poisoned vehicles approached the original baseline values after a few tankfuls of unleaded gasoline. However, hydrocarbon emissions remained approximately 10% above the baseline values even after continued use of unleaded gas. In general, it was observed that the greater the amount of leaded fuel consumed, the greater the emission increase and the lower the likelihood of recovery due to subsequent return to proper fuel. The catalytic activity with respect to HC conversion was the most affected by the lead poisoning. Oxidation of CO continued but at a lower efficiency.

EFFECT OF FUEL SWITCHING ON EXHAUST EMISSIONS

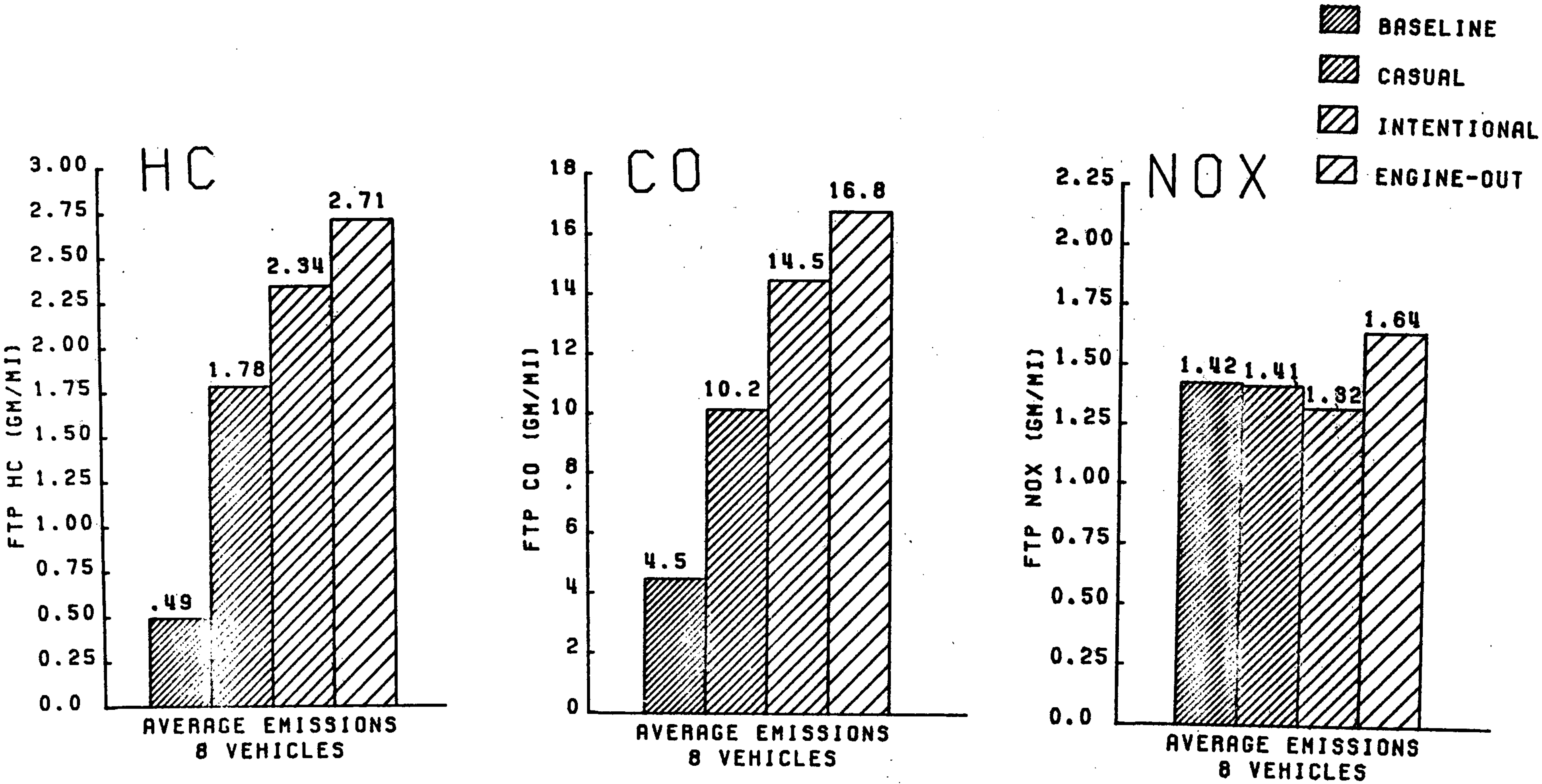

Figure 1: Average Emission Levels of Misfueled Vehicles Equipped with Oxidation Catalysts

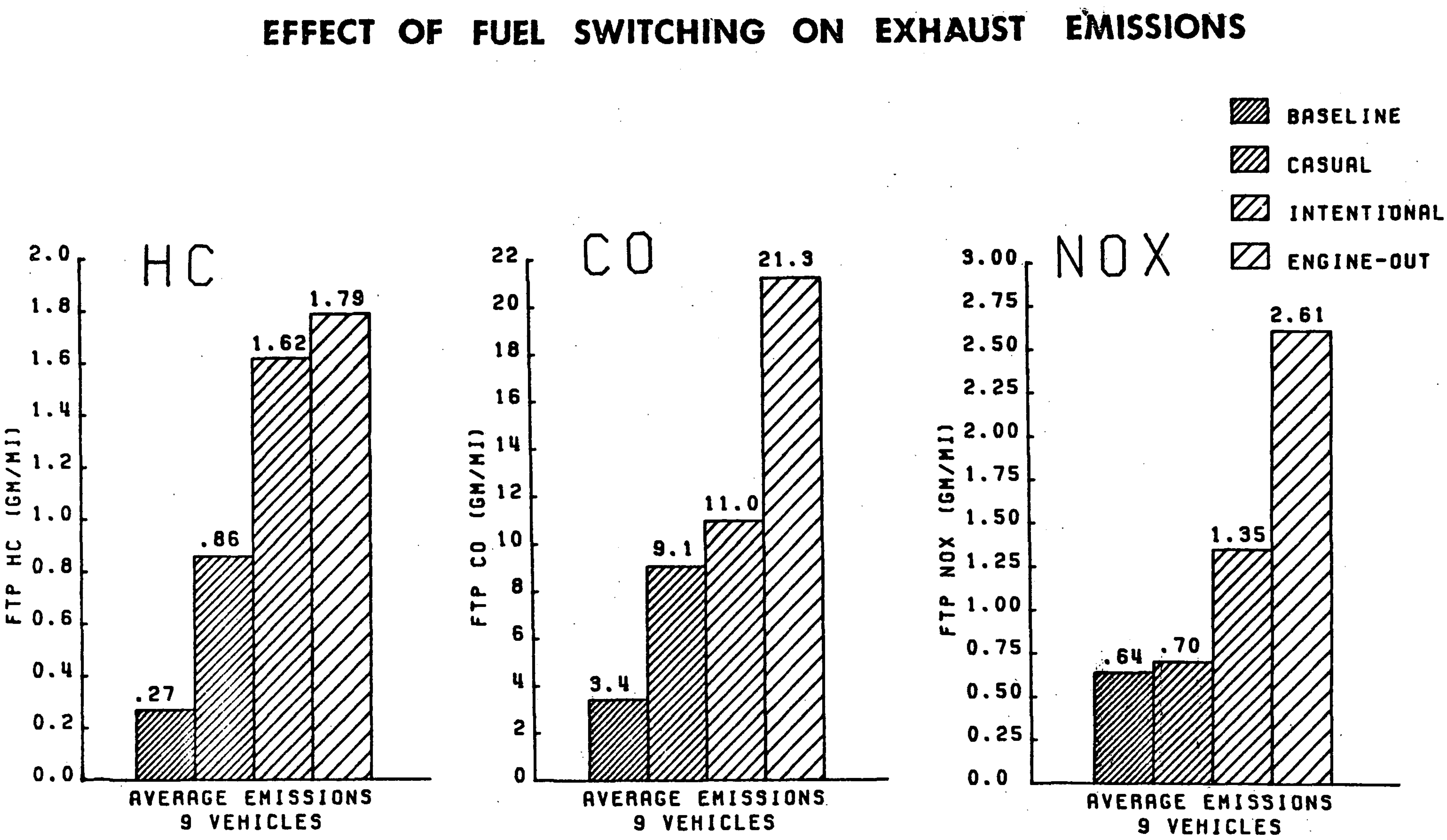

Figure 2: Average Emission Levels of Misfueled Vehicles Equipped with 3-Way Catalysts

While the thrust of these test programs concerned the effect on HC and CO emissions, the effect on NOx control was also investigated. Nine of the vehicles tested were equipped with three-way catalyst systems. Two or three tankfuls of leaded gas were needed to realize an increase in NOx emissions rather than just one tankful of fuel. Poisoning rate notwithstanding, these catalysts also exhibited degeneration of emission control due to misfueling. The end result of misfueling is the destruction of catalytic activity with the emission levels eventually approaching "engine out" values. Figure 2 describes the rise in emission levels of these vehicles. The vehicles represented in this figure were designed to meet 1978 California Emission Standards (.41 gm/mi HC/9.0 gm/mi CO/1.5 gm/mi NOx). For the purpose of these tests programs, it was assumed that the same type of systems would be employed to meet 1980 Federal Standards (.41 gm/mi HC/7.0 gm/mi CO/2.0 gm/mi NOx). The "engine-out" emissions were obtained by replacing the catalyst with a pipe equipped with baffles designed to simulate the backpressure caused by the catalyst.

The test programs were designed to assess HC increases with the testing continuing until 90% of the "engine-out" values of HC were reached. The emission levels of CO and NOx increased during the test program although they did not increase as rapidly as the HC levels. The programs were restricted by budget constraints and the ultimate poisoning of the converter with respect to CO and NOx was never fully achieved. However, the "engine-out" values could be considered estimates of this total poisoning. It is reasonable to conclude that continued use of leaded fuel in a vehicle designed to meet 1980 Federal Emission Standards will result in a regression in emission control to a level somewhat greater than 1975 Emission Control levels.

The three-way catalyst systems employed an oxygen sensor to allow control of the air/fuel ratio. From these test programs, it appears that the sensor is also affected by the use of leaded gasoline (Figure 3). A poisoned oxygen sensor tends to cause the air/fuel ratio to drift towards a rich setting (6). The more the sensor is poisoned, the greater the shift towards a rich mixture. Therefore, not only will the catalyst lose its ability to control the emissions of HC and CO, but the amount of excess HC and CO reaching the catalyst will increase.

EFFECT OF MISFUELING ON OXYGEN SENSOR PERFORMANCE

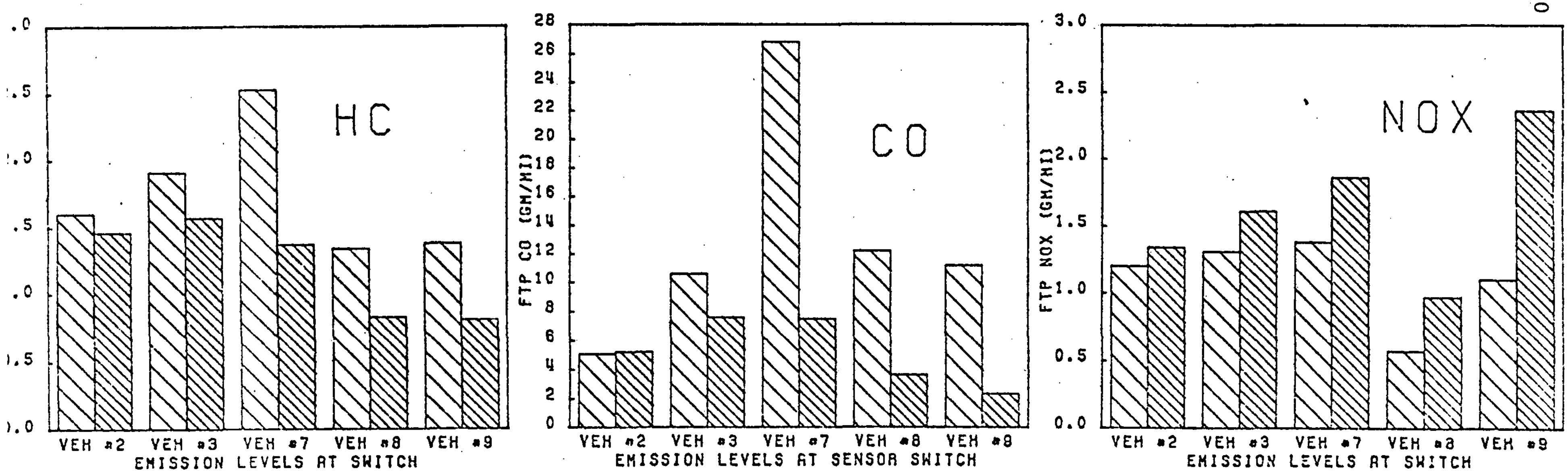

Figure 3: Emission Levels of Oxygen Sensor Equipped Vehicles
(Five vehicles-CARB test program)

Because of the almost instantaneous rise in emissions upon introduction of leaded fuel it was felt that a fuel effect may be present. This was assessed by performing emissions tests on both fuels at approximately the same mileage points. Some tests were performed with the catalyst in place. Others were performed with the catalysts replaced with a bypass pipe (Table 3). Analysis of this data (Table 4) reveals a fluctuation of emission levels. However, the magnitude of this fluctuation reflects test variability (approximately 5%). It does not reflect the major shift associated with poisoning (200% increase after one tankful). Therefore, the rapid rise in emissions can be attributed to poisoning.

Table 3

Assessment of Fuel Effect on Emission Control

(gm/mi Determined by 1975 FTP)

	Leaded				Unleaded				
Vehicle	Odom.	HC	CO	NOx	Odom.	HC	CO	NOx	Comment
9401	11831	2.85	22.51	1.28	11909	2.93	9.35	1.29	At switch [1]
9402	11841	3.04	12.98	1.68	11946	3.24	6.26	1.57	At switch
9403	9922	1.61	6.92	1.59	9943	1.68	8.77	1.44	At switch
9404	10134	2.06	15.29	0.97	10199	2.09	13.38	0.86	At switch
9405	7184	2.99	36.42	1.87	7241	2.83	35.07	1.66	Bypass [2]
	7213	2.82	32.97	1.87	7269	2.82	32.16	1.83	Bypass
9406	8220	1.54	19.18	3.05	8280	1.55	20.01	3.70	Bypass
	8250	1.51	20.69	3.75	8309	1.52	20.24	3.71	Bypass
9407	8006	1.55	14.52	2.89	8062	1.79	18.26	2.65	Bypass
	8034	1.52	14.36	2.85	8090	1.76	16.47	2.67	Bypass

Notes: 1. "At switch" indicates tests with both fuels with no appreciable mileage accumulation between tests to provide rejuvenation.

2. "Bypass" indicates "engine-out" emissions due to removal of catalyst from exhaust system.

Table 4

Percent Change in Emissions Due to Fuel Effect

Vehicle	HC	CO	NOx
9401	2.8	-58.4	0.8
9402	6.6	-51.7	-6.5
9403	4.3	26.7	-9.4
9404	1.4	-12.5	-11.3
9405	-5.4	-3.7	-11.2
	0.0	-2.5	2.1
9406	0.6	4.3	21.3
	0.7	-2.2	-1.1
9407	15.5	25.7	-8.3
	15.8	14.7	-6.3
Mean	4.23	-5.96	-2.99
Std. Dev.	6.77	28.9	9.79

$$\text{Percent Change} = \frac{\text{Leaded Value} - \text{Unleaded Value}}{\text{Leaded Value}} \times 100$$

The various short cycle tests that were performed in conjunction with the 1975 FTP have not yet been analyzed. The tests that were performed varied from program to program because the level of interest in any given short cycle varied during the period of time that these test programs were performed. The data from these tests are available in the individual reports.

Exhaust pipe skin temperatures before and after the catalyst were measured in the CARB test programs. The intent of this measurement was to assess the ability to predict catalyst efficiency by measuring the temperature rise (or lack of rise) across the catalyst. This assumes that an active catalyst would generate heat (temperature rise) while an inactive catalyst would radiate heat (temperature drop). Preliminary analysis revealed substantial data scatter with no trends immediately evident. Since the basic theory appears sound, the scatter is probably due to the measurement techniques.

Conclusion

The use of leaded fuel in catalyst equipped vehicles results in increased emissions. This increase is primarily due to the poisoning of catalytic material. Three-way catalyst systems experience an additional increase due to the poisoning of the oxygen sensor. A casually poisoned vehicle will recover some of its activity. However, the stabilized emission levels of these vehicles will be above the original baseline. The amount of activity lost is directly related to the amount of leaded fuel used. Continued use of leaded fuel results in emissions approaching engine-out values with no recovery evident.

References:

1. "Fuel Switching Analysis", Draft Final Report on Task No. 2 to The Mobile Source Emission Analysis Contract for the National Commission on Air Quality, prepared by Energy and Environmental Analysis, Inc.

2. Thomas C. Austin and Mary Eichbauer, "Vehicle Misfueling in California During 1979", SAE 800397, February 1980

3. "A Study of the Effects of Fuel Switching on Catalyst Equipped Vehicles", Final Report on Tasks #4 and #7 to EPA Contract #68-03-2693, Automotive Testing Laboratories, Inc., August 1980.

4. "Catalyst Poisoning and Catalyst Recovery Due to Misfueling", Final Report on Tasks #2 and #3 to EPA Contract #68-03-2783, California Air Resources Board, October 1979.

5. James Long, "Casual Misfueling of Catalyst Equipped Vehicles", Report No. EPA-AA-TAEB-80-1, U.S. Environmental Protection Agency, October 1979.

6. H. U. Gruber and H. M. Wiedenmann, "Three Years Field Experience with the Lambda-Sensor in Automotive Control Systems, SAE 800017, February 1980.

Attachment A
Test Program Description
Contract No. 68-03-2783, Task No. 2
Catalyst Poisoning and Catalyst Recovery Due to Misfueling

This test program was performed by the California Air Resources Board at the Haagen-Smit Laboratory in El Monte, CA. during the period from July 15, 1979 to October 28, 1979. The intent of the program was to assess the rate of catalyst deterioration due to continual misfueling of the test vehicles. The gasoline used for this program contained 2.5 gms/gal. of lead. The vehicle fleet for this program is described below:

Test Vehicle No.	Description	CID	Odometer
1	1979 Camaro	305	3544
2	1978 Pinto	140	20109
3	1978 Pinto	140	16203
4	1979 Granada	250	10414
5	1979 Futura	302	20041
6	1979 Camaro	350	3078
7	1979 Malibu	231	1275
8	1979 Sunbird	151	4667
9	1977 Volvo 242 DL	130	26855
10	1977 Volvo 242 DL	130	11982

The vehicles utilized in this program reflected the different types of catalyst systems available at the time of the program. This selection allowed an assessment of the impact of misfueling on the present in-use fleet of consumer-owned vehicles as well as a projection of impact on future fleets with three-way catalyst systems in the vehicle mix. Following is a description of the catalysts and associated exhaust emission control systems on the ten test vehicles:

Vehicle #	Catalyst Type*	Other Emission Control Systems**
1	OC-Pellet #6498369	AIR-EGR-EFE
2	TWC-Monolithic #D8EE-5E212-HA	AIR-EGR-OS
3	TWC-Monolithic #D8EE-5E212-HA	AIR-EGR-OS

4	OC-Monolithic #D7BE-6E212-LA	AIR-EGR
5	OC-Monolithic #D9BE-5E212-JA	AIR-EGR
6	OC-Pellet #6498369	AIR-EGR
7	TWC-Pellet #6498369	EGR-EFE-OS
8	TWC-Pellet #8998673	EFR-EFE-OS
9	TWC-Monolithic #1219798	FI-OS
10	TWC-Monolithic #1219798	FI-OS

*OC- Oxidation Catalyst
TWC- Three-Way Catalyst

** EFE- Early Fuel Evaporation
AIR- Air Injection Reaction
EGR- Exhaust Gas Recirculation
OS- Oxygen Sensor
FI- Fuel Injection

These ten late model vehicles were procured and tested first in the "as is" condition (screening test) to see whether they were acceptable, based on their emission characteristics (high emitter) and mechanical condition (leakage in the exhaust system), for the test program. They were then equipped with new catalysts; reconditioned for 500 miles on unleaded fuel and tested on unleaded fuel. After completion of these baseline tests, the vehicles were operated on leaded fuel and tested at about 200 mile intervals until the catalyst efficiency dropped to 25% of the baseline values.

The baseline catalyst efficiency of the fleet vehicles was based on the results of the 1975 FTP used as a screening test. The subsequent catalyst efficiency of the individual vehicle was calculated from the results of the "High Cruise" mode of the Federal Three-mode test.

Final tests were performed with unleaded gasoline to compare with the initial baseline test data. After the accumulation of 200 miles of operation on unleaded gasoline to minimize the possible "residue" effect of "lead coating" on the engine parts of the test vehicles, the poisoned catalysts were replaced with the original catalysts.

The exhaust emissions of the vehicles were measured over a variety of driving cycles. The 1975 FTP was performed to compare the emissions to the applicable standards. A number of short-cycles were performed to provide data on the feasibility of using these cycles to identify failed catalysts in Inspection/ Maintenance situations. The following sequence details the overall test plan.

1. Receive vehicle.

2. Check and adjust to OEM specifications.

3. If test data are acceptable replace OEM catalyst with new catalyst and precondition the new catalyst with a 500 mile driving schedule consisting of 45%/55% Highway/City driving miles. Then install probes and measure exhaust pipe temperatures and raw exhaust emissions upstream and downstream of catalyst.

4. Run one 1975 FTP and one Short Cycle Test Sequence (SCTS) to establish baseline tailpipe exhaust emissions.

5. Replace new catalyst with a bypass pipe which reproduces the backpressure characteristics.

6. Run one 1975 FTP and one SCTS to establish baseline engine exhaust emissions.

7. Replace bypass with new catalyst.

8. Start the poisoning procedure by fueling with leaded gasoline and running one 1975 FTP and one SCTS at approximately 200 mile intervals until catalyst efficiency (based on the high cruise mode of the Federal 3-mode test) has deteriorated to 25% of the baseline value. For vehicles equipped with three-way catalyst, oxygen sensors are to be checked and serviced/replaced as needed.

9. Start fueling with unleaded gasoline.

10. Run one reassessment 1975 FTP test.

11. Replace oxygen sensor with new one and run one 1975 FTP test. If vehicle is not equipped with oxygen sensors, go to step 12.

12. Remove poisoned catalyst.

13. Install bypass and accumulate 200 miles to minimize the effect on emissions of lead residue on engine parts.

14. Run one 1975 FTP and one SCTS test as a final test for baseline engine exhaust emissions.

15. Replace bypass with OEM catalyst, remove temperature probes and restore to original condition.

16. Run one final 1975 FTP test to ensure that vehicle meets exhaust emissions standards.

17. Do necessary repair if needed.

18. Release vehicles or repeat steps 16 through 17 if necessary.

Mileage accumulation was performed by laboratory technicians. The vehicles were driven on freeways and city streets near the Haagen-Smit laboratory. A ratio of 45%/55% Highway/City operation was maintained.

The following figures present the catalyst deterioration of the ten vehicles as a percent increase from baseline values. The emission values have been normlized with respect to baseline to allow the display of the various emissions on one graph.

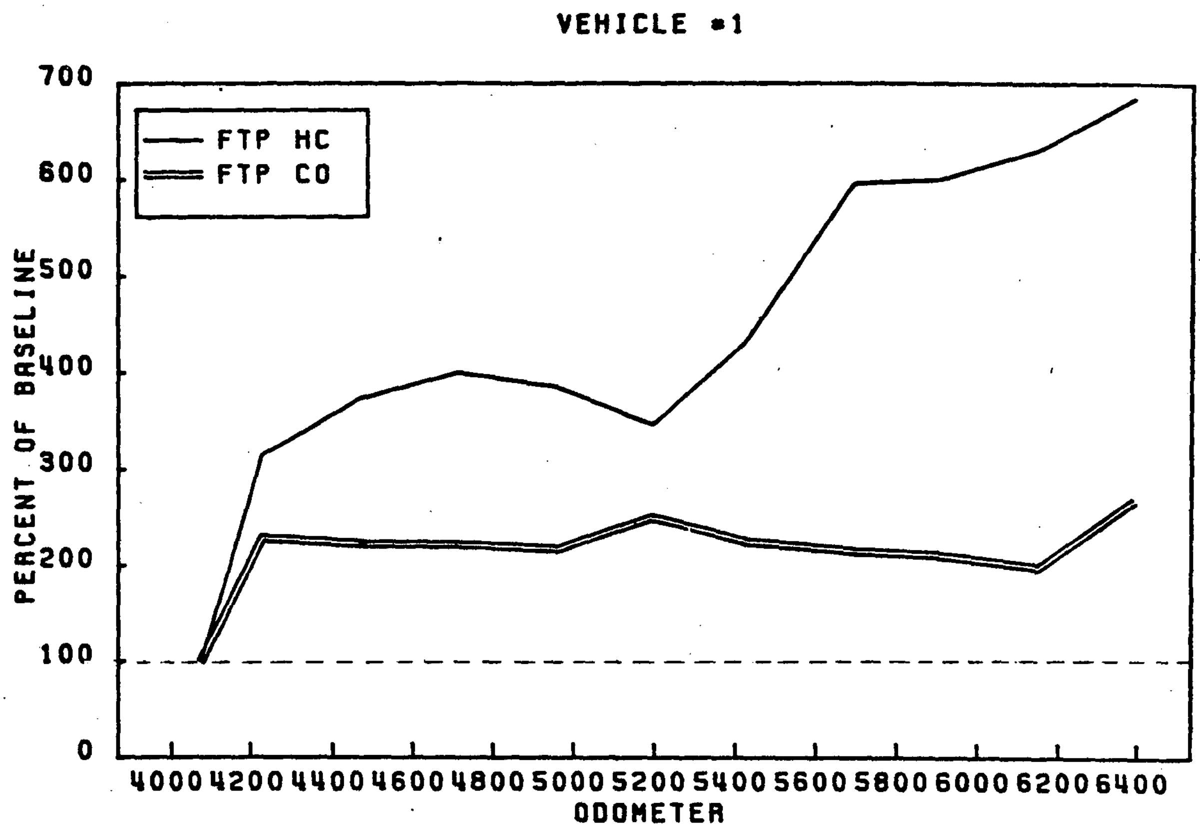

FIGURE A-1: CATALYST DETERIORATION

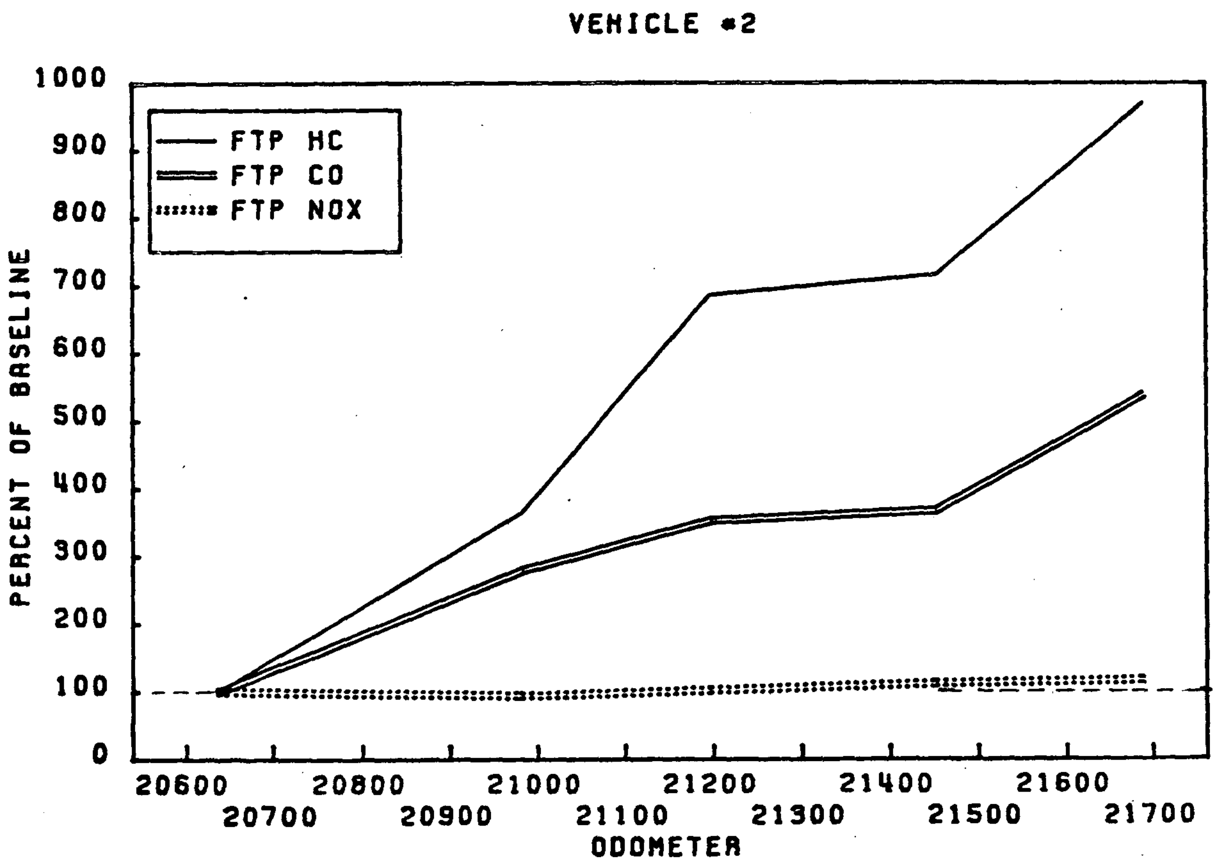

FIGURE A-2: CATALYST DETERIORATION

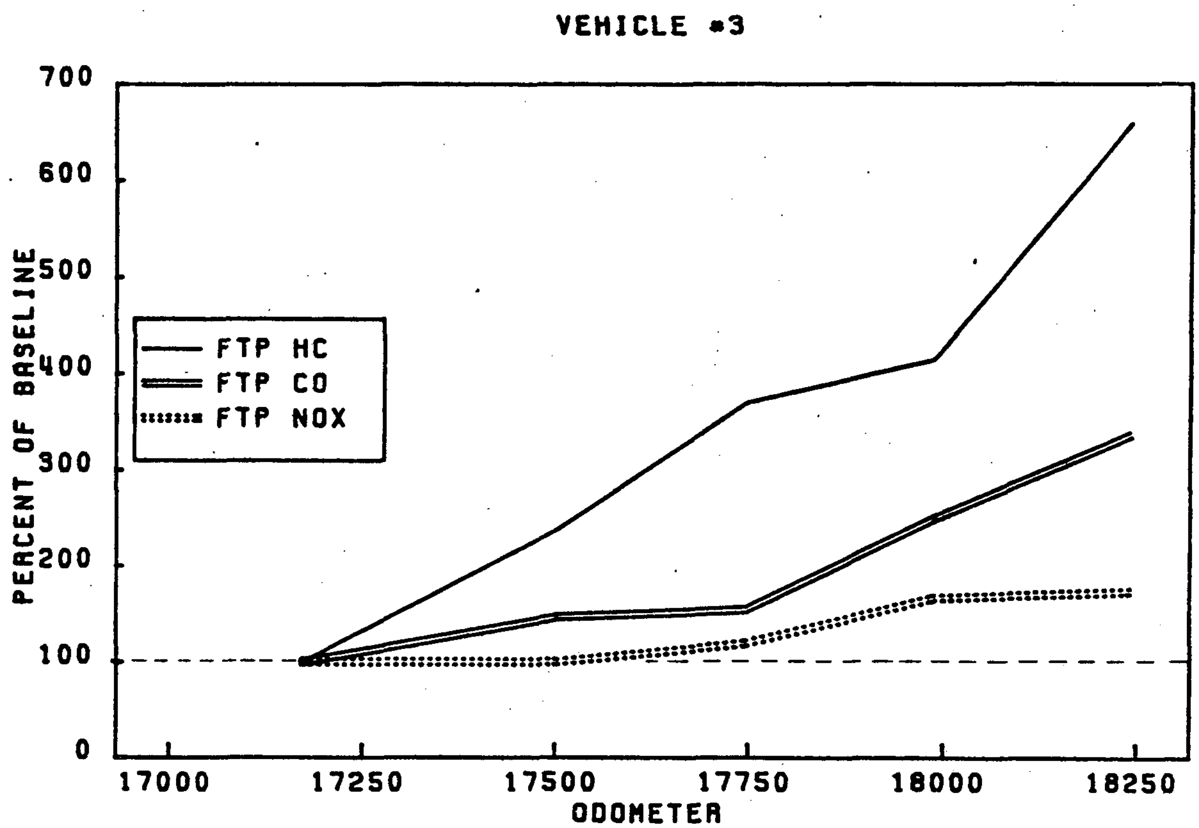

FIGURE A-3: CATALYST DETERIORATION

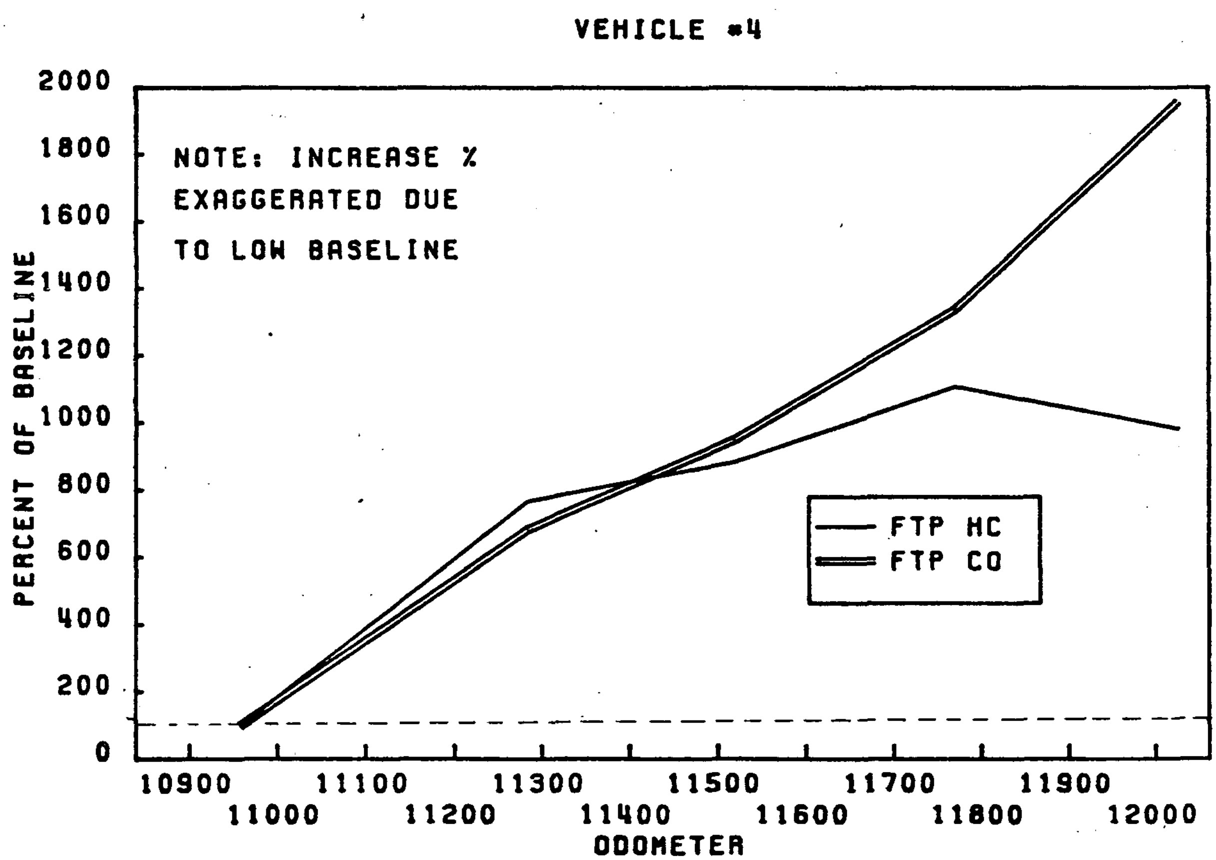

FIGURE A-4: CATALYST DETERIORATION

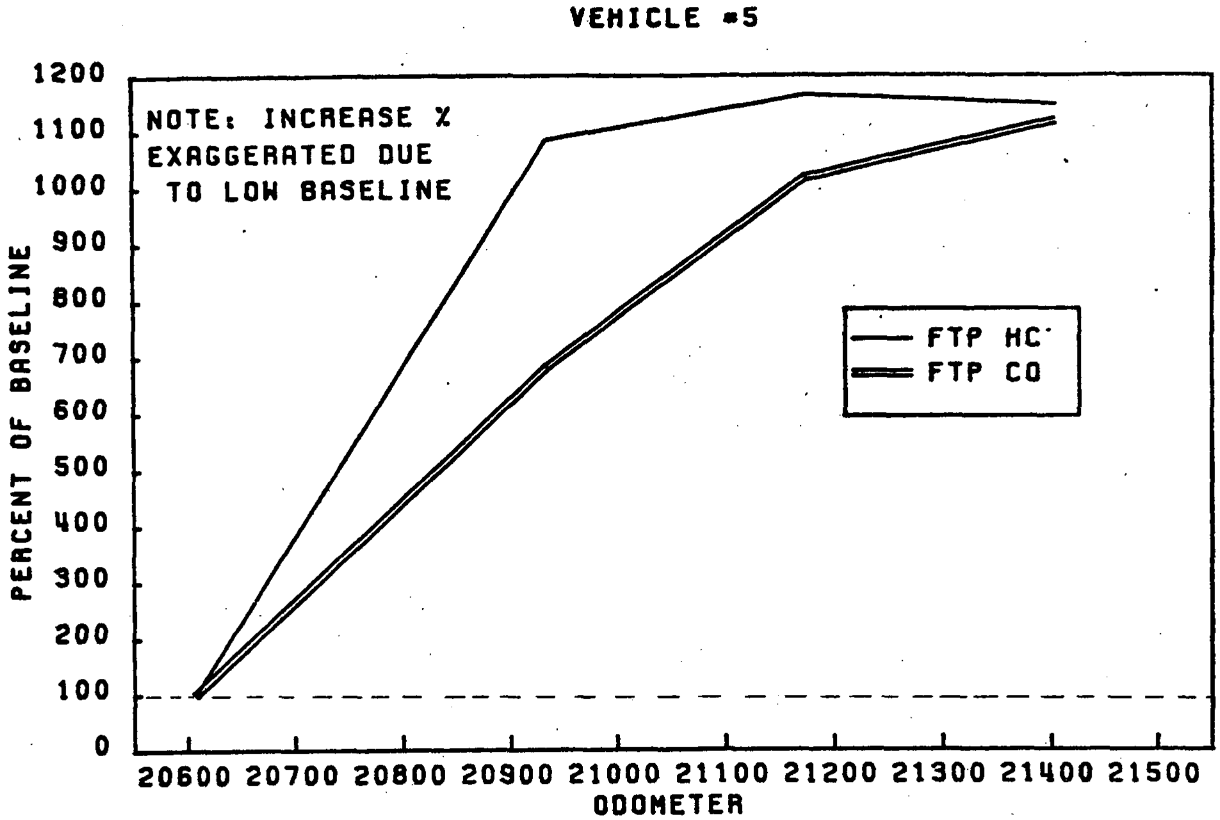

FIGURE A-5: CATALYST DETERIORATION

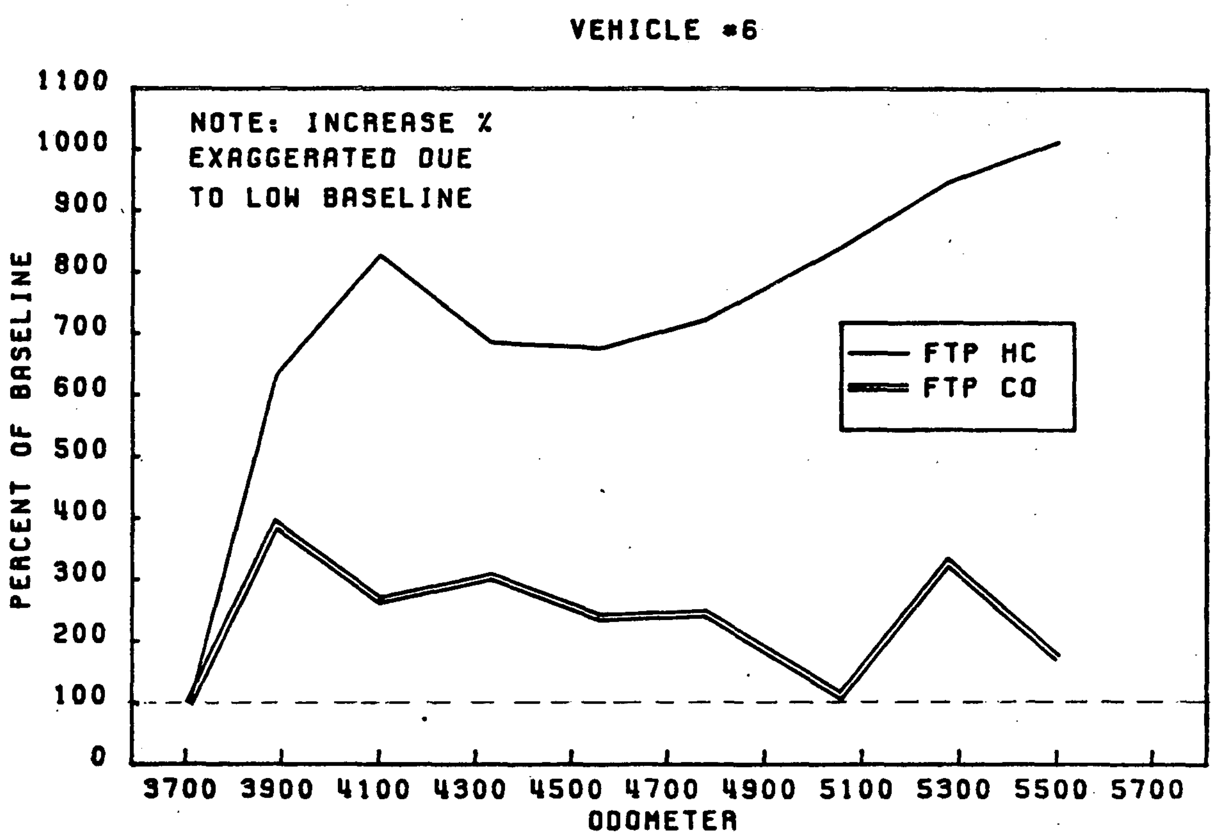

FIGURE A-6: CATALYST DETERIORATION

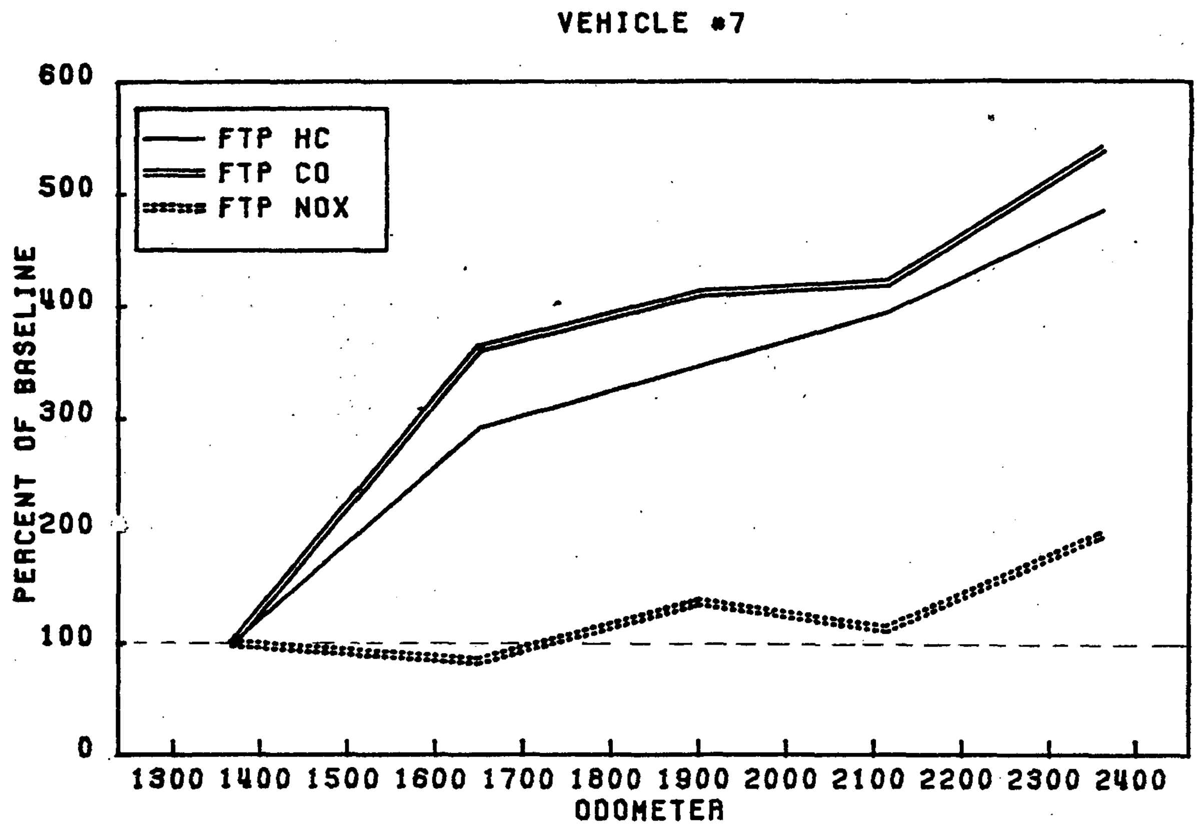

FIGURE A-7: CATALYST DETERIORATION

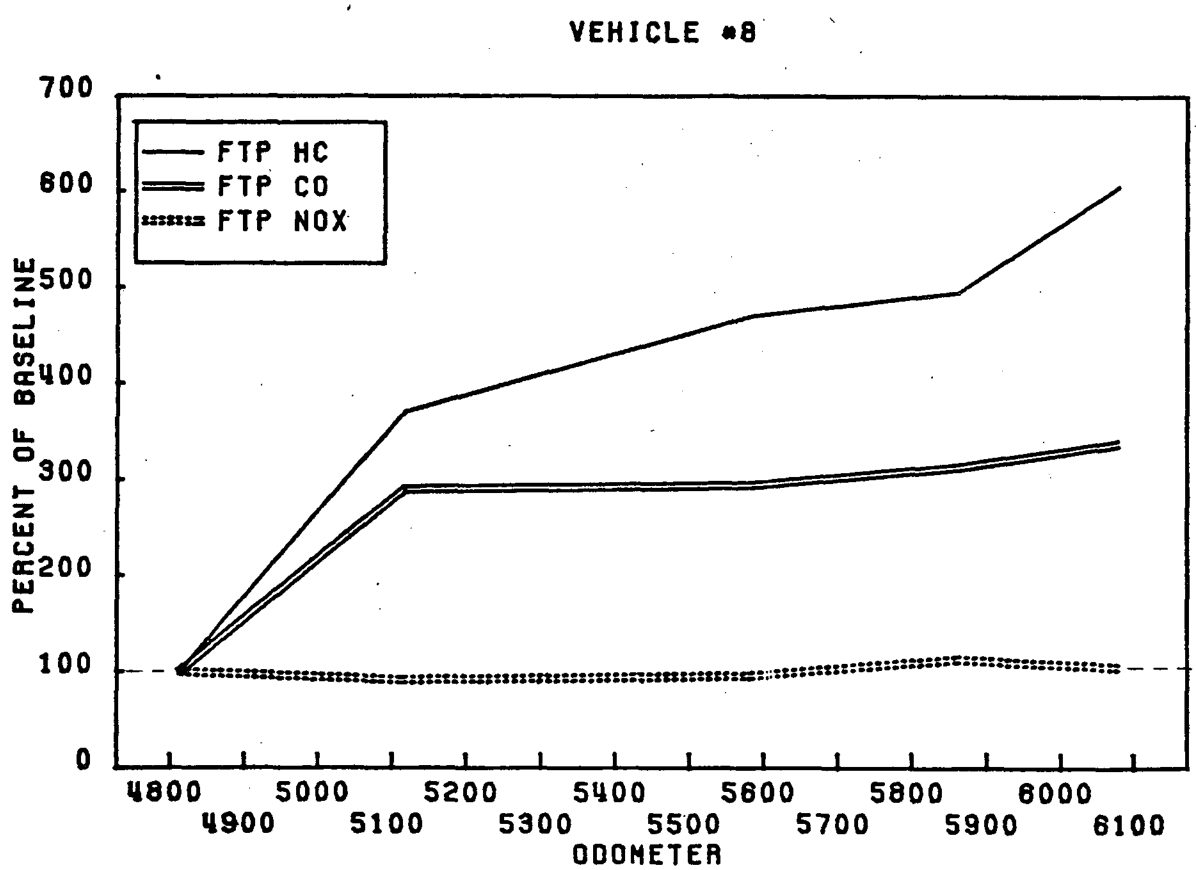

FIGURE A-8: CATALYST DETERIORATION

VEHICLE #9

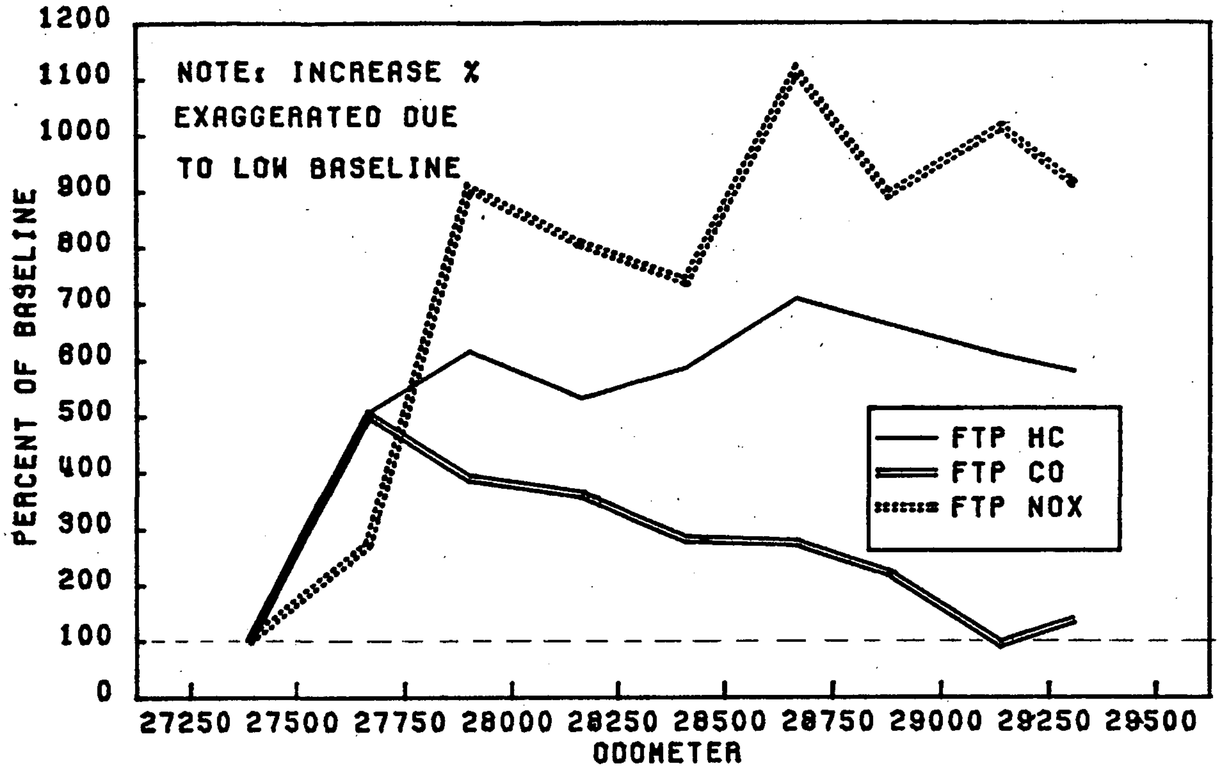

FIGURE A-9: CATALYST DETERIORATION

VEHICLE #10

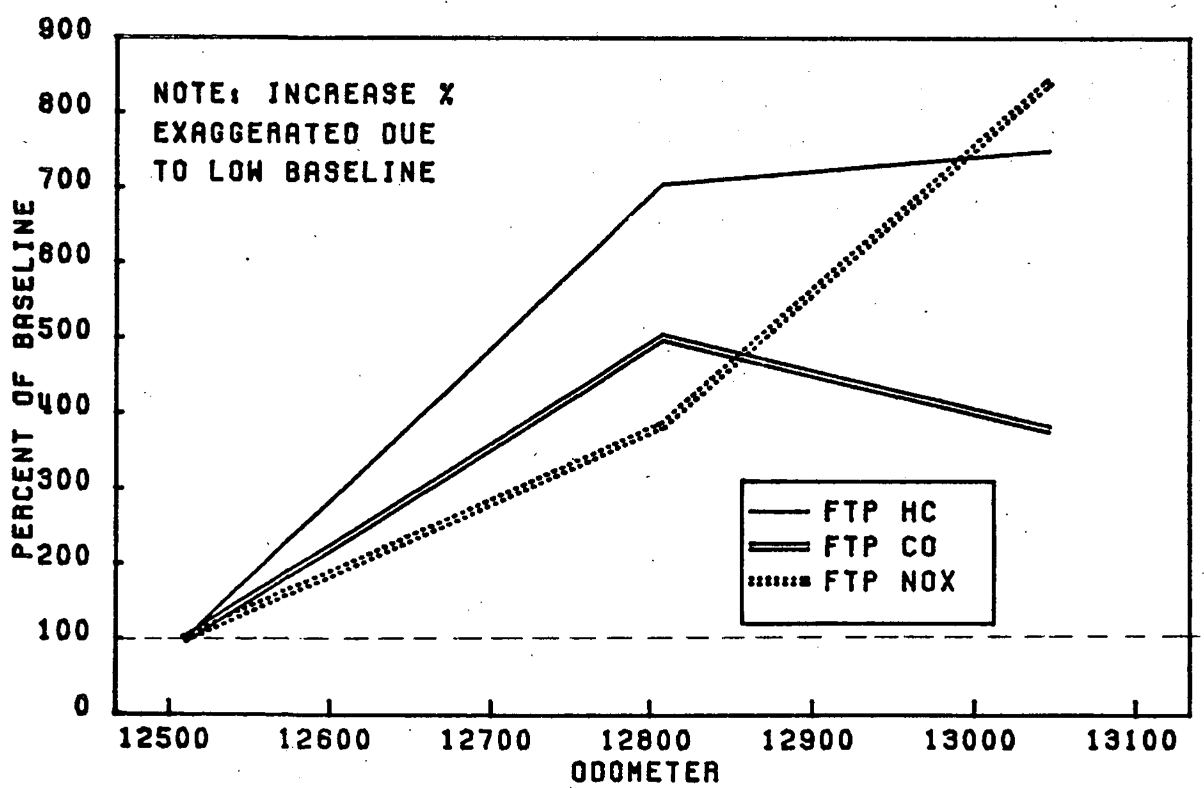

FIGURE A-10: CATALYST DETERIORATION

Attachment B

Test Program Description

Contract No. 68-03-2693 Task No. 4 and Task No. 7

A Study of the Effects of Fuel Switching on Catalyst Equippped Vehicles

This test program was performed by Automotive Testing Laboratories. The initial catalyst deterioration work was performed at their St. Louis facility while the recovery attempt was performed at their laboratory in E. Liberty, OH.

Testing was performed on a sample of seven 1979 catalyst-equipped vehicles as described below. These vehicles were selected from the loan vehicle fleet utilized in an ongoing Emission Factor Program in St. Louis. Each vehicle had accumulated between 4,000 and 10,000 miles at the beginning of the project.

Table 1

Veh. #	Make	Model	CID	Catalyst	Odometer
9401	Ford	Thunderbird	302	Oxidation	8316
9402	Ford	Thunderbird	302	Oxidation	9287
9403	Oldsmobile	Cutlass	260	Oxidation	6818
9404	Oldsmobile	Cutlass	260	Oxidation	7283
9405	Mercury	Marquis	351	Three-way	4179
9406	Volvo	245DL	130	Three-way	5795
9407	Chevrolet	Monza	151	Three-way	5182

Upon arrival at the laboratory, each vehicle was examined to ensure that no extensive modifications had been performed and that the vehicle was safe to operate. Following a brief driveability evaluation, the vehicles were placed in soak for a period between 12 and 24 hours.

An underhood inspection was performed prior to the initial as-received tests. During this examination each vehicle was inspected for modifications to the emission control system and maladjustments to basic engine parameters. Disabled and maladjusted components were identified and repaired at this time. The performance of each component within the emission control system was also evaluated according to procedures specified by the manufacturer. Those components found to be malfunctioning were immediately corrected or replaced. Additionally, routine tune-up actions were performed, which included spark plug replacement, oil change, oil and air filter and PCV valve replacement. All vehicles were tuned to manufacturer's specifications.

Each vehicle then received three test sequences conducted to determine the as-received level of emissions and three test sequences with the catalyst replaced with a bypass pipe that simulated the back pressure of the catalyst. This latter series of tests determined the emission levels of the vehicle with a totally ineffective catalyst.

A specific test sequence was performed without modification at designated intervals during the St. Louis phase of the program. The test sequence consisted of a driveability evaluation, engine status and propane enrichment measurements, a 12 to 24 hour soak, a 1975 Federal Test Procedure (without evaporative test), a Federal Short Cycle Test, a Federal Three-Mode Test, and a Two Speed Idle Test. In addition to these standard tests, the concentrations of HC and CO in the undiluted exhaust were measured before and after the catalyst at idle and at 50 mph.

A second series of three baseline tests were designed to determine the emission levels of the vehicle with an ineffective catalyst. For this series, the catalytic converters were removed from each vehicle and replaced with a bypass unit. These units were constructed with baffles to simulate the average back pressure created by the catalyst.
Following the six baseline test sequences, the vehicles were fueled with commercially-available leaded fuel (Table 2). The standard gas caps were replaced with locking models to ensure control of the type of fuel used.

Table 2
Lead Content of Fuel

Date	Lead Content (gm/gal)*
9-6-79	0.84
9-10-79	0.75
9-11-79	1.22
9-22-79	.90
10-1-79	1.49
10-2-79	1.32
10-10-79	1.32
10-15-79	1.14
10-23-79	1.16
11-8-79	0.54
11-12-79	0.43
11-19-79	0.45
11-26-79	0.50
12-3-79	1.30
12-10-79	1.25

* The fuel used in this program was drained from vehicles submitted for test in the Emission Factors Program. This as-received fuel was analyzed for lead content before being placed in one of two reservoirs. If supposedly unleaded fuel was found to contain any lead at all, it was considered "leaded" and was placed in the leaded fuel reservoir. This resulted in slightly lower lead levels than anticipated. The values given above were obtained from the analysis of the reservoir at the intervals indicated.

A series of test sequences were then performed on the seven vehicles at mileage intervals representing approximately one tankful of fuel. This progression of testing continued until the catalyst was found to be "deactivated".

The original work effort provided for a final bypass test sequence and a test sequence with the new catalyst. The modification to the work effort which added the rejuvenation test series included a series of bypass and replacement test sequences. Accordingly, those vehicles that had not completed the catalyst deterioration phase of the project at the time of the work effort modification did not undergo these final deterioration test sequences.

During January of 1980, all seven vehicles were transported to the East Liberty, Ohio test facility. In some instances, the deterioration phase of testing was completed prior to transporting. For those vehicles which had not completed this phase, deterioration was concluded at the Ohio location.

The test sequence at the Ohio location was modified to include additional testing for determination of catalyst efficiency The Federal Short Cycle Test was eliminated and the raw exhaust was measured before and after the catalyst during the Federal Three Mode Test and the Two-Speed Idle Test. Additionally, a pair of thermocouples were installed 1.5 inches upstream of each catalyst on both sides of the pipe and another pair of thermocouples were installed 1.5 inches downstream of each catalyst on both sides of the pipe. Catalyst skin temperatures were recorded for the steady state conditions during the idle and 50 mph cruise portion of the test sequence.

Because the vehicles were being tested at a new location, a new baseline was obtained. The testing program was designed to include misfueling and rejuvenation effects on the oxygen sensor for the three vehicles equipped with three-way catalysts. For these three vehicles, a series of baseline test sequences were performed immediately following the final deterioration sequence.

The baseline series for three-way catalyst equipped vehicles was:

1. Two test sequences using <u>leaded</u> gasoline, catalyst <u>bypassed,</u> and <u>original</u> O_2 sensor.

2. Two test sequences using <u>unleaded</u> gasoline, catalyst bypassed, and original O_2 sensor.

3. Two test sequences using unleaded gasoline, catalyst bypassed, and <u>new</u> O_2 sensor.

4. One test sequence using unleaded gasoline, <u>original</u> catalyst <u>on</u>, and new O_2 sensor.

5. One test sequence using unleaded gasoline, original catalyst on, and <u>original</u> O_2 sensor.

Four vehicles were equipped with oxidation catalyst only. For these vehicles, the baseline series consisted of a single test sequence using unleaded fuel with the original catalyst in place.

Following the baseline tests, all seven vehicles were subjected to mileage accumulation using unleaded gasoline with test sequences run at approximately one tankful intervals. For the vehicles equipped with three-way catalysts, two test sequences were performed at each interval; one sequence with the original poisoned oxygen sensor installed and one with a new oxygen sensor installed. Mileage accumulation was performed using the poisoned oxygen sensor.

For the vehicles equipped with oxidation catalysts, a single test sequence, using unleaded gasoline with the original catalyst in place, was performed.

Mileage accumulation and test sequences for all seven vehicles continued until at least four full tanks of unleaded gasoline had been consumed. From the test results, it had been determined that no appreciable rejuvenation was occurring.

After completion of the mileage accumulation sequences, the four oxidation catalyst equipped vehicles received a final test sequence using unleaded gasoline with a new catalyst in place. The three vehicles equipped with three-way catalysts received a final series of test sequences consisting of:

1. One test sequence using unleaded gasoline, catalyst bypassed, and the original O_2 sensor.

2. One test sequence using unleaded gasoline, catalyst bypassed, and new O_2 sensor.

3. One test sequence using unleaded gasoline, new catalyst in place, and original O_2 sensor.

4. One test sequence using unleaded gasoline, new catalyst in place, and new O_2 sensor.

The following figures present the catalyst deterioration/recovery of the seven vehicles as a percent increase from the baseline. The emission values have been normalized with respect to baseline to allow the display of the various emissions on one graph.

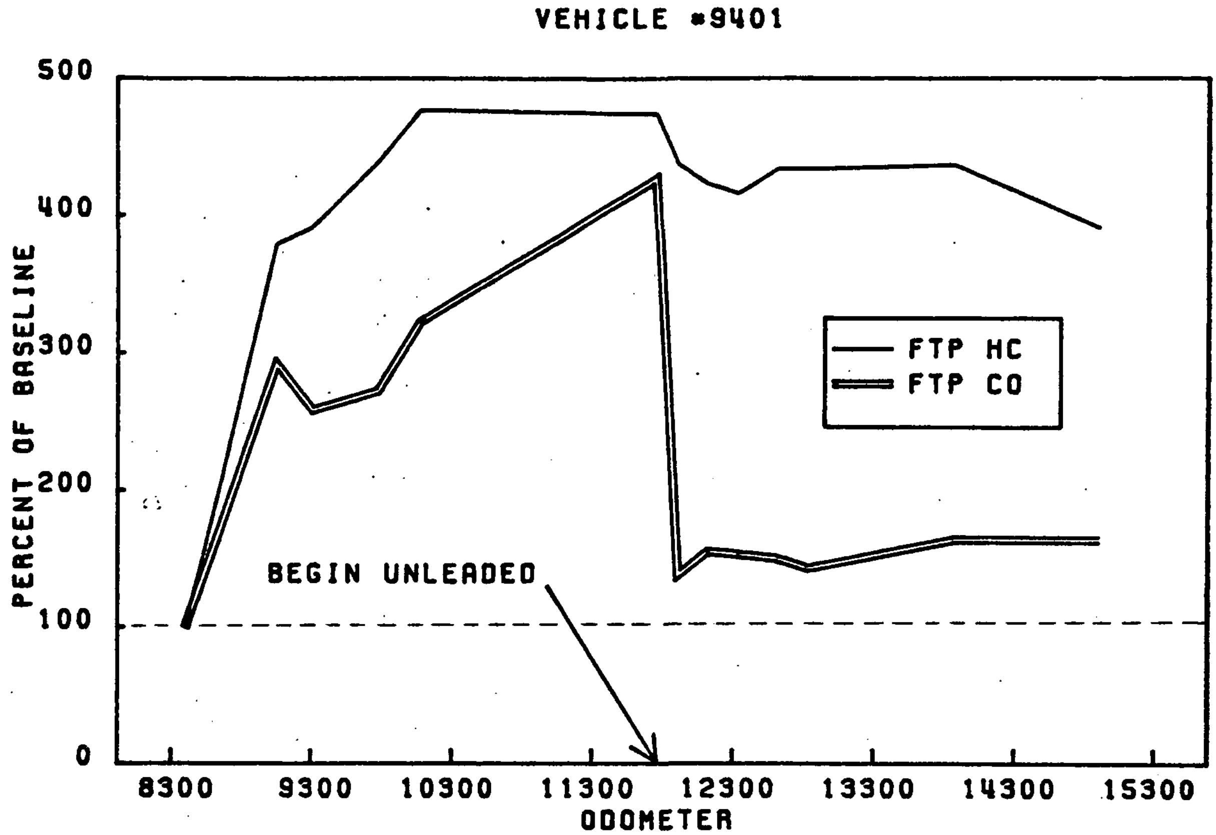

FIGURE B-1: CATALYST DETERIORATION/RECOVERY

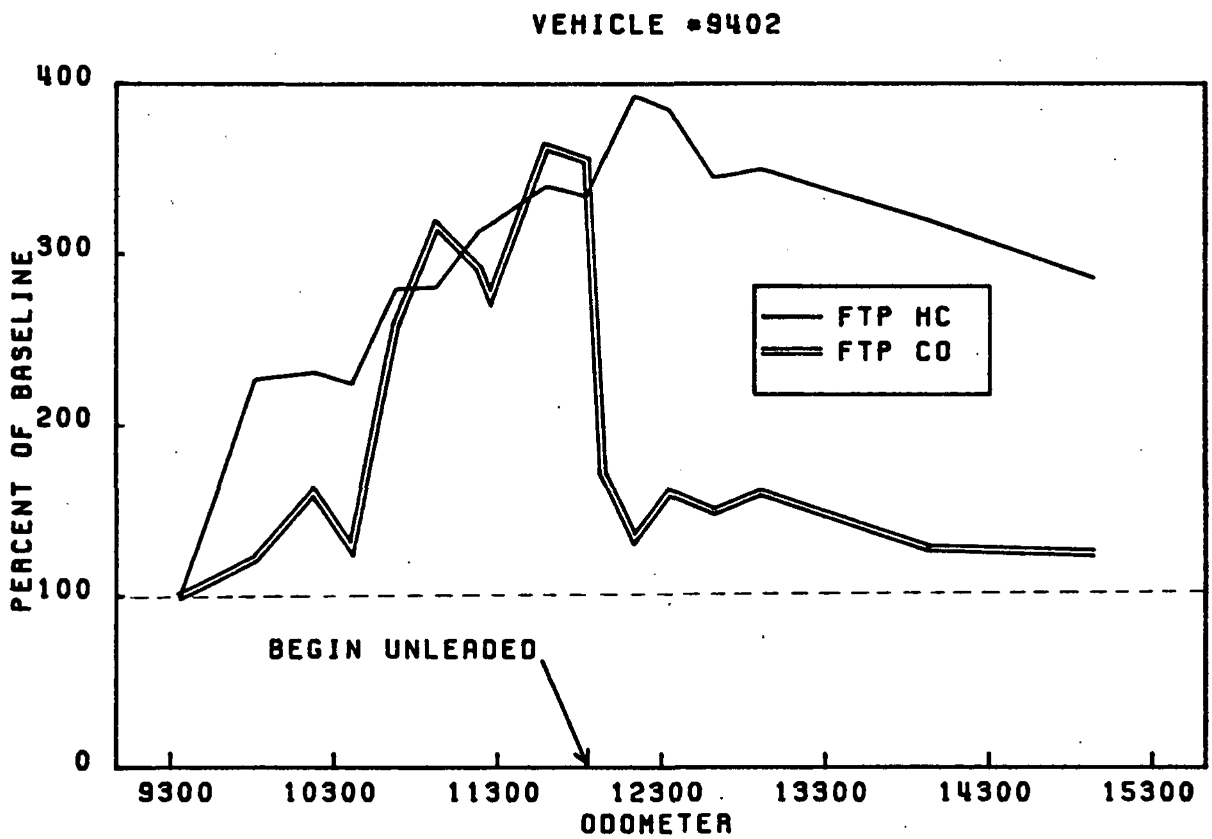

FIGURE B-2: CATALYST DETERIORATION/RECOVERY

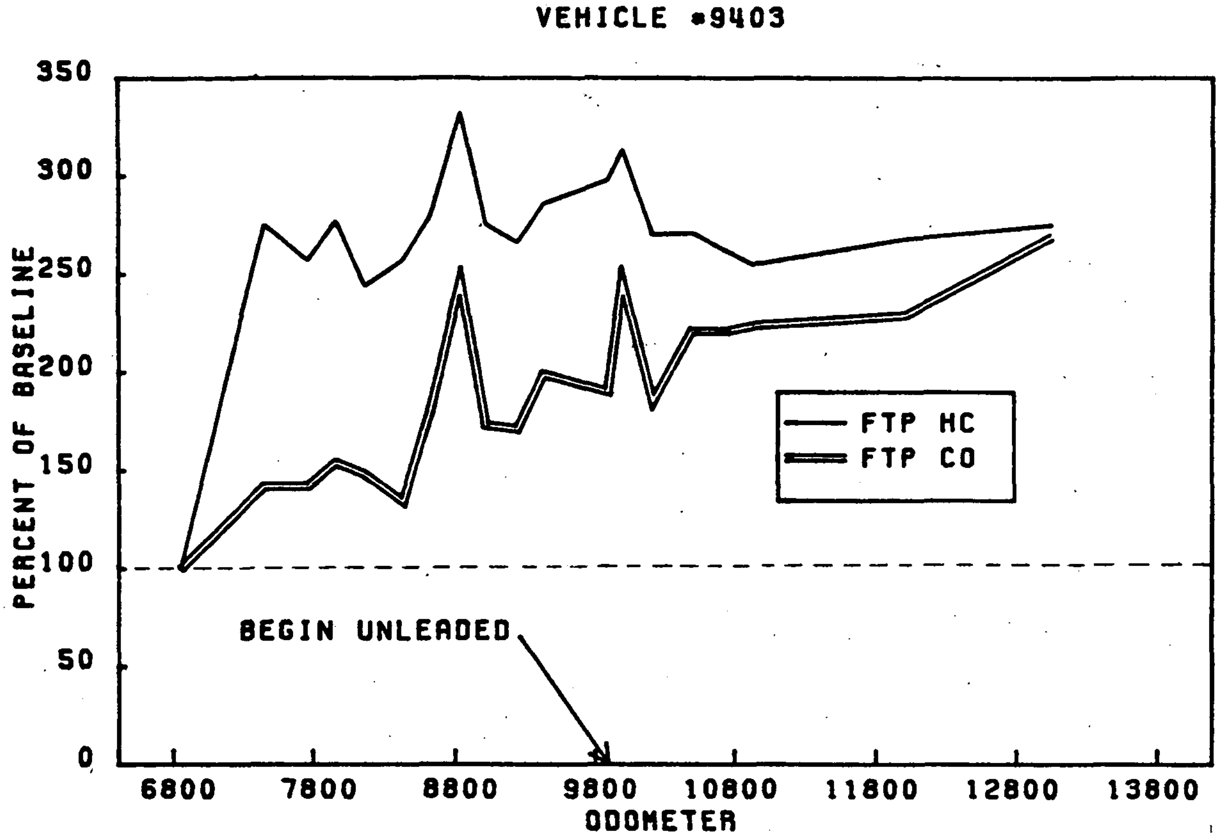

FIGURE B-3: CATALYST DETERIORATION/RECOVERY

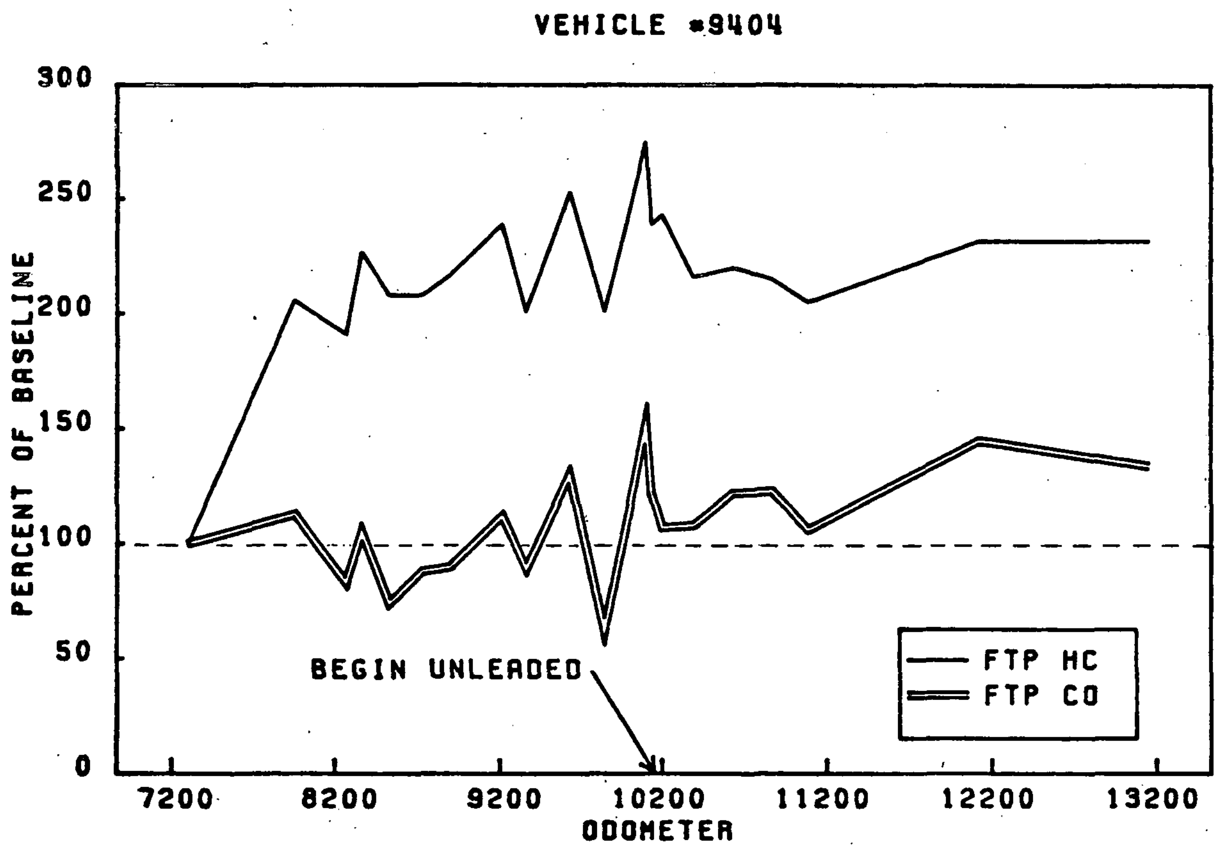

FIGURE B-4: CATALYST DETERIORATION/RECOVERY

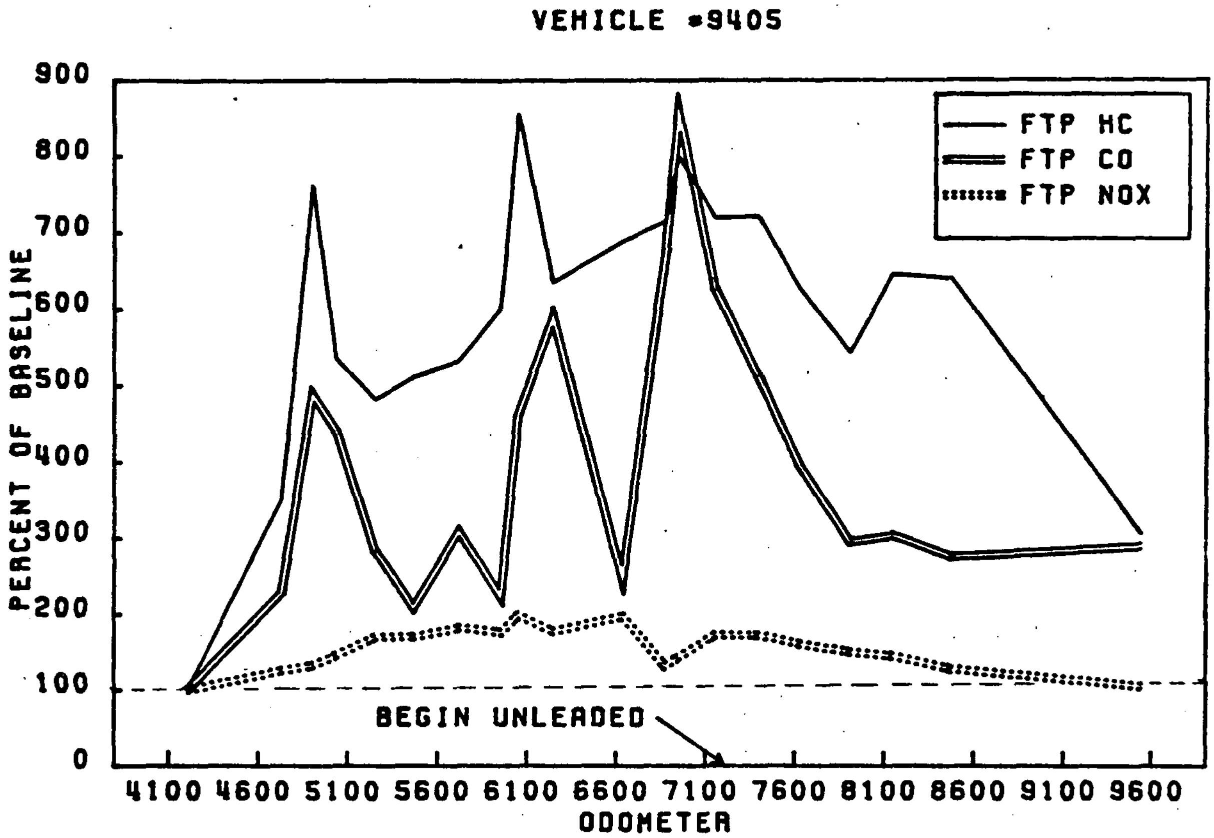

FIGURE B-5: CATALYST DETERIORATION/RECOVERY

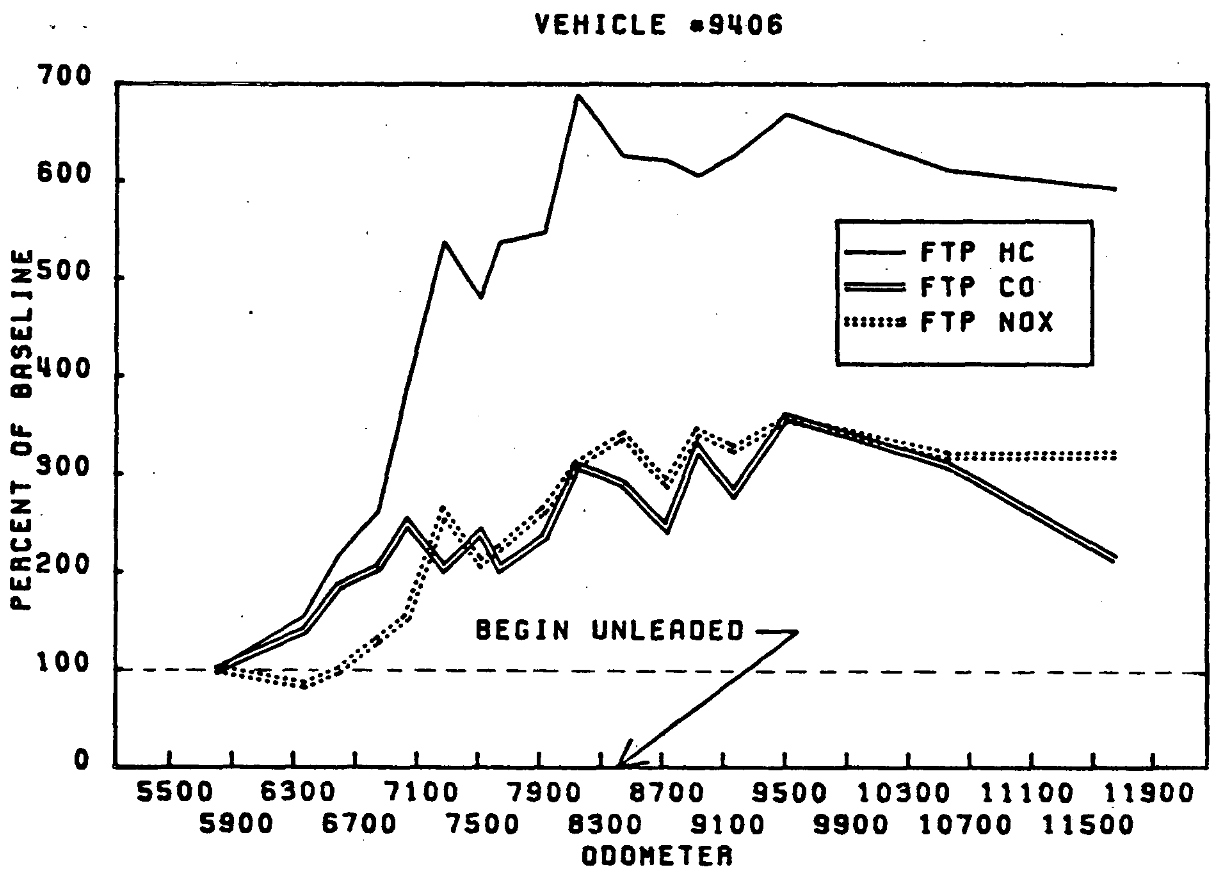

FIGURE B-6: CATALYST DETERIORATION/RECOVERY

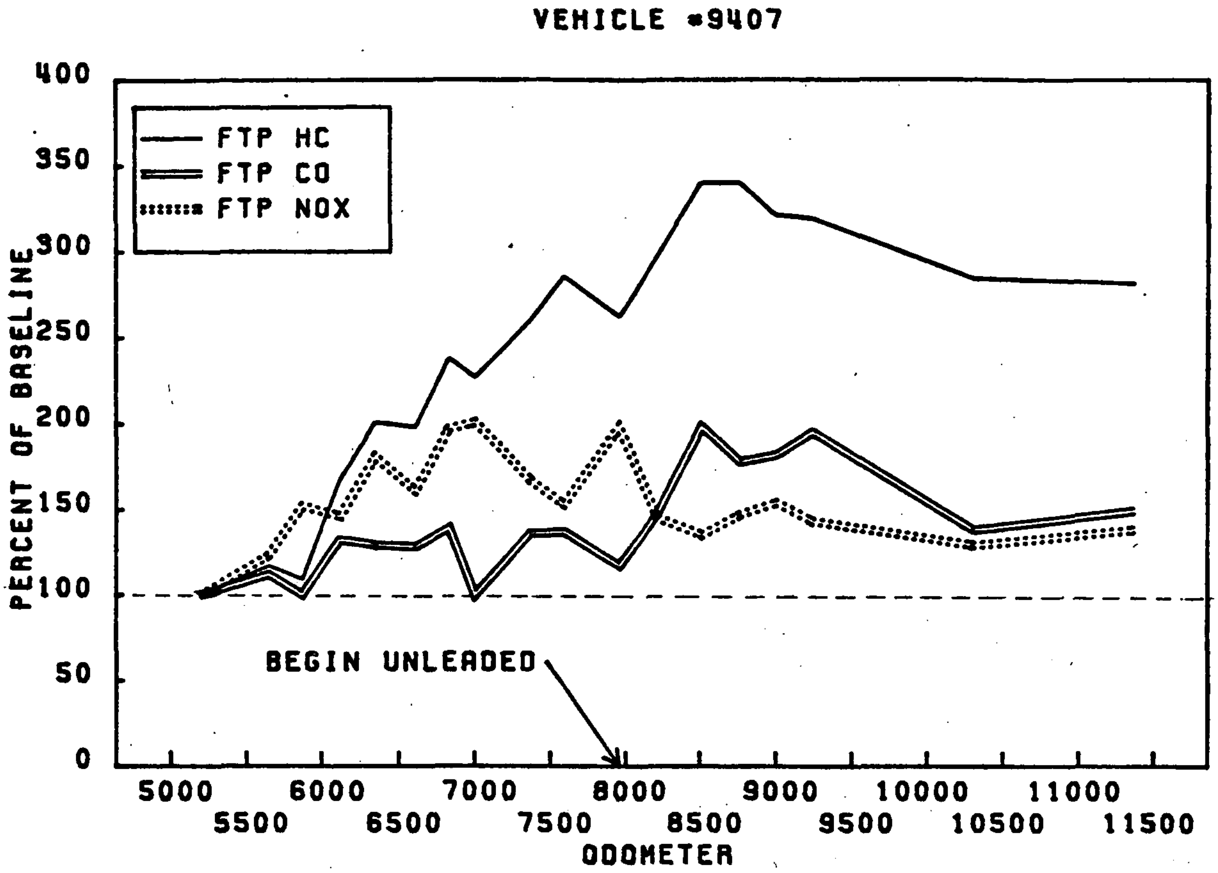

FIGURE B-7: CATALYST DETERIORATION/RECOVERY

Attachment C
Test Program Description
Contract No. 68-03-2783 Task No. 3
Catalyst Poisoning and Catalyst Recovery due to Misfueling

This test program was performed by the California Air Resources Board at the Haagen-Smit Test Laboratory in El Monte, California during the period of time between July 15, 1979 and October 28, 1979. The intent of this program was to determine the recovery rate of vehicles equipped with catalysts that were operated on one tankful of leaded gasoline and subsequently operated on unleaded gasoline. The five vehicles which were chosen for this program were each equipped with oxidation catalysts. The intent of the program was to assess the effect of casual misfueling of the existing vehicle fleet. Therefore, 3-way catalysts were not included in the sample.

Five late model vehicles with odometer readings between 10,000 and 20,000 miles were used in this test program. They were baseline tested on unleaded fuel and then driven with one full tank of leaded fuel until fuel gauge read "empty". The lead content of the fuel was 2.5 grams per gallon. The vehicles were then tested to determine the initial (poisoning) effects of leaded gasoline on the catalysts. The vehicles were fueled with unleaded gasoline thereafter and tested at every refueling until the catalyst efficiencies had recovered to about 90% of their respective original values. The catalyst efficiency values were calculated from the 1975 FTP test results. Restoration work, such as engine adjustments, oxygen sensor replacement, etc., was performed (if required) before the vehicles were released.

Test Vehicles and Catalysts

The following five vehicles were procured for this project:

Date Received	Test Vehicle No	Description	CID	Odometer
7/18/79	21	1979 Granada	250	15010
7/18/79	22	1979 Fairmont	302	13637
7/17/79	23	1979 Chev.Caprice	305	18454
7/17/79	24	1979 Cordoba	360	10336
7/27/79	25	1979 Chev. Malibu	231	13940

The following is a description of the catalysts used in this program:

Vehicle#	Catalyst Type	Other EEC Systems
21	OC-Monolithic #D7BE-5E212-LA	AIR-EGR
22	OC-Monolithic #D9BE-5E202-JA	AIR-EGR
23	OC-Pellet #6498369	AIR-EGR-EFE
24	OC-Monolithic #4004714	AIR-EGR-ESA*
25	OC-Pellet #6498369	AIR-EGR-EFE

*Electronic Spark Advance

Only 1975 FTP tests were performed on the five vehicles. The test schedule was as follows:

1. Check and adjust to manufacturer's specifications.

2. Run three consecutive 1975 FTP exhaust emissions tests as initial baseline tests. Omit the third test if the first two are agreeable.

3. Drain tank fuel and fuel with one tankful of leaded gasoline.

4. Accumulate mileage (45%/55% Highway/City) until fuel tank is empty.

5. Fuel with unleaded gasoline and run one 1975 FTP at every refueling.

6. Repeat step 5 until catalyst efficiency has recovered to 90% of its initial value.

Mileage accumulation was performed by laboratory technicians. The vehicles were driven over a set route on freeways and city streets near the Haagen-Smit Laboratory.

The following figure presents the catalyst deterioration as a percent increase from baseline values. The normalization allows grouping of all five vehicles in one figure.

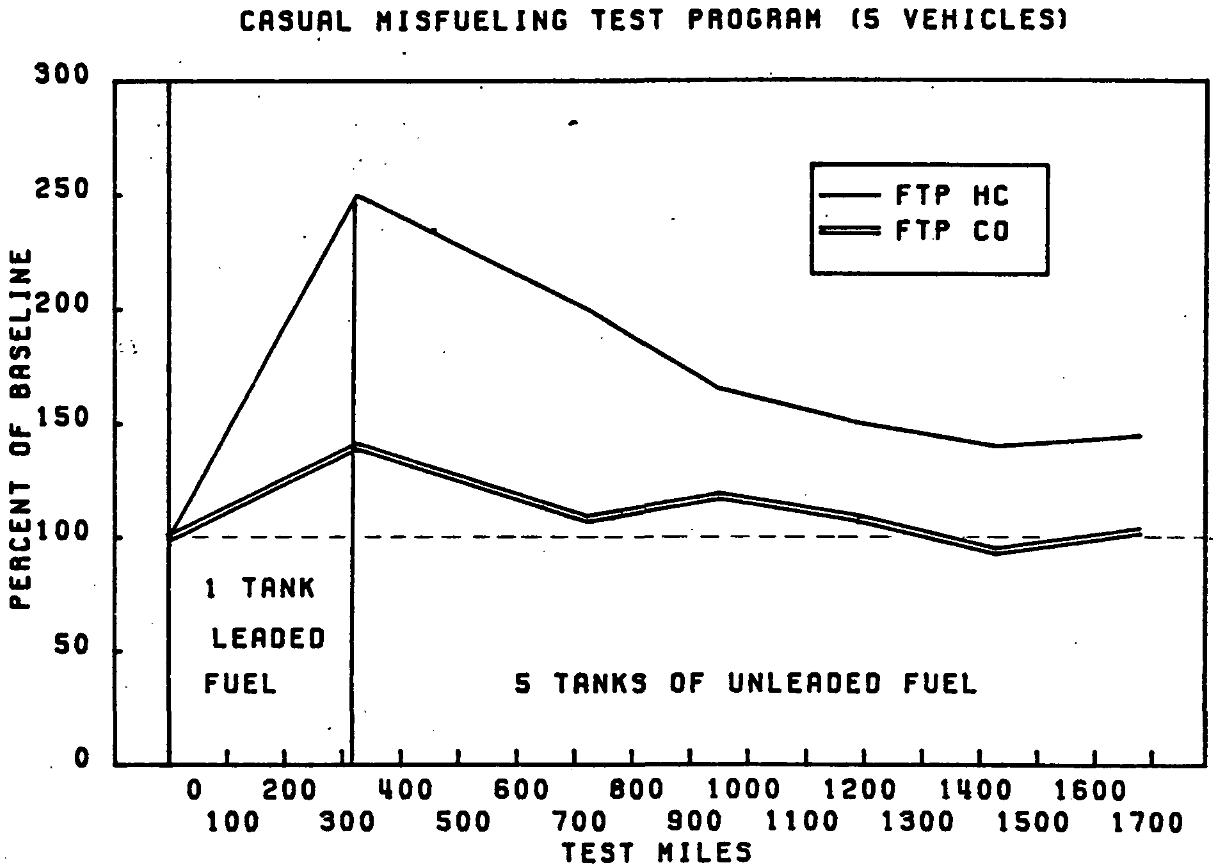

FIGURE C-1: AVERAGE EMISSION INCREASE CARB TEST PROGRAM

Attachment D
Test Program Description
Casual Misfueling of Catalyst Equipped Vehicles

This test program was performed by the Environmental Protection Agency at the Motor Vehicle Emission Laboratory in Ann Arbor. The intent of this program was to assess the rate of catalyst recovery after operation of the vehicle on one tankful of leaded fuel. The program was subsequently modified to perform a second poisoning/recovery series. The vehicle fleet for this program is described below:

Vehicle Number	Vehicle Description	Model Year	CID	Catalyst Odometer	Type
#1	Citation	1980	171	4884	Pellet
#2	Catalina	1978	301	34259	Pellet
#3	Mustang	1979	140	6665	Monolithic
#4	Fury	1978	318	34495	Monolithic
#5	Corona	1979	134	3894	Pellet

The leaded fuel used in this program was Indolene 30. The lead content of this fuel was 3.09 grams per gallon. Compared to leaded fuel which is now commercially available, this lead content is quite high. It was selected for this program because of the uncertainty regarding the effect of lead exposure on the catalyst and the need for accelerated testing.

The test program consisted of two sequences of misfueling and recovery. Three 1975 FTPs were conducted on the vehicles as they were received in order to establish baseline emissions for each. One tank of leaded fuel was then used to drive one of four established road routes. Two 1975 FTPs were performed still using leaded fuel. One 1975 FTP was conducted after the fuel was switched to unleaded.

The recovery sequence was comprised of mileage accumulation on three tanks of unleaded fuel with two 1975 FTPs between each refueling. This misfueling/recovery cycle was then repeated with slight variations. After the third tank of Indolene Clear had been consumed and the car tested, it was refueled with leaded fuel and tested before any further mileage accumulation. Also, after the tank of leaded fuel and the subsequent FTP were run, the car was refueled with unleaded fuel and tested prior to the start of the second recovery sequence. The following outline provides a detailed explanation of the test program.

Fuel	Step
Indolene Clear	1 - Vehicle checkout.
	2 - Obtain tailpipe scraping sample to verify that leaded fuel had not been previously used in the vehicle.
	3 - Fuel vehicle to 40% of tank capacity with Indolene Clear.

4 - Precondition with one LA-4 cycle.

5 - 12 to 36 hour soak.

6 - Cold start 1975 FTP and I/M sequence.

a. I/M Sequence:

Using a garage type analyzer, record idle HC and idle CO during:

1. Idle
2. 2500 rpm
3. Idle
4. 30 mph/9AHP/1750 IW
5. Idle

7 - Repeat 3-6 twice (total of 3 FTPs).

Indolene 30

8 - Fuel vehicle with Indolene 30

9 - Run mileage accumulation road route until 1/8 tank remains.

10 - Take tailpipe scraping sample.

11 - Fill tank with Indolene 30 to determine the amount of fuel used during mileage accumulation. Drain tank to 40% level.

12 - Precondition one LA-4 cycle.

13 - 12 - 36 hour soak.

14 - Cold start FTP and I/M sequence.

15 - Repeat 11-14 once (total of 2 FTPS).

Indolene Clear

16 - Fuel vehicle with Indolene Clear

17 - Run mileage accumulation road route until 1/8 tank remains.

18 - Take tailpipe scraping sample.

19 - Fuel vehicle to 40% of tank capacity with Indolene Clear.

20 - Precondition one LA-4 cycle.

21 - 12 to 36 hour soak.

22 - Cold start FTP and I/M sequence.

23 - Repeat 22 to 25 once (total of 2 FTPs).

24 - Fuel vehicle to full tank capacity with Indolene Clear.

25 - Repeat 17-24.

The following figure presents the deterioration/recovery as a percent increase from baseline values. This normalization allow the grouping of four vehicles on one figure. The Plymouth Fury was omitted from this figure because of the high baseline values of this car. This car appeared to have operated on leaded fuel previously and it was dropped from the sample. The tailpipe scrapings revealed a lead level of 11.3% by weight for the Fury compared to less than 3% by weight for the other four vehicles.

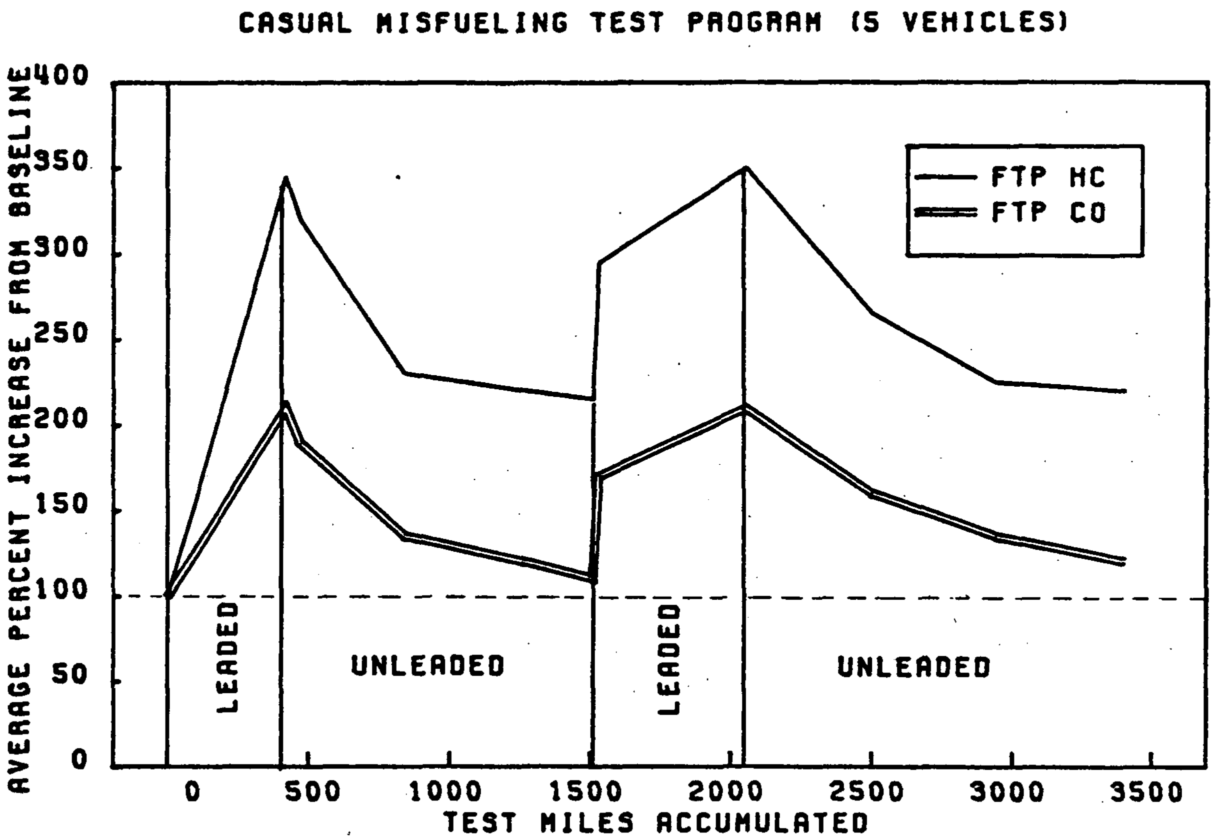

FIGURE D-1: EPA IN-HOUSE MISFUELING TEST PROGRAM

Appendix E

Effect of One Tankful of Leaded Gasoline on Emission Control

1975 FTP (gm/mi)

	Baseline			1 Tank		
CARB Task #3	HC	CO	NOx	HC	CO	NOx
Veh. #21	.43	3.66	.82	1.03	5.29	.97
Veh. #22	.53	2.73	.67	1.68	9.48	.67
Veh. #23	.40	5.98	.98	.71	7.65	.98
Veh. #24	.36	2.21	1.03	1.02	4.67	1.02
Veh. #25	.56	10.50	.72	1.14	8.45	.75
EPA In-House						
Veh. #1	1.00	6.13	1.71	3.12	9.15	1.80
Veh. #2*	2.46	17.10	2.24	3.97	33.05	2.45
Veh. #3	.48	5.70	1.41	1.77	9.25	1.88
Veh. #4	.22	5.07	1.17	.75	15.65	1.18
Veh. #5	.25	1.72	1.53	1.08	4.01	1.53
CARB Task #2						
Veh. #1	.26	4.10	1.13	.82	9.38	1.02
Veh. #2	.20	1.95	.98	.73	5.45	.92
Veh. #3	.34	4.23	.78	.81	6.24	.78
Veh. #4	.22	1.46	1.56	1.69	9.98	1.41
Veh. #5	.23	1.35	1.18	2.50	9.21	.91
Veh. #6	.21	2.38	1.09	1.33	9.27	1.14
Veh. #7	.40	4.04	.77	1.17	14.71	.65
Veh. #8	.20	3.56	.47	.74	8.41	.48
Veh. #9	.24	3.69	.15	1.22	18.57	.41
Veh. #10	.18	2.60	.07	1.27	13.05	.27
ATL St. Louis						
Veh. #9401	.67	6.79	1.59	2.55	19.61	1.82
Veh. #9402	.91	3.69	2.04	2.07	4.52	2.12
Veh. #9403	.53	3.56	1.68	1.48	5.12	1.71
Veh. #9404	.86	12.45	1.05	1.78	14.14	1.12
Veh. #9405	.30	2.09	1.03	1.06	4.78	1.30
Veh. #9406	.21	2.20	.76	.32	3.06	.64
Veh. #9407	.37	6.56	.71	.44	7.41	.88
Mean	.48	4.72	1.09	1.41	9.98	1.14
Std. Dev.	.45	3.6	.51	.83	6.35	.54

* This vehicle was eventually eliminated from the program after determining that it had been previously operated on leaded fuel.