Investigation of MOBILE5a Emission Factors:

Evaluation of IM240-to-FTP Correlation and Base Emission Rate Equations

HEALTH AND ENVIRONMENTAL SCIENCES

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American Petroleum Institute
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Health and Environmental Sciences Department

API PUBLICATION NUMBER 4605

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JUNE 1994

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ABSTRACT

The U.S. Environmental Protection Agency's (EPA's) on-road motor vehicle emission factors model, MOBILE5a, is being used increasingly as a regulatory and public policy tool. It is used to determine compliance with motor vehicle related control programs such as enhanced inspection and maintenance (I/M) and highway conformity determinations; its outputs were also used to formulate EPA's Complex model for reformulated gasoline. Although MOBILE5a outputs are used for a broad array of purposes, the methods used to develop inputs to the model are largely undocumented. This report evaluates and documents the methods used by EPA to generate the exhaust base emission rate (BER) equations for MOBILE5a, which were developed from data collected with the IM240 test procedure at an operating I/M lane in Hammond, IN. EPA had to convert the IM240 data to a Federal Test Procedure (FTP) basis prior to developing the BER equations because the exhaust relations in MOBILE5a are based on emissions measured according to the FTP. This study critiques the adjustments used to correct the IM240 emissions test procedure for variations in fuel and temperature relative to those specified for the FTP, and it reviews the correlations between emissions based on the IM240 test procedure and emissions measured on the FTP. In addition, the methods used by EPA to develop emission control system deterioration rates for MOBILE5a were assessed and recommendations for alternative methods to estimate in-use exhaust emission rates were made. The evaluation revealed that suspect statistical and analytical techniques were employed in the development and application of the IM240-to-FTP conversion procedure. Further, the methods used to generate exhaust base emission rate equations from the converted IM240 data resulted in a significant overprediction of emission rates at vehicle odometer readings above 75,000 miles.

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EXECUTIVE SUMMARY

The Clean Air Act Amendments (CAAA) of 1990 mandated a wide array of reductions in mobile source emissions. The revised provisions specified more stringent certification standards for new vehicles, changes in inspection and maintenance (I/M) program requirements, implementation of gasoline regulations, new categories of emissions standards and a host of other changes. The primary tool used to track the effect of these changes on the emissions of the in-use vehicle fleet is the MOBILE series of models developed by the U.S. Environmental Protection Agency (EPA). Over the years, the role and influence of this model have expanded considerably. Its original purpose was to support the development of mobile source emission inventories. It is now used to determine compliance with I/M program requirements, support conformity determinations, and estimate the benefits of changes in selected fuel factors such as oxygenate content and volatility. Its outputs were also used to develop some of the components of the "Complex" model that EPA uses to evaluate the emissions performance of gasoline under the reformulated gasoline regulation.

The American Petroleum Institute (API) contracted with Sierra Research, Inc. (Sierra) to prepare an evaluation of the MOBILE model. The original scope of that effort was to assess how the MOBILE4.1 and MOBILE5a versions of the model account for I/M effects and how MOBILE5a modeled the impact of California low-emission vehicles. The results of that study were published in a June 1994 companion report entitled "Investigation of MOBILE5a Emission Factors: Evaluation of I/M Program and LEV Program Emission Benefits". Subsequent to the completion of that investigation, API amended the contract and issued a revised statement of work authorizing additional effort to be directed at determining how the exhaust base emission rate equations were developed for MOBILE5a. This report summarizes the findings from that evaluation.

With the release of MOBILE5a, EPA made a significant departure from the historical process of vehicle emissions data collection and analysis. In previous versions of the model, the exhaust base emission rate equations (i.e., "emission factors") were developed from test data collected according to the Federal Test Procedure (FTP). The FTP is conducted in a controlled laboratory environment with a standardized test fuel (i.e., Indolene). However, for MOBILE5a, the base emission rate equations for 1981 and later model year vehicles were developed from data that were collected at an I/M lane in Hammond, IN, over the IM240 test cycle. Since most of the exhaust relations (e.g., temperature corrections, speed corrections, etc.) contained in MOBILE5a are based on the FTP, it was necessary for EPA to convert the IM240 data to an FTP basis prior to developing the base emission rate equations. API requested an evaluation of the IM240-to-FTP conversion process because the available documentation of this procedure is limited and because MOBILE5a plays an important role in many regulatory and policy decisions. In addition to assessing the procedure by which the IM240 data were converted to an FTP basis, this study also investigated how the converted data were then utilized to derive inputs to the emission factors preprocessor model, TECH5, which computes the base emission rate equations for MOBILE5a. Finally, an evaluation of IM240 data collected in Mesa, AZ, was performed to serve as a cross-check of the IM240-to-FTP conversion procedure.

After a review of the analytical procedure used by EPA and its contractor, it became clear that questionable statistical techniques were employed in the development and application of the IM240-to-FTP correlation equations for MOBILE5a. First, the development of correlations between the FTP and the IM240 involved a data replacement procedure that resulted in the IM240 data being regressed against itself for one-third of the hydrocarbon test scores for a key technology group, resulting in misleading R^2 values. Second, the application of regression residuals to the correlation equations (which is not appropriate for this type of analysis) inflated average FTP values by approximately 20%.

The evaluation of EPA's derivation of base emission rate equations from the "FTP-equivalent" IM240 data indicated that the data were treated in a subjective and inconsistent manner. Individual emitter category emission rates (an input to TECH5) were generated in a completely different fashion than emitter category growth rates (also an input to TECH5), analysis methods differed by emitter category, and modifications to the methods to account for technology differences were not applied consistently when the emission and growth rates were estimated.

This study required that Sierra obtain the data used by EPA and its contractors and replicate each of the procedures involved in the IM240-to-FTP conversion process and the development of base emission rates from the converted data. Completing these tasks reinforced the findings of the earlier analysis about the lack of documentation for many of the key inputs for both MOBILE and the "TECH" models. Numerous phone calls to EPA staff were required to understand the motivations behind methodologies employed, why data points were deleted or modified, etc. While EPA staff were generally helpful, there were significant time lags between questions and responses as staff members had to review their work or try to remember what they did. <u>It is clear that large portions of MOBILE5a and its supporting model, TECH5, are undocumented.</u>

The summary below highlights the major findings of the study.

IM240-TO-FTP CORRELATIONS

The IM240-to-FTP conversion was a multi-step procedure consisted of (1) adjusting the Hammond "lane" IM240 scores to account for differences in fuel and temperature between individual vehicle IM240 and FTP tests, (2) developing correlation equations relating the IM240 and the FTP, and (3) applying those correlations to all of the IM240 data collected at the Hammond lane. Main points of the IM240-to-FTP conversion process developed by EPA are summarized below.

<u>Fuel and Temperature Adjustments</u>

The fuel and temperature adjustments were developed from a subset of vehicles tested in the Hammond program. Those vehicles received an IM240 test at the lane on tank fuel, and then were brought to a local laboratory for additional testing. One of the tests performed at the laboratory was an IM240 that was conducted with Indolene over the FTP temperature range. This testing provided a basis for the fuel and temperature adjustment factors that were applied to all lane IM240 scores prior to performing the IM240-to-FTP conversion. In developing the adjustment factors, data were stratified by "season" (i.e., March and April; May and June; July through September; and October through February) and by lane IM240 emission level.

Significant findings from the evaluation of the fuel and temperature adjustments include the following.

- Although 380 vehicles were in the original data base, test scores from 332 vehicles were used to develop the fuel and temperature adjustment factors. EPA was unable to identify the vehicles and reasons for deleting test points in this analysis (i.e., the final data set used for the analysis was not documented).

- A regression analysis performed for this study did not indicate a better statistical fit when the data were stratified by season. Although seasonal adjustments are logical from an engineering perspective (i.e., fuel RVP and ambient temperature at the lane should be similar for each season), the value of applying those adjustments is questionable and the results do not justify their use.

- The fuel and temperature adjustments were developed by taking the ratio of the mean of the laboratory IM240 scores and the mean of the lane IM240 scores (by season and emitter class); the basis for this approach is not documented. Because the adjustments were ultimately applied to individual data points, taking the mean of the individual vehicle lane/lab ratios (by season and emitter class) would be more appropriate.

- As a sensitivity analysis, alternative fuel and temperature adjustments were developed in this study. The results from that analysis indicated very little change from the factors developed for MOBILE5a.

The effect of the seasonal fuel and temperature adjustments on the hydrocarbon (HC) IM240 scores is summarized in Figure ES-1 for 1983 and later multipoint fuel-injected, closed-loop

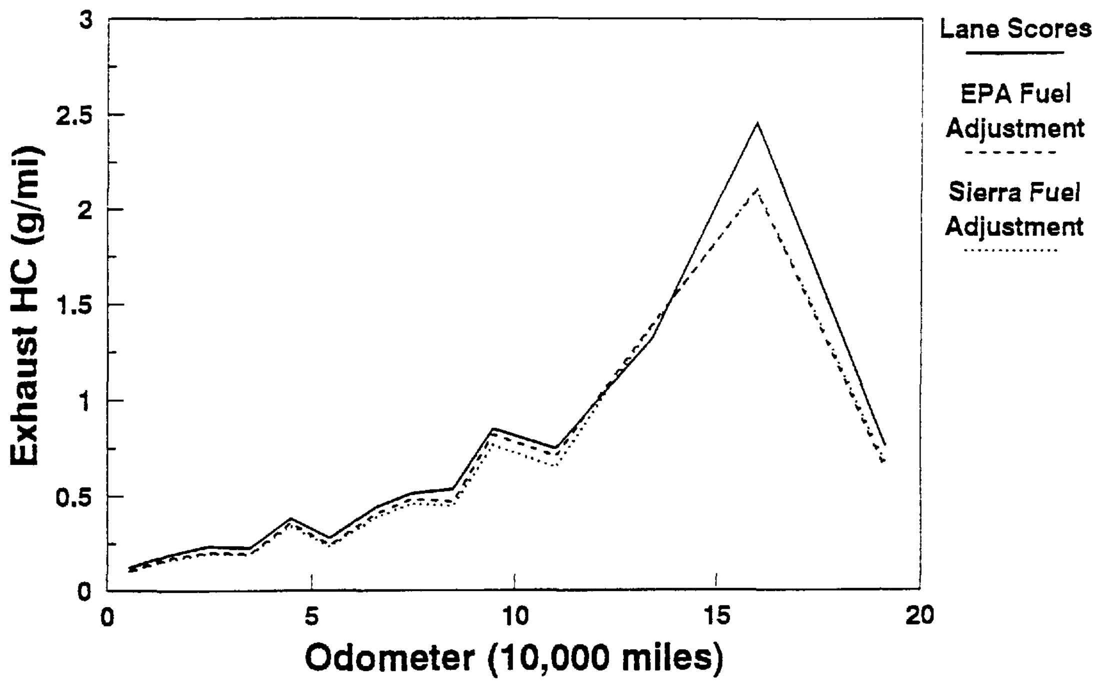

Figure ES-1. Effect of Seasonal Fuel and Temperature Adjustments on 1983+ MPFI/CL IM240 HC Emission Rates, EPA vs. Sierra Adjustments

(MPFI/CL) vehicles. As seen, the application of fuel and temperature adjustments had only a moderate impact on the lane IM240 scores, and very little difference is observed when comparing the results of EPA's analysis and the alternative analysis prepared for this study. Given the small effect and the additional variability incorporated by applying these adjustments, it may have been more appropriate to forego the fuel and temperature adjustments and simply develop the IM240-to-FTP correlations directly from the lane IM240 scores.

Development and Application of Correlation Equations

The IM240-to-FTP correlations were developed by regressing FTP data (developed in the lab on Indolene) against IM240 data that were also collected in the lab on Indolene. (Hence the need for the fuel and temperature adjustments described above, which are used to get the lane IM240 scores on a lab/Indolene basis.) Two data bases were used for this analysis: (1) a subset of the Hammond vehicles that had lab/Indolene FTP scores and lab/Indolene IM240 scores, and (2) a group of vehicles tested at EPA's Ann Arbor lab that had both lab/Indolene FTP and lab/Indolene IM240 scores. Prior to developing the correlations, the data were stratified according to model year group and technology type.

For HC and carbon monoxide (CO), the correlations were performed in log space, while the oxides of nitrogen (NOx) correlations were based on a linear model. Because the IM240 test procedure does not include a cold start (i.e., the test is conducted with the vehicle in a warm stabilized condition), the correlations developed for HC and CO included a "cold start offset" term; since the cold start mode has less influence on NOx emissions, an offset was not included in the NOx correlations. The HC and CO correlations were developed according to the following equation:

$$\text{Log}_{10}(\text{FTP - X}) = b + m^*\text{Log}_{10}(\text{IM240})$$

where X represents the cold start offset, and Log_{10}(FTP - X) was regressed against Log_{10}(IM240) to generate a slope (m) and an intercept (b).* The value of X was determined by taking the mean of the cold start offset (i.e., FTP Bag 1 - FTP Bag 3) for "normal" emitters in the correlation sample.

When the correlation equations were applied to the fuel- and temperature-adjusted IM240 data, EPA added randomized residuals to the equations prior to taking the anti-log, i.e.,

$$\text{Log}_{10}(\text{FTP - X}) = b + m^*\text{Log}_{10}(\text{IM240}) + \text{res}$$

---

* EPA has used "ZML" to represent the intercept term and "DET" to represent the slope in the limited documentation available on the IM240-to-FTP correlations. However, that notation may lead to some confusion, since ZML and DET are generally used to represent the base emission rate zero-mile level and deterioration rate, respectively. Thus, the more generic "b" and "m" are used to represent the intercept and slope in this report.

where "res" represents regression residuals from the correlation sample. According to EPA staff, the reason for applying residuals is because emission data generally demonstrate considerable scatter, and adding residuals back into the correlation equations re-introduces that scatter.

Several items are worth noting with respect to the method used to develop and apply the IM240-to-FTP correlations for MOBILE5a:

- For vehicles with FTP scores less than X, the value of (FTP - X) was negative. Because it is not possible to take the logarithm of a negative number, the IM240 score was used in place of (FTP - X) when (FTP - X) was less than 0.01 grams/mile (g/mi) for HC and less than 0.1 g/mi for CO. When this occurred, the IM240 score was essentially being regressed against itself. Although the contractor memo outlining this procedure indicated that "three or four cars were affected in most technology groups," this actually occurred for <u>82 of the 266 1983+ MPFI/CL vehicles</u> in the HC correlation. Clearly, when one-third of a sample is regressed against itself, the correlation is likely to improve, and the R^2 values reported by EPA to support the IM240-to-FTP correlations are extremely misleading. Although this example was the most extreme case of data replacement, it also occurred for CO and other technology groups.

- Including randomized residuals in applying the HC correlation equations resulted in a 20% <u>increase</u> in average emissions. This results from the differential impact of the log transformation approach on negative versus positive residuals. Thus, although the residuals may have been applied randomly, the net effect was to increase FTP values. This is shown graphically in Figure ES-2.

- An alternative correlation methodology was developed for this study. That analysis resulted in FTP values similar to those that would have been obtained from EPA's correlations <u>if residuals had not been applied</u>.

Clearly, some questionable statistical techniques were employed in the development and application of the IM240-to-FTP correlation equations for MOBILE5a. First, replacement of (FTP - X) values with IM240 scores resulted in misleading R^2 values. Second, application

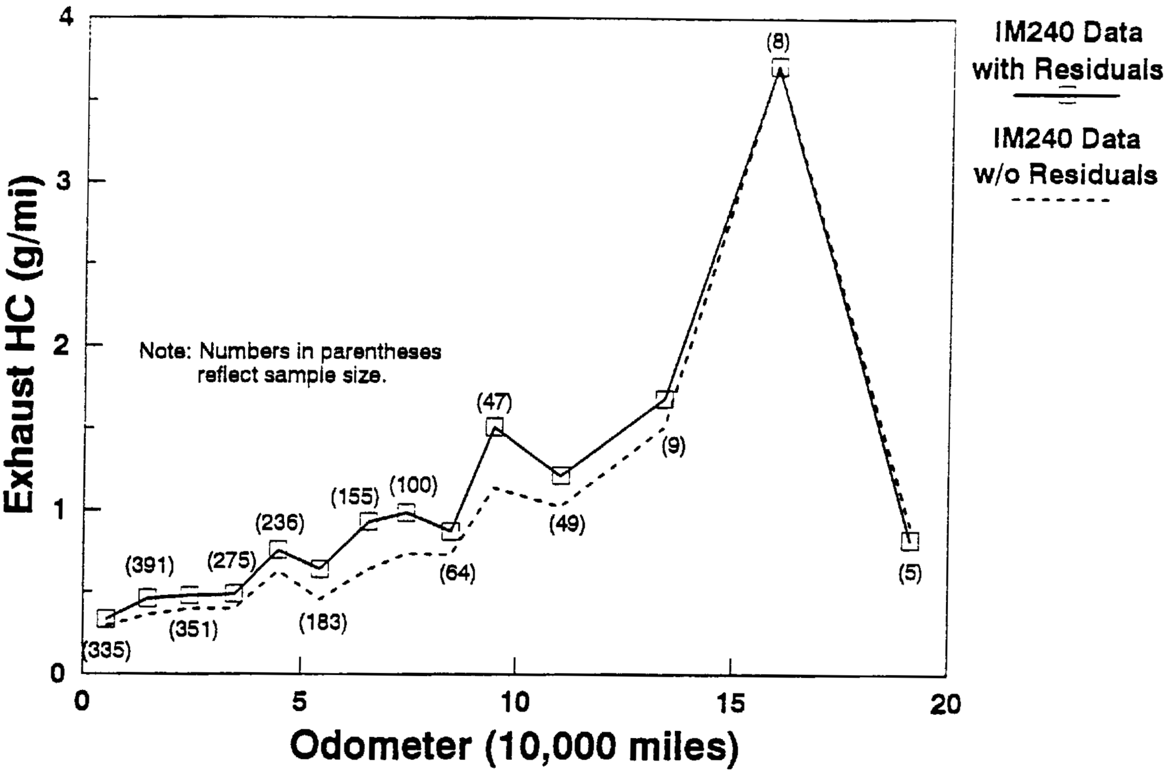

Figure ES-2. Effect of Adding Residuals to IM240-Converted, FTP-Based 1983+ MPFI/CL Exhaust HC Emission Rates

of residuals, which is not appropriate for this type of analysis, inflated average FTP values by approximately 20%.

DERIVATION OF EMISSION CONTROL SYSTEM DETERIORATION RATES

Following the IM240-to-FTP conversion procedure, the resulting "FTP-equivalent" data were used to develop the non-I/M exhaust base emission rate equations for MOBILE5a. A comparison of the Hammond data for 1983+ MPFI/CL vehicles and the 1992 HC base emission rate developed for MOBILE5a is presented in Figure ES-3. (1983+ MPFI/CL vehicles were chosen for the comparison because that model year group/technology comprises 81.5% of the 1992 model year fleet.) As seen in the figure, close agreement between the data and the MOBILE5a predictions is observed up to 50,000 miles, but there is

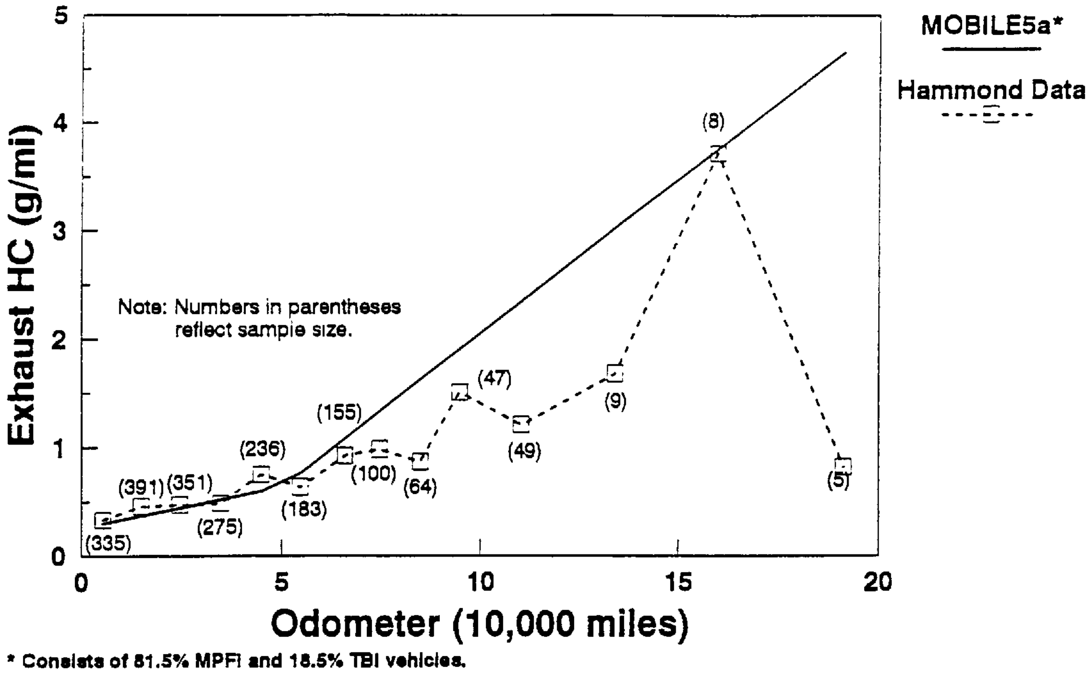

Figure ES-3. Comparison of MOBILE5a 1992 Model Year HC Base Emission Rate Equation to the Hammond 1983+ MPFI/CL Data

a significant over-prediction of emissions by MOBILE5a at higher mileages (similar trends are also observed for CO and NOx and for the throttle-body fuel-injection technology). The results depicted in Figure ES-3 led to a more thorough evaluation of the procedure used by EPA to develop base emission rate equations for MOBILE5a. A summary of that evaluation is described below.*

* Note that the evaluation performed for this study was focused at the development of HC and CO base emission rate equations. Resource constraints did not allow for a thorough assessment of EPA's development of NOx base emission rate equations for MOBILE5a.

MOBILE5a Methodology

The base emission rate equations (i.e., zero-mile levels and deterioration rates) developed for MOBILE5a were generated from the emission factors pre-processor model, TECH5. The function of TECH5 is detailed in Section 3 of this report, but a brief review is useful to understand some of the findings presented below. TECH5 uses a "regime" approach to develop emission rates (as a function of vehicle mileage) by model year group (i.e., 1981-1982 and 1983+*) and technology (i.e., MPFI/CL, closed-loop throttle-body injection (TBI/CL), closed-loop carbureted (CARB/CL), and open-loop). Four emitter groups (or regimes) are defined in TECH5: normals, highs, very highs, and supers. Emission rates (by model year group/technology) are determined by multiplying the emission rate of each emitter category by the fraction of each emitter category making up the fleet at mileage intervals corresponding to vehicle age. Thus, two primary inputs to the TECH5 model are the emitter category emission rates and the emitter category population growth rates. Once the model year group/technology emission rates are developed, model year specific emission factors (which are input to MOBILE5a) are generated by weighting the emission rates of each group by its expected fraction of the fleet.

In developing inputs for TECH5, EPA attempted to incorporate both vehicle age and mileage into the analysis. The reasoning behind this approach is that EPA felt uncomfortable with basing emission control system deterioration rates solely on mileage accumulation (which was generally done in previous emission factors development). EPA's rationale in support of this approach is that many vehicles accumulate mileage quickly, and the deterioration rates from those vehicles are likely to be lower than if mileage was accumulated at a more standard rate. Thus, to account for vehicle age as well as mileage accumulation, 1981-1982 data were combined with 1983+ data. However, as described below, the data were treated

* It is generally recognized that the early 1980s model years have different emissions characteristics than later model years because they represent the first widescale introduction of closed-loop, three-way catalyst technology. For example, this distinction is made by the California Air Resouces Board in its development of emission factors for light-duty vehicles.

inconsistently for the development of emitter category emission rates and population growth rate:

- For the development of emission rates by emitter category, EPA performed an analysis with a covariance procedure that used data from 1981+ model years to establish a deterioration rate (as a function of vehicle mileage) for 1981+ model years, while the zero-mile level for each model year group (i.e., 1981-1982 and 1983+) was allowed to vary. It is interesting to note that this approach resulted in higher HC and CO emissions being predicted by TECH5 for 1983+ MPFI/CL vehicles than 1981-1982 MPFI/CL vehicles. This is illustrated for HC in Figure ES-4, which implies that from an emissions perspective, auto manufacturers would have been better off maintaining the designs introduced in 1981.

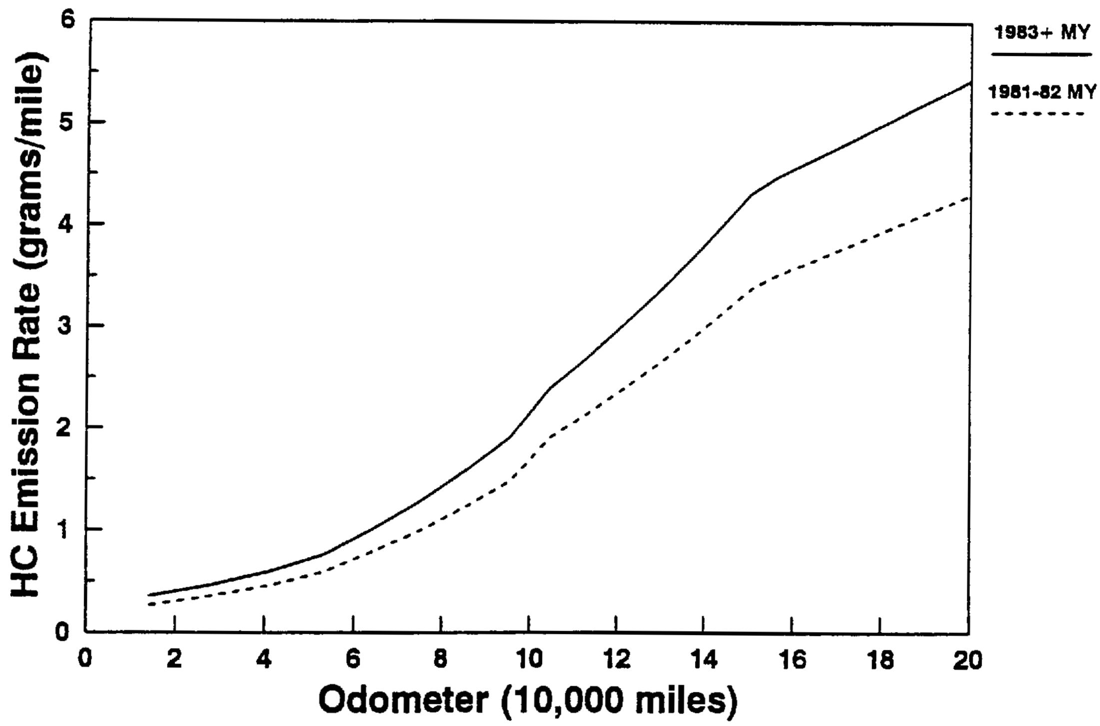

Figure ES-4. Comparison of TECH5 HC Emission Estimates for 1981-1982 and 1983+ Model Year MPFI/CL Vehicles

- Emitter category population growth rates were also developed by combining data from 1981+ model years. However, the procedure used was much different than that outlined above for the emitter category emission rates. Data from 1987 and later model years were used to establish the growth rates for vehicle mileage below 50,000. For mileage above 50,000, data from the 1981-1986 model years were used for the TBI/CL, CARB/CL, and open-loop technology groups; 1984-1986 model years were used for the MPFI/CL vehicles. EPA used the 1984-1986 model years for MPFI/CL vehicles because earlier model years represented "prototype" technology for this class of vehicles. It is unclear why the same reasoning was not also applied to the other closed-loop technologies or for the development of the emission rates for MPFI/CL vehicles.

In addition to inconsistent treatment of data in TECH5, the methodology used by EPA to develop emitter category growth rates overstates the number of high-emitting vehicles in the fleet relative to the data. This is shown in Figure ES-5, which compares the [very high + super] emitter fractions as a function of vehicle odometer developed for TECH5 versus the Hammond data for MPFI/CL vehicles. The "87+ (<50K); 84-86 (>50K)" line represents the data that were used for TECH5 (i.e., 1987 and later model years were analyzed for mileage below 50,000 and 1984-1986 model years were analyzed for mileage above 50,000); the "87+ (<50K); 83-86 (>50K)" line is the same as above except that the model year coverage was extended to include the 1983 model year for mileage above 50,000; and the "1983+" line represents data from all 1983 and later model years. (The 1983 model year was considered in this analysis because that model year historically has been used as a breakpoint between "developmental" and standard technology.) It is clear that TECH5 is over-estimating the number of very highs and supers in the fleet beyond 75,000 miles.

A final point related to EPA's development of emitter category growth rates for MOBILE5a is that a different method was used for super emitters. For that category, the data were stratified into three model year groups: 1987+ for mileage below 50,000; 1983-1986 for mileage from 50,000 to 100,000; and 1981-1982 for mileage above 100,000. Further, because of the limited number of super emitters in the fleet, all technologies were combined.

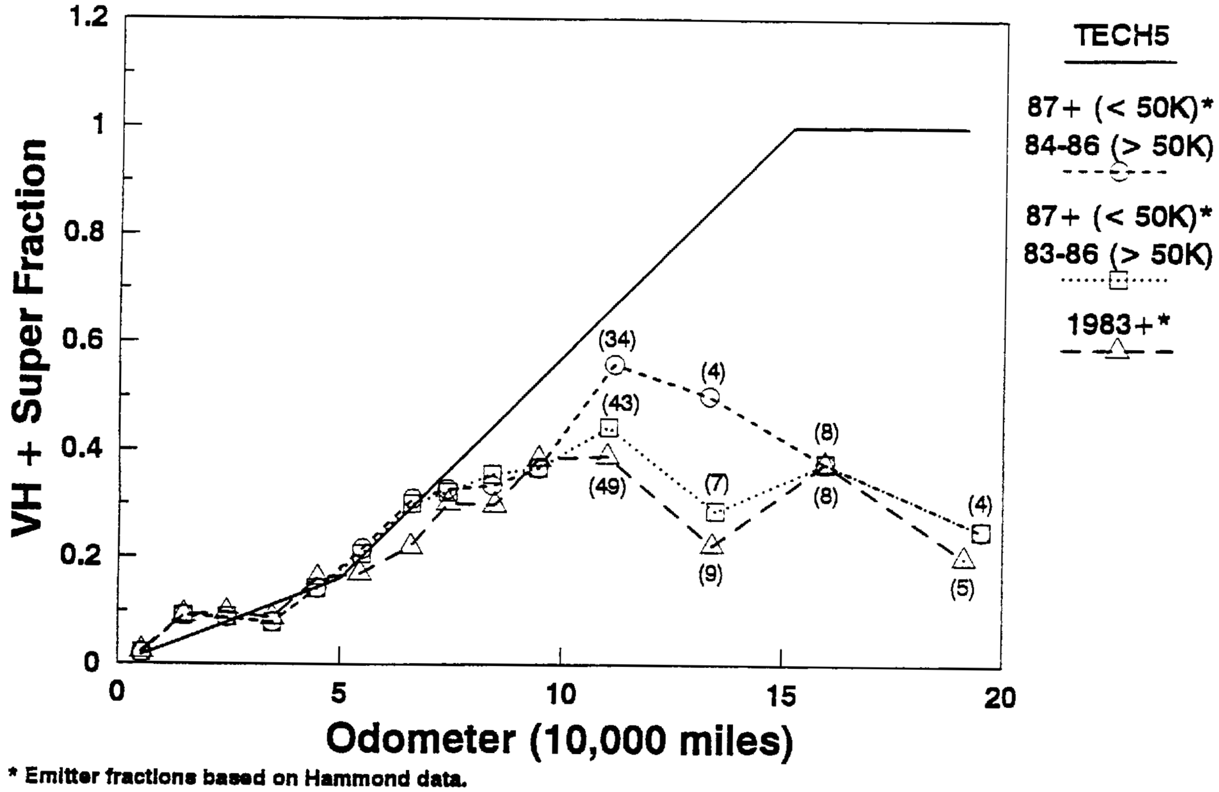

Figure ES-5. Comparison of [Very High + Super] Emitter Fractions - TECH5 vs. Hammond Data for MPFI/CL Vehicles

This approach resulted in a step function increase in the number of super emitters at 100,000 miles from 1.7% to 3.7%.

Based on a review of the procedures that EPA used to develop the emitter category emission rates and growth rates for MOBILE5a, it is apparent that the data were analyzed in a subjective and inconsistent manner. Emission rates were generated in a completely different fashion than emitter growth rates, analysis methods differed by emitter category, and modifications to the methods to account for technology differences were not applied consistently when the emission rates and growth rates were estimated.

Alternative Methodology

Because a number of assumptions used by EPA to develop the base emission rate equations for MOBILE5a appear somewhat questionable, an alternative analysis was performed in which HC and CO base emission rates were developed for 1983 and later MPFI/CL vehicles. Although not a detailed analysis, the evaluation provides an alternative to the MOBILE5a approach. The alternative method generally follows that developed by EPA and demonstrates that with just a few seemingly minor changes (i.e., basing the emitter category emission rates on 1983+ model years, and developing the emitter category growth rates with a regression technique that more appropriately reflected the influence of high mileage vehicles), the resulting base emission rates are significantly impacted. This is illustrated in Figure ES-6, which shows the HC emission rates predicted by TECH5 and the alternative analysis. As seen, the emission rates calculated by the two methods deviate substantially at mileages above 50,000. The 1983+ MPFI/CL vehicle mean emission rates by vehicle mileage calculated from the Hammond data are also shown in the figure. These show much better agreement with the alternative analysis. Clearly, the base emission rates developed for MOBILE5a represent a worst-case scenario for emission control system deterioration.

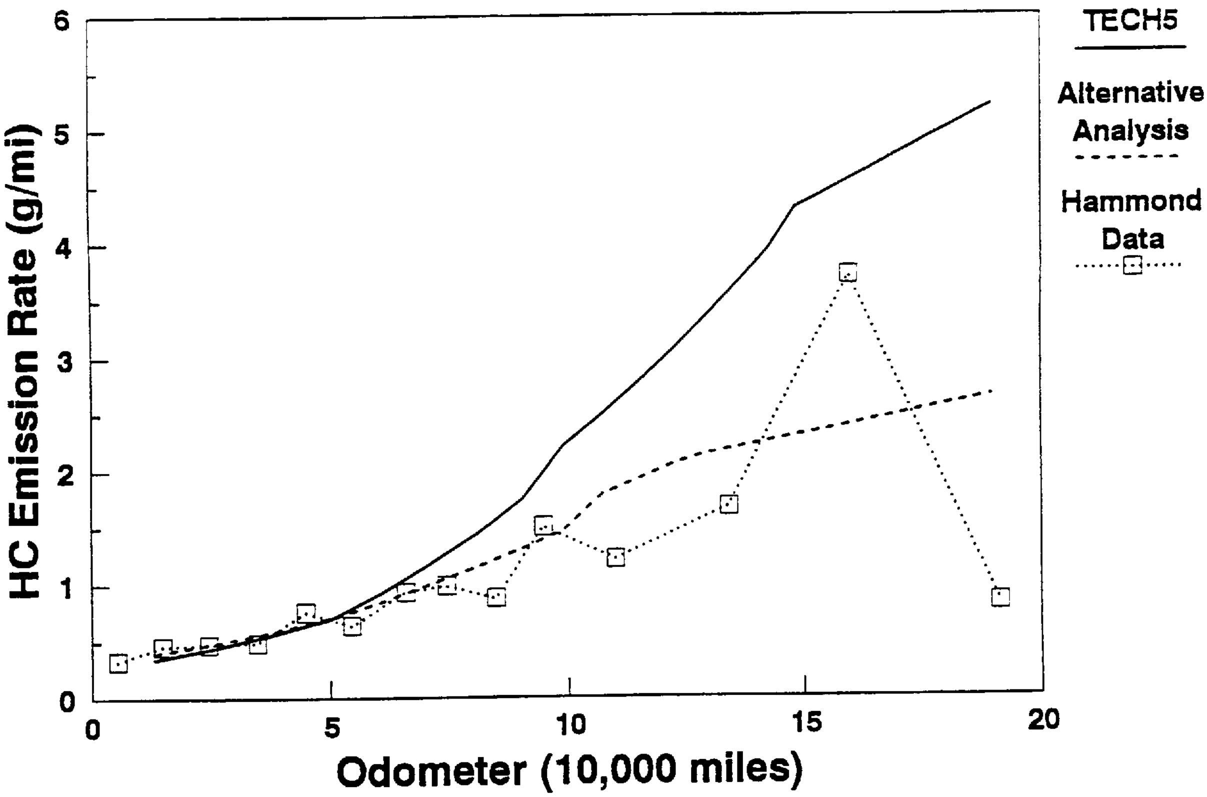

Figure ES-6. Comparison of MPFI/CL Exhaust Emission Rates - TECH5 vs. Alternative Analysis Methodology

Section 1
INTRODUCTION

BACKGROUND

EPA's emission factors model, MOBILE5a, is being used increasingly as a regulatory tool for evaluating the impacts of policies and motor vehicle control programs. For example, MOBILE is used to evaluate compliance with enhanced I/M regulations and for conformity determinations. Further, output from the model was used in the development of the Complex model which will be used by refiners to determine if particular fuel formulations comply with the reformulated gasoline performance standards. Because of EPA's reliance upon the MOBILE series of models, the American Petroleum Institute (API) contracted with Sierra Research, Inc. (Sierra) to perform an evaluation of MOBILE5a, with particular emphasis on how inspection and maintenance (I/M) programs are modeled. Subsequent to the completion of that effort[1*], API amended the contract and issued a revised statement of work authorizing the following work:

- critique of the fuel and temperature adjustments developed by EPA to correct data collected using the IM240 emissions test procedure for variations in fuel and temperature relative to those specified for the Federal Test Procedure (FTP);
- explanation and critique of the correlations between emissions based on the IM240 test procedure and emissions measured on the FTP that were developed by EPA;
- evaluation and critique of the methodology used by EPA to develop the emission control system deterioration rates for MOBILE5a; and
- assessment of the degree to which MOBILE5a predictions overestimate or underestimate actual in-use data and recommendations for alternative methodologies to estimate in-use exhaust emission rates.

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* Superscripts denote references listed at the end of this report.

This report documents the additional analyses noted above and summarizes the results that were presented in the technical memoranda submitted to API during the course of this study.

ORGANIZATION OF THE REPORT

Immediately following this introduction, Section 2 provides a discussion of the IM240-to-FTP correlation. This includes an analysis of the fuel and temperature adjustments employed by EPA to account for variations between the lane conditions and the laboratory FTP tests, an evaluation of the correlation procedure used by EPA, and a recommended alternative to that approach. Section 3 compares the exhaust emission and deterioration rates from MOBILE5a to the data that were used to develop those rates. In addition, IM240 data from EPA's I/M test program in Mesa, AZ, are compared to those collected in Hammond, IN. New correlation equations relating the IM240 results to the FTP for the Arizona data are also presented in Section 3, and the resulting FTP values are compared to the Hammond, IN, data.

Section 2
IM240-TO-FTP CORRELATIONS

BACKGROUND

With the development of MOBILE5a, EPA made a significant departure from the historical method of using its Emission Factors data base to develop exhaust base emission rate equations (i.e., the non-I/M emission rates input to the model). In previous versions of MOBILE, data used for the base emission rates were collected through a process often referred to as "surveillance" testing, where vehicle owners are randomly contacted (usually by letter) and asked to give up their cars for a week of testing. Over the years, EPA has become concerned that the vehicles they receive for surveillance testing are not representative of the in-use fleet, particularly with respect to the fraction of poorly maintained, high-emitting vehicles. This has been primarily attributed to a sample selection bias, e.g., if vehicle owners know that their car has been poorly maintained or has been tampered, they will not voluntarily submit it for emissions testing.

To overcome sample bias concerns, EPA used IM240 emissions data collected during the initial two years of an inspection and maintenance (I/M) program in Hammond, IN, to develop the exhaust base emission rate equations for MOBILE5a.* It was felt that this approach would provide an unbiased sample because vehicle owners had to participate in the program. However, because all of the exhaust emission relations (e.g., temperature corrections, speed corrections, etc.) contained in MOBILE are based on FTP testing with certification fuel (Indolene), a means to convert the IM240 data collected at the lane on tank fuel to an FTP/Indolene basis was needed. This conversion process was a multi-step procedure, consisting of the steps listed below.

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* Vehicles were tested in their first I/M "cycle" and therefore the data represent emissions from a non-I/M fleet.

- Factors that accounted for the differences in ambient temperatures and fuel characteristics between conditions experienced during IM240 testing at the I/M lane and IM240 testing in the laboratory were developed from a subset of Hammond lane vehicles.

- Those factors were used to convert all the Hammond lane IM240 data (tested with tank fuel) to a laboratory/Indolene IM240 basis.

- Correlation equations between IM240 emissions measured in the lab on Indolene and FTP values in the lab on Indolene were developed from a sample of vehicles.

- These correlation equations were then applied to all of the Hammond IM240 data (adjusted for fuel and temperature differences) to put all data on an FTP/Indolene basis.

- In the application of the above correlation equations, residuals from the IM240-to-FTP regression analysis were randomly applied to the data.

Although each of these steps is evaluated and discussed in detail below, it is helpful to first review the process on a single vehicle. As an example, consider vehicle number 12612 from the Hammond data base, which was a 1985 multi-point fuel-injected, closed-loop (MPFI/CL) vehicle tested on 8/9/90 with an odometer reading of 66,177 miles. The lane IM240 exhaust HC score for this vehicle was 0.18 g/mi. Applying the seasonal fuel/temperature adjustment factor (to put the lane score on a lab/Indolene basis) gives:

$$IM240_{Lab/Indo} = 0.8229 * 0.18 \text{ g/mi} = 0.148 \text{ g/mi}.$$

The IM240 lab/Indolene score is then used in conjunction with the IM240-to-FTP correlation equation:

$$\mathrm{Log}_{10}(FTP - X) = b + m*\mathrm{Log}_{10}(IM240_{Lab/Indo}) + res$$

where X represents the cold start offset, b and m are the intercept and slope, respectively, from the regression analysis, and res is a randomly applied residual from the correlation sample. For 1983+ MPFI vehicles, EPA's contractor found that b was insignificant at the 95% confidence level; thus, the correlation for this technology group was modeled without an intercept. The slope (m) in this case was 0.952, X was 0.2088*, and the residual applied to this vehicle was -0.04994. The FTP value calculated from these parameters was then:

$$\mathrm{Log}_{10}(\mathrm{FTP} - 0.2088) = 0.952*\mathrm{Log}_{10}(0.148) - 0.04994$$

$$\mathrm{FTP} = 0.3534 \text{ g/mi}$$

The same procedure was used to calculate FTP values from all of the Hammond lane IM240 scores. However, for vehicles that had received FTP testing as part of the test program (about 400 vehicles), the actual FTP values were used in place of the IM240-based results.

The data bases used to perform the above analyses can be summarized as follows.

- The original Hammond lane IM240 data set used for MOBILE5a consisted of 6,597 light-duty gasoline vehicles (LDGVs). EPA made adjustments to this data base to more accurately reflect the fraction of foreign vehicles (i.e., foreign vehicles were counted 2 to 4 times), remove data points with missing or suspicious odometer readings, and delete data collected on 15 test dates in March and April when the ambient temperature was 25°F or more above the monthly average. The final data set used for analysis consisted of 6,826 vehicles.

- The IM240 lane/tank-to-lab/Indolene data base consisted of 380 vehicles. These vehicles are a subset of the Hammond lane IM240 data base and were recruited for additional testing at the EPA contractor's laboratory in Indiana. A series of tests were performed on these vehicles at the lab, including IM240 tests on tank fuel, IM240 tests on Indolene, and FTP tests on Indolene. In EPA's final analysis of the seasonal fuel and temperature corrections, 48 vehicles were removed from this data set, but the reason(s) for their removal is not documented.

* Note that "X" is a function of vehicle mileage and is calculated individually for each vehicle. A more thorough description of this parameter is contained in a later section of this report.

- The IM240-to-FTP correlation sample consisted of 637 1981 and later model year LDGVs. Both IM240/Indolene and FTP/Indolene tests were performed for all vehicles in this data set, 413 of which were a subset of the Hammond IM240 data and 224 of which were tested at EPA's Ann Arbor lab as part of their standard surveillance testing.

It should be noted that the data collected in Hammond were primarily from 1981 and later model year vehicles. Thus, only the 1981 and subsequent exhaust emission factors were revised with the release of MOBILE5a. The pre-1981 exhaust emission factors have not been revised in over 10 years.

DEVELOPMENT OF LANE-TO-LAB (I.E., FUEL/TEMPERATURE) ADJUSTMENTS

<u>MOBILE5 Methodology</u>

To develop IM240-to-FTP correlations, several approaches can be taken. Two more obvious choices are (1) to develop correlations between the IM240 scores collected at the <u>lane</u> on tank fuel and the FTP conducted in the lab with Indolene, or (2) to develop correlations between IM240 data collected at a <u>laboratory</u> on Indolene and the FTP conducted with Indolene. (Because of the way MOBILE5a is structured, the base emission rates need to be developed with FTP/Indolene data.) Since the correlations are ultimately applied to all lane data, the latter approach necessitates the development of an adjustment to get the lane data on a lab/Indolene basis. The correlations for the Hammond data were based on the second method. Presumably, that approach eliminated some of the variability in IM240 scores because tests were conducted in the lab on a standardized fuel. In addition, that approach allowed the use of IM240 and FTP data collected at the Ann Arbor lab, which increased the correlation data sample size by over 50%.*

* An issue related to the IM240-to-FTP procedure is how well the lane scores correlate with bag 3 of the FTP. Since the IM240 was developed from a portion of bag 3, the correlation should be reasonably good. If it is not, then the appropriateness of using IM240 scores to predict FTP values is questionable. Appendix A further discusses this point.

As alluded to above, a significant drawback in choosing to develop the IM240-to-FTP correlations from lab/Indolene IM240 scores is that an adjustment must be made to account for the differences between the lane and the lab. For the Hammond data, EPA felt that those differences were primarily related to tank fuel versus Indolene and the temperature differences occurring between the lane and the lab.* In reviewing the data from the Hammond data base in which lane/tank and lab/Indolene IM240 scores are available, EPA's contractor concluded that the differences observed were seasonal in nature. This is illustrated in Figure 2-1, which shows the ratios of the lane/tank IM240 HC scores to the lab/Indolene HC scores (by month) for the 380 vehicles that received both tests.**

Several items are worth noting with respect to Figure 2-1. First, the sample size for some of the months is very small. Given the inherent scatter associated with vehicle emission data, it is unclear if the month-by-month differences are real or are due to test variability. In fact, the number of vehicles that had lane/tank fuel and lab/Indolene scores that differed by more than a factor of three was significant. Of the 380 vehicles included in this data set, this occurred (for HC, CO, and/or NOx) with 117 vehicles. Although some of these vehicles had relatively low IM240 scores (e.g., below 0.2 g/mi HC) where equipment sensitivity and background concentrations may have been an issue, the majority had emission rates above that point. In addition, analyzing the laboratory IM240 tests conducted on tank fuel does little to help explain the unreasonably large differences observed between some of the

* It could also be argued that numerous other differences impact test variability between the lane and the lab. These include items such as vehicle preconditioning, inconsistent dynamometer settings, and the ability of test personnel to follow the IM240 speed-time profile.

** In developing the lane-to-lab adjustments, EPA took the mean value of the lab/Indolene scores and divided that result by the mean value of the lane/tank fuel scores for the same set of vehicles (i.e., the ratio of the means). This results in a different value than taking the mean of the ratios. EPA followed this approach because they felt that the results were more reflective of a "fleet-average" value.

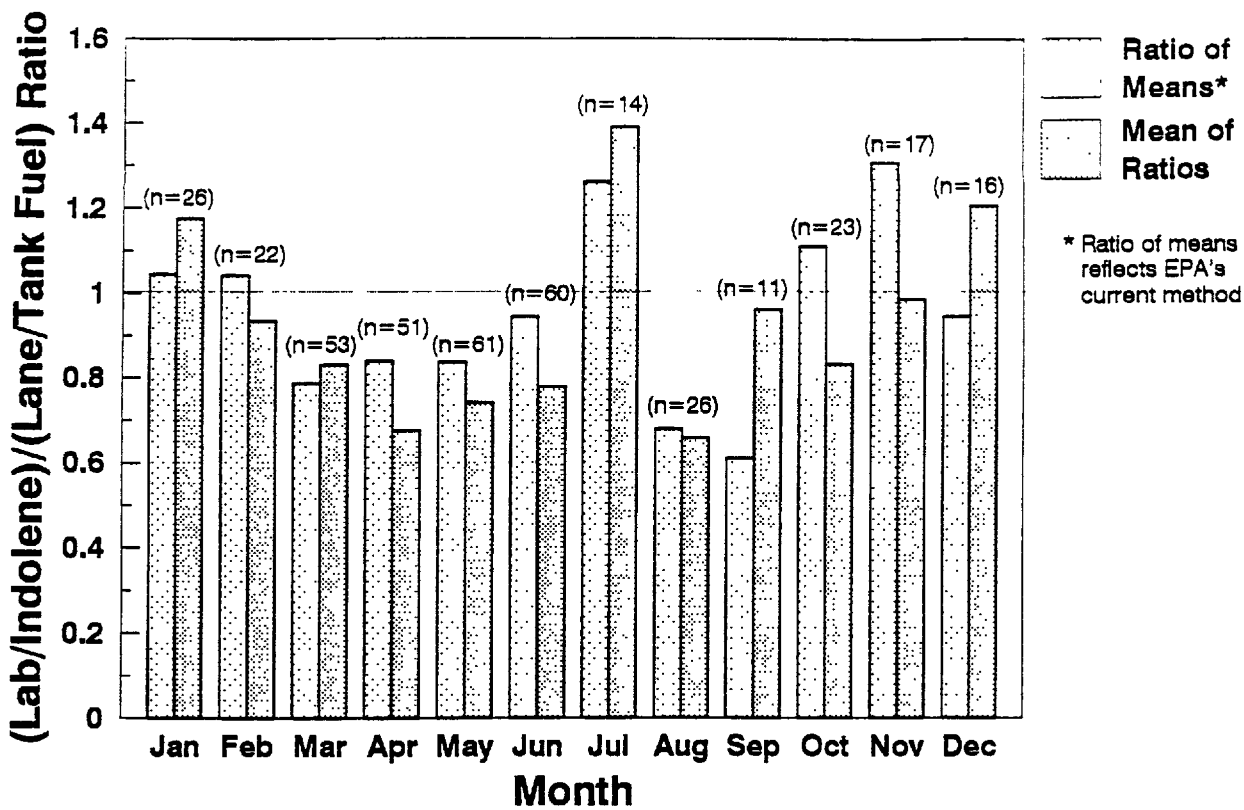

Figure 2-1. Lane/Tank Fuel vs. Lab/Indolene IM240 HC Ratios by Month (Sample sizes indicated in parenthesis.)

lane/tank fuel and lab/Indolene scores. As an example, consider vehicles 576 and 583. Vehicle 576 had lane HC and CO scores well below the lab/Indolene results, while the lane results for vehicle 583 were significantly above the lab/Indolene results:

	Lane/Tank		Lab/Tank		Lab/Indo	
Vehicle	HC	CO	HC	CO	HC	CO
576	0.75	6.69	2.24	13.03	3.61	57.60
583	0.31	3.20	0.34	4.53	0.17	0.16

For vehicle 576, it appears that a failure of the emission control system may have occurred between the time that it was tested at the lane and when it was tested at the lab. It is not reasonable to expect that emissions would increase 3 times for HC and nearly double for CO by running the vehicle on the same fuel at the lab versus the lane. The results got even worse when the fuel was switched to Indolene. On the other hand, vehicle 583 had relatively constant results when comparing the lane/tank fuel and lab/tank fuel data. However, when tested on Indolene, CO emissions decreased by 20 times. Clearly this is not solely the result of switching fuels.

A second point to be made in reference to Figure 2-1 is that both the ratios of the means and the means of the ratios are shown. As might be expected, the results are often very different, particularly for the months with a small sample size where individual vehicles can have a significant influence on the overall results. Although EPA ultimately chose to use the ratio of means in the development of the seasonal fuel and temperature adjustments, it is unclear that this choice is completely defensible. That is because the adjustment factors were applied to individual data points; thus, it can be argued that the adjustment factors should also be developed from individual data points (i.e., the mean of a sample of ratios). However, given the wide variability in the data (which simply cannot be fully explained by fuel and temperature effects), they appeared to feel more comfortable with an averaging approach.

Prior to developing the final fuel/temperature corrections, EPA's contractor consolidated the data into "seasons," consisting of:

- March and April,
- May and June,
- July through September, and
- October through February.

In addition, the data were further stratified according to emission level. The emitter groups chosen for this analysis were:

- Normal HC/CO - lane IM240 below 1.64 g/mi HC and 13.6 g/mi CO,
- High HC/CO - lane IM240 above 1.64 g/mi HC or 13.6 g/mi CO,
- Normal NOx - lane IM240 below 2.0 g/mi NOx, and
- High NOx - lane IM240 above 2.0 g/mi NOx.

Once the data were segregated as outlined above, the mean emission levels for the lane/tank fuel scores and the lab/Indolene scores were determined. Adjustment factors, shown in Table 2-1, were then developed from the ratio of these mean values.

Table 2-1. Final Seasonal Fuel/Temperature Adjustments Used for MOBILE5a (Ratio of Lab/Indolene IM240 Scores to Lane/Tank Fuel IM240 Scores)

Pollutant	Emitter Group	Seasonal Adjustment Factor			
		Mar-Apr	May-Jun	Jul-Sep	Oct-Feb
HC	Normal High	0.766 0.851	0.884 0.940	0.823 0.935	0.880 1.137
CO	Normal High	1.072 0.934	1.007 1.038	0.792 0.880	1.036 1.074
NOx	Normal High	0.809 0.784	0.825 0.736	0.913 0.669	0.862 0.826

In the final fuel adjustments shown in Table 2-1, it appears that 48 vehicles were dropped from the original sample of 380. Although EPA staff has been contacted regarding the deletion of these test points from the sample, they have been unable to identify the exact vehicles and the reasons for deleting those vehicles. Several theories have been offered, but those theories are inconsistent with the final sample sizes used in the analysis. For example:

- The test dates in March and April with temperatures 25°F above the mean that were deleted in the lane data were also deleted for the seasonal adjustments.

  This impacts 30 vehicles in the seasonal adjustment data base, not 48, and the number of vehicles deleted from the Mar-Apr season was only 15. This means that at least some of the vehicles from the test dates where the ambient temperature was 25°F above average were used in developing the seasonal adjustment factors.

- Vehicles with lane-to-lab ratios above or below a certain point (e.g., above 3.0 or below 0.33; above 10 or below 0.1) were deleted.

  This also does not appear to be the case because at least some vehicles with ratios outside the cutpoints discussed in the EPA and contractor correspondence remained in the final analysis.

- Pre-1981 vehicles were deleted from the sample.

  This also does not explain the deleted data points since it appears that several pre-1981 vehicles were left in the final sample.

The effect of the fuel and temperature adjustments on the IM240 HC scores for 1983 and later MPFI/CL vehicles is illustrated in Figure 2-2. The figure shows the mean IM240 HC scores by odometer "bin" (i.e., 0-10,000 miles, 10,000-20,000 miles, etc.; beyond 100,000 miles, the bins were defined in 25,000-mile increments) for the unadjusted lane results and with the above adjustments applied. The effects of the adjustments are fairly moderate, with the corrected emission levels decreasing by 5% to 15% in most cases. (One exception is the 125,000-150,000 mile bin, which showed a slight increase in the adjusted scores; however, the sample size of this bin is very small (9 vehicles). Up through the 100,000-125,000 mile bin, the sample size is at least 47 vehicles, while bins under 80,000 miles all have 100 vehicles or more.)

Given the above, development of the seasonal fuel and temperature adjustments does not appear to have much value and adds a degree of uncertainty to the resulting lab/Indolene based IM240 scores. However, it should be pointed out that both EPA and the contractor performing the lane-to-lab analyses appeared to be truly grappling with the most appropriate approach to use in developing these adjustments, and numerous memos outlining various approaches and correlations were sent to EPA during the course of development. Unfortunately, the rationale underlying the choice of the final data set used to develop the corrections was not documented. It is not clear why the IM240-to-FTP correlations were not simply developed without seasonal fuel and temperature adjustments to the data (i.e., based on the lane IM240 scores).

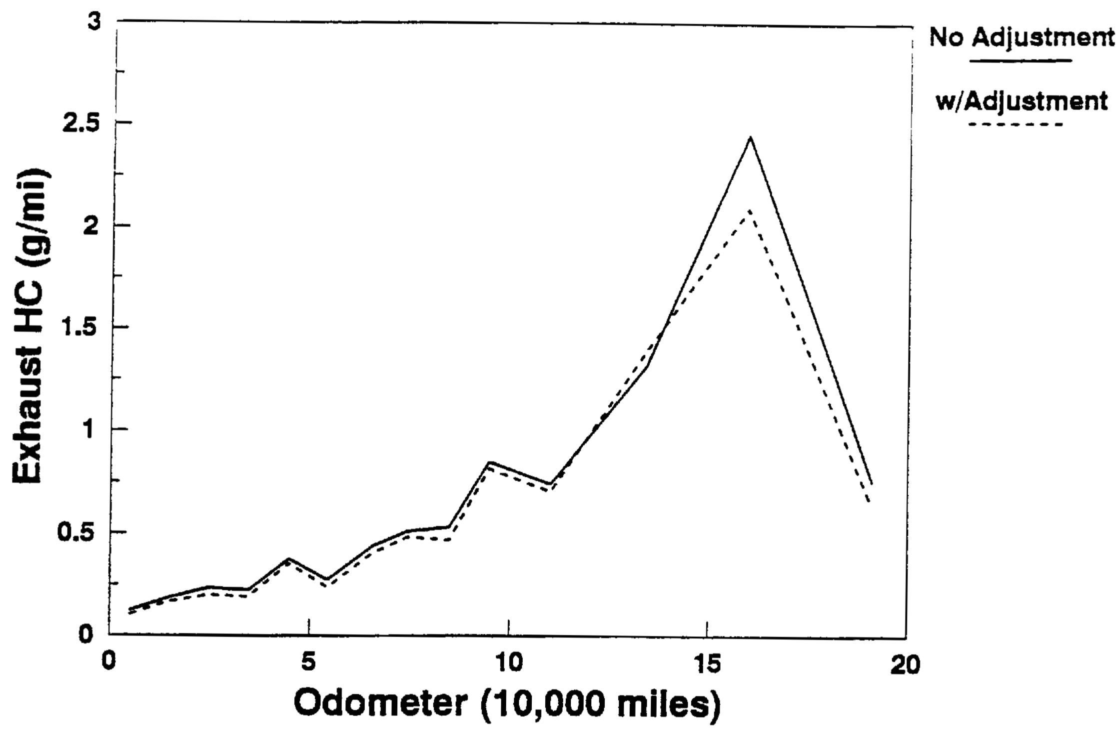

Figure 2-2. Effect of Seasonal Fuel/Temperature Adjustments on 1983+ MPFI IM240 HC Emission Rates

Regression Analysis of Lane-to-Lab Adjustments

The analysis above indicates that there is considerable variation among IM240 test results (i.e., lane-to-lab on tank fuel and lab/tank fuel to lab/Indolene) for many of the vehicles. Since IM240 test results should be largely repeatable (i.e., within +/- 50%), a large variation might indicate a flaw in the test procedure employed in the program. To investigate these concerns, a series of checks were performed to validate the quality of the data.

One method of assessing the consistency between the lane and lab scores is to perform a regression analysis and evaluate the regression statistics. This was accomplished by regressing the lab/Indolene IM240 scores against the lane/tank fuel IM240 scores; the regression statistics for HC, CO, and NOx are summarized in Table 2-2 for 1981 and later vehicles.* As evidenced in the table, the correlation coefficients (R-square values) are not particularly strong. Part of the reason for this is that a substantial number of vehicles had lane/tank fuel and lab/Indolene HC, CO, or NOx IM240 scores that differed by a factor of 3 or more, as shown in Table 2-3.

Table 2-2. Regression Results of Lab/Indolene IM240 Scores vs. Lane/Tank Fuel IM240 Scores

Pollutant	Sample Size	Slope		Intercept		R-Square
		Value	Prob > |T|	Value	Prob > |T|	
HC	345	0.957	0.0001	-0.095	0.2530	0.67
CO	345	0.892	0.0001	2.028	0.1649	0.66
NOx	345	0.697	0.0001	0.077	0.1445	0.71

Table 2-3. Distribution of Vehicles Based on the Ratio of Lane/Tank Fuel and Lab/Indolene IM240 Scores

Pollutant	< 2X Difference[a]		2X-3X Difference[a]		≥ 3X Difference[a]	
	Number	Fraction	Number	Fraction	Number	Fraction
HC	205	0.594	68	0.197	72	0.209
CO	225	0.652	49	0.142	71	0.206
NOx	271	0.786	45	0.130	29	0.084

[a] Refers to the ratio of lane/tank fuel to lab/Indolene scores, e.g., $IM240_{Lane/Tank} = 0.20$ and $IM240_{Lab/Indo} = 0.60$ differ by a factor of 3.

* It appears that in EPA's analysis, several pre-1981 vehicles were included. The impact of these vehicles on the overall results, however, is not likely to be very significant.

The regression results summarized in Table 2-2 include tests conducted over all seasons. To determine if seasonal differences significantly impacted the results (i.e., changed the correlation statistics), the same evaluation was performed over the four seasons defined in EPA's analysis: March/April, May/June, July-September, and October-February. A summary of the R-square values for each of these seasons is contained in Table 2-4. As seen in the table, running the regressions by season showed mixed results, with some pollutant/season combinations improving, while others worsened (i.e., there does not appear to be a strong statistical basis for seasonal adjustments). The same result is also observed if all vehicles with lane/tank fuel and lab/Indolene HC, CO, or NOx IM240 scores that differ by a factor of 3 or more are removed from the analysis. (As expected, the absolute value of the R^2 statistic improved greatly when these vehicles were removed from the analysis.) This is shown in Table 2-5.

Table 2-4. Summary of R-Square Values by Season for the Lab/Indolene vs. Lane/Tank IM240 Fuel Correlations

Season	Sample Size	R^2 Value		
		HC	CO	NOx
Mar/Apr	90	0.59	0.75	0.84
May/Jun	104	0.52	0.74	0.85
Jul-Sep	51	0.71	0.49	0.48
Oct-Feb	100	0.86	0.60	0.60
All Data	345	0.67	0.66	0.71

Several methods have been suggested to account for the lane/tank fuel and lab/Indolene differences, but there remains no strong evidence to support one choice over another. Although seasonal fuel and temperature effects would be expected to influence the lane/tank fuel scores, analyzing data according to season does not appear to greatly improve the correlation statistics.

Table 2-5. Summary of R-Square Values by Season for the Lab/Indolene vs. Lane/Tank Fuel Correlations (All Vehicles with IM240 HC, CO, or NOx Scores Differing by Three Times or More Deleted)

Season	Sample Size	R^2 Value		
		HC	CO	NOx
Mar/Apr	61	0.89	0.94	0.93
May/Jun	65	0.80	0.86	0.91
Jul-Sep	32	0.81	0.88	0.84
Oct-Feb	68	0.92	0.84	0.84
All Data	226	0.87	0.87	0.87

Alternative Fuel/Temperature Correction Factor Analysis

It is clear that many different approaches could be taken to develop fuel and temperature corrections. Thus, to assess the sensitivity of correction factors to different assumptions, an alternative analysis was performed. In attempting to develop a different fuel correction methodology, Sierra faced the same dilemma that EPA had to consider, i.e., the data do not show any strong trends upon which to base an analysis. Given that, considerable judgement had to be exercised when developing the lane-to-lab adjustments. Because similar RVP and temperature conditions at the lane would be expected to lead to similar trends in emission differences at the lab when the vehicle is operated on Indolene, the alternative analysis presented below also segregated data by season. However, the seasons were defined differently, based on ASTM volatility class and EPA's volatility rule. The volatility classes applicable to Indiana are:

Month	ASTM Class	Volatility Rule in Effect?
Jan	E	No
Feb	E	No
Mar	E/D	No
Apr	D	No

May	D/C	Yes
Jun	C	Yes
Jul	C	Yes
Aug	C	Yes
Sep	C	Yes
Oct	C/D	No
Nov	D/E	No
Dec	E	No

Based on the above, three seasons were defined: summer (May-Sep), winter (Nov-Feb), and spring/fall (Mar/Apr/Oct). In addition, the analysis was performed with the following data adjustments:

- only model years 1981 and later were considered;
- vehicles that had lane/tank fuel IM240 scores more than 10 times higher or lower than the lab/Indolene scores were deleted; and
- vehicles tested on dates in March and April when the ambient temperature was 25°F or more above the average were deleted (consistent with the treatment applied to the lane data).

Sierra also stratified the emission levels according to high/normal regimes, but chose 0.82 g/mi HC and 10.2 g/mi CO as the cutpoints for the HC/CO group. (This resulted in a more even distribution of vehicles between the normal and high groups.) Analyzing the data according to the parameters described above resulted in the adjustment factors shown in Table 2-6 (based on the mean of the ratios), and the application of these adjustments to the lane IM240 scores is illustrated in Figure 2-3. The figure indicates very little difference between the correction factors developed by EPA and those developed in this study, although the adjustments from this work are slightly lower. This again calls into question the value of developing fuel and temperature corrections; factors other than seasonal effects (e.g., vehicle preconditioning differences between the lane and the lab) may have contributed significantly to the differences observed between the lane scores and the lab scores.

Table 2-6. Alternative Seasonal Fuel/Temperature Adjustments (Ratio of Lab/Indolene IM240 Scores to Lane/Tank Fuel IM240 Scores)

Pollutant	Emitter Group	Season		
		Summer	Winter	Spr/Fall
HC	Normal High	0.823 0.832	0.850 1.118	0.690 0.857
CO	Normal High	1.073 0.987	0.949 1.131	1.088 1.025
NOx	Normal High	0.813 0.661	0.897 0.749	0.751 0.735

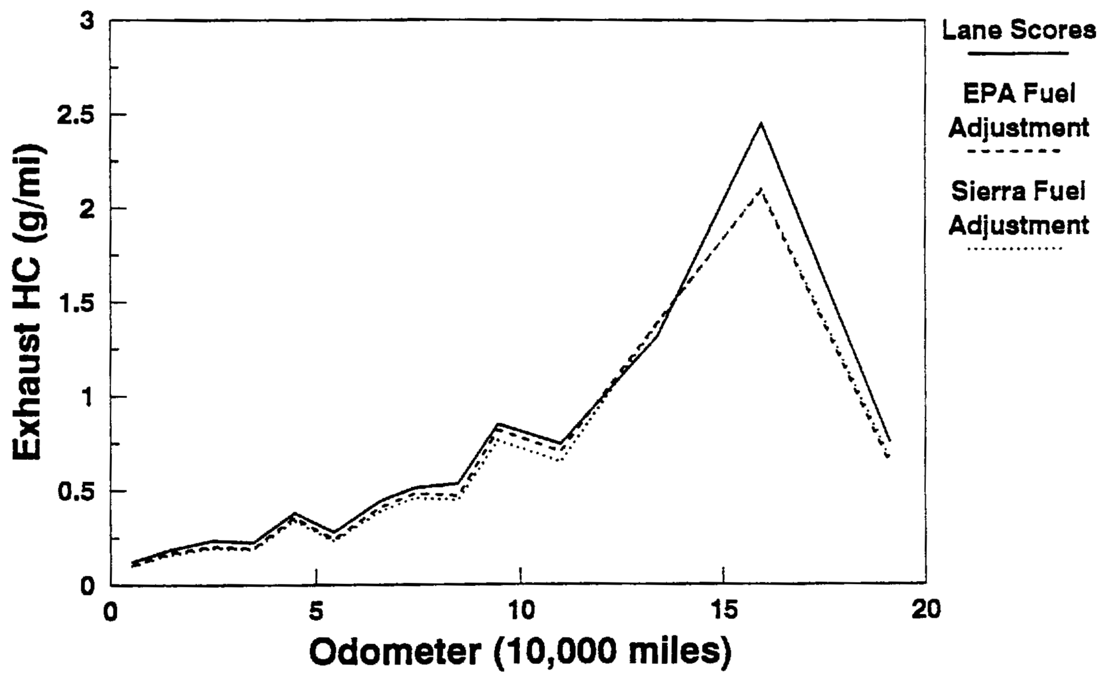

Figure 2-3. Effect of Seasonal Fuel/Temperature Adjustments on 1983+ MPFI IM240 HC Emission Rates, EPA vs Sierra Fuel Adjustments

DEVELOPMENT OF IM240-TO-FTP CORRELATIONS

MOBILE5a Methodology

Once the lane IM240 data were corrected to a lab/Indolene basis, correlation equations relating the IM240 to the FTP were applied to the data. The IM240-to-FTP correlations developed by EPA's contractor were based on a regression analysis of data collected from vehicles that were tested over the IM240 cycle on Indolene and the FTP on Indolene.* The regressions were performed according to the following model year groups and technology types:

- 1981-1982,
- 1981+ open-loop,
- 1983+ carbureted/closed-loop (CARB/CL),
- 1983+ throttle-body injection/closed-loop (TBI/CL), and
- 1983+ MPFI/CL.

For HC and CO, the correlations were performed in Log space, while the NOx correlations were based on a linear model.

A significant difference between the IM240 test and the FTP is that the IM240 is conducted with the vehicle in a warm stabilized state, whereas the FTP consists of a cold-start mode (bag 1), a stabilized mode (bag 2), and a hot-start mode (bag 3). The FTP g/mi results from each mode are then weighted according to the length of each segment and the expected occurrence of cold versus hot starts (which is based on data collected in the late 1960s and early 1970s). For the FTP, the weighting factors are 0.206 for bag 1, 0.521 for bag 2, and 0.273 for bag 3. The cold-start mode is particularly important in terms of its contribution to HC and CO FTP results because a large fraction of these emissions occur during this phase

* Note that this approach necessitated the development of the fuel and temperature corrections described in the last section (i.e., the lane IM240 data to which the correlations are applied must first be converted to a lab/Indolene basis).

of the test. For that reason, the HC and CO correlations were developed according to the following equation:

$$\mathrm{Log}_{10}(\mathrm{FTP} - \mathrm{X}) = \mathrm{b} + \mathrm{m}*\mathrm{Log}_{10}(\mathrm{IM240})$$

where X represents the cold-start offset, and $\mathrm{Log}_{10}(\mathrm{FTP} - \mathrm{X})$ was regressed against $\mathrm{Log}_{10}(\mathrm{IM240})$ to generate a slope (m) and an intercept (b). On the other hand, the cold-start mode is less important for NOx, and the NOx correlations were based on a simple linear equation (i.e., FTP = b + m*IM240).

The cold-start offset, X, was developed from the mean value of the difference between the FTP and the IM240 for normal emitters with an FTP value greater than the IM240 value, i.e., (FTP - IM240) was determined for each such vehicle and X was determined from the mean of this value.* (Although not clearly defined in the documentation received from EPA, normal emitters for this analysis appear to be those vehicles with FTP scores less than or equal to 0.82 g/mi HC and 10.2 g/mi CO.) For the case of 1983 MPFI/CL vehicles, the X offset for HC was determined to be 0.222. Using this value in conjunction with the above logarithmic equation resulted in an intercept value that was not significant at the 95% confidence level, so the regression was re-run based on a no-intercept model. That correlation resulted in a slope of 0.952, and the complete HC IM240-to-FTP equation for 1983+ MPFI/CL vehicles can be written:

$$\mathrm{Log}_{10}(\mathrm{FTP}_{HC} - 0.222) = 0.952*\mathrm{Log}_{10}(\mathrm{IM240}_{HC}).$$

---

* Although the X offset was developed only from normal emitters, the correlation equations were developed from FTP and IM240 scores from all vehicles in the sample. Also, the X offset was considered a constant in developing the regression equations. As described later in this section, when the correlation equations were applied to the lane IM240 data (which had been adjusted to a lab/Indolene basis), the X offset was modified to account for vehicle mileage.

It is interesting to note that EPA's contractor obtained very good R^2 values for most of the correlations that were performed. In the case of the HC correlation above, R^2 was 0.915. However, some alternative methodologies being investigated by Sierra (described below) did not demonstrate nearly as good a fit. That led to a closer evaluation of the correlations developed for MOBILE5a, which, as described below, revealed a very questionable technique that was employed on a substantial number of vehicles.

Vehicles that had FTP HC emissions below 0.222 g/mi created a problem in the above correlation equation. In those cases, the $(FTP_{HC} - X)$ value is negative, and it is not possible to take the logarithm of a negative number. To get around this problem, for cases in which the $(FTP_{HC} - 0.222)$ value was less than 0.01, the $(FTP_{HC} - 0.222)$ value was set to the IM240 value. When this occurred, the IM240 score was essentially being regressed against itself. Although the EPA contractor memo outlining this procedure indicated that "three or four cars were affected in most technology groups," this actually occurs for <u>82 of the 266 1983+ MPFI/CL vehicles included in the HC correlation sample</u>. Clearly, when one-third of a sample is regressed against itself, the correlation is likely to improve, and the R^2 values reported by EPA to support the IM240-to-FTP correlations are extremely misleading. Although the example cited above was the most extreme case of data replacement, it also occurred for CO and other technology groups. A summary of the number of vehicles for which this replacement was performed is contained in Table 2-7.

<u>Cold Start Offset</u>

An issue related to the IM240-to-FTP conversion procedure is the effect that vehicle mileage was assumed to have on the cold-start offset. From an engineering perspective, it makes sense that the cold-start offset would increase with vehicle age, particularly because catalysts take longer to reach light-off as they age. However, the way in which this effect was modeled is somewhat curious. (It is also difficult to understand by simply reading the limited documentation related to this.) The application of this effect is explained as follows.

Table 2-7. Number of Vehicles in the Correlation Sample in Which the (FTP-X) Value Was Replaced by the IM240 Score

Model Year	Technology Group	Sample Size	Occurrences of (FTP-X) Replacement	
			HC	CO
81-82	CLLP	58	3 (5.2%)	0 (0%)
1981+	OPLP	24	1 (4.2%)	1 (4.2%)
1983+	CARB/CL	73	13 (17.8%)	7 (9.6%)
1983+	TBI/CL	224	35 (15.6%)	8 (3.6%)
1983+	MPFI/CL	266	82 (30.8%)	41 (15.4%)

As discussed above, X in the correlation equations was developed from the mean of the (FTP - IM240) values from the correlation sample; thus, it reflects the cold-start offset at the mean mileage of the sample. At mileages less than this mean, it follows that X should be decreased by some amount to account for the fact that the catalyst has been aged less and would be more active. (Alternatively, X should be increased at mileages above the mean.) Thus, the cold-start offset is actually X plus an increment that is a function of vehicle odometer, i.e.,

$$\text{Cold-Start Offset} = f(x) = X + f(\text{Odometer}).$$

EPA has defined this f(Odometer) increment to be the "difference of the model year means regression for normal emitters and a 'New' line created by connecting a point on the model year means regression line at the mean mileage of the correlation sample with the zero mile level used in MOBILE4.1." In equation form, the cold start offset is described by:

$$f(x) = X + ZML_{MOBILE4.1} - ZML_{MY\ MEANS} + MILES * (DET_{'NEW'} - DET_{MY\ MEANS})$$

Although the above explanation is somewhat confusing, it is helpful to look at a plot of the two lines described above, which is shown in Figure 2-4. As seen, the f(Odometer) value is most pronounced at odometer readings away from the mean. For example, at zero mileage it is equal to -0.039 g/mi, making the cold-start offset equal to (0.222 - 0.039) or 0.183 g/mi. Thus, for 1983+ MPFI/CL vehicles, the cold-start offset is not dramatically influenced by vehicle mileage.

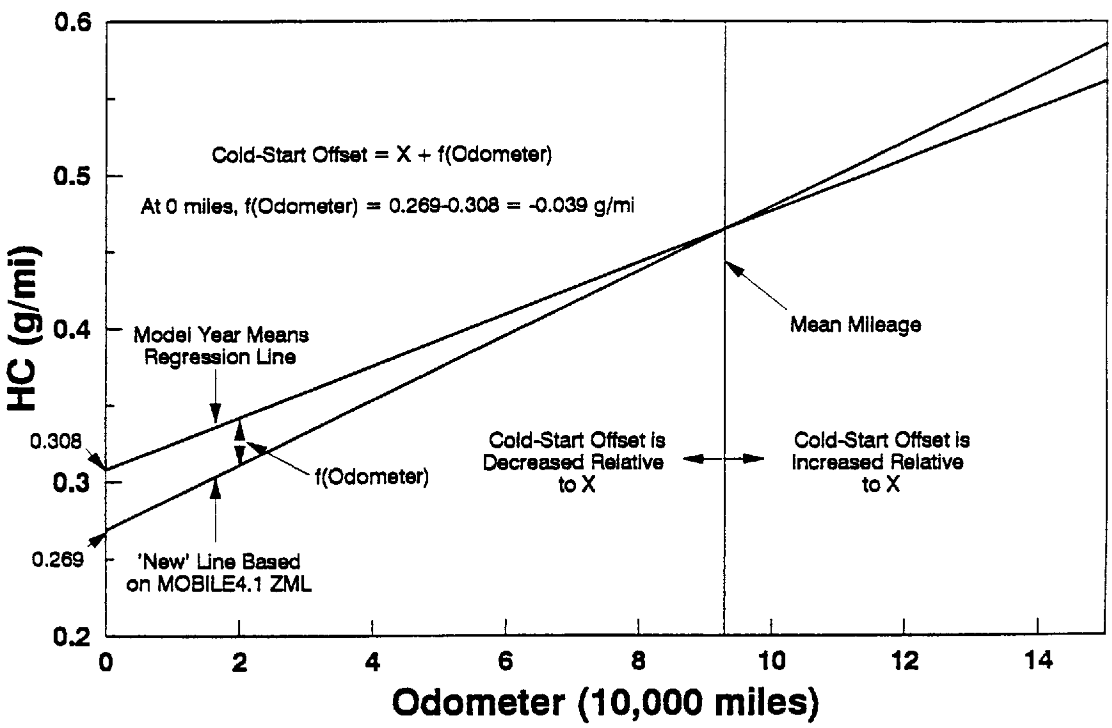

Figure 2-4 Change to the HC Cold-Start Offset as a Function of Mileage for 1983+ MPFI Vehicles

Effects of Adding Regression Residuals

Another point related to the IM240-to-FTP correlations is that when the correlation equations were applied to the lane IM240 data, EPA added randomized residuals to the equations before taking the anti-log, i.e.,

$$\mathrm{Log}_{10}(\mathrm{FTP} - X) = b + m*\mathrm{Log}_{10}(\mathrm{IM240}) + \mathrm{res}$$

where "res" represents regression residuals from the correlation sample. According to EPA staff, the reason for applying residuals is that emission data generally demonstrate considerable scatter, and adding residuals back into the correlation re-introduces that scatter. Although including residuals may be appropriate in some cases (e.g., I/M cutpoint analyses), it is inappropriate for the IM240-to-FTP conversion procedure and cannot be justified on statistical grounds. The impact of this adjustment was to <u>increase</u> the FTP results by about 20%. This is shown in Figures 2-5a and 2-5b, which give the HC and CO FTP values for 1983+ MPFI/CL vehicles both with and without the application of residuals.* (The same mileage bins were used in this figure as in Figures 2-2 and 2-3.) At first glance, it is unclear why the random application of residuals would cause an increase in average bin emission level. However, it appears that this is partially the result of the log transformation. For example, again taking 1983+ MPFI/CL vehicles, the correlation equation is:

$$\mathrm{Log}_{10}(\mathrm{FTP}_{HC} - 0.222) = 0.952*\mathrm{Log}_{10}(\mathrm{IM240}_{HC}) + \mathrm{res}$$

If a vehicle has an IM240 HC score of 0.6 g/mi, its FTP value without the addition of a residual (and neglecting the effect of mileage on the cold-start offset) would be 0.837 g/mi. Applying a residual of -0.1 would give 0.710 g/mi (a 15.2% decrease), and a residual of +0.1 would give 0.996 g/mi (a 19.0% increase). Thus, although the residuals may have been applied randomly, the net effect was an increase in the FTP values.

* It appears that residuals were not included in the NOx transformations.

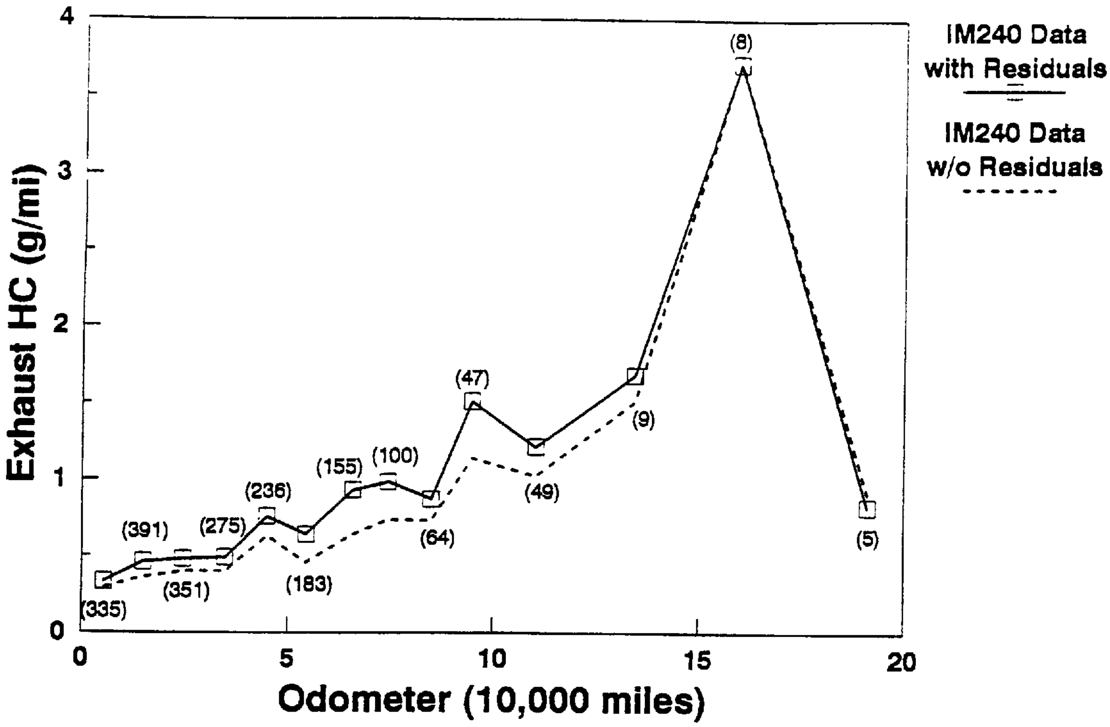

Figure 2-5a. Effect of Adding Residuals to IM240-Converted, FTP-Based 1983+ MPFI Exhaust HC Emission Rates (Sample sizes indicated in parenthesis.)

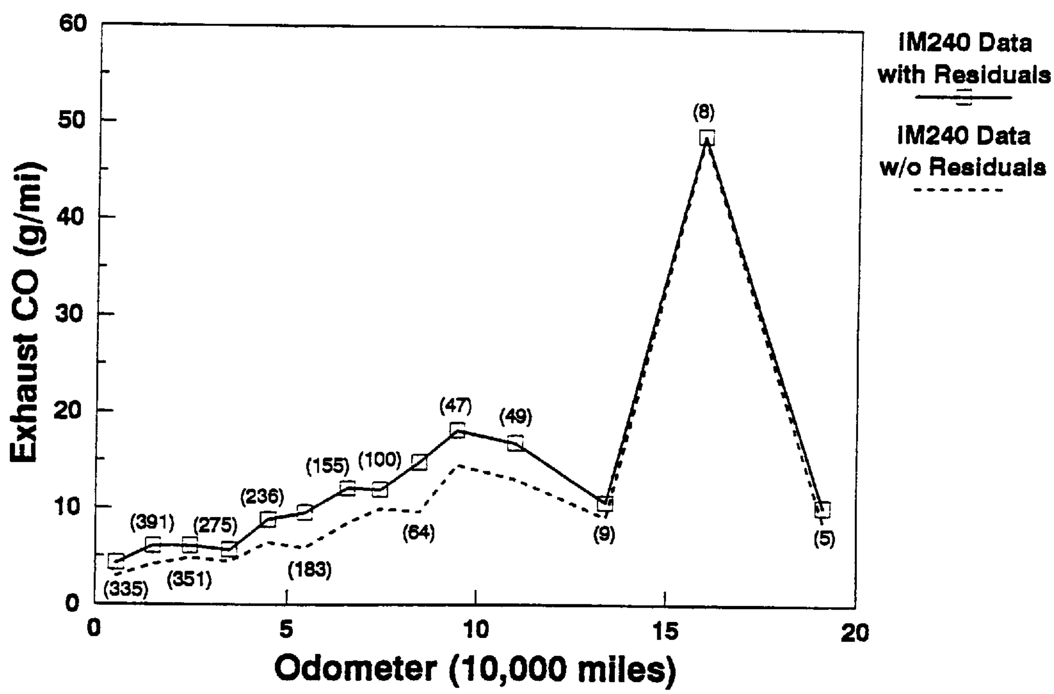

Figure 2-5b. Effect of Adding Residuals to IM240-Converted, FTP-Based 1983+ MPFI CO Emission Rates (Sample sizes indicated in parenthesis.)

Table 2-8 summarizes the impact of adding residuals on the distribution of normals, highs, very high, and supers (as defined in the TECH5 model) in the Hammond data base. As seen, addition of residuals increases the fraction of all non-normal emitter categories, with the most pronounced effect being on very high emitters. This results in an overall increase in emission rate.

Table 2-8. Effect of Adding Residuals on the Distribution of Emitter Categories by Technology Type for 1983 and Later Model Years.

Technology	Total Data Points	Emitter Category Fraction			
		Norm	High	V. High	Super
With Residuals[a]					
MPFI/CL	2208	0.788	0.077	0.131	0.004
TBI/CL	1991	0.718	0.141	0.135	0.007
CARB/CL	1654	0.540	0.149	0.303	0.008
OPEN LOOP	252	0.214	0.210	0.567	0.008
Without Residuals					
MPFI/CL	2208	0.902	0.060	0.036	0.002
TBI/CL	1991	0.805	0.108	0.084	0.003
CARB/CL	1654	0.654	0.119	0.223	0.004
OPEN LOOP	252	0.226	0.246	0.524	0.004

[a] Represents data used for MOBILE5a.

Effect of Multiple Counting of Foreign Vehicles

A final item related to the Hammond data base used to develop the base exhaust emission rates for MOBILE5a was the adjustment made to account for underrepresentation of foreign vehicles in Indiana. As described above, the foreign vehicles were counted multiple times to adjust their fraction in the data base so they matched the national fleet. This adjustment tended to slightly decrease HC and CO emission rates, while mixed results occurred for NOx. This is illustrated in Figures 2-6a to 2-6c for HC, CO, and NOx, respectively, for MPFI/CL vehicles. Table 2-9 shows how the distribution of emitter categories changed as a result of multiple counting foreign vehicles.

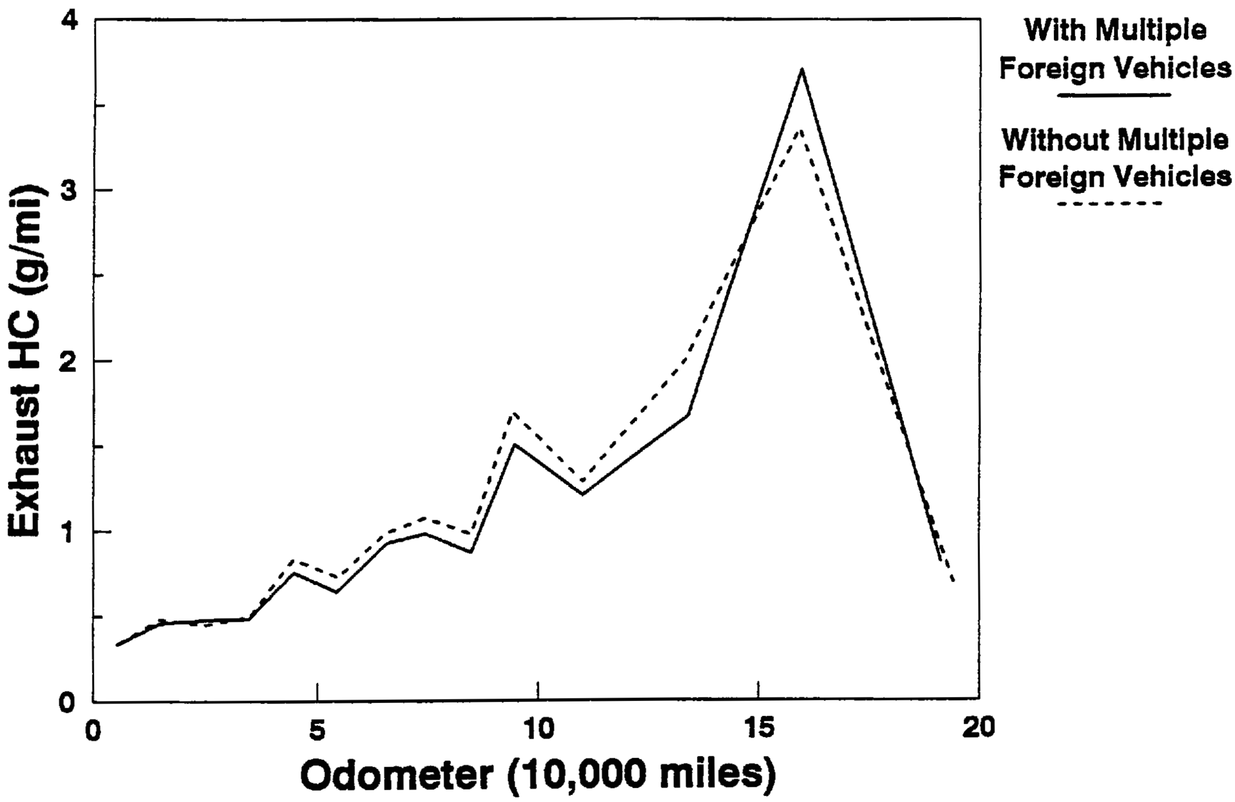

Figure 2-6a. Effect of Multiple Counting of Foreign Vehicles on the 1983+ MPFI HC Emission Rates

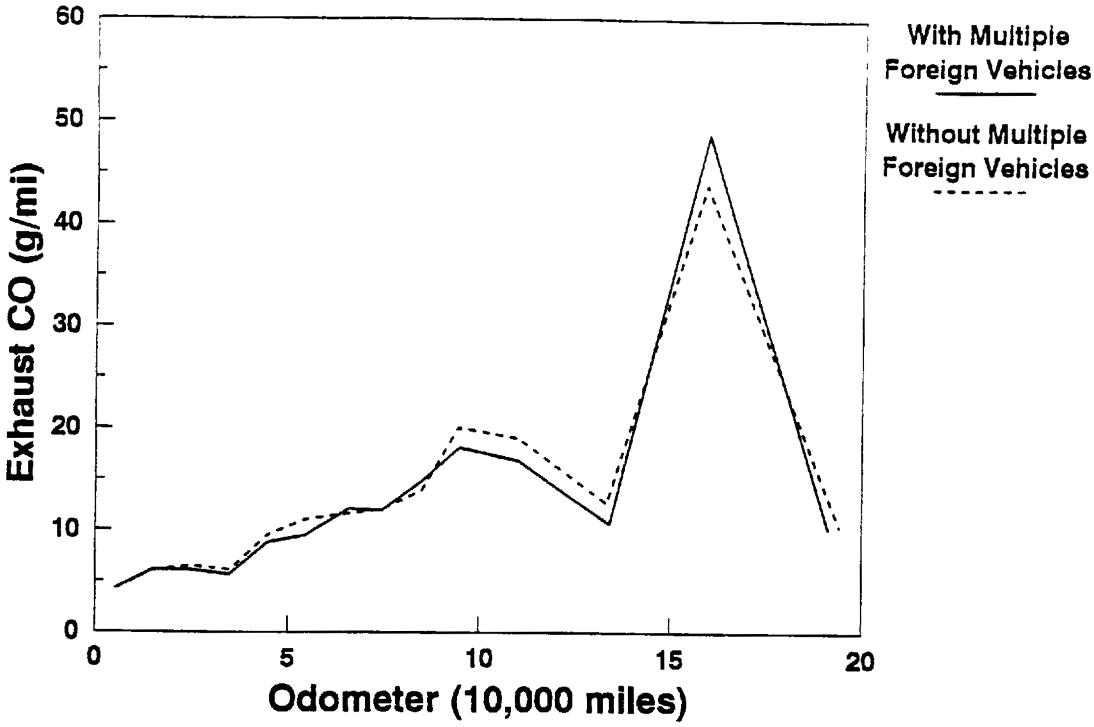

Figure 2-6b. Effect of Multiple Counting of Foreign Vehicles on the 1983+ MPFI CO Emission Rates

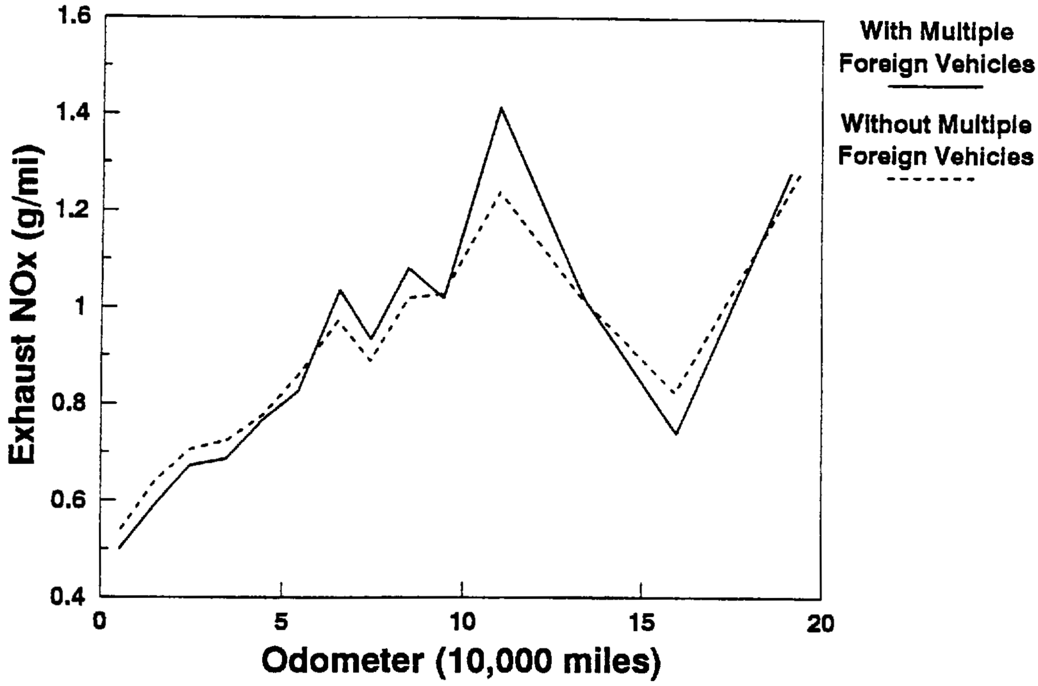

Figure 2-6c. Effect of Multiple Counting of Foreign Vehicles on the 1983+ MPFI NOx Emission Rates

Table 2-9. Effect of Multiple Counting of Foreign Vehicles on the Distribution of Emitter Categories by Technology Type for 1983 and Later Model Years.

Technology	Total Data Points	Emitter Category			
		Norm	High	V. High	Super
Multiple Foreigns[a]					
MPFI/CL	2208	0.788	0.077	0.131	0.004
TBI/CL	1991	0.718	0.141	0.135	0.007
CARB/CL	1654	0.540	0.149	0.303	0.008
OPEN LOOP	252	0.214	0.210	0.567	0.008
Single Foreigns					
MPFI/CL	1742	0.776	0.082	0.138	0.005
TBI/CL	1873	0.722	0.138	0.133	0.007
CARB/CL	1344	0.503	0.158	0.331	0.008
OPEN LOOP	196	0.189	0.194	0.607	0.010

[a] Represents data used for MOBILE5a.

ALTERNATIVE IM240-TO-FTP CORRELATION METHODOLOOGY

Several alternative methods to convert IM240 data into FTP values were investigated during the course of this study. The one that shows the most promise, and makes the most intuitive sense, separates stabilized operation and the cold-start offset. This approach is described below.

As discussed previously, the FTP is a compilation of three segments - cold start (Bag 1), stabilized (Bag 2), and hot start (Bag 3). Bag 1 consists of the first 3.59 miles of the LA-4 cycle and is conducted after the vehicle has "soaked" in a temperature-controlled environment for a period of 12 - 36 hours. Bag 2 is the final 3.91 miles of the LA-4, and at this point the vehicle is generally considered to be in a stabilized operating mode. After a 10-minute engine-off period, the first 3.59 miles of the LA-4 is re-run, and this constitutes Bag 3. A cold-start offset can be defined as the difference between Bag 1 and Bag 3 of the

FTP. Since these modes consist of the same speed-time profile, the difference in emission rates is the result of different starting conditions.

In addition to defining a cold-start offset, a "HOT FTP" can be defined as:

HOT FTP = 0.473*Bag 3 + 0.521*Bag 2

where the 0.473 value represents a "full" weighting of Bag 3 (i.e., 3.59 miles divided by 7.5 miles) and the units are grams/mile. Since the IM240 is also a "hot" test, correlations can be developed that relate IM240 scores to the HOT FTP. If the cold-start offset and HOT FTP values are obtained independently, the full FTP can be obtained from the following relation:

FTP = (0.206*Bag 1) + (0.521*Bag 2) + (0.273*Bag 3)

but,

Bag 1 = (Bag 3 + CS)

where CS is the cold start offset. Substituting this into the FTP equation gives:

FTP = [0.206*(Bag 3 + CS)] + (0.521*Bag 2) + (0.273*Bag 3)

FTP = (0.206*CS) + (0.473*Bag 3 + 0.521*Bag 2)

<u>FTP = 0.206*CS + HOT FTP</u>

Thus, the cold-start offset can be determined as a function of vehicle mileage from the correlation sample, and correlation equations relating the IM240 and HOT FTP can be determined by regressing the HOT FTP results against the lane IM240 scores (i.e., fuel and temperature adjustments were unnecessary). As explained below, this approach was used for HC and CO from normal emitting vehicles.

In developing alternative correlation equations, the data were first stratified according to their lane IM240 scores. One item that became apparent is that for IM240 scores above about 2.0 g/mi HC and 16.0 g/mi CO, the cold-start offset became negative for a number of vehicles (i.e., Bag 3 was greater than Bag 1). Thus, it was decided that the data would be broken into two regimes (normals and highs) based on the lane IM240 score, and regressions were performed on these sets independently.

For the analysis of normals, the HOT FTP results were regressed against the IM240 scores for HC and CO. However, because the cold-start offset was so variable for the high IM240 emitters, the full FTP results were regressed against the IM240 scores for that subset of vehicles. In addition, because the high IM240 vehicle sample was relatively small, all closed-loop technologies were combined. For NOx, there was no specific accounting for the cold-start offset and the full FTP values were regressed against the IM240 scores. The results of this regression analysis are summarized in Table 2-10 for MPFI/CL vehicles and Table 2-11 for TBI/CL vehicles. For cases in which the intercept term in the regression results was not significant at the 95% confidence level, the regressions were re-run with a no-intercept model. Those cases are noted in the tables.

Once the correlations summarized in Tables 2-10 and 2-11 were developed, it was necessary to generate HC and CO cold start offsets for the IM240 normal emitting vehicles. The offsets were determined by subtracting the FTP bag 3 results from bag 1 results. The HC and CO cold start offset for IM240 normal emitters as a function of odometer bin (i.e., 0 - 20,000; 20,000 - 40,000; 40,000 - 60,000; 60,000 - 80,000; 80,000 - 100,000; and over 100,000) is given in Tables 2-12 and 2-13 for MPFI/CL and TBI/CL vehicles, respectively. For the few cases in which the cold start offset was negative, the data point was excluded.

Table 2-10. Summary of Alternative IM240-to-FTP Regression Equations Developed from the Hammond Data for MPFI/CL vehicles.

Pollutant	Regressor Variable	(n)	Slope	Intercept	R^2
HC					
Normal	Hot FTP	78	1.102	ns[a]	0.81
High[b]	Full FTP	33	1.359	ns	0.68
CO					
Normal	Hot FTP	73	0.709	ns	0.70
High[b]	Full FTP	70	1.168	ns	0.80
NOx	Full FTP	90	0.486	0.205	0.66

[a] Intercept term was not significant at the 95% confidence level and the regression was re-run with a zero intercept.
[b] All closed-loop technologies were combined for analysis of highs.

Table 2-11. Summary of Alternative IM240-to-FTP Regression Equations Developed from the Hammond Data for TBI/CL vehicles.

Pollutant	Regressor Variable	(n)	Slope	Intercept	R^2
HC					
Normal	Hot FTP	116	1.662	-0.218	0.56
High[b]	Full FTP	33	1.359	ns[a]	0.68
CO					
Normal	Hot FTP	96	0.860	ns	0.69
High[b]	Full FTP	70	1.168	ns	0.80
NOx	Full FTP	128	0.662	ns	0.89

[a] Intercept term was not significant at the 95% confidence level and the regression was re-run with a zero intercept.
[b] All closed-loop technologies were combined for analysis of highs.

Table 2-12. Summary of the HC and CO Cold Start Offset for Normal IM240 Emitters from the Hammond Data for MPFI/CL Vehicles

Odometer Bin	HC		CO	
	(n)	Mean (g/mi)	(n)	Mean (g/mi)
0 - 20K	13	0.482	13	4.48
20 - 40K	15	0.583	15	4.76
40 - 60K	13	0.520	12	4.63
60 - 80K	23	0.872	19	6.56
80 - 100K	10	1.271	9	9.21
100K+	4	1.485	4	5.43

Table 2-13. Summary of the HC and CO Cold Start Offset for Normal IM240 Emitters from the Hammond Data for TBI/CL Vehicles

Odometer Bin	HC		CO	
	(n)	Mean (g/mi)	(n)	Mean (g/mi)
0 - 20K	13	0.352	12	4.13
20 - 40K	19	0.391	18	3.73
40 - 60K	32	0.565	25	3.43
60 - 80K	19	0.555	14	4.66
80 - 100K	17	0.789	13	7.00
100K+	14	0.891	11	10.38

The alternative correlations and cold start offsets described above were then applied to the Hammond lane IM240 scores to develop FTP values for the 1983+ MPFI/CL fleet, and the results are shown graphically in Figures 2-7a to 2-7c for HC, CO, and NOx, respectively. The figures show that the alternative method results in estimates that are slightly lower than the method used by EPA for MOBILE5a. However, if the results are compared to the EPA approach without the addition of residuals, close agreement is observed for HC and CO. The NOx results presented in Figure 2-7c are somewhat surprising, in that closer

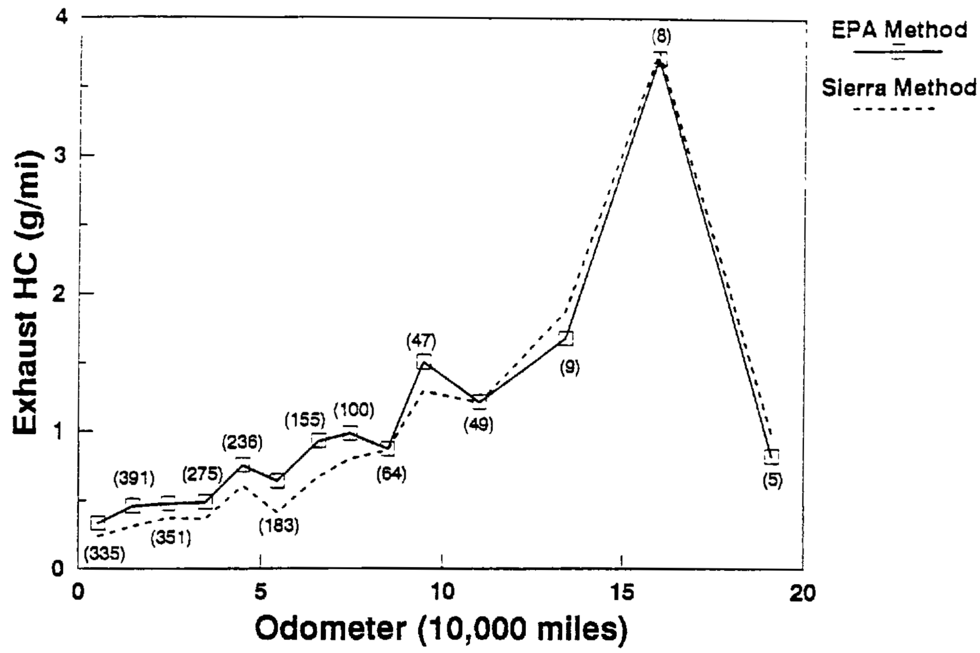

Figure 2-7a. Comparison of MPFI/CL Exhaust HC Emission Rates, EPA vs. Sierra IM240-to-FTP Conversion Methods

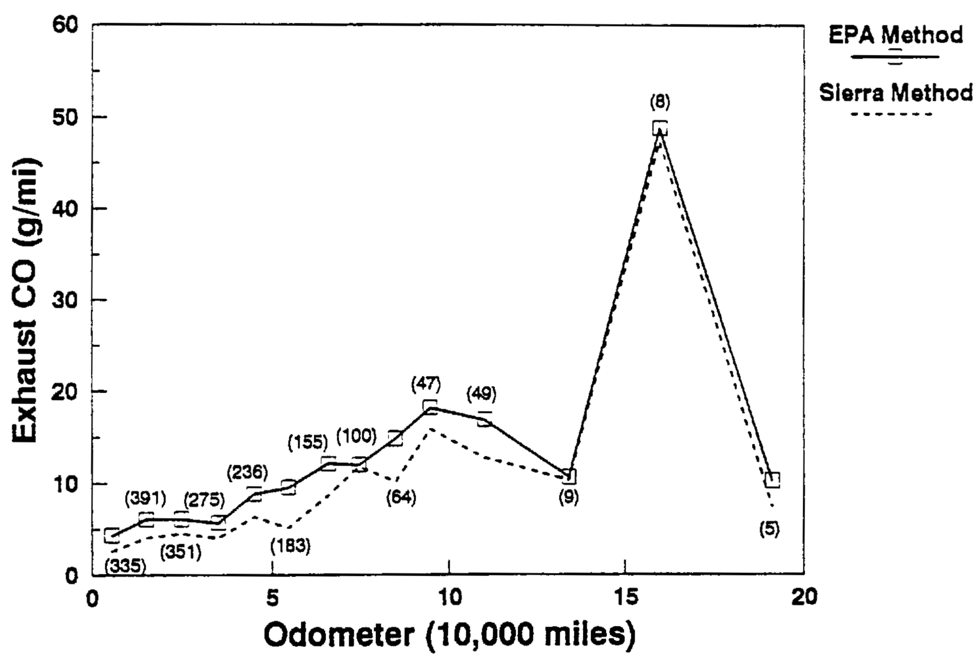

Figure 2-7b. Comparison of MPFI/CL CO Emission Rates, EPA vs. Sierra IM240-to-FTP Conversion Methods

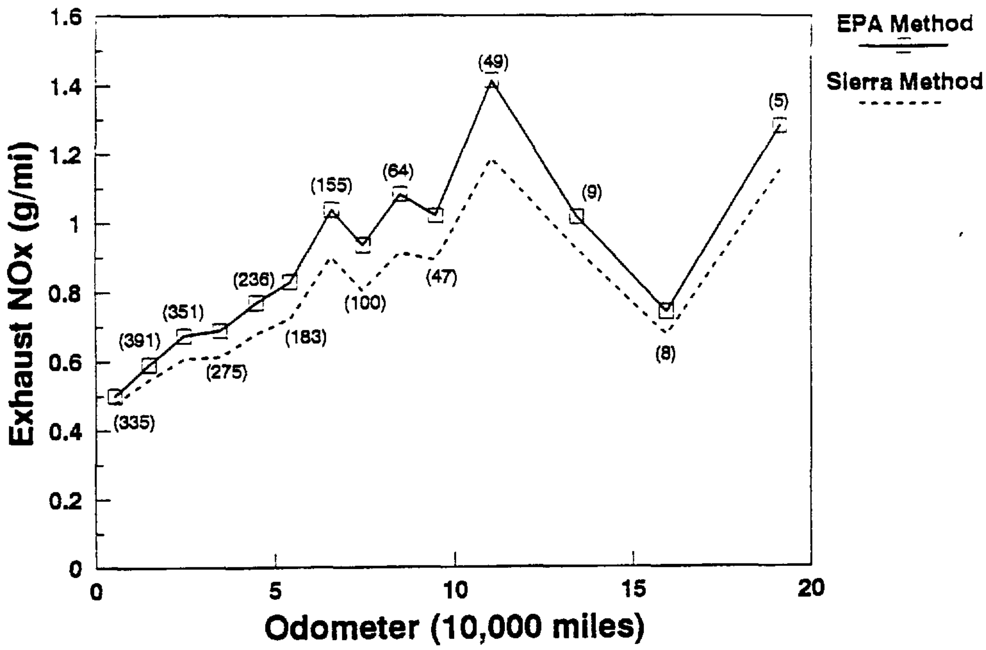

Figure 2-7c. Comparison of MPFI/CL NOx Emission Rates, EPA vs. Sierra IM240-to-FTP Conversion Methods

agreement between the two methods was expected. However, the alternative method presented above was based on fewer data points since the vehicles tested in Ann Arbor from the correlation data base were excluded because they did not have lane IM240 scores. That, coupled with the fact that the regressions in the alternative analysis did not utilize a fuel/temperature adjustment, likely explains the differences observed. Figures 2-7a to 2-7c indicate that althougth the alternative method is quite different than the approach used by EPA, the overall results are very similar.

Section 3

EVALUATION OF MOBILE5a EXHAUST EMISSION RATES

This section presents an evaluation of the exhaust base emission rates developed for MOBILE5a from the Hammond, IN, data discussed in Section 2. It should be noted that the base emission rate equations utilized by MOBILE5a are non-I/M rates.* The impact of I/M is accounted for by applying a fractional reduction to the non-I/M model-year specific emission rate. (Details of how this adjustment is calculated by the TECH5 model and applied in MOBILE5a can be found in the initial evaluation of the MOBILE5a model.[1]) Thus, the results presented in this section are largely based on a non-I/M case (with the exception of the analysis of Arizona data).

A primer on the methods used in MOBILE5a to calculate exhaust emission rates is provided below. In addition, a description of how TECH5 calculates the base emission rate equations for MOBILE5a is included. Following this background material, this section compares model output to (a) the Hammond data used to develop base emission factors for MOBILE5a and (b) data collected from a test program conducted in Mesa, Arizona.

OVERVIEW OF MOBILE5a

The MOBILE models have been developed by EPA to estimate in-use emissions of HC (exhaust and nonexhaust), CO, and NOx from eight separate classes of on-road motor vehicles (i.e., light-duty gasoline vehicles (LDGV), light-duty gasoline trucks under 6,000 lbs. gross vehicle weight (LDGT1), light-duty gasoline trucks from 6,000 to 8,500 lbs. gross vehicle weight (LDGT2), heavy-duty gasoline vehicles (HDGV), light-duty Diesel vehicles (LDDV), light-duty Diesel trucks (LDDT), heavy-duty Diesel vehicles (HDDV), and motorcycles (MC)). Those estimates are typically generated for the entire on-road fleet of

* The Hammond, IN, data were collected during the first "cycle" of an I/M program that began in early 1990. Thus, the emissions data represent a non-I/M fleet of vehicles.

vehicles in a metropolitan area, and results are used to prepare emissions inventories, evaluate control measure effectiveness. and more recently, to determine compliance with federal regulations such as enhanced I/M and conformity.

MOBILE calculates emission rates for each vehicle class (in grams/mile) by first determining the emission rate of each model year making up the vehicle class, weighting the model-year-specific emission rate by fractional usage (i.e., VMT or travel fraction), and summing over all model years that comprise the vehicle class. In addition, a variety of corrections are applied to the base emission rates to account for conditions that are not included in the standard test procedures used to develop the base emission rates (e.g., exhaust emission rates may be corrected for nonstandard speeds, evaporative emissions may be corrected for differing fuel volatility and temperature).

In equational form, the calculation can be described by:

$$EF_{i,j,k} = \sum_{m=1}^{n} VMT_m * (BER_{j,k,m} * CF_{j,k,m...})$$

where $EF_{i,j,k}$ = fleet-average emission factor for calendar year i, pollutant j, and process k (e.g., exhaust, evap);

VMT_m = fractional VMT attributed to model year m (the sum of VMT_m over all model years n is unity);

$BER_{j,k,m}$ = base emission rate for pollutant j, process k, and model year m;

$CF_{j,k,m}$ = correction factor(s) (e.g., temperature, speed) for pollutant j, process k, model year m.

and the sum is carried out over the n model years making up the vehicle class (e.g., 20 years for LDGV in MOBILE4, 25 years in MOBILE4.1 and MOBILE5a). This process is repeated for the 8 vehicle classes, and the results are weighted by the travel fraction associated with each class and summed over all classes to develop a fleet-average emission rate.

OVERVIEW OF THE "TECH" MODELS

The exhaust base emission rate equations used by MOBILE (i.e., zero mile and deterioration rates) are developed outside of the model by a companion series of programs termed the "TECH" models. The "TECH IV" model,[2] initially developed to determine I/M benefits for 1981 and later model-year vehicles for MOBILE3, has been revised with each version of the MOBILE series. (The MOBILE4.1 version is termed TECH4.1, and the MOBILE5 version is known as TECH5.) These models estimate both the baseline emission factors (by model year) and the I/M program benefits associated with various program types.

The "TECH" series of models utilizes a "regime" approach in developing baseline emission factors and I/M benefits. After segregating emissions data by certification standard and technology (i.e., closed-loop multiport fuel-injection (MPFI/CL), closed-loop throttle-body injection (TBI/CL), closed-loop carbureted (CARB/CL), and open-loop), the data are stratified into four basic emitter groups (or regimes), which are defined as:

- Normal: $\leq 2 \times$ HC Std. and $\leq 3 \times$ CO Std.
- High: $> 2 \times$ HC Std. or $> 3 \times$ CO Std.
- Very High: $> 4 \times$ HC Std. or $> 4 \times$ CO Std.
- Super: > 10 g/mi HC or > 150 g/mi CO

The definition of these groups remained unchanged between MOBILE4.1 and MOBILE5; however, the distribution of vehicles among the categories is significantly different, with MOBILE5 generally having a larger proportion of very high emitting vehicles at a given vehicle age. Note that NOx is determined independently in the model, with only two emitter categories: normals (≤ 2.0 g/mi) and highs (> 2.0 g/mi).

The baseline emission rates (as a function of vehicle mileage or age) are determined by multiplying the emission rate of each emitter category by the fraction of each category making up the fleet at the mileage intervals corresponding to vehicle age. EPA developed both the emitter category emission rates and growth functions (i.e., the change in the mix of normals, highs, very highs, and supers with mileage) for MOBILE5a from data collected in the Hammond program.

As an example of the procedure used in TECH5, the incidence of emitter groups in the fleet is illustrated in Figure 3-1 for 1983 to 1993 model-year MPFI/CL light-duty gasoline vehicles,* and the exhaust HC emission rate of each group (as a function of vehicle age) is shown in Figure 3-2. Combining the data illustrated in Figures 3-1 and 3-2 results in the baseline HC emission rate shown in Figure 3-3. The same calculations were performed for the remaining pollutants and technologies included in TECH5, and the results are illustrated in Figures 3-4a to 3-4c for HC, CO, and NOx, respectively. Emission factors for each model year are generated by weighting the technology-specific emission rates by the fraction of each technology in the fleet.

Several items are worth noting with respect to the above figures. First, Figure 3-3 illustrates that the very high emitter group is assumed to be the largest contributor to the MPFI/CL vehicle HC emission rate as the vehicle ages. This indicates that careful attention should be given to how the emission rates and growth functions were developed for that category. Second, Figures 3-4a and 3-4b show that the model predicts MPFI/CL vehicles to have the poorest emission control system performance (for HC and CO) at high mileage of the four technology groups considered by TECH5.

* The MPFI/CL technology group is the focus of many of the analyses that follow because it represents 81.5% of the LDGV fleet for 1992 and subsequent model years. Thus, it has the greatest influence on future-year model predictions.

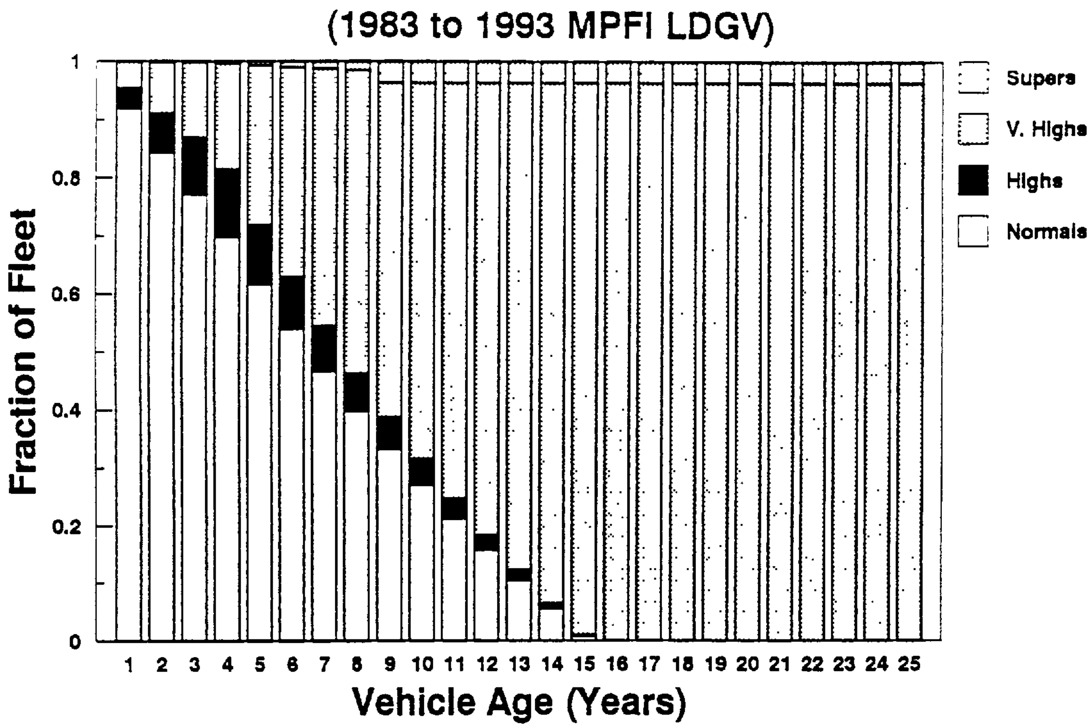

Figure 3-1. Incidence of Emitter Groups as a Function of Vehicle Age

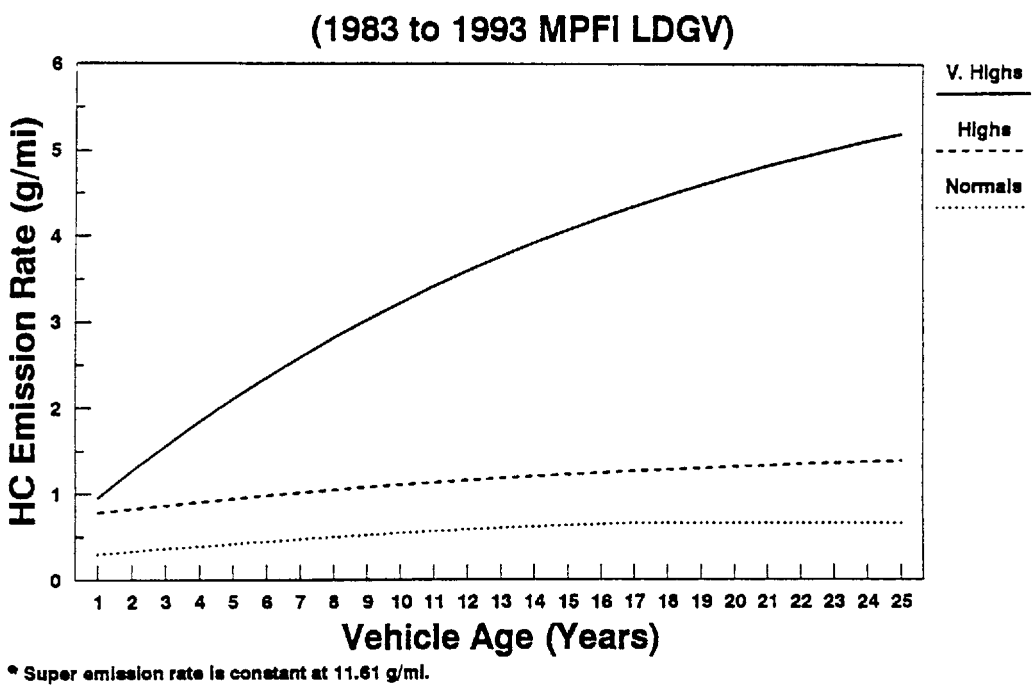

Figure 3-2. HC Exhaust Emission Rate by Emitter Category as a Function of Vehicle Age

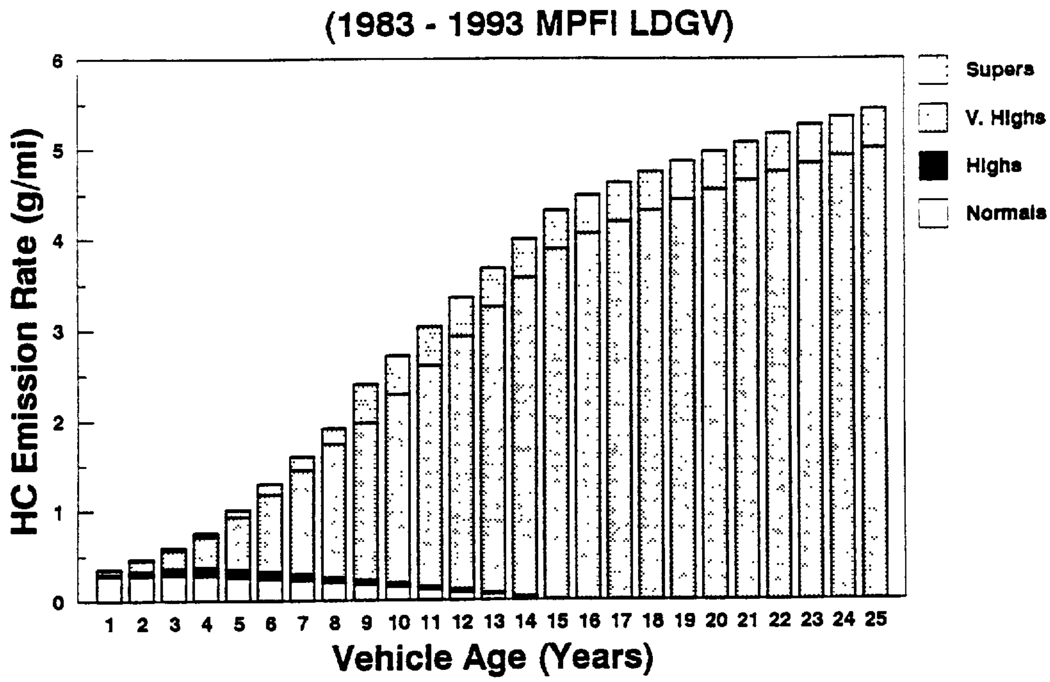

Figure 3-3. Contribution of Emitter Categories to Baseline HC Emission Rate

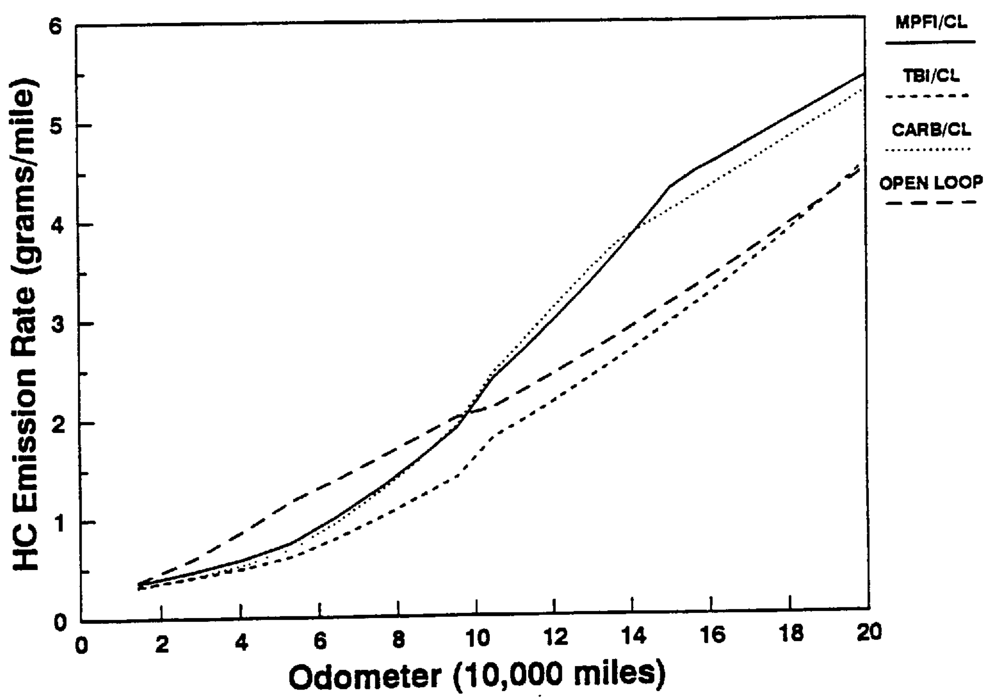

Figure 3-4a. TECH5 HC Emission Rate by Technology Type

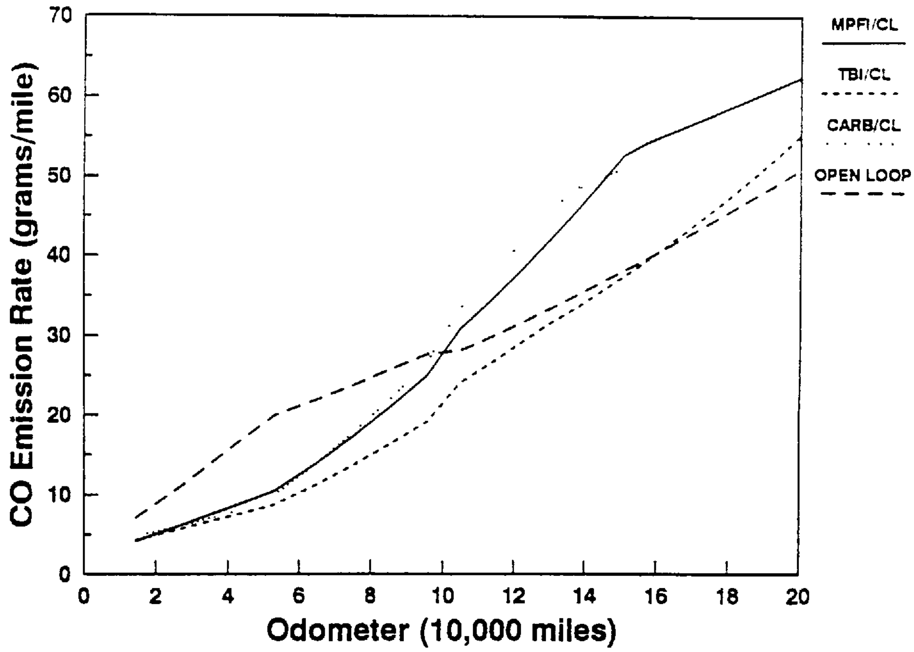

Figure 3-4b. TECH5 CO Emission Rate by Technology Type

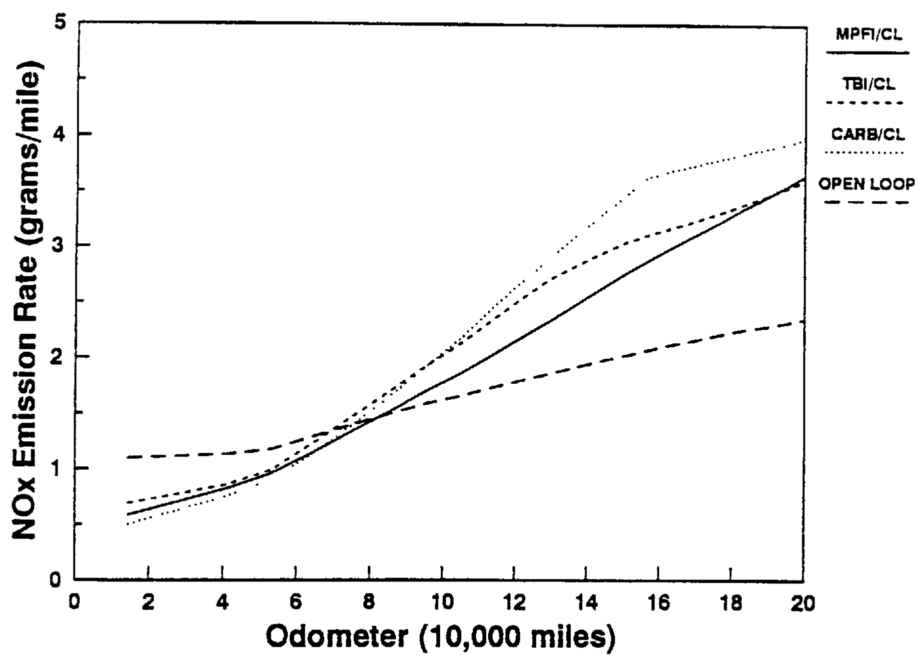

Figure 3-4c. TECH5 NOx Emission Rate by Technology Type

COMPARISON OF HAMMOND DATA TO MOBILE5a BASE EMISSION RATES

Because of the methodology used by TECH5 to generate the base emission rates for MOBILE5a, it is difficult to make direct comparisons between the data used as input to the model and the model output. That is because each model year base emission rate equation is a combination of up to four technologies (i.e., MPFI/CL, TBI/CL, CARB/CL, and open loop) and four emitter categories (i.e., normals, highs, very highs, and supers). For that reason, the comparisons that follow rely on the same approach used in Section 2 of this report, i.e., the Hammond data were segregated into 10,000-mile bins and the mean emission level was calculated for each bin.

Figures 3-5a to 3-5c compare the mean emissions by odometer bin for Hammond MPFI/CL vehicles to the 1992 base emission rate used in MOBILE5a for HC, CO, and NOx, respectively.* The 1992 model year is assumed to consist of 81.5% MPFI/CL vehicles and 18.5% TBI/CL vehicles, so making comparisons to the MPFI/CL data is reasonable since that technology group contributes most significantly to the 1992 base emission rate equation. As shown in Figures 3-5a to 3-5c, close agreement between the data and the MOBILE5a predictions is observed up to 50,000 miles, but there is a significant over-prediction of emissions by MOBILE5a at mileages above 50,000. (The sample size of each bin is noted on the figures.) The above comparison for HC was also made for the TBI/CL technology group, which is shown in Figure 3-6. As with the MPFI/CL group, emissions are overpredicted by the model at high mileages.

Although some discrepancy between the data and model predictions is understandable, the differences observed in Figures 3-5 and 3-6 appear extreme. When questioned about this difference, EPA staff indicated that the base emission rate equations developed for MOBILE5a were based on a methodology that incorporated both vehicle age <u>and</u> mileage.

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* The Hammond data have been converted to an FTP basis using the EPA methodology described in Section 2. Thus, these are the data used by EPA in developing the MOBILE5a base emission rate equations.

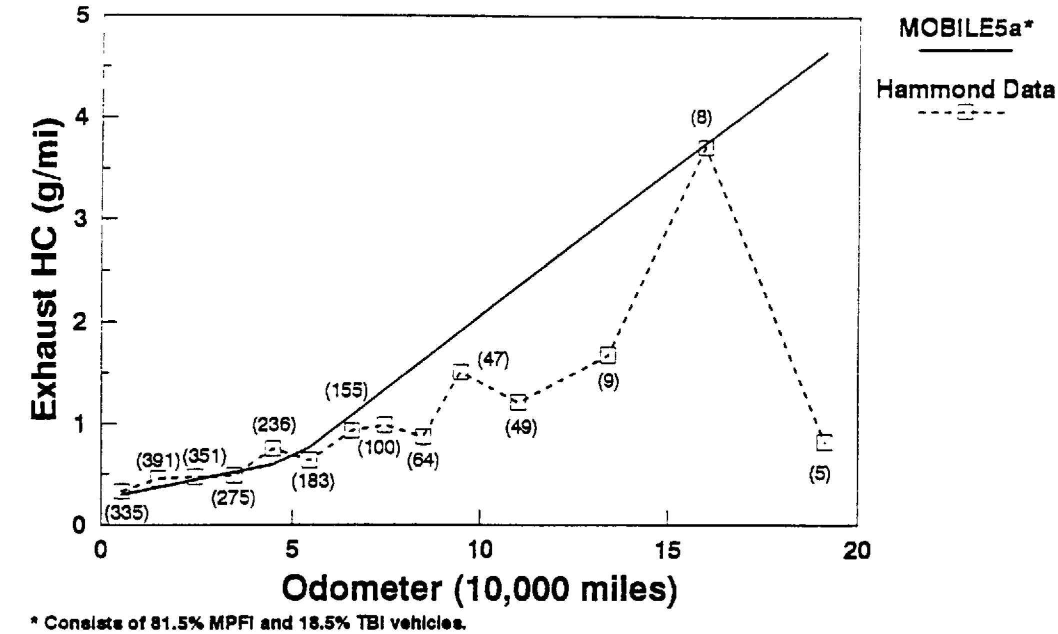


Figure 3-5a. Comparison of MOBILE5a 1992 Model Year HC Base Emission Rate Equation to the Hammond 1983+ MPFI/CL Data

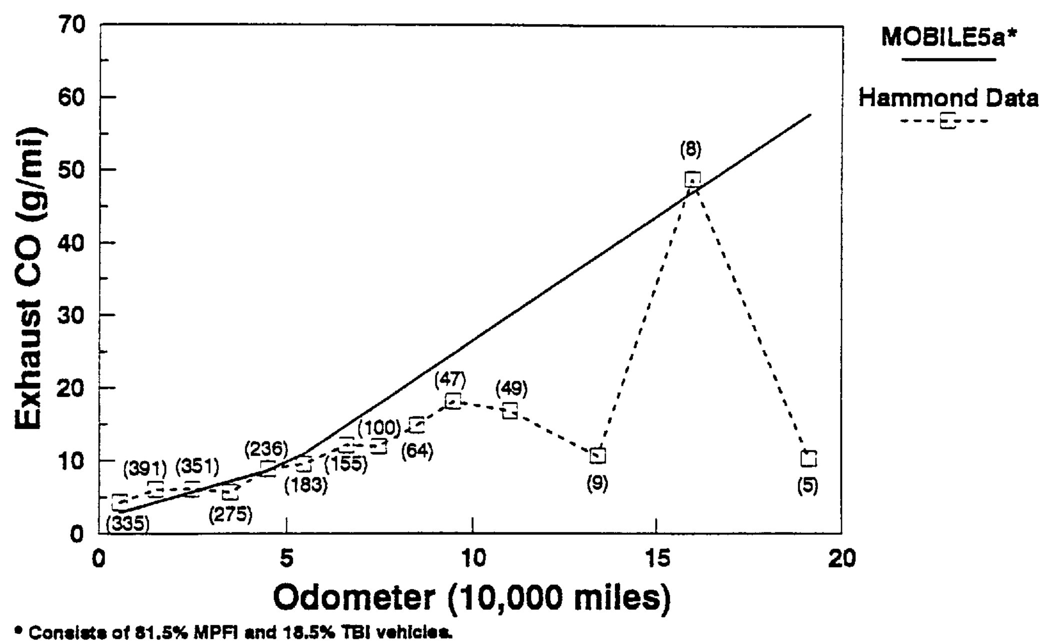


Figure 3-5b. Comparison of MOBILE5a 1992 Model Year CO Base Emission Rate Equation to the Hammond 1983+ MPFI/CL Data

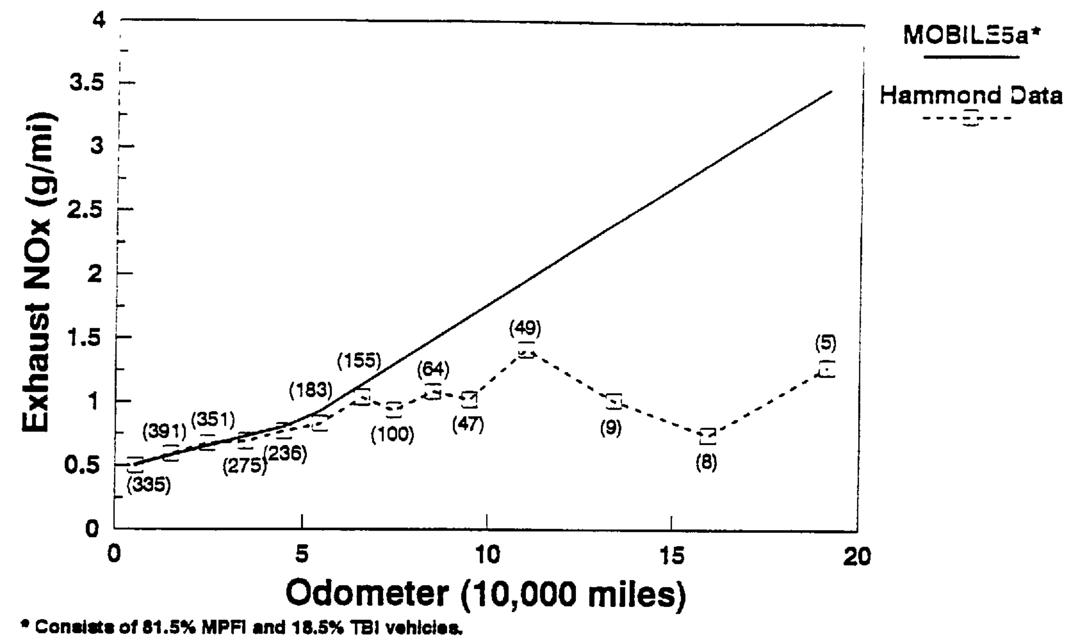


Figure 3-5c. Comparison of MOBILE5a 1992 Model Year NOx Base Emission Rate Equation to the Hammond 1983+ MPFI/CL Data

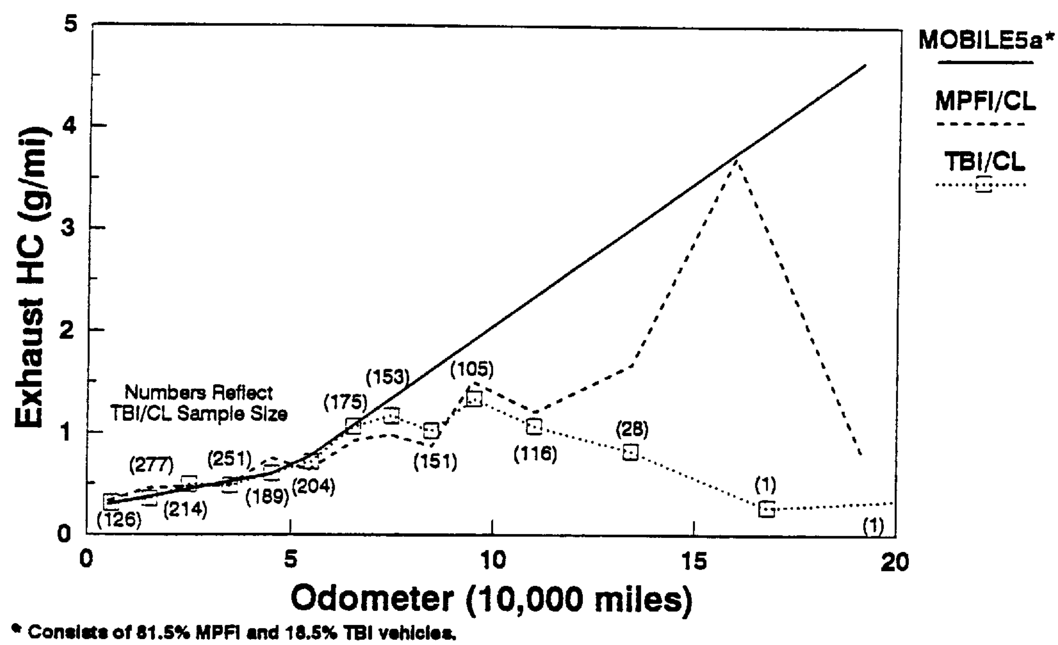


Figure 3-6. Comparison of MOBILE5a 1992 Model Year HC Base Emission Rate Equation to the Hammond 1983+ MPFI/CL and TBI/CL Data

The reasoning behind this approach is that EPA felt uncomfortable with basing the emission control system deterioration rates solely on mileage accumulation. EPA's rationale in support of this approach is that many vehicles accumulate mileage quickly, and the deterioration rates from those vehicles are likely to be lower than if mileage was accumulated at a more standard rate. Thus, to account for vehicle age as well as mileage accumulation, 1981-1982 data were combined with 1983+ data (albeit somewhat arbitrarily) to develop emitter category (i.e., normals, highs, very highs, and supers) growth rates and emission rates by technology type (i.e., MPFI/CL, TBI/CL, CARB/CL, and open loop). That approach is summarized below.*

Calculation of Emitter Category Growth Rates and Emission Rates for MOBILE5a

As described above, the two primary inputs to the TECH5 model are growth rates (a function of vehicle mileage) and emission rates (also a function of vehicle mileage) for each emitter category. These rates were determined separately for each technology type, since emission control system deterioration is expected to differ between older (e.g., open loop) and newer (e.g., MPFI/CL) technologies. In developing the MOBILE5a 1981 and later model year base emission rates, EPA constructed the emitter category emission rates for 1981-1982 and 1983+ model year groups. Because the 1981-1982 model years represented the first widescale introduction of closed-loop technology, it is generally accepted that the 1981-1982 model year group has very different emissions characteristics relative to later model years. The emitter category growth rates were developed with a procedure that combined data from all model years.

In previous emission factor development, the 1981-1982 model year group has generally been analyzed separately from 1983+ model years. However, for MOBILE5a, EPA combined data from the 1981-1982 and 1983+ groups to develop the inputs for TECH5. The emitter

* Note that the evaluation that follows is focused on the development of HC and CO base emission rate equations. Resource constraints did not allow for a thorough assessment of EPA's development of NOx base emission rate equations for MOBILE5a.

category emission rates were constructed with a covariance analysis that essentially used data from both groups to establish the same deterioration rate for the two model year groups, while the zero-mile level for each group was allowed to vary. The emission rates for HC and CO (zero-mile (ZM) levels and deterioration rates (DR)) are summarized in Table 3-1.

Table 3-1. Comparison of 1981-1982 and 1983+ Emitter Category Emission Rates for MPFI/CL Vehicles

Emitter Category	Model Year	HC[a]		CO[a]	
		ZM	DR	ZM	DR
Normal	81-82 1983+	0.188 0.263	0.0247 0.0247	1.548 1.995	0.6314 0.6314
High	81-82 1983+	0.661 0.735	0.0326 0.0326	7.040 8.561	0.1578 0.2588
Very High	81-82 1983+	0.255 0.631	0.1888 0.2285	7.761 20.315	1.9568 1.9568
Super	81-82 1983+	11.61 11.61	na[b] na[b]	139.49 139.49	na[b] na[b]

[a] Units: ZM - g/mi; DR - g/mi/10,000 mi
[b] na - not applicable

It is interesting to note that the above procedure resulted in higher emission rates being predicted for the 1983+ MPFI/CL emitter categories than the 1981-1982 model years. (This holds true for normals, highs, and very highs; supers were assumed to have the same emission rate for both model year groups.) This is observed in Table 3-1, which shows that the zero-mile levels for the 1981-82 group are lower in all cases (except for super emitters, which are the same for both model year groups). In addition, there are two cases in which the deterioration rates for the 1981-82 group are also lower, which is inconsistent with the methodology described by EPA staff. The emission rates contained in Table 3-1 result in the TECH5 HC emissions predictions illustrated in Figure 3-7. That figure implies that auto

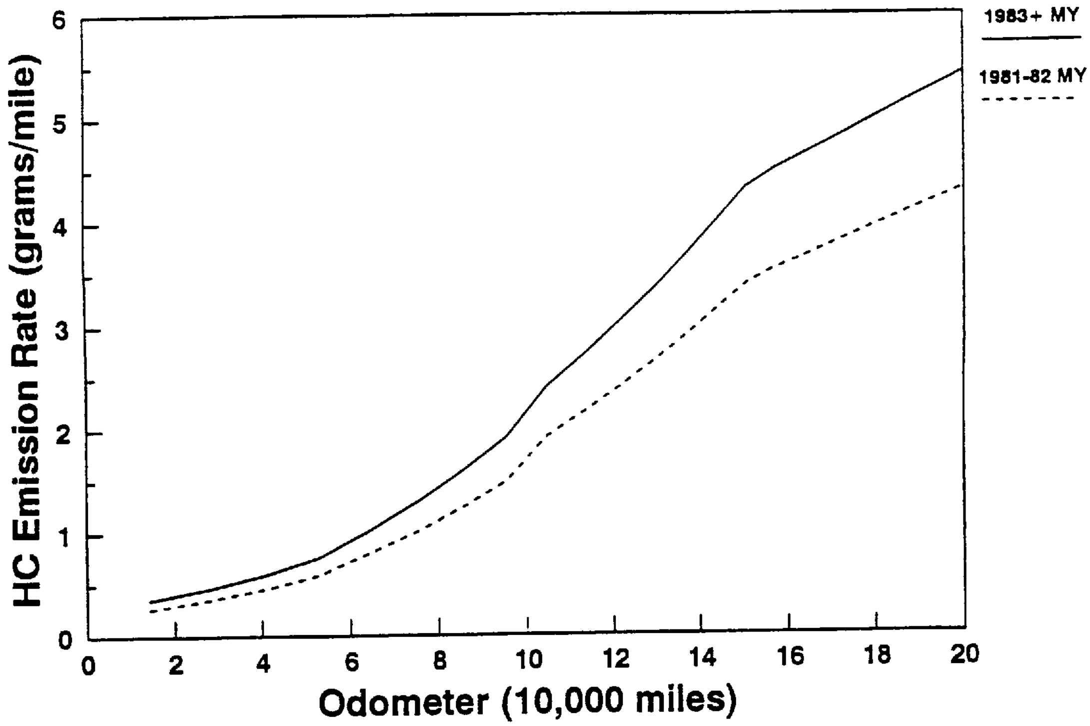


Figure 3-7. Comparison of TECH5 HC Emission Prediction for 1981-1982 and 1983+ Model Year Groups for MPFI/CL Vehicles

manufacturers have not improved emission control system deterioration over the last 10 years. In fact, from an emissions control perspective, they would have been better off maintaining the designs that were introduced in 1981. Clearly this does not make sense.

The second parameter used by TECH5 to generate the technology-specific emission rates is the emitter category growth rate (or growth function). These were also developed for MOBILE5a by combining data from all model years. However, this was handled differently than as described above for the emitter category emission rates. As described previously, EPA wanted to base the emission control system deterioration on both vehicle age and mileage. This was done by using data from the 1987 and later model years to establish the growth rate of non-normals (i.e., highs + very highs + supers) for mileages less than

50,000. For mileages above 50,000, data from the 1981-1986 model years were used for the TBI/CL, CARB/CL, and open-loop technology groups, whereas the 1984-1986 model year group was used for the MPFI/CL vehicles. EPA used the 1984-1986 model years for MPFI/CL vehicles because they judged that earlier model years represented "prototype" technology. It is unclear why the same reasoning was not also applied to the development of emitter category growth rates for the other closed-loop technologies or to the development of emitter category emission rates for the MPFI/CL group.

In concept, a model-year or age-based approach does have some merit. It is likely that a vehicle that accumulates mileage rapidly has different emission control system deterioration characteristics than a vehicle that accumulates mileage at a more moderate rate. EPA applied this concept to the growth rate functions only; when the emitter category emission rates were developed, all data were included.

The method EPA used to develop the emitter category growth rates was based on first establishing growth rates for the following emitter group combinations:

- supers
- very highs + supers
- highs + very highs + supers.

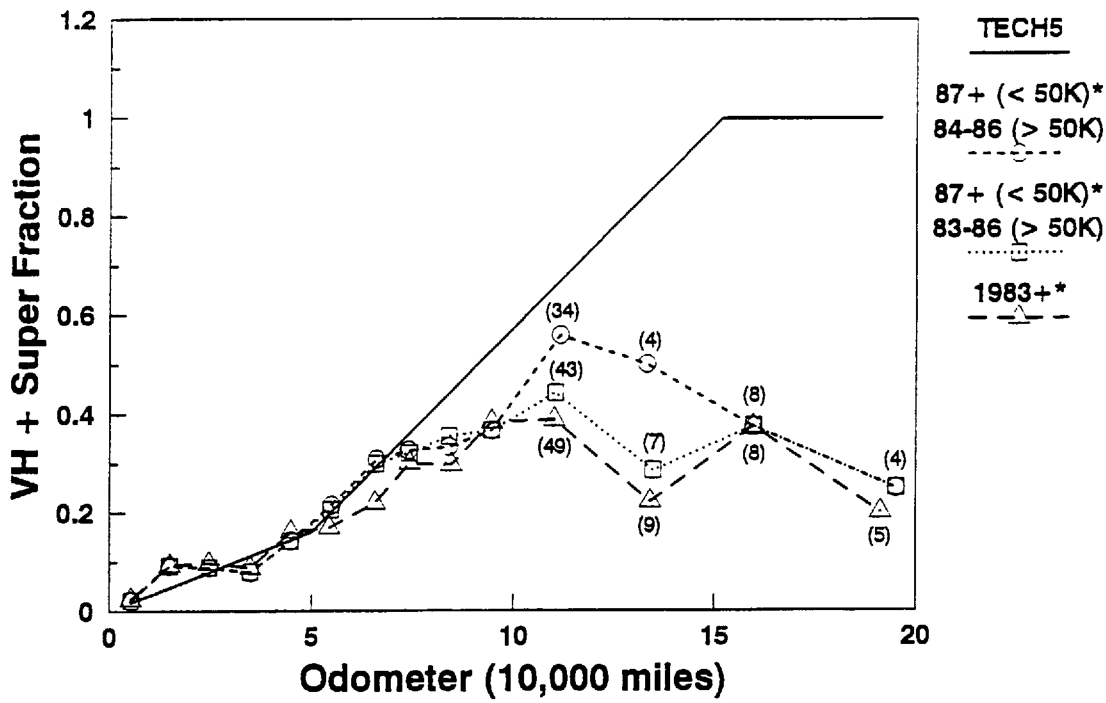
Once these rates are established as a function of vehicle mileage, the individual emitter categories are determined by subtraction (e.g., the fraction of super emitters is determined first, which is then subtracted from the [very high + super] group to obtain the fraction of very highs; this process is continued until the fraction of each emitter group is calculated). To determine the emitter growth rates, EPA used a very simplistic method, which is best illustrated with an example as outlined below.

To develop the growth rates for the [very high + super] group for MPFI/CL vehicles, a two-step process was used. First, the $<50,000$ mile growth rate was established by determining the fraction of [very highs + supers] from all 1987+ MPFI/CL data (this data set was not cut off at 50,000 miles). In the Hammond sample, there were 155 [very highs + supers] out of 1,716 total vehicles in this group (i.e., 9.03%). This fraction was then divided by the average mileage of the group (28,182) to obtain a growth rate of 0.03205/10,000 mi. The growth rate beyond 50,000 miles was then calculated by determining the fraction of [very highs + supers] in the 1984-1986 model year group (138/460, or 30.0%) and the average mileage of that group (68,464). The second growth rate was then determined by linear extrapolation of a line connecting the fraction of [very highs + supers] at 50,000 miles (i.e., 5 * 0.03205, or 16.0%) and the point established from the 1984-1986 group (i.e., 0.300 at 68,464 miles). This resulted in a growth rate beyond 50,000 of 0.07568/10,000 mi.*

There are several concerns with the above method of developing growth rates. First, it would seem logical to only use data from those vehicles with less than 50,000 miles to generate the <50,000 mile growth rates. A similar statement can be made about the data used to develop the growth rates for beyond 50,000 miles. EPA chose to use all of the data within each model year group because they felt that approach was more reflective of an age (or model year) based analysis. However, such an overlapping approach tends to soften the impact of each distinct data set. Second, by using a simple averaging approach to generate the growth rates, vehicles at higher mileage are not weighted as heavily (because there are fewer of them).

A comparison of the [very high + super] growth rate calculated by TECH5 and the data from Hammond is shown in Figure 3-8. The data were stratified by mileage bin as in the previous figures, and the sample sizes for the high mileage bins are shown as well. Four

* Note that the value used in the TECH5 model was 0.08257/10,000 mi for MPFI/CL vehicles over 50,000 miles. That is because of an apparent error in the spreadsheet used by EPA to develop these rates.



* Emitter fractions based on Hammond data.

Figure 3-8. Comparison of [Very High + Super] Emitter Fractions - TECH5 vs. Hammond Data for MPFI/CL Vehicles (Sample sizes indicated in parenthesis.)

lines are plotted in Figure 3-8. The "TECH5" line represents the fraction of [very highs + supers] calculated by TECH5; the "87+ (<50K); 84-86 (>50K)" line represents the data used by EPA to develop the TECH5 line (i.e., 1987 and later model years were analyzed for mileages under 50,000; 1984-1986 model years were used for mileages greater than 50,000); the "87+ (<50K); 83-86 (>50K)" line is the same as above, except the model year coverage for mileages above 50,000 was extended to include the 1983 model year; and the "1983+" line represents data from all 1983 and later MPFI/CL vehicles. As seen in the figure, the growth rate calculated for TECH5 does not match the data at mileages above 75,000. It is interesting to note that adding the 1983 model year to the >50,000 mile data set results in a decrease in the fraction of [very highs + supers] at high mileage. This fraction is further decreased when <u>all</u> 1983 and later data are evaluated (i.e., this case did not consider different model year groupings for the <50,000 and >50,000 mileage intervals).

The "1983+" line reflects the addition of vehicles at mileages above 50,000 that have accumulated mileage rapidly, which results in a lower fraction of [very highs + supers] beyond 50,000 miles.

A final point related to EPA's development of growth rates for TECH5 is that a slightly different method was used for the super emitter category. For that category, the data were stratified into three model year groups: 1987+ for mileages below 50,000; 1983-1986 for mileages from 50,000 to 100,000; and 1981-1982 for mileages above 100,000. Further, because of the small number of super emitters in the fleet, all technologies were combined. At mileages under 100,000, the same method described above was used to develop the two (i.e., <50,000 and >50,000) growth rates. However, beyond 100,000 miles, EPA assumed that the fraction of super emitters in the fleet is constant at the level obtained from the 1981-1982 data (i.e., 26/705, or 3.7%). This approach results in a step function increase in the fraction of super emitters at 100,000 miles: at 99,999 miles, the super emitter fraction is 1.7%; at 100,001 miles, it is 3.7%.

In summary, the procedures that EPA used to develop the emitter category emission rates and growth rates for MOBILE5a treated data subjectively and inconsistently. Emission rates were generated in a completely different fashion than emitter growth rates, methods differed by emitter category, and modifications to the methods to account for technology differences were not applied consistently when the emission and growth rates were estimated.

To support the above approach, EPA has compared the mean emission rate by model year (at that model year's mean mileage) versus emission rates calculated by TECH5, which is shown in Figure 3-9. The figure demonstrates relatively good agreement between the data and the model predictions. That comparison, however, is misleading because the model year values displayed in the figure actually represent a wide span of mileage intervals (e.g., 1982 has values well below and well above 100,000 miles). A more realistic comparison would contrast emission levels at comparable mileage intervals. This is particularly important at

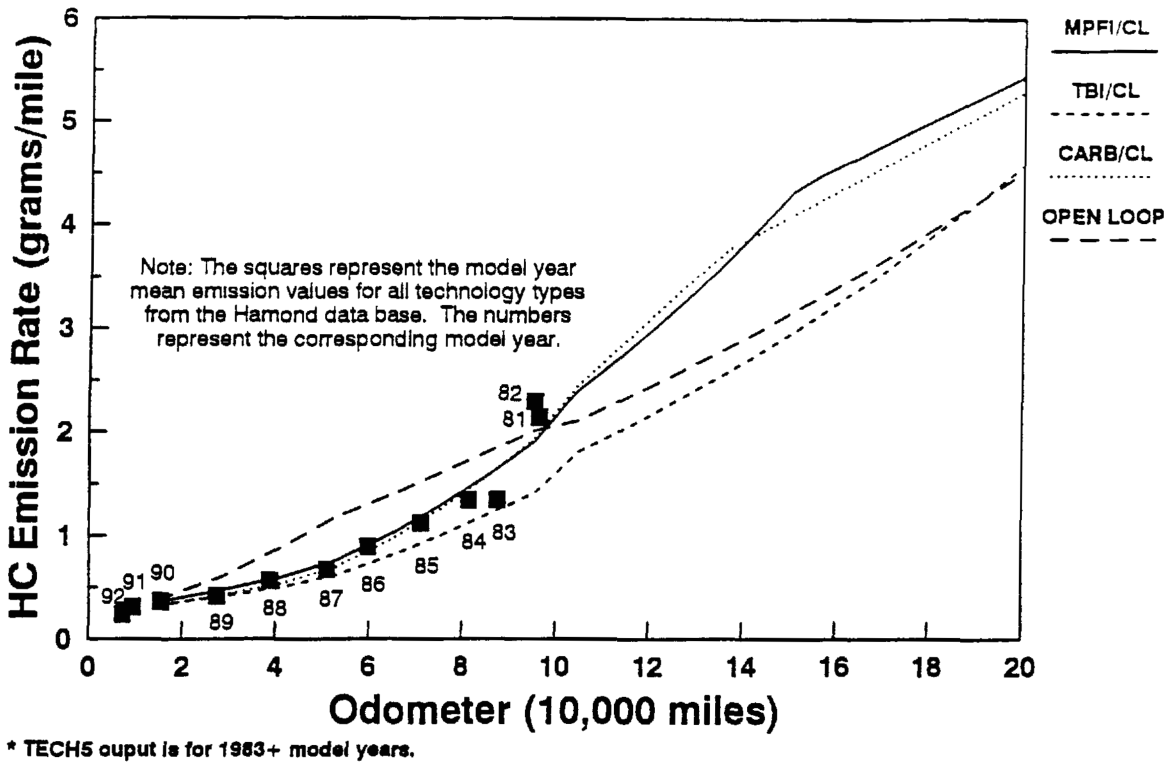


Figure 3-9. Comparison of Model Year Mean HC Emission Rates from the Hammond Data Base and TECH5 Output

high mileages (i.e., above 100,000) where the figure provides no contrast at all. Finally, the TECH5 results shown in the figure are for 1983 and later model years. If the model-year-based data from only the 1983 and later model years were projected to higher mileage (i.e., if a linear regression were performed on the 1983-1992 data points), the results would fall well below those estimated by TECH5.

Development of Alternative Base Emission Rate Equations

Because a number of the assumptions used by EPA to develop the base emission rate equations for MOBILE5a appear somewhat questionable, an alternative analysis was performed in which HC and CO base emission rate equations were developed for 1983 and later MPFI/CL vehicles. Although not a detailed analysis, the evaluation (which is presented below) provides an alternative to the MOBILE5a methodology. The method generally follows that developed by EPA for TECH5 and demonstrates that with just a few seemingly minor changes, the resulting base emission rates are significantly impacted.

The approach employed to develop alternative base emission rate equations for MPFI/CL vehicles is summarized as follows.

- Emitter category emission rates were based only on 1983 and later model years for normals, highs, and very highs. Emission rates (ZM and DR) were developed from regressing emissions versus vehicle mileage. Super emitter emission rates were those developed by EPA.

- Emitter category growth rates for the [very high + super] and [high + very high + super] groups were based on a regression technique, rather than the "means" method used by EPA. These rates were developed by regressing the fraction of each emitter group by odometer bin (e.g., Figure 3-7) against the mean odometer reading of each bin. This was done up to the 125,000 mile bin. Although the data show a decrease in the [very high + super] fraction beyond 125,000 miles (again refer to Figure 3-7), those fractions are based on limited data. Thus, beyond 125,000 miles, the fraction of [very highs + supers] and [highs + very highs + supers] was assumed to remain constant at the 125,000 mile value. As with the EPA method, the data for <50,000 miles were from 1987 and later model years; however, the >50,000 mile data included 1983-1986 model years. Because of the "bin" approach used for this analysis, only vehicles with less than 50,000 miles were included in the <50,000 group and only vehicles with more than 50,000 miles were included in the >50,000 group. For super emitters, the growth rate was assumed to be that developed by EPA for MOBILE5a.

The results of the above analysis are shown in Figures 3-10a and 3-10b for HC and CO, respectively. As seen in the figures, the emission rates calculated by the two methods deviate substantially at mileages above 50,000, even though the alternative method retained the assumption of a step function increase in super emitters at 100,000 miles. Also shown in the figures are the 1983+ MPFI/CL vehicle mean emission rates of each odometer bin calculated from the Hammond data, which show much better agreement with the alternative

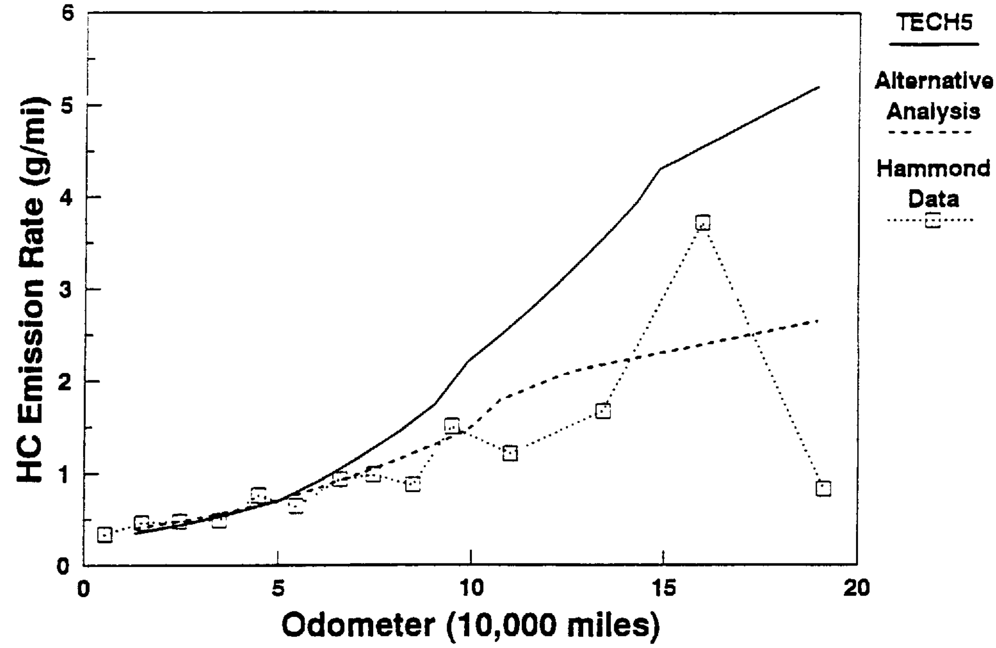


Figure 3-10a. Comparison of MPFI/CL HC Exhaust Emission Rates - TECH5 vs. an Alternative Analysis Methodology.

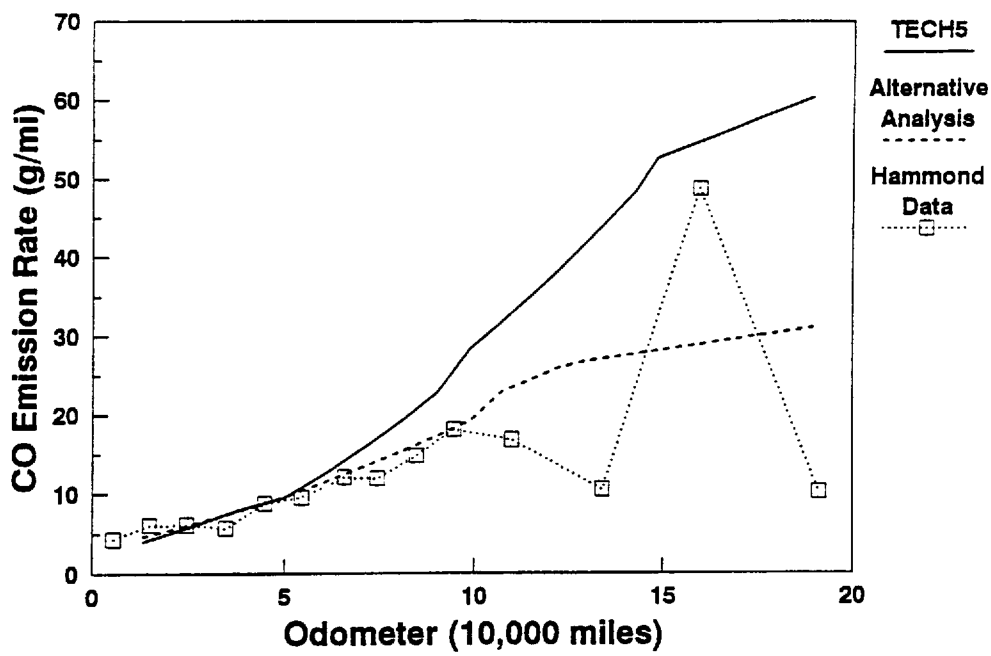


Figure 3-10b. Comparison of MPFI/CL CO Exhaust Emission Rates - TECH5 vs. an Alternative Analysis Methodology.

analysis than the method developed for MOBILE5a. Clearly, the base emission rates developed for MOBILE5a represent a worst-case scenario for emission control system deterioration.

Additional Issues Related to the Hammond Data Base and MOBILE5a

As described above, EPA's use of the Hammond data appears to be flawed with respect to the way in which high-mileage, 1983+ vehicles were treated. This is somewhat curious, particularly since the reason for using the Hammond data base in the first place was because it resulted in a better representation of the in-use fleet. However, reviewing statistics from the Hammond data base indicates that high-mileage, fuel-injected vehicles make up a relatively small fraction of the test records. This is shown in Table 3-2, which summarizes the fraction of MPFI/CL and TBI/CL vehicles tested at the Hammond site as a function of vehicle mileage bin (i.e., 0 - 50,000; 50,000 - 100,000; and over 100,000). Also shown in the table are MOBILE5a estimates of VMT, non-I/M HC exhaust emissions, and the I/M credit associated with each mileage bin for the MOBILE5a input parameters specified for the development of the complex model. The table indicates that although vehicles with over 100,000 miles are significant contributors to the fleet-average emission rate, they are grossly underrepresented in the data base used to develop inputs to MOBILE5a.

COMPARISON OF MOBILE5a TO DATA COLLECTED IN ARIZONA

In late 1992 and early 1993, EPA conducted a test program in Mesa, Arizona (a suburb of Phoenix), that compared the relative effectiveness of the transient IM240 test procedure and a proposed steady-state test procedure that contains two modes simulating vehicle acceleration (hence, this alternative I/M test procedure has been termed the "Acceleration Simulation Mode" (ASM) test)[3]. Over 1,500 vehicles were tested in this program at an operating I/M lane where they received both IM240 and ASM tests. In addition, a subset of vehicles was recruited for testing at a local contractor laboratory where FTP tests were performed. Thus, using data from vehicles tested over the FTP and IM240 cycles, it is possible to develop IM240-to-FTP correlations that can be applied to the larger set of vehicles that received only

Table 3-2. Summary of MPFI/CL and TBI/CL Data from the Hammond Test Program and MOBILE5a Output

Parameter	Mileage Bin		
	0-50,000	50,000-100,000	Over 100,000
Percent of Vehicles in Data Base	62.5%	32.2%	5.2%
Contribution to VMT	45.3%	32.7%	22.0%
Contribution to Non-I/M HC Emission Rate	15.4%	35.0%	49.6%
Contribution to I/M Emission Reduction	4.0%	29.5%	66.5%

IM240 tests. As described above, this is a similar procedure that EPA used to develop the base emission rate equations for MOBILE5a.

Description of Arizona Data

Since the test program conducted in Arizona was designed to evaluate I/M test procedures rather than determine average emission rates from the fleet, the sample selection process was somewhat biased. For example, the focus was on late-model (i.e., 1983 and later model years) fuel-injected vehicles. This was necessary because the results were being used to project future-year I/M benefits, and those benefits are primarily influenced by fuel-injected vehicles. For the analysis that follows, the fuel-injection bias does not greatly impact the results because the focus of previous analyses has been on fuel-injected vehicles.

IM240 Scores

Before presenting the correlation equations and the IM240-based FTP results, it is useful to compare the raw IM240 scores (i.e., vehicles tested at the lane on tank fuel) from the Arizona and Hammond programs. This comparison is made in Figures 3-11a to 3-11c, which indicates that, on average, the Arizona fleet is cleaner than the Hammond fleet. Possible explanations for this result include the following.

- The Hammond data represent a non-I/M fleet of vehicles (i.e., these vehicles were tested during the first cycle of an I/M program), whereas there has been a reasonably stringent I/M program in place in Arizona for several years.

- The Hammond data were collected over a two-year period encompassing all seasons, whereas the Arizona data were collected over a six-month period in the fall and winter. The IM240 scores reflect the fact that oxygenated gasoline was used during most of the data collection period in Arizona. Although the Arizona program was conducted in winter, the ambient temperatures during the program were fairly mild. This would tend to lessen the impact of ambient temperature on emission rates.

- Different test equipment was used to collect the IM240 data. The Hammond data were collected using "bag" samplers, whereas the equipment used in Arizona relied on integrating second-by-second concentration data to obtain the mass emission rate. It is unclear, however, how much this may have contributed to the differences in test results.

IM240-to-FTP Correlations

One check that was applied previously to the Hammond data to determine the suitability of lane IM240 data to predict FTP scores is the degree of correlation between Bag 3 of the FTP and the IM240 results. (See Appendix A.) Because the IM240 is a subset of Bag 3, a good correlation should be observed. This check was performed on the 106 vehicles from Arizona that received IM240 tests and FTPs, and the results are given in Table 3-3. Note that two sets of values are given in the table, one that includes vehicle number 3211, and one that does not. In its evaluation of the Arizona data, EPA noted that vehicle 3211 was an outlier

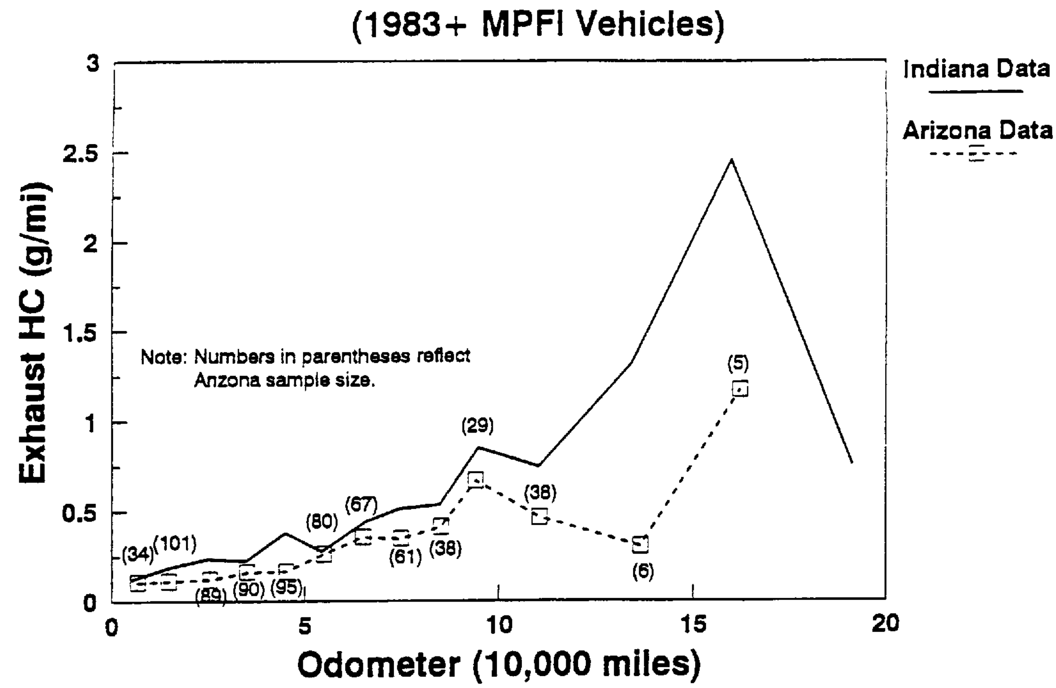


Figure 3-11a. Comparison of Indiana and Arizona Lane IM240 HC Results for MPFI/CL Vehicles

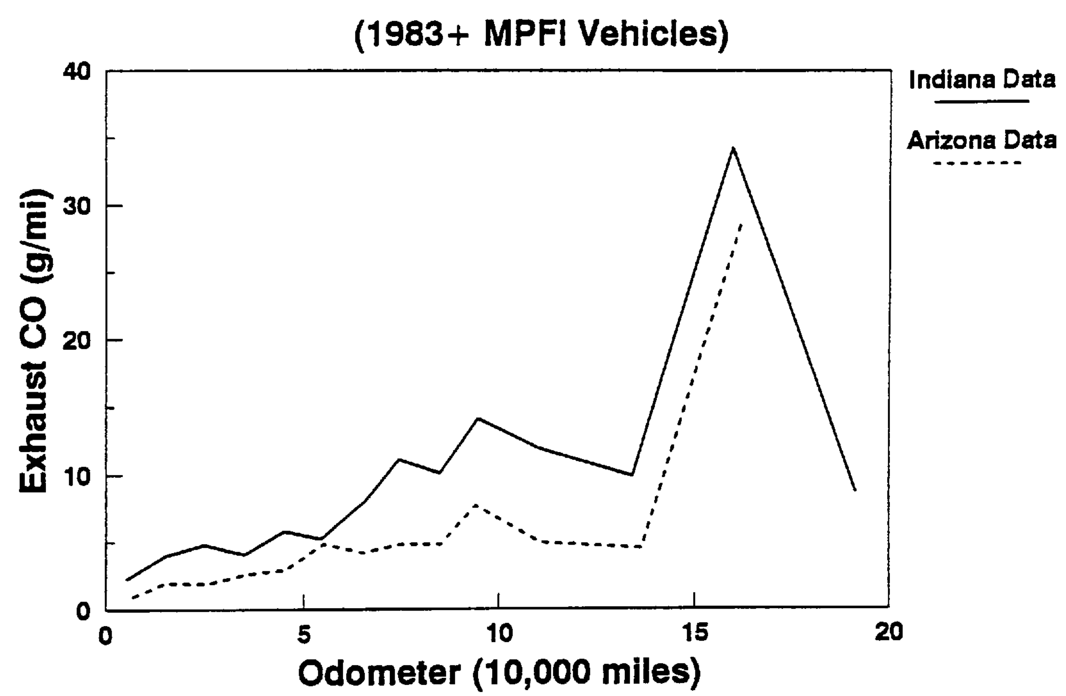


Figure 3-11b. Comparison of Indiana and Arizona Lane IM240 CO Results for MPFI/CL Vehicles

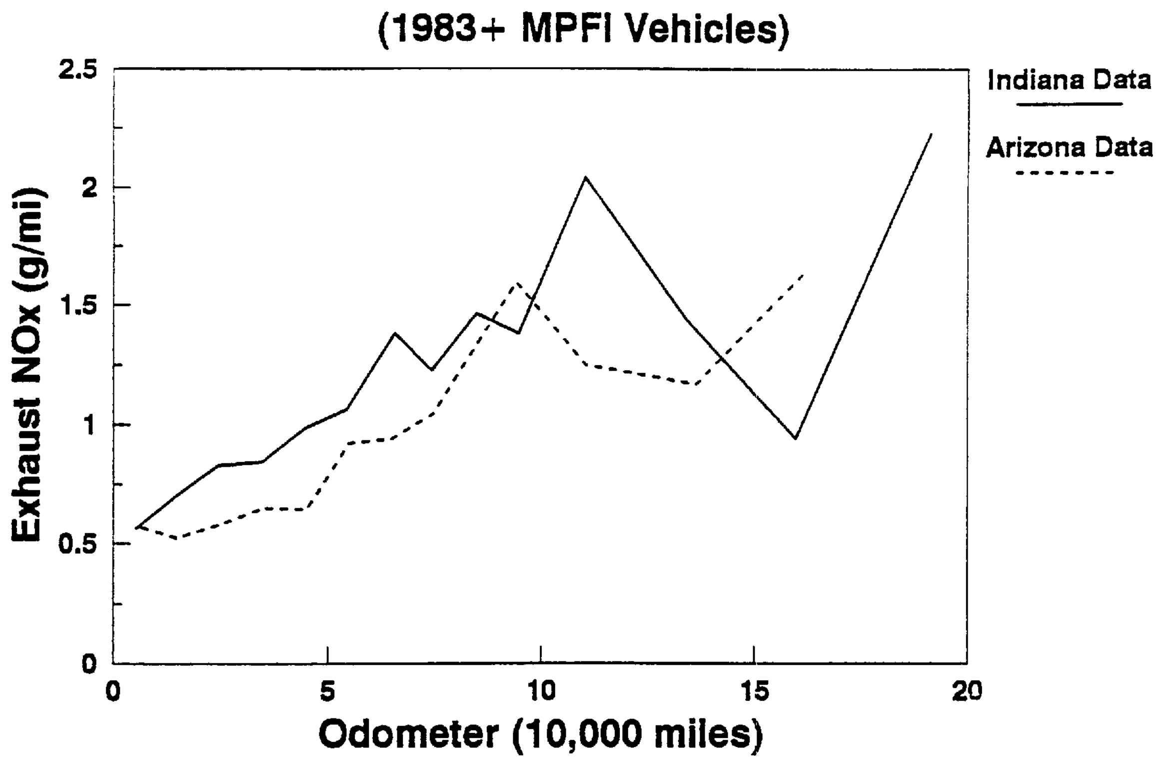


Figure 3-11c. Comparison of Indiana and Arizona Lane IM240 NOx Results for MPFI/CL Vehicles

Table 3-3. Summary of Correlation Coefficients (R^2) for Regressions of Bag 3, Hot FTP, and Full FTP versus the IM240.

Pollutant	Bag 3	Hot FTP	Full FTP
With Veh #3211			
HC	0.81	0.83	0.82
CO	0.53	0.54	0.54
NOx	0.71	0.69	0.70
w/o Veh #3211			
HC	0.81	0.83	0.83
CO	0.63	0.72	0.74
NOx	0.72	0.69	0.70

for CO and excluded it in the analysis. As seen in Table 3-3, including vehicle 3211 results in very poor R^2 values for the CO correlations. In the evaluation that follows, this vehicle was excluded.

The alternative correlation methodology outlined in Section 2 was applied to the Arizona sample that had both IM240 and FTP tests performed. That method relied on regressing the "Hot FTP" results for low IM240 HC and CO emitters (i.e., less than 2.0 g/mi for HC; 16.0 g/mi for CO) against the lane IM240 scores (no adjustment for tank fuel was attempted). The HC and CO cold start offset was determined by calculating the mean value of the offset in 20,000-mile bins. For high IM240 emitters, a simple regression of the full FTP versus the IM240 was performed. Finally, because the cold start offset is less discernable for NOx, the NOx correlations were developed by regressing the full FTP against the corresponding IM240 scores without a cold start offset. Since the sample size was rather small (106 vehicles), both TBI and MPFI technologies were combined. A summary of the regression results is contained in Table 3-4, and Table 3-5 contains the cold-start offset values as a function of odometer bin.

Several items are worth noting with respect to Tables 3-4 and 3-5. First, the sample sizes are not very large, particularly for the high IM240 emitters. Clearly, a larger sample size would give more confidence in the results. Second, the cold-start offset values at low mileage are based on just a few data points, and are greater than those for the higher mileage bins; it might be expected that an increase in the cold-start effect would be observed at higher mileage. Nonetheless, although the data may be sparse, the results of the correlation analysis were used to determine the FTP values for the vehicles IM240 tested as part of the Arizona I/M evaluation project. Those results are summarized below.

Table 3-4. Summary of IM240-to-FTP Regression Equations Developed from the Arizona Data.

Pollutant	Regressor Variable	(n)	Slope	Intercept	R^2
HC					
Normal	Hot FTP	95	0.936	ns[a]	0.79
High	Full FTP	9	2.315	-3.748	0.96
CO					
Normal	Hot FTP	86	0.933	ns[a]	0.67
High	Full FTP	18	1.296	ns[a]	0.83
NOx	Full FTP	104	0.708	ns[a]	0.85

[a] Intercept term was not significant at the 95% confidence level and the regression was re-run with a zero intercept.

Table 3-5. Summary of the HC and CO Cold-Start Offset for Normal IM240 Emitters from the Arizona Data

Odometer Bin	HC		CO	
	(n)	Mean (g/mi)	(n)	Mean (g/mi)
0 - 20K	6	0.675	5	7.20
20 - 40K	7	0.621	7	5.41
40 - 60K	13	0.597	11	6.24
60 - 80K	24	0.600	21	6.79
80 - 100K	23	0.691	22	7.81
100K+	20	0.893	16	6.19

Comparison of Arizona "FTP" Scores to the Hammond Results

The correlations developed above were applied to the IM240 scores collected in the Arizona test program. These were then compared to the results from the Hammond data that were used in MOBILE5a, which is illustrated in Figures 3-12a to 3-12c for HC, CO, and NOx

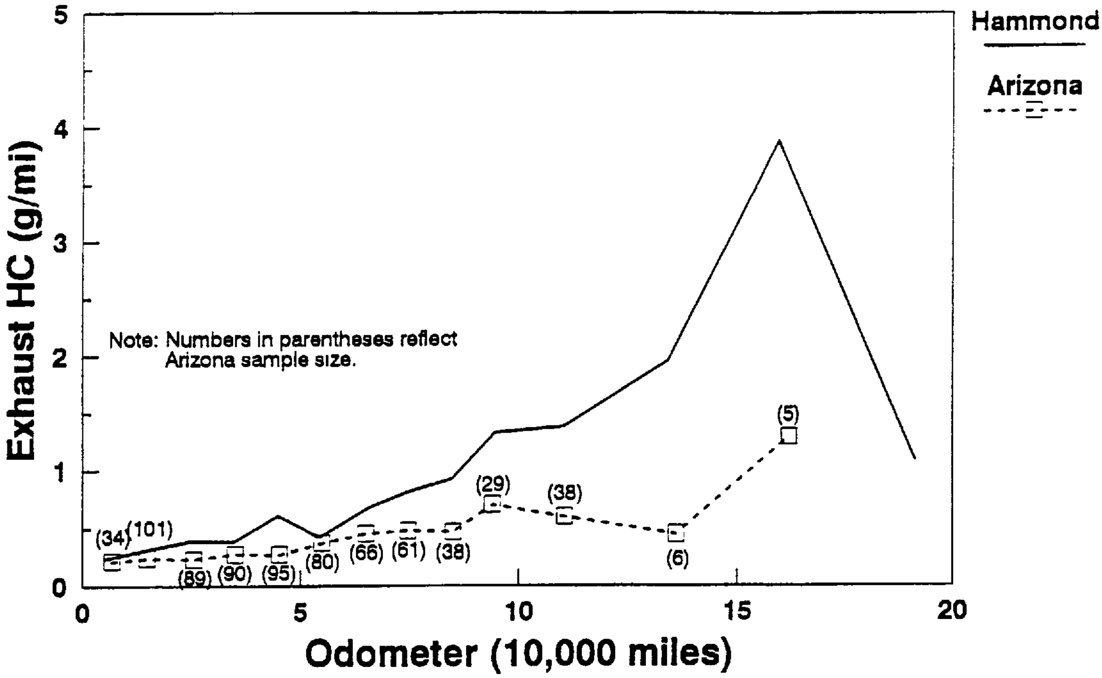


Figure 3-12a. Comparison of Hammond and Arizona IM240-Based FTP HC Emission Rates for MPFI/CL Vehicles

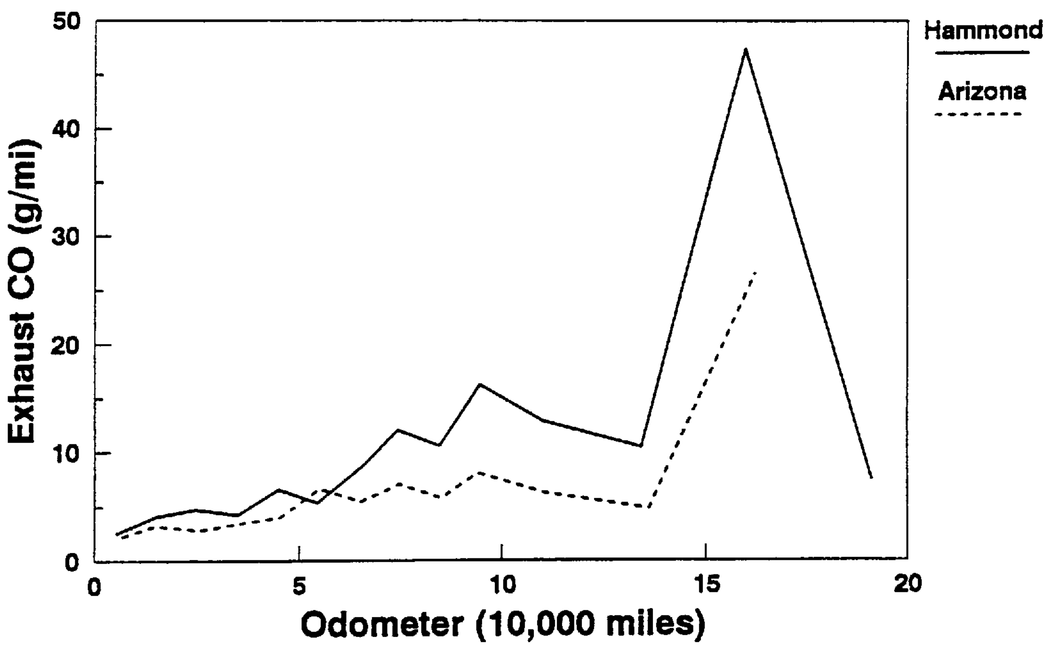


Figure 3-12b. Comparison of Hammond and Arizona IM240-Based FTP CO Emission Rates for MPFI/CL Vehicles

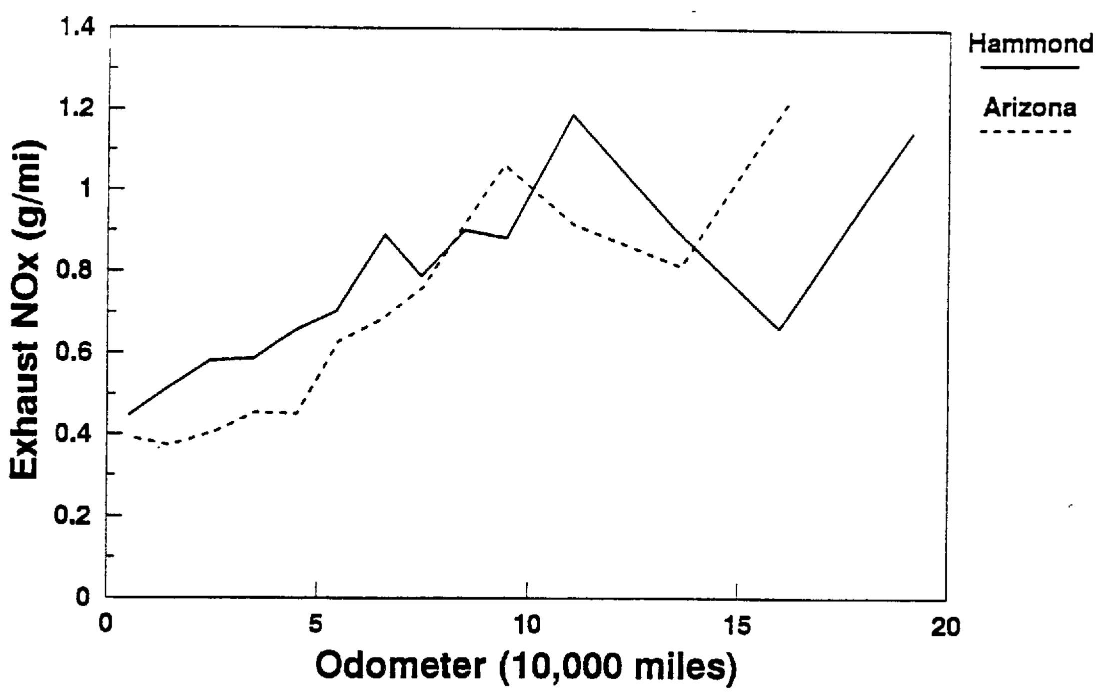


Figure 3-12c. Comparison of Hammond and Arizona IM240-Based FTP NOx Emission Rates for MPFI/CL Vehicles

emissions, respectively, for 1983 and later MPFI/CL vehicles. Note that to be on a consistent basis for the comparison, both the Hammond IM240 data and the Arizona IM240 data were converted to an FTP basis using the alternative methodology described above, and actual FTP data were used in place of the correlation equations for vehicles receiving FTP tests. As seen in the figures, the emission rates for the Arizona data are lower than the Indiana data. As discussed above, this is likely the result of Arizona vehicles being subject to I/M and oxygenated fuels during the time period in which the data were collected. (It should be noted that the comparisons shown in Figures 3-12a to 3-12c are valid up to about 125,000 miles. Beyond that point, the sample sizes for both Hammond and Arizona data sets are very small.)

For areas that routinely conduct IM240 emissions tests (which will be a considerable number when EPA's enhanced I/M requirements are fully implemented), IM240 data have the potential to better represent locality-specific emission rates than the standard version of MOBILE5a. Developing FTP-based emission rates directly from IM240 data has the advantage of by-passing many corrections built into MOBILE5a that add a degree of uncertainty to the final results (e.g., fuel and I/M adjustments). Clearly, the IM240-to-FTP conversion process needs refinement, particularly in terms of how differences between the lane and the lab are accounted for and how the cold start offset is developed. Nonetheless, a methodology and data base could ultimately be constructed to allow communities to develop base emission rate equations from their I/M program test results.

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2. "Tech IV Credit Model: Estimates for Emission Factors and Inspection and Maintenance Credits for 1981 and Later Vehicles for MOBILE3," D.J. Brzezinski, U.S. Environmental Protection Agency, October 1985.

3. "Evaluation of a Four-Mode Steady-State Test with Acceleration Simulation Modes as an Alternative Inspection and Maintenance Test for Enhanced I/M Programs," U.S. Environmental Protection Agency, May 1993.

Appendix A

COMPARISON OF IM240 AND FTP BAG 3 RESULTS

Because the IM240 driving cycle was developed from portions of Bag 3 of the FTP, a strong correlation between Bag 3 and the IM240 is expected. (Bag 3 is used rather than Bag 1 because both Bag 3 and the IM240 are stabilized tests.) Thus, an analysis of the lane IM240 scores relative to Bag 3 of the FTP can give an indication of the variability of the lane data. Such an analysis was performed for the 1983+ MPFI/CL vehicles in the Hammond correlation data set. Regressions were performed on the following quantities:

- Bag 3 vs. lab/Indolene IM240,
- Bag 3 vs. lab/tank fuel IM240, and
- Bag 3 vs. lane/tank fuel IM240.

It would be expected that the correlation between Bag 3 and the lab/Indolene IM240 scores would provide the best fit, followed by Bag 3 vs. lab/tank fuel, and then Bag 3 vs. lane/tank fuel. This result was observed, as seen in Table A-1 which summarizes the regression R-square values. The table indicates very good correlation for CO for all three IM240 tests, while the lane/tank fuel correlation is poorer for HC and NOx compared to the other IM240 tests. Nonetheless, the data collected at the lab show reasonable correlation to the Bag 3 scores.

Table A-1. Summary of R-Square Values for Bag 3 vs. IM240 Scores (1983+ MPFI Vehicles)

Bag 3 vs...	HC	CO	NOx
Lab/Indolene IM240	0.91	0.93	0.82
Lab/Tank Fuel IM240	0.91	0.91	0.75
Lane/Tank Fuel IM240	0.81	0.93	0.62

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