EPA-AA-IMS/80-8

Derivation of 1981 and Later Light Duty Vehicle Emission Factors for Low Altitude, Non-California Areas

November, 1980

NOTICE

This report does not necessarily represent the final EPA decisions or positions. It is intended to present a technical analysis of the issue using data which are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments which may form the basis for a final EPA decision, position or regulatory action.

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I. INTRODUCTION

A. Purpose and Coverage.

The purpose of this document is to describe the methodology used in revising the emission factor equations for the post-1980 Light Duty vehicle fleet. The available data will be presented and discussed and the pertinent assumptions and analyses will be outlined. Low Altitude, Non-California, gasoline-fueled Light Duty vehicles will be the only category of vehicles covered in this report. Light Duty Trucks, Light Duty Diesels, California vehicles, and High Altitude vehicles are all covered under separate analyses, although the other analyses will often use this document as a source analysis. This document is only concerned with the non-I/M case. The I/M case will be discussed in a separate analysis and will result in substantially different emission factor equations. This document is one contributor to a larger effort designed to revise the entire Mobile Source Emission Factors Document (EPA-400/ 9-78-005).

B. Background on the Post-1980 Fleet.

The post-1980 Light Duty vehicle fleet merits a separate analysis from the current fleet for several reasons. Beginning in 1981, the Federal exhaust emission standard for oxides of nitrogen (NOx) drops from 2.0 g/mi to 1.0 g/mi. The hydrocarbon (HC) standard remains at 0.41 g/mi in 1981 and the carbon monoxide (CO) standard drops to 3.4 g/mi for most vehicles. It is the change in the NOx standard specifically that is of significance. The effect of this change in the standard will be to lead manufacturers of most vehicles to adopt a technology which utilizes what has become known as a Three-Way catalyst. It is called a Three-Way catalyst because it allows not only the conversion of hydrocarbons (HC) and carbon monoxide (CO) as with a conventional Oxidation or Two-Way catalyst, it also allows the catalytic conversion of NOx. Thus it provides a new and previously unused source of NOx control. To enable the catalyst to perform these three conversion functions simultaneously, precise control of the air/fuel ratio is required. This is most often accomplished through the use of an on-board microprocessor which receives inputs from a variety of sensors (notably the oxygen sensor, which is located in the exhaust stream and provides an indication of the air/fuel ratio), processes these inputs continuously, and then provides an output signal to the carburetor or fuel injectors to adjust the air/fuel ratio. The system thereby provides a feedback loop and is therefore also known as a Closed Loop system. A microprocessor can be designed to control other engine functions as well, such as spark timing, idle speed, and EGR flow rate. Thus the net effect of the change in the NOx standard will be to introduce significantly different technology into the fleet in large measure beginning in 1981.
Due to the differences between this new technology and the more conventional technology of the past several years, it is to be expected that there will be differences in the in-use emissions performance of the

post-1980 fleet. These differences in in-use performance necessitate a separate analysis. This fact was recognized in the previous edition of the Mobile Source Emission Factors Document (EPA-400/ 9-78-005) which this document revises and updates.

Two other considerations that affect the post-1980 fleet need to be raised here. First, beginning in 1981, the "Parameter Adjustment" regulations (44 F.R. 2960) will be applied to the fleet. These regulations will cause limitations in the adjustability of some of the basic parameters of the engine. In 1981, these regulations will be applied idle mixture and choke, and in 1982, they will be applied to timing. While these regulations have less of an effect on most Closed Loop vehicles than on most Oxidation catalyst vehicles, due to the largely self-adjusting nature of the former, the Parameter Adjustment regulations will nonetheless have an impact, especially on certain parts of the fleet. The effect of the Parameter Adjustment regulations has been taken into account throughout this analysis.

A second consideration affecting the post-1980 fleet is the presence of the Clean Air Act Section 202(b)(5) waiver fleet: those cars that received a CO waiver from 3.4 g/mi to 7.0 g/mi in 1981 and 1982. In 1981, and to a lesser extent in 1982, a portion of the fleet will be designed to meet a 7.0 g/mi CO standard as a result of these waivers. These cars can be expected to have higher CO emissions in general due to the higher standard, and the impact of those higher emissions, although small, has been figured into the fleet-average emissions in this analysis.

C. Composition of the Fleet: Technology Types.

Before discussing the methodology in depth, the projected make up of the fleet needs to be discussed. In terms of the emission control systems to be employed there will essentially be three different systems in the post-1980 fleet, however two of these three are assumed to have similar emissions performance. Thus, this analysis distinguishes only two technology types with unique emissions performance from among the fleet. The distinguishing characteristics of the two technology types will be briefly presented below.

1. Closed Loop Vehicles.

By far the largest percentage of the fleet will be comprised of this technology type. The distinguishing characteristics of this technology type are feedback control of the air/fuel ratio and the use of a Three-Way catalyst. In reality, as was alluded to above, this technology type could be further broken down into two separate technology types: those vehicles equipped with an Oxidation catalyst, supplied with air by an air pump, following the Three-Way catalyst and those vehicles without the additional Oxidation catalyst and air pump. Three reasons were responsible for not making this further division of Closed Loop vehicles. First, the manufacturers of most vehicles have indicated that during significant failure modes of their Closed Loop vehicles, the air flow from the air pump will be diverted to the atmosphere (or to the air cleaner for silencing) instead of to the Oxidation catalyst. This is due to concerns for catalyst protection. As will be discussed later, it is these significant failure modes of Closed Loop vehicles that are assumed to make large contributions to the overall fleet composites. During a failure mode of this type, without the benefit of air being supplied to the Oxidation catalyst, the in-use data indicates that these systems have HC and CO emission levels as high as systems without the additional Oxidation catalyst and air pump. Thus, there is no need to distinguish between these two systems during significant failure modes.

Second, examination of in-use data from both types of vehicles (with and without the additional Oxidation catalyst and air pump) did not reveal a significant and consistent difference between the emissions of the two systems when operating at other than significant failure modes.

Third, the presense or absence of an Oxidation catalyst and air pump is not assumed to effect NOx significantly.

In summary then, the two systems will be treated as one technology type having a unique emissions performance.

One final point to be made regarding this technology type has to do with Ford Motor Company vehicles in the 1981-1983 timeframe. Ford has indicated that it intends to certify a large portion of its 1981-1983 fleet as open loop vehicles equipped with Three-Way catalysts. That is, these vehicles would not employ an on-board microprocessor with a feedback oxygen sensor but would still have a Three-Way catalyst to enable some catalytic reduction of NOx. Due to a lack of any in-use data on these systems at the time of this analysis, as well as to uncertainty as to the fraction of Ford vehicles which will have open loop systems, these vehicles were included under the Closed Loop technology type. In 1984, any Ford vehicles which had been open loop are assumed to go closed loop due to the advent of the High Altitude regulations.

2. Oxidation Catalyst Vehicles.

Some vehicles, notably small foreign vehicles and vehicles with unique engine configurations, will be able to meet the 1981 standards without the catalytic control of NOx provided by Three-Way catalyst technology. Instead, they will rely on an Oxidation catalyst, air pump or pulse-air system, and, in most cases, EGR. These vehicles are expected to comprise a relatively small segment of the fleet.

D. Summary of Results.

The results of this analysis can best be presented by discussing the various failure modes expected to occur and by briefly characterizing the performance of each pollutant (HC, CO, NOx). For the majority of the fleet, which consists of Closed Loop vehicles, the principal failure mode resulting in significant emission increases occurs through the loss of the closed loop capability of the system and a resultant rich mode of operation. These failure modes, while not initially very numerous, have a large impact on the overall fleet emissions for HC and CO due to the very high emissions resulting for those two pollutants. Thus, a relatively small percentage of the fleet contributes a disproportionately large share of the final composite emissions for HC and CO. This is especially true for CO. The data base of in-use vehicles which was relied on in performing this analysis gave significant indication of this type of behavior for Closed Loop vehicles. NOx emissions for those cars with an open loop failure will decrease due to the rich operating condition.

For Oxidation Catalyst vehicles, which are designed to operate open loop, a more traditional deterioration pattern is assumed to occur. Briefly stated, the regression methodology used for the 1975-1980 Light Duty fleet was revised to represent 1981 and later Oxidation Catalyst vehicles. The revised methodology accounts for the effect of the Parameter Adjustment regulations and for the fact that the 1981 standards are more stringent than the 1975-1980 standards.

A graphical comparison of the new emission composites with the emission composites arrived at in the 1978 analysis (Appendix E of the Mobile Source Emission Factors Document, EPA-400/9-78-005) will be presented in Section IX. To generally characterize that comparison however, there is a slight increase in the HC composite at 50,000 miles, a definite increase in the CO composite at 50,000 miles, and a slight increase in the NOx composite at 50,000 miles.

The following table presents the new emission factor equations:

Table I-1
Exhaust Emission Rates for Light Duty Vehicles
For All Areas Except California and High Altitude

Pollutant	Model Year	New Vehicle Emission Rate (g/mi)	Deterioration Rate (g/mi/10,000 miles)
HC	81	0.39	0.19
HC	82	0.39	0.19
HC	83+	0.39	0.19
CO	81	5.60	2.75
CO	82	5.21	2.76
CO	83+	5.00	2.76
NOx	81	0.75	0.15
NOx	82	0.75	0.15
NOx	83+	0.75	0.15

II. DESCRIPTION OF THE DATA BASE

A. Introduction.

The data used in this analysis come from a variety of sources. The bulk of the data comes from EPA testing programs in Los Angeles designed to test in-use Closed Loop vehicles.[1,2,3]* In addition, data from 50 in-use Closed Loop vehicles tested in Portland, Oregon were used.[4]* For each set of data, the effect of the Parameter Adjustment regulations was accounted for by removing from the data base those cars which showed evidence of removal of idle mixture limiting devices where applicable, a maladjustment of idle speed of greater than 200 rpm**, or a timing maladjustment of greater than $\pm 5°$. In some cases, data from vehicles with evidence of maladjusted parameters, but which also had evidence of other non parameter-related problems, were retained in the calculations of the levels of pollutants not primarily affected by the maladjusted parameter and/or in the calculation of the incidence of non parameter-related problems.

A final preliminary consideration which needs to be mentioned at this point has to do with the methane correction factor for vehicles certified in California. The California certification process accounts for the fact that a certain portion of the HC measured in the exhaust is methane (CH_4). Vehicles being certified in California are allowed to claim a "credit" for that portion of the HC exhaust which is methane. The default credit is 11% methane, however manufacturers can claim more credit by demonstrating that their vehicles emit a higher fraction of methane. Since most of the vehicles in the data base were certified in California, yet this analysis is concerned with non-California vehicles, this difference needed to be accounted for. Use of the methane credit has the effect of raising the total HC design standard from the perspective of this analysis. For example, vehicles receiving the default methane credit of 11% can emit up to 0.46 g/mi total HC and still pass California certification after the credit has been applied. This analysis accounted for this relative difference in effective design standards by applying a ratio of those design standards (e.g. 0.41/0.46) to the HC emission levels found in the data base, except in those cases where the emission levels were judged to be independent of the design standard. These exceptions will be pointed out as they occur.

The principal data used for analyzing the emissions performance of the two technology types will be briefly presented in the following sections.

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* Numbers in brackets indicate references listed at the end of the Section.
** At the time the analysis was finalized, idle speed was included in the Parameter Adjustment regulations as a parameter which would need to be designed to be non-adjustable beginning in 1982. That requirement has since been lifted. The analysis was not revisted to account for the change since it was determined to not have a significant impact and due to the fact that the composite emission factors had already been finalized.

B. Closed Loop Vehicle Data Base.

The vehicles from the following four groups were combined to create an overall data base to be used in determining the emissions characteristics of Closed Loop vehicles. An assortment of various systems and engine sizes are represented. This data base is assumed to give representative emission values for Closed Loop vehicles. The four groups which make up the data base represent the most recent and advanced technology put forward by the various manufacturers. The simpler, first generation systems were excluded from the data base (e.g. 1978/ 1979 Ford Pintos, 1978/1979 Pontiac Sunbirds) due to being judged unrepresentative.

1. 1979 Ford/Mercury 351 CID engine family (5.8WBV2TT95x95) equipped with Electronic Engine Control II (EEC-II).

a. A total of 97 in-use vehicles were tested. 82 vehicles were tested by contractors in Los Angeles, and 15 vehicles were tested in Portland, Oregon. Six vehicles were eliminated due to Parameter Adjustment concerns. This engine family is equipped with an Oxidation catalyst following the Three-Way catalyst and an air pump which supplies air to the Oxidation catalyst.

b. This engine family uses a digitally based microprocessor which allows very sophisticated control of the engine. It regulates not only the air/fuel ratio, but also spark timing, EGR flow rate, and the deployment of air flow from the air pump.

c. Of the 15 vehicles tested in Portland, Oregon, one was from California and was therefore designed to meet the 1979 California emissions standards (0.41/9.0/1.5). The other vehicles, while being sold outside of California, were nonetheless assumed to be designed to meet the 1979 California standards for HC and CO and the 1979 Federal Standard for NOx (2.0 g/mi). This was done based on the technical assumption that the 1979 351 CID engine family was intended to be an in-the-field test of the EEC system. As such, it was primarily designed to meet the tighter California standards to give a better indication of how well the system would perform under the eventual 1981 Federal standards (0.41/3.4/1.0). Thus the basic system calibration was designed to meet the 1979 California standards rather than the looser 1979 Federal standards (1.5/15.0/2.0). For the vehicles sold outside California, however, (i.e. the vehicles tested in Portland) it is assumed that the calibrations pertaining to NOx (e.g. spark timing, EGR flow rate) were relaxed due to fuel economy and driveability concerns. This could easily be done without significantly affecting the primary HC and CO calibration. The in-use data from Portland well supports this assumption: the average HC and CO levels from Portland are the same as or lower than the average HC and CO levels from Los Angeles and the average Portland NOx levels are higher.

d. These vehicles received a 17% Methane credit.

2. 1980 General Motors California X-Body vehicles (01C2XCP 01C2XC, and 02X2NC) equipped with the Computer Controlled Catalytic Convertor system (C-4). 151 and 171 CID.

a. A total of 92 in-use vehicles were tested, all in the Los Angeles area. 9 vehicles were eliminated due to Parameter Adjustment concerns.

b. These vehicles employ a digitally based control system. The C-4 system in this application primarily controls the air/fuel ratio. The C-4 system is the basic system projected to be employed by General Motors throughout the early 1980's.

c. These vehicles received the standard 11% Methane credit.

3. 1979 Toyota Celica Supra vehicles (4M-E) 156 CID.

a. A total of 25 in-use vehicles were tested, all in the Los Angeles area. Two vehicles were eliminated due to Parameter Adjustment concerns.

b. These vehicles are fuel injected and employ an analog based control system.

c. These vehicles received the standard 11% Methane credit.

4. 1979 VW Audi: 5000. 131 CID.

a. A total of 4 in-use vehicles were tested, all in the Los Angeles area. No vehicles were eliminated due to Parameter Adjustment concerns.

b. These vehicles are fuel injected. They do not use EGR.

c. These vehicles received the standard 11% Methane credit.

C. Oxidation Catalyst Vehicle Data Base.

1. Data support for this technology type, which is similar in most respects to current oxidation-catalyst-and-air-pump technologies, was obtained from the analysis completed to revise the emission factor equations for 1975-1980 vehicles. That analysis was based on in-use data obtained from a wide array of 1975-1979 model year vehicles tested around the country through EPA's Emission Factor Program. The specific methodology involved in applying that data to this analysis will be presented later (Sections IV and V).

D. Miscellaneous Data. 1978-79 Volvos and Saabs equipped with the Lambda Sond system (4CL, 6CL, BT20CA and BSI20CA). A total of 162 Volvos and Saabs were tested in programs in Los Angeles and Portland.[1,2,3,4] Data from these vehicles were used chiefly in determining deterioration rates for Closed Loop vehicles (see Section IV.A.2.b.).

This fleet has a much wider mileage spread than found in the major Closed Loop vehicle data base and could therefore be used in determining deterioration rates. All Volvo and Saab vehicles marketed west of the Mississippi have the same engine calibrations, so the Portland and Los Angeles vehicles could be analyzed together without needing to take different standards into account.

References for Section II.

1. EPA Contract No. 68-03-2590 with Automotive Environmental Systems, Inc. Results published in EPA document EPA-460/3-79-004.

2. EPA Contract No. 68-03-2889 with Automotive Environmental Systems, Inc. Results published in EPA document EPA-460/3-80-006.

3. EPA Contract No. 68-03-2774 with Automotive Testing Laboratories, Inc. Results not published at the time of this report.

4. EPA Contract No. 68-03-2829, Test Group No. 1, with Hamilton Test Systems, Inc. Results published in EPA document EPA-460/3-80-006.

III. GENERAL METHODOLOGY

A. Introduction.

This section presents the general methodology used in constructing the emission factor model for the post-1980 fleet. Specific methodologies are presented in detail in Sections IV and V. The HC/CO methodology and the NOx methodology will be discussed separately. HC and CO have been analyzed together due to a basic similarity in the in-use failure modes which result in high HC and CO emission levels, whereas the failure modes to which NOx is sensitive are relatively independent. The general methodology used in this analysis is similar in concept to that used in the 1978 analysis (Appendix E) as will be discussed later in this section.

B. HC/CO Methodology.

1. Unit of Analysis. The basic units of analysis (i.e., the unique subfleets of similar vehicles for which unique analyses are performed and which are aggregated later into a fleet-composite analysis) are individual technology types certified to specific pairs of HC/CO standards. Thus, each of the two technology types discussed in Section I.C. will comprise a separate unit of analysis for each of two possible combinations of HC/CO standards, for a total of four units of analysis. The two possible combinations of HC/CO standards are 0.41 g/mi HC with 3.4 g/mi CO, and 0.41 g/mi HC with 7.0 g/mi CO. This second combination stems from the CO waiver decision.

2. Categories. Each unit of analysis representing Closed Loop vehicles will be divided into categories (i.e. groupings of vehicles within the overall unit of analysis which have similar emission characteristics). Several different vehicle conditions could be included under and contribute to the size of a category, but a single set of emission characteristics for each pollutant describes the category. Oxidation Catalyst vehicles will not be divided into categories.

3. Emissions Performance of the Categories. The average emission characteristics of each category for a given pollutant are described by two parameters:

a. Zero-mile level. The zero-mile level is the average emission level for a pollutant at zero miles.

b. Deterioration rate. The deterioration rate is the amount of increase in the emission level of a pollutant per 10,000 miles.

The unit of measurement for the zero-mile level is g/mi. The unit of measurement for the deterioration rate is g/mi/10,000 miles. The deterioration rate should not be confused with the "deterioration factor" which is the ratio of the emission level at 50,000 miles to the emission level at 4,000 miles. The concept of the deterioration factor will be used later.

4. Migration between Categories. Within a given unit of analysis, for example the Closed Loop vehicle technology type designed to meet a 0.41 g/mi HC standard and a 7.0 g/mi CO standard, the size of the different categories will change with time. As would be expected, the general movement over time is from categories representing more well-maintained vehicles with lower emissions to categories representing less well-maintained vehicles or vehicles with some component failure with correspondingly higher emissions. The growth rates for the categories are expressed in units of percentage of the total unit which enters the category per 10,000 miles. Some categories of course will have negative growth rates. That is, as some categories grow, others must decrease in size.

5. Unit-of-Analysis Composite Emissions. The emissions from each of the categories within a unit of analysis will be weighted together every 10,000 miles to arrive at a composite emission characteristic for that unit. This will be done by weighting the emission levels of each category at a given mile point by the fraction of the unit of analysis represented by that category at the given mile point. The net result will be a table of the unit's emission levels at each 10,000 mile point. This table will reflect the relative contribution of the various categories based on the size of the categories as well as their individual emission levels. Examples of this concept can be found in Sections IV and V.

6. Fleetwide Composite Emissions. To obtain a fleetwide composite emission factor for a given model year, the emission composites from each of the units of analysis will be combined according to a weighting scheme similar to that described above for combining categories within a unit of analysis. The separate unit-of-analysis emission composites will be weighted according to the respective fractions of that model year's fleet represented by those units of analysis. These fractions were determined by examining manufacturer's statements and certification data. The determination of how the fleet was broken down into the various units of analysis will be discussed in depth for each model year in Sections VI through VIII.

C. NOx Methodology.

The NOx methodology is essentially identical in concept to the HC/CO methodology. In the following subsections only the pertinent differences will be mentioned.

1. Unit of Analysis. For NOx, there are only two units of analysis. There is only one applicable NOx standard, 1.0 g/mi, and NOx is not assumed to be affected by the different CO standards introduced by the waiver decision. Thus the two units of analysis are:

a. Closed Loop vehicles
b. Oxidation Catalyst vehicles.

2. Categories.

a. Closed loop vehicles will have four categories of operating condition.

b. Oxidation Catalyst vehicles will not be divided into categories.

3. Emissions Performance of the Categories. - No difference.

4. Migration between Categories. - No difference.

5. Unit-of-Analysis Composite Emissions. - No difference.

6. Fleetwide Composite Emissions. - No difference.

D. Comparison to the Methodology used in the Previous Analysis.

1. The methodology used in this analysis is similar to that used in developing Appendix E (Appendix E of the Mobile Source Emission Factor Document EPA-400/9-78-005). Appendix E divided a unit of analysis into different categories with independent emission performance characteristics (zero-mile levels and deterioration rates) as has been done in this analysis. Those categories also grew or declined in size over time, and a unit composite was obtained by weighting the various categories and adding them together. The chief methodological difference between Appendix E and this analysis is that Appendix E used a single unit of analysis to represent the entire fleet for all model years after 1980 whereas this analysis has four distinct units of analysis for HC and CO and two units of analysis for NOx. Appendix E assumed one technology type; this analysis assumes two different technology types. Appendix E treated only one pair of HC and CO standards; this analysis has needed to account for a wider array of combinations of HC and CO standards due to the waiver decisions. As will be apparent later, the categories defined for this analysis are also very different from the categories used in Appendix E, as are the categories' emission levels.

IV. SPECIFIC UNIT ANALYSES - HC/CO

A. Closed Loop vehicles designed to meet 0.41 g/mi HC and 3.4 g/mi CO standards.

1. Category definitions.

a. Primary. This category is comprised of those vehicles, designed to operate closed loop, which have either lost their closed loop capacity, or have had it severely restricted. These vehicles are assumed to then operate in a rich mode. Possible contributors to this category include vehicles with catastrophic oxygen sensor failure, microprocessor failure, other sensor failures or tampering with the closed loop system.

It was necessary to select from the data base the subset of vehicles which would be relied upon in predicting the emission characteristics of this category. This was done by selecting all vehicles which had CO emission levels greater than 50.0 g/mi, on the premise that any vehicle with CO emissions this high must be experiencing rich operation due to a failure of the closed loop control system.

b. Secondary. This category is comprised of all the vehicles in the fleet not in the Primary category and not in the Misfueling category (see below). Contributors to the Secondary category include vehicles experiencing general malmaintenance, failure or degradation of sensors not leading to loss of closed loop operation, tampering, as well as a large percentage of vehicles experiencing generally good maintenance with resultant low emission levels.

As with the Primary category, a subset of the data base fleet was selected to be used in predicting the emission characteristics of this category. This was done by selecting all vehicles which had CO emission levels less than 50.0 g/mi.

c. Misfueling. This category is comprised of vehicles which have been misfueled and have therefore had their emission control systems damaged. Misfueling refers to the use of leaded fuel in vehicles equipped with catalysts. The leaded fuel in effect "poisons" the catalyst and dramatically reduces its ability to convert HC, CO and NOx to harmless by-products. Misfueling also damages the oxygen sensor on Closed Loop vehicles. It affects the output voltage of the sensor as well as hindering the ability of the sensor to respond quickly to changes in the composition of the exhaust stream. This normally results in more rich operation and consequently higher HC and CO emission levels. The interaction of this category with the other two will be described in a later section dealing with category sizes (Section IV.A. 3).

2. Emission levels of the categories.

a. Primary Category.

i. Zero mile levels. The average measured HC/CO emission levels and the average odometer mileage of the vehicles selected from the data base to represent the Primary category are:

Average HC = 3.85 g/mi	(n = 10)
Average CO = 108.0 g/mi	(n = 10)
Average Mile = 9,163 miles	(n = 10)

(Note: Of the ten vehicles in the data base which met the criteria to be selected to represent the Primary category (greater than 50.0 g/mi CO) five were from the General Motors X-Body fleet and five were from the Ford 351 fleet.)

Applying the deterioration rates (see below) to these average emission levels results in the following back-projected emission levels at zero miles:

HC = 3.74 g/mi
CO = 107.36 g/mi

(Note: The reader will note that for the Secondary category discussed below, the zero-mile CO level was adjusted by a ratioing factor of 3.4/9.0 to account for the fact that the vehicles in the data base were designed to the California CO emission standard of 9.0 g/mi rather than to the 3.4 g/mi standard which applies to this unit of analysis. The CO emission level was not ratioed to the 3.4 g/mi CO standard for the Primary category since this category represents vehicles with a major failure mode during which CO emissions are assumed to be effectively independent of the CO design standard. This same logic dictated that the HC emission levels need not be ratioed to account for the various effective HC design standards resulting from the application of methane credits. See Section II.A. for a more complete discussion of this issue.)

ii. Deterioration rates. The HC/CO deterioration rates for the Primary category were obtained by adopting the deterioration rates developed for the Secondary category. That development will be presented in the next section. The deterioration rates for the Secondary category were adopted due to a lack of data describing the deterioration of Primary category vehicles. The deterioration rates arrived at are:

HC= 0.12 g/mi/10,000 miles
CO= 0.71 g/mi/10,000 miles

b. Secondary Category.

i. Zero-mile levels. The average measured HC/CO emission levels and the average odometer mileage of the vehicles in the data base which represent the Secondary category are:

Average HC = 0.32 g/mi	(n = 191)*
Average CO = 5.47 g/mi	(n = 195)*
Average Miles = 8,064 miles	(n = 191)

Applying the deterioration rates (see below) to these average emission levels to back-project the levels to zero miles and then applying a ratio of 3.4/9.0 to the CO emission level to reflect the fact that the vehicles in the data base were designed to meet a 9.0 g/mi CO standard and not the 3.4 g/mi standard which is the focus of this analysis, results in the following Zero-mile emission levels:

HC = 0.23 g/mi
CO = 1.86 g/mi

ii. Deterioration rates.

The development of deterioration rates for the Secondary category was an involved process. Before presenting that process in detail, several points can be made which will give helpful background on why the deterioration rates were developed as they were.

First, the vehicles in the Closed Loop vehicle data base do not have a large enough mileage spread to support a credible regression analysis (which would yield a deterioration rate and zero-mile level). The vast majority of vehicles in the data base have odometer mileages between 6,000 and 12,000 miles.

* The sample sizes used to calculate the average emission levels for the two pollutants differ due to the fact that Parameter Adjustment concerns eliminated vehicles for one pollutant but not for the other. See Section II.A.

The next most apparent source of data for examining the deterioration of Closed Loop vehicles is the deterioration observed in the EPA Certification process. For each engine family with a unique emission control system produced in a given model year, a representative vehicle from that family must demonstrate the ability to meet the applicable emission standards out to 50,000 miles in order to be certified. While the deterioration observed in the Certification process is believed to be a good measure of the relative durability of a given vehicle's emission control system, it does not, however, give an accurate picture of how the vehicle will perform out in the field. It has always been the case that in-use vehicles deteriorate at a faster rate than that observed in Certification. This is due to owner malmaintenance and tampering, harsh real-world conditions, and other factors. This is assumed to still be the case in the post-1980 timeframe.

Given the fact then, that the data base used to determine zero-mile levels could not be relied upon to predict deterioration and that the use of Certification deterioration factors by themselves would be unrealistic, it was necessary to rely on other sources of data to determine the deterioration rates. As was mentioned in Section II.D., there is a fleet of in-use Closed Loop vehicles, the Volvo/Saab fleet, which does have a significant mileage spread. This fleet is made up of 162 1978 and 1979 Volvos and Saabs with a mileage spread of between 0 and 30,000 miles. There are, however, substantial reasons why the in-use deterioration observed for these vehicles could not be adopted outright to represent the in-use deterioration of the post-1980 fleet. These reasons center around differences in technology between the Volvos and Saabs and typical post-1980 vehicles. The Volvos and Saabs are fuel injected as opposed to carbureted, have an analog based control system as opposed to a digitally based control system, do not use EGR and have a European manufacturer. These differences are significant, especially so for NOx. Since an approach was needed which could be applied consistently to all three regulated pollutants, (HC, CO, NOx), the differences in technology needed to be taken into account.

In view of all of the above-mentioned considerations, the following procedure was decided upon. First, a regression was performed on the Volvo/Saab fleet after removing vehicles due to Parameter Adjustment concerns. Two vehicles with FTP CO emissions greater than 50.0 g/mi were also removed from the fleet since these vehicles would be classified as Primary category vehicles. The regression yielded a zero-mile level and a slope which represent in-use deterioration. Second, the deterioration predicted by Certification for the 1978 and 1979 Volvos and Saabs was quantified by weighting together the Certification deterioration factors (d.f.'s) for each of the possible model year/engine size combinations among the Volvo/Saab fleet. The weighting technique was based on the number of vehicles in the fleet which came from the various model year/engine size combinations. There were some HC d.f.'s from some of the model year/engine size combinations which were less than 1.0 which were raised to 1.0 for the purposes of calculating the weighted average. Third, a ratio was formed using the in-use deterioration and the Certification deterioration. This ratio gives an indication of how Secondary category Closed Loop vehicles deteriorate in the field relative to how prototypes of the same models deteriorate in the Certification process; the ratio can be used as an adjustment, or correction factor, to predict in-use deterioration of Secondary category vehicles given a figure of Certification deterioration. This ratio was based on units of the "deterioration factor minus one" (d.f.-1). (The in-use deterioration regression was easily converted to a d.f.-1 by first finding the emissions at 50,000 miles and 4,000 miles, taking the ratio of those two figures to obtain a d.f. and then subtracting one to obtain the d.f.-1). The d.f.-1 was used in the ratio since it is the portion of the d.f. greater than one which represents the percent increase in a pollutant over 50,000 miles. To use the d.f. by itself in the ratio would have been misleading since the d.f. is itself a ratio (the emissions at 50,000 miles over the emissions at 4,000 miles).

Finally, the ratio described above, which predicts the relationship between Certification deterioration and in-use deterioration, was applied to an average Certification d.f.-1 for 1981 Closed Loop vehicles in the Certification process (n = 89). Applying the ratio yields a figure for an in-use d.f.-1 which can be used to represent the in-use deterioration of Secondary category post-1980 vehicles. The following equation illustrates this relationship:

$$(d.f.-1)_{1981\ Cert} \times \frac{(d.f.-1)_{Volvo/Saab\ in\text{-}use}}{(d.f.-1)_{Volvo/Saab\ Cert.}} = (d.f.-1)_{1981+\ in\text{-}use}$$

The in-use d.f.-1 arrived at can be converted to a d.f. by adding one. This deterioration factor (d.f.) can then be converted to a deterioration rate (d.r.) by using the following equation and the average emission levels at the average mileage (approximately 8,000 miles) of the Secondary category vehicles found in the Closed Loop in-use data base.

$$\text{d.f.[in-use]} = \frac{\text{Emissions at 50,000 miles}}{\text{Emissions at 4,000 miles}} = \frac{\text{Emissions at 8,000 miles} + (4.2)(\text{d.r.})}{\text{Emissions at 8,000 miles} - (.4)(\text{d.r.})}$$

The only unknown in this equation is the deterioration rate (d.r.) which can therefore be easily solved for.

Two exceptions to this procedure need to be mentioned here before presenting a table of the values used in the calculations and the deterioration rates arrived at. First, for HC, the average Volvo/Saab Certification d.f. (1.02) was so low that using the d.f.-1 to find the ratio between in-use and Certification deterioration resulted in an unrealistically high ratio (40.5). In view of how low the HC d.f. is and how it thereby unrealistically inflates the in-use/Certification ratio, it was decided to regard the HC Certification d.f. as an anomaly and to adopt the ratio observed for CO (5.6) to be used for HC as well. Given the fact that HC and CO emissions are both affected in the same way by relatively similar malperformances for Closed Loop vehicles, this approach is judged to give a better estimate for the HC ratio.

The second exception to the general procedure outlined above has to do with the fact that for CO, the vehicles in the data base were designed under a 9.0 g/mi CO standard whereas this unit of analysis consists of vehicles designed to meet a 3.4g/mi standard. The following set of equations was used to translate from the in-use data point based on 9.0 g/mi CO standard vehicles to arrive at a slope for vehicles designed to a 3.4 g/mi CO standard. These equations incorporate the assumption of equal slopes (or deterioration rates) for vehicles designed to meet 3.4 g/mi or 9.0 g/mi CO standards and the assumption that the Zero-mile levels for vehicles designed to 3.4 g/mi or 9.0 g/mi CO standards are in the same ratio as their standards (9.0/3.4).

1. $\text{d.f.}_{81} = \frac{a + 4.2(s)}{a - .4(s)}$

2. $Z_9 = b - (.8)(s)$

3. $Z_{3.4} = a - (.8)(s)$

4. $Z_9/Z_{3.4} = 9.0/3.4$

d.f._{81} = in-use d.f. for post-1980 vehicles (derived as described above for the general case).

a = CO emissions at 8,000 miles for Secondary vehicles designed to meet the 3.4 g/mi CO standard (an unknown).

s = in-use deterioration rate (unknown).

b = CO emissions at 8,000 miles for Secondary vehicles designed to meet the 9.0 g/mi CO standard (known from the in-use data).

Z_9 = Zero-mile CO emissions for Secondary vehicles designed to meet the 9.0 g/mi CO standard (unknown).

$Z_{3.4}$ = Zero-mile CO emissions for Secondary vehicles designed to meet the 3.4 g/mi CO standard (unknown).

These equations can be combined given the in-use data point (b) and the calculated d.f. ($d.f._{81}$) to arrive at a CO deterioration rate (s) for vehicles designed to meet the 3.4 g/mi CO standard.

The following table presents the pertinent values used in calculating the HC/CO deterioration rates.

Table IV-1
Input Values to the Calculation of Deterioration Rates

	Volvo In-Use d.f.-1	Volvo Cert. d.f.-1	Actual In-Use/ Cert Ratio	Ratio Used for In-Use/ Cert.	Average 1981 Cert. d.f.-1	Resultant d.f.-1	Resultant 1981+ d.f.
HC	0.81	0.02	40.5	5.65	0.37	2.09	3.09
CO	0.96	0.17	5.65	5.65	0.27	1.52	2.52

Applying the resultant d.f.'s to the in-use data points found in the data base as described above gives the following HC/CO deterioration rates:

HC = 0.12 g/mi/10,000 miles
CO = 0.71 g/mi/10,000 miles

c. Misfueling Category.

i. Zero-mile levels. The zero-mile levels for the Misfueling category were obtained in a two-stage process. First, the amount of damage caused by misfueling was quantified. This was done by examining the results from two programs which measured a number of vehicles' emissions before and after extensive misfueling. Both of these programs were performed under contract to EPA. One was performed by the California Air Resources Board (CARB)[1] and the other was performed by an independant contractor, Automotive Testing Laboratories Inc. (ATL).[2] These two programs tested a total of nine Closed Loop vehicles. Three of the nine vehicles were removed from the analysis due to concerns about engine problems the car might have been experiencing or due to the vehicle having only had a small amount of leaded fuel run through it. For the remaining six cars, the average emission levels before and after misfueling were examined to determine the average percent increase in emissions due to misfueling. Those average percent increases are:

HC = 364% (n=6)
CO = 128% (n=6)

These figures represent increases due to oxygen sensor damage and other engine-out effects as well as catalyst damage.

The second stage of the procedure was to add these percent increases onto the Zero-mile emission levels for the Secondary category. Vehicles in the Primary category are also expected to be misfueled, at the same proportional rate experienced by the rest of the fleet, but the effects of misfueling (for HC and CO) are assumed to be overshadowed by the effects due to experiencing a Primary category failure. The rich operation assumed for Primary category vehicles, results in essentially zero catalyst efficiency for HC and CO by itself due to lack of oxygen in the catalyst bed(s).

The resulting Zero-mile levels for the Misfueling category are:

HC = 1.05 g/mi
CO = 4.24 g/mi

ii. Deterioration rates. The HC/CO deterioration rates for the Misfueling category were obtained by adopting the deterioration rates developed for the Secondary category. There is insufficient data on misfueled Closed Loop vehicles to allow a separate analysis of the deterioration of these vehicles. The development of the deterioration rates for the Secondary category can be found in Section IV.A.2.b.

HC = 0.12 g/mi/10,000 miles
CO = 0.71 g/mi/10,000 miles

3. Category Size.

The size of a category is described by two parameters: the size at zero miles, expressed in percent of the unit of analysis, and the growth rate of the category as expressed by the percent of the original unit which "migrates" into the category per 10,000 miles.

a. Primary. The size parameters of the Primary category were estimated by considering a number of separate sources of information. First, the incidence of vehicles from the in-use vehicle data base which would fall into the Primary category was examined. A total of ten Primary category vehicles was found in the fleet. The total fleet size is 203 vehicles after taking Parameter Adjustment concerns into account.* Using these figures results in an incidence of 5.0 percent for the Primary category. This is at an average mileage of 9,163 miles.

The second piece of evidence used to determine the size parameters of the Primary category came from looking at the fleet of 162 Volvos and Saabs (described in Section II.D.1). These

* Note: There are a total of 201 cars used in the HC analysis and 205 cars used for CO since some cars were removed due to Parameter Adjustment concerns for one pollutant but not for the other, as discussed previously (Section II.A.). 203 was used as the average.

vehicles employ the Lambda Sond system: a closed loop system with ported fuel injection and a Three-Way catalyst. One of the distinguishing characteristics of this fleet is that it contains a wider range of vehicle odometer mileages than the Closed Loop vehicle data base. This fact was used to examine the growth of Primary category problems with increasing mileage. The fleet was divided into two groups based on mileage intervals, and the incidence of vehicles with some malperformance of the Lambda Sond system was noted (eg. oxygen sensor failure, defective electronic control unit). The first group contained vehicles with between 0 and 10,000 accumulated miles. This group consisted of 64 vehicles, three of which had a Lambda Sond malperformance indicated. This translates to an incidence of 4.7 percent. Those vehicles with a Lambda Sond malperformance had average CO emission levels over 400 percent higher than the group's overall average. The average mileage of the first group was approximately 5,800 miles. The second group was made up of vehicles with between 10,000 and 20,000 accumulated miles. This group consisted of 65 vehicles, five of which had a Lambda Sond malperformance. This translates to an incidence of 7.7 percent. Those vehicles with a Lambda Sond malperformance had average CO emission levels 390 percent higher than the group's overall average. The average mileage of the second group was approximately 14,400 miles.

In comparing these two groups of vehicles, the chief conclusion to be drawn is the trend towards an increase in malperformance of the closed loop control system with increasing mileage. The two groups examined are of essentially the same size, the only difference being between their average mileages. The difference in the incidence of malperformance for the two groups is 3.0 percent.

To arrive at the size parameters for the Primary category, the preceding findings were combined and supplemented with technical judgment. In applying the data from the in-use data base, a figure of 5 percent was taken as the incidence of Primary category vehicles at 10,000 miles. The 3% difference between the two mileage groups of Volvos and Saabs is taken as an indication that there will be a measurable increase in Primary category failures with increasing mileage. Due to the small sample size of vehicles, however, and due to differences between the Volvo/Saab system and the variety of systems to be seen in the post-1980 fleet, this figure does not necessarily indicate the definitive growth rate for 1981 and later vehicles. This analysis assumes that the growth rate will be somewhat lower: 2%/10,000 miles. This is based on the assumption that due to improved assembly line testing, the presence of on-board diagnostics, and other reasons, the performance in the field of the majority of the fleet will be better than what was seen among the in-use Volvos and Saabs.

Combining this growth rate with the incidence of 5% at 10,000 miles resulted in the following size parameters:

Initial Size = 3%.
Growth Rate = 2%/10,000 miles.

b. Secondary. The size parameters for the Secondary category were determined by simply taking what was left of the fleet after establishing the sizes of the Primary category and the Misfueling category (see below).

The size parameters for the Secondary category are:

Initial Size = 89.24%.
Growth Rate = -1.84%/10,000 miles

c. Misfueling. The size of the Misfueling category was determined by adopting the rate observed in an EPA covert observation study performed by the Mobile Sources Enforcement Division.[3] This study observed the fueling practices of over 22,000 catalyst-equipped vehicles in 36 states and has the largest sample size of any study of its kind. It observed vehicles of various model years and manufacturers. While arguments are often put forward as to trends in the misfueling rate with regard to vehicle age, model year, engine technology etc., none of those trends have been substantiated or quantified to the extent necessary to be used in an analysis of this sort. Therefore the observed rate of 8% was adopted for this analysis as a best estimate. The category is not assumed to grow with time. As was mentioned earlier, however, vehicles which have a Primary category type of failure and which are misfueled are assumed to be best represented by the Primary category emission levels. Thus, the overlap of the Primary and Misfueling categories is represented by the Primary category. As the Primary category grows with time therefore, the percentage of cars represented by the separate Misfueling category emission levels declines. This growth of the overlap between the two categories, although small, has been accounted for and is the source of the negative growth rate below. Thus, the Misfueling category size parameters are:

Initial Size = 7.76%
Growth Rate = -0.16%/10,000 miles

4. Unit-of-Analysis Composite.

The table below presents the composite emissions of Closed Loop vehicles designed to meet standards of 3.4 g/mi CO and 0.41 g/mi HC. These composites were arrived at by weighting together the various categories as was described in Section III.B.5. The following tables present the composites and illustrate how the various categories were weighted together. The HC and CO values are presented in g/mi at 10,000 mile intervals.

Table IV-2
HC Emissions

Miles	E**(Pri.)	S*(Pri.)	E**(Sec.)	S*(Sec.)	E**(Misfuel.)	S*(Misfuel.)	Comp.
0	3.74	0.03	0.23	0.89	1.05	0.08	0.40
1	3.86	0.05	0.35	0.87	1.17	0.08	0.59
2	3.98	0.07	0.47	0.86	1.29	0.07	0.77
3	4.10	0.09	0.59	0.84	1.41	0.07	0.96
4	4.22	0.11	0.71	0.82	1.53	0.07	1.15
5	4.34	0.13	0.83	0.80	1.65	0.07	1.34
6	4.46	0.15	0.95	0.78	1.77	0.07	1.53
7	4.58	0.17	1.07	0.76	1.89	0.07	1.72
8	4.70	0.19	1.19	0.75	2.01	0.06	1.91
9	4.82	0.21	1.31	0.73	2.13	0.06	2.10
10	4.94	0.23	1.43	0.71	2.25	0.06	2.29

* S = Size
** E = Emission Level

Table IV-3
CO Emissions

Miles	E(Pri.)	S(Pri.)	E(Sec.)	S(Sec.)	E(Misfuel.)	S(Misfuel.)	Comp.
0	107.36	0.03	1.86	0.89	4.24	0.08	5.21
1	108.07	0.05	2.57	0.87	4.95	0.08	8.02
2	108.77	0.07	3.27	0.86	5.65	0.07	10.83
3	109.48	0.09	3.98	0.84	6.36	0.07	13.65
4	110.18	0.11	4.68	0.82	7.06	0.07	16.46
5	110.89	0.13	5.39	0.80	7.77	0.07	19.27
6	111.60	0.15	6.10	0.78	8.48	0.07	22.08
7	112.30	0.17	6.80	0.76	9.18	0.07	24.90
8	113.01	0.19	7.51	0.75	9.89	0.06	27.71
9	113.71	0.21	8.21	0.73	10.59	0.06	30.52
10	114.42	0.23	8.92	0.71	11.30	0.06	33.33

These composites yield the following regression equations:

HC = 0.40 + (0.19)(m)
CO = 5.21 + (2.81)(m)

(m = miles/10,000)

These regression equations were not used in determining the final fleet composite emissions, although very little difference results if they are. They are presented for those interested as an aid in comparing the emissions performance of various units of analysis.

B. Closed Loop vehicles designed to meet 0.41 g/mi HC and 7.0 g/mi CO standards.

The reader will note that the definitions, rates and levels defined for this unit of analysis borrow extensively from the previous unit of analysis. This is due to the fact that the only difference between the two units of analysis is the CO design standard. This difference will effect only certain CO emission levels. While the emission control technology used under these two standards will differ (vehicles designed to meet the 7.0 g/mi CO standard will not use a back-up oxidation catalyst and air pump in many cases), this difference is not expected to cause much difference in in-use emissions performance as discussed in Section I.C.1.

1. Category definitions.

The categories for this unit of analysis are defined to be the same as those defined in Section IV.A.1.

2. Emission levels of the categories.

a. Primary Category.

i. Zero-mile levels. The zero-mile levels are the same as those determined for the Primary category of the unit representing Closed Loop vehicles designed to meet 0.41 g/mi HC and 3.4 g/mi CO standards (Section IV.A.2.a):

HC = 3.74 g/mi
CO = 107.36 g/mi

(Note: The CO emission level is not ratioed to the 7.0 g/mi CO standard since the Primary category represents vehicles with a major failure mode whose emissions would be independent of the design standard. Similarly, the HC emission level is not ratioed to take the different standards resulting from the Methane correction factor into account, as discussed in Section II.A.)

ii. Deterioration rates. The HC/CO deterioration rates are the same as those determined for Closed Loop vehicles designed to meet 0.41 g/mi HC and 3.4 g/mi CO standards (Section IV.A. 2.b.). This was done to follow the principle that similar technologies deteriorate at the same rate. This principle was widely used in the 1978 analysis (EPA-400/9-78- 005) and has been widely used in the 1980 revision of that document for both pre-1981 and post-1980 vehicles. The deterioration rates arrived at are:

HC = 0.12 g/mi/10,000 miles
CO = 0.71 g/mi/10,000 miles

b. Secondary Category.

i. Zero-mile levels. The average HC/CO emission levels and the average mileage of the vehicles in the data base which represent the Secondary category are:

Average HC = 0.32 g/mi	(n = 191)*
Average CO = 5.47 g/mi	(n = 195)*
Average Miles = 8,064 miles	(n = 191)

Applying the deterioration rates (see below) to these average emission levels to project them to zero miles and then applying a ratio of 7.0/9.0 to the CO emission level to reflect the fact that the vehicles in the data base were designed to meet a 9.0 g/mi CO standard and not a 7.0 g/mi standard, results in the following Zero mile emission levels:

HC = 0.23 g/mi
CO = 3.83 g/mi

ii. Deterioration rates. The HC/CO deterioration rates are the same as those determined for Closed Loop vehicles designed to meet 0.41 g/mi HC and 3.4 g/mi CO standards. (Section IV.A.2.b.). This follows the principle that similar technologies deteriorate at the same rate.

HC = 0.12 g/mi/10,000 miles
CO = 0.71 g/mi/10,000 miles

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* These sample sizes differ due to the fact that Parameter Adjustment concerns eliminated vehicles from the calculations for one pollutant, but not for the other. See Section II.A.

c. Misfueling Category.

i. Zero-mile levels. The Zero-mile levels of the Misfueling category for this unit of analysis (Closed Loop vehicles designed to meet standards of 0.41 g/mi HC and 7.0 g/mi CO) were developed in the same way as for the previous unit of analysis (Section IV.A.2.c.). The figures for percent increase due to misfueling were simply added onto the Zero-mile levels of the Secondary category. The Zero-mile levels arrived at for the Misfueling category are:

HC = 1.05 g/mi
CO = 8.73 g/mi

ii. Deterioration rates. The HC/CO deterioration rates for the Misfueling category are the same as those developed for Closed Loop vehicles designed to meet standards of 0.41 g/mi HC and 3.4 g/mi CO (Section IV.A.2.b.). This follows the principle that similar technologies deteriorate at the same rate. The deterioration rates arrived at are:

HC = 0.12 g/mi/10,000 miles
CO = 0.71 g/mi/10,000 miles

3. Category Size.

The category size parameters for this unit of analysis are the same as those developed for the previous unit of analysis (Section IV.A.3.).

a. Primary Category.

i. Initial Size = 3%.

ii. Growth Rate = 2%/10,000 miles.

b. Secondary Category.

i. Initial Size = 89.24%.

ii. Growth Rate = -1.84%/10,000 miles.

c. Misfueling Category

i. Initial Size = 7.76%.

ii. Growth Rate = -0.16%/10,000 miles.

4. Unit-of-Analysis Composite.

Tables IV-4 and IV-5 below present the composite emissions of Closed Loop vehicles designed to meet standards of 0.41 g/mi HC and 7.0 g/mi CO. The HC and CO values are presented in units of g/mi at 10,000 mile intervals.

Table IV-4
HC Emissions

Miles	E(Pri.)	S(Pri.)	E(Sec.)	S(Sec.)	E(Misfuel.)	S(Misfuel.)	Comp.
0	3.74	0.03	0.23	0.89	1.05	0.08	0.40
1	3.86	0.05	0.35	0.87	1.17	0.08	0.59
2	3.98	0.07	0.47	0.86	1.29	0.07	0.77
3	4.10	0.09	0.59	0.84	1.41	0.07	0.96
4	4.22	0.11	0.71	0.82	1.53	0.07	1.15
5	4.34	0.13	0.83	0.80	1.65	0.07	1.34
6	4.46	0.15	0.95	0.78	1.77	0.07	1.53
7	4.58	0.17	1.07	0.76	1.89	0.07	1.72
8	4.70	0.19	1.19	0.75	2.01	0.06	1.91
9	4.82	0.21	1.31	0.73	2.13	0.06	2.10
10	4.94	0.23	1.43	0.71	2.25	0.06	2.29

Table IV-5
CO Emissions

Miles	E(Pri.)	S(Pri.)	E(Sec.)	S(Sec.)	E(Misfuel.)	S(Misfuel.)	Comp.
0	107.36	0.03	3.83	0.89	8.73	0.08	7.32
1	108.07	0.05	4.54	0.87	9.44	0.08	10.09
2	108.77	0.07	5.24	0.86	10.14	0.07	12.85
3	109.48	0.09	5.95	0.84	10.85	0.07	15.62
4	110.18	0.11	6.65	0.82	11.55	0.07	18.39
5	110.89	0.13	7.36	0.80	12.26	0.07	21.16
6	111.60	0.15	8.07	0.78	12.97	0.07	23.93
7	112.30	0.17	8.77	0.76	13.67	0.07	26.70
8	113.01	0.19	9.48	0.75	14.38	0.06	29.47
9	113.71	0.21	10.18	0.73	15.08	0.06	32.24
10	114.42	0.23	10.89	0.71	15.79	0.06	35.00

These composites yield the following regression equations:

$$HC = 0.40 + (0.19)(m)$$
$$CO = 7.32 + (2.77)(m)$$

(m = miles/10,000)

C. Oxidation Catalyst vehicles designed to meet standards of 0.41 g/mi HC and 3.4 g/mi CO.

1. Discussion of the analysis.

Since the units of analysis which represent Oxidation Catalyst vehicles are not broken down into categories, the approach used in determining their emission rates will be presented in a much different format. As was discussed in Section I.D., Oxidation Catalyst vehicles in the post-1980 timeframe are assumed to have an emissions performance similar to current Oxidation Catalyst vehicles. Oxidation Catalyst vehicles after 1980 are not assumed to experience significant changes in basic emission control technology. They are assumed to rely on EGR and engine modifications for the control of NOx and to be equipped with Oxidation catalysts and air pumps for the control of HC and CO. This assumption largely determined what data could best be used to predict the emissions for these vehicles. In essence, the emission rates developed for 1980 Oxidation Catalyst vehicles from the 1980 revision of the Mobile Source Emission Factors Document (EPA-400/ 9-78-005) were adopted after two important factors were taken into account: the effect of the Parameter Adjustment regulations and the difference in CO standards.

First, the effect of the Parameter Adjustment regulations was accounted for. This was done in the following three step procedure. First, the data base assembled to analyze the emissions performance of current technology vehicles (1975-80) was stratified to look at only those vehicles equipped with Oxidation catalysts and air pumps, i.e., those vehicles equipped with the control technology most similar to that which is assumed to be used in the post-1980 timeframe. Most of these vehicles were also equipped with EGR, but the presence of EGR was not used as a stratifying criteria since some unique engine configurations are assumed to meet the 1.0 g/mi NOx standard without EGR. From this subset of the data base, the average emission levels for HC, CO and NOx were determined. In the second step, vehicles were eliminated from the subset of the data base described above if they showed evidence of maladjustments which can be expected to be prevented by the Parameter Adjustment regulations. The average emission levels for HC, CO and NOx were then calculated for these vehicles. Comparing the average emissions before and after removing those vehicles affected by the Parameter Adjustment regulations led to the calculation of a "percent benefit" figure due to the regulations. (The "percent benefit" approach was taken rather than performing separate regressions on the subsets of vehicles described above, due to those subsets having relatively small sample sizes. For example, there were only 85 vehicles in the subset used to predict the percent benefit due to the regulations in the 1982 model year). This procedure was performed in a stepwise fashion to account for the fact that the Parameter Adjustment regulations are applied to idle mixture and choke in 1981 and then applied to timing in 1982. Thus, there is a separate "percent benefit" for both of those years. The 1981 "percent benefit" reflects the impact of limiting the adjustability of idle mixture and choke while the 1982 "percent benefit" reflects the impact of limiting the adjustability of timing. Thus, the total impact of the regulations is staggered between 1981 and 1982. The following table presents the calculated figures of "percent benefit" for HC and CO.

Table IV-6
Percent Benefit from Parameter Adjustment Regulations

	1981	1982*
HC	16.2%	16.7%
CO	25.0%	27.3%

Finally, these figures of percent benefit were applied to the zero mile levels and deterioration rates determined for the 1980 low altitude, non-California Light Duty Vehicle (LDV) fleet. Table IV-7 presents the zero mile emission levels and deterioration rates for that fleet before applying any benefits or modifications.

*Cummulative benefit.

Table IV-7
1980 Light Duty Vehicle Emission Factors

	Zero Mile	Deterioration Rate
HC	0.29	0.29
CO	6.14	2.86

(Note: The zero mile levels and deterioration rates from the 1980 LDV fleet presented above incorporate the effect of misfueling at the same misfueling rate projected for the Closed Loop vehicles of the post-1980 fleet).

Account must also be taken of the difference in design standards for CO between 1980 and 1981. The 1980 Federal CO standard is 7.0 g/mi while it is 3.4 g/mi for this unit of analysis. (The difference in NOx standards will be discussed in a similar way in Section V.B.1.) To account for this difference in standards, the zero-mile CO emission level for the 1980 model year, after being modified as discussed above to account for the effect of the Parameter Adjustment regulations, was ratioed by a factor of 3.4/7.0. The deterioration rate was not factored to account for the difference in standards in order to follow the principle that similar technologies deteriorate at the same rate. This principle was widely used in the 1978 analysis (EPA-400/9-78-005) and has been widely used in the 1980 revision for both pre-1981 and post1980 vehicles. The deterioration rate was modified to account for the effect of the Parameter Adjustment regulations since those regulations represent a change in technology which will affect the rate of in-use deterioration.

Table IV-8 presents the final HC and CO zero mile emission levels and deterioration rates determined for Oxidation Catalyst vehicles for 1981 and 1982-and-beyond (1982+).

D. Oxidation Catalyst vehicles designed to meet standards of 0.41 g/mi HC and 7.0 g/mi CO.

1. Discussion of the analysis.

This unit of analysis represents Oxidation Catalyst vehicles granted a CO waiver to 7.0 g/mi under Section 202(b)(5) of the Clean Air Act. The different CO standard is the only difference between this unit of analysis and the unit of analysis described in the previous section. This difference in CO standards is not expected to result in a significant difference in the basic nature of the emission control technology to be used. Vehicles which receive a CO waiver to 7.0 g/mi are expected to simply use less stringent air/fuel control and less efficient catalysts than vehicles designed to meet the 3.4 g/mi standard. The analysis for these vehicles is therefore essentially the same as that performed for the previous section. The one exception being that the 1980 Light Duty Vehicle CO emission level does not need to be ratioed to account for a difference in standards since there is no difference.

The resultant zero mile emission levels and deterioration rates for this unit of analysis are presented in Table IV-10.

Table IV-10
Oxidation Catalyst Vehicle Emission Factors (7.0 g/mi CO Standard)

	1981		1982+	
	Zero Mile	Deterioration Rate	Zero Mile	Deterioration Rate
HC	0.24	0.24	0.24	0.24
CO	4.61	2.15	4.47	2.08

2. Unit-of-Analysis Composite.

This section presents the composite emissions of Oxidation Catalyst vehicles designed to meet standards of 0.41 g/mi HC and 7.0 g/mi CO. The HC and CO values are presented in units of g/mi at 10,000 mile intervals. Table IV-11 is simply a tabulation of the equations shown in Table IV-10.

Table IV-11
Oxidation Catalyst Vehicle Emission Composites (7.0 g/mi CO Standard)

	1981		1982+	
Miles	HC	CO	HC	CO
0	0.24	4.61	0.24	4.47
1	0.48	6.76	0.48	6.55
2	0.72	8.91	0.72	8.63
3	0.96	11.06	0.96	10.71
4	1.20	13.21	1.20	12.79
5	1.44	15.36	1.44	14.87
6	1.68	17.51	1.68	16.95
7	1.92	19.66	1.92	19.03
8	2.16	21.81	2.16	21.11
9	2.40	23.96	2.40	23.19
10	2.64	26.11	2.64	25.27

References for Section IV.

1. EPA Contract No. 68-03-2783, Work Effort No. 2 with the California Air Resources Board.

2. EPA Contract No. 68-03-2693, Work Effort No. 4 with Automotive Testing Laboratories, Inc.

3. EPA Internal Memorandum; August 2, 1979; from Benjamin R. Jackson, Deputy Assistant Administrator, Mobile Source and Noise Enforcement, to all Regional Administrators.

V. SPECIFIC UNIT ANALYSES - NOx

A. Closed Loop vehicles designed to meet a 1.0 g/mi NOx standard.

1. Category definitions.

There are four categories of vehicles in this unit of analysis. Each category will be presented and briefly characterized.

a. EGR. This category is comprised of those vehicles with inoperative EGR systems. This includes cases where the EGR system is inoperative due to tampering, in-use failure, or manufacturing defect. It also includes cases of EGR failure where EGR operation falls under computer control and is therefore subject to computer malfunction. Vehicles were selected from the data base to represent this category on the basis of a diagnostic assessment of EGR function and measured NOx emissions. Vehicles diagnosed as having an EGR problem and whose NOx emissions exceeded their design standard were selected.

b. Misfueling. This category is comprised of vehicles which have been misfueled, i.e. they have had extensive damage done to their emission control system through the use of leaded rather than unleaded gas. As will be discussed below, misfueling is assumed to overlap with each of the other three NOx categories.

c. Low. This category is made up of vehicles which would fall into the Primary HC/CO category and which are therefore assumed to have lower than normal NOx levels. This assumption is based on the fact that rich operation (as found in Primary category vehicles) inherently implies lower NOx production in the engine, as well as the fact that rich operation improves the catalytic conversion of NOx in a Three-Way catalyst.

d. Secondary. As in the HC/CO analysis, this category includes the remainder of the fleet.

2. Emission levels of the categories.

Before discussing how the emission levels of the categories were determined, several preliminary points need to be made. First, unlike for HC and CO, the vehicles in the Closed Loop Vehicle data base were designed to meet several different NOx standards. The 1980 General Motors X-Body vehicles were designed to meet a 1.0 g/mi NOx standard. The other vehicles tested in Los Angeles were 1979 models (the Ford 351's, Celica Supra's and Audi 5000's) and were therefore designed to meet a 1.5 g/mi standard. A third group of vehicles are the Ford 351's tested in Portland, Oregon. As was discussed in Section II.B., these cars are assumed to have been designed to meet the Federal 2.0 g/mi NOx standard. Since this analysis is concerned with predicting NOx emissions under a 1.0 g/mi standard, the NOx emissions from all vehicles designed under the 1.5 g/mi or 2.0 g/mi standards were divided by 1.5 or 2.0 respectively before being used in the analysis. This was done due to the fact that NOx emission levels are determined by the interaction of timing, air/fuel ratio, catalyst design, and rate of EGR, all of which are balanced in order to meet the NOx design standard. A vehicle is therefore assumed to perform in direct relation to its design standard. The reader may note that this same principle was used in ratioing the CO emission levels for Secondary category vehicles to be applicable to the analysis of the various CO standards.

The second preliminary point that needs to be made has to do specifically with the Ford 351's from Los Angeles. During the course of the analysis it became clear that these vehicles had a unique NOx problem. Of the 73 Los Angeles 351's not in the Low category, 17 vehicles were found to have an EGR problem with NOx emissions above the standard and an additional 20 vehicles had NOx emissions significantly above standard without indication of an EGR problem. It appears that the 351 system, which controls the EGR flow rate by command of the on-board computer, had an operating problem resulting from either a design or manufacturing flaw. Since these vehicles represent a substantial fraction of the data base and since the size of the problem observed with the 351's was judged to be atypical of the 1981 and later fleet, it was decided to reweight the various categories within the 351 fleet for data analysis purposes. The internal weighting from the General Motors X-Body fleet (roughly the same size) was therefore applied to the Ford 351 fleet to be able to use this data in a representative way. The internal weighting of the X-Body fleet (without Low category cars) was: four vehicles in the EGR category, five cars without an EGR problem but with NOx emissions above standard and 70 cars with NOx emissions below standard. The average emission levels from the Ford 351's grouped by these same internal divisions were reweighted to match the weighting of the X-Body fleet.

The emission characteristics of the various categories will next be presented.

a. EGR Category.

i. Zero-mile level. The average NOx emission level and the average mileage of the vehicles in the fleet selected to represent the EGR category are:

Average NOx = 1.71 g/mi (n = 9)*
Average Miles = 9,510 miles (n = 9)

The deterioration rate (see below) was then applied to work backwards to arrive at a Zero-mile level of:

NOx = 1.58 g/mi

ii. Deterioration rate. The deterioration rate for the EGR category was obtained by adopting the deterioration rate developed for the NOx Secondary category (see below). This was done due to a lack of data describing the deterioration of EGR category vehicles.

NOx = 0.13 g/mi/10,000 miles

b. Misfueling Category.

i. Zero-mile level. As was mentioned above, the Misfueling category overlaps with the other three NOx categories. For example, some vehicles are assumed to have an EGR problem and to have been misfueled. As could be expected, each of the possible overlap situations is assumed to have a unique emissions performance. This might appear to be a different approach than was used for the HC/CO analysis. For HC/CO the overlap of the Misfueling category and the Primary category was handled by assuming the emissions of the overlap vehicles were represented by the emissions of the Primary category, rather than establishing a new, distinct category. In that case however, Primary category vehicles, due to the rich operation inherent to such vehicles, are already experiencing essentially zero catalytic activity for HC and CO. This is due to the lack of oxygen in the catalyst bed(s). Thus, misfueling, which primarily damages the catalyst, will have a negligible incremental effect on Primary HC and CO emission levels. NOx, however, is a very different case. None of the operating modes represented by the other three NOx categories are assumed to have a comparable effect on NOx conversion in the catalyst. Misfueling will therefore incrementally damage the NOx control capability of vehicles in each of the other categories. In essence then, the Misfueling category is made up of three sub-categories: Misfueled/EGR,

* In accordance with the explanation above regarding EGR failures among Ford 351 vehicles in Los Angeles, this sample of "9" is in fact composed of 4 X-Body vehicles, 17 Ford 351 vehicles from Los Angeles collectively having the weight of only 4 vehicles and 1 Ford 351 from Portland.

Misfueled/Low, Misfueled/Secondary. The emission characteristics of each sub-category were developed by following a common procedure. That procedure will first be explained below and then applied to each sub-category.

The procedure for calculating the damage resulting from misfueling parallels the procedure adopted for HC/CO. The same fleet of six Closed Loop vehicles described in Section IV.A.2.c was examined to quantify the percent increase in NOx emissions due to misfueling. The average percent increase observed was 197% (n = 6).

This percent increase was then applied across the board to the Zero-mile NOx levels of the EGR, Low and Secondary categories. Table V-1 presents the resultant Zero-mile levels for each of the misfueling sub-categories.

Table V-1
Zero-mile Levels of the Misfueling Sub-categories

Sub-Category	NOx Zero-mile level
Misfueled/EGR	4.69 g/mi
Misfueled/Low	0.80 g/mi
Misfueled/Secondary	1.72 g/mi

ii. Deterioration rate. The deterioration rate used for each of the Misfueling sub-categories was obtained by adopting the deterioration rate determined for the NOx Secondary category (see below). This implies that vehicles with badly damaged catalysts will deteriorate at the same rate as vehicles with relatively undamaged catalysts. While this assumption is not perfectly accurate, the deterioration rate for the Secondary category was adopted due to a lack of any data describing the deterioration of misfueled vehicles and because the stated deterioration rate includes the deterioration due to engine wear and other phenomenon rather than just due to catalyst deterioration. The deterioration rate arrived at is:

NOx = 0.13 g/mi/10,000 miles

c. Low Category.

i. Zero-mile level. The average NOx level and the average mileage of the vehicles in the data base selected to represent the Low category are:

Average NOx = 0.40 g/mi (n = 9)
Average Miles = 9,539 miles (n = 9)

(Note: One vehicle from the GM X-Body fleet which had high HC/CO emission levels was not used to calculate the Low category NOx emission level due to its having an inoperative EGR system. Its emission levels were therefore not representative of vehicles in the Low category. Vehicles with this combination of high HC/CO emissions yet with an inoperative EGR system will be discussed in the next section on category sizes).

The deterioration rate (see below) was then used to work backwards and arrive at a zero mile level of:

NOx = 0.27 g/mi

ii. Deterioration Rate. The deterioration rate for the low category was obtained by adopting the rate developed for the NOx Secondary category (see below). This was done due to a lack of data describing the deterioration of Low category vehicles. The deterioration rate arrived at is:

NOx = 0.13 g/mi/10,000 miles

d. Secondary Category.

i. Zero-mile level. The average NOx level and the average mileage of the vehicles in the data base selected to represent the OK category are:

Average NOx = 0.68 g/mi (n = 155)
Average Miles = 7,814 miles (n = 155)

The deterioration rate (see below) was then used to work backwards and arrive at a zero mile level of:

NOx = 0.58 g/mi

ii. Deterioration Rate. The deterioration rate for the NOx Secondary category was obtained in essentially the same way as was done for the HC/CO Secondary category (Section IV.A.2. b). It will therefore not be discussed in depth, rather the pertinent numbers will be briefly presented. The NOx d.f. obtained from the in-use 1978-79 Volvo/Saab fleet was 2.56 and the 1978-79 Volvo/ Saab Certification fleet had an average weighted d.f. of 1.27. Thus the ratio of in-use to certification d.f.-1 values is 5.78 (1.56/.27). The average Certification d.f.-1 for vehicles being certified for the 1981 model year was 0.16.

Applying the Volvo/ Saab ratio to this figure and adding 1 results in a projected 1981 in-use d.f. of 1.92. Applying this d.f. to the data point found in the data base (0.68 g/mi NOx at 7,814 miles) and converting to a deterioration rate gives a deterioration rate of:

NOx = 0.13 g/mi/10,000 miles

3. Category Size.

The sizes of the various categories are described by two parameters: the initial size, expressed in percent, and the growth rate of the category as expressed in percent of the original unit which "migrates" into the category per 10,000 miles. These two parameters are developed for each of the four NOx categories.

a. EGR.

Several sources of information contributed to the development of the size parameters of the EGR category. Each will be presented separately, followed by a summary discussion.

i. 1980 General Motor's X-Body Fleet.

The first source of information examined was the incidence of EGR category vehicles in the 1980 X-Body fleet. A total of 5 vehicles was found in the EGR category out of a total fleet size of 92 vehicles This results in an incidence of 5.4% at an average mileage of 5,500 miles. It should be noted here that since we are only looking at the incidence of a particular problem within the fleet, the effect of the Parameter Adjustment regulations need not be taken into account. This is especially true for EGR problems, which will not be affected by the Parameter Adjustment regulations.

ii. 1979 Ford 351 Fleet.

The second source of information examined was the incidence of EGR category vehicles in the 1979 Ford 351 fleet. The microprocessor used on this engine family controls the EGR flow rate through a system of sensors and solenoids. As was previously discussed, for an unusually large number of the vehicles tested, the EGR system was found to be malperforming. In many cases, there was either no voltage signal or an inadequate voltage signal coming from the microprocessor unit to the EGR-controlling solenoid. 20 vehicles out of a total fleet size of 97 were found to be in the EGR category. (This includes vehicles which were removed from the calculation of NOx emission levels due to Parameter Adjustment concerns.) This gives an incidence of 20.6% at an average mileage of approximately 11,000 miles.

iii. Surveillance Data on Current Technology Vehicles.

The final source of information relevant to this discussion deals with the magnitude of EGR malperformance among the current in-use fleet. The information comes from an internal EPA analysis of data from the EPA Emission Factors Program (EFP) and the 1978 EPA Tampering Survey.[1] The analysis examined the initial incidence and growth rate of EGR problems. Data from vehicles from the 1973 through 1978 model years were included in the analysis. For purposes of this document however, only the 1977-1978 model year vehicles will be considered. (The earlier model years show a significantly higher incidence of EGR malperformance). These vehicles are equipped with the most recent EGR systems. It is assumed that these EGR systems are most representative of the EGR systems to be employed in the post-1980 fleet. The results of the study which are applicable to this analysis are presented below:

Table V-2
1977-78 Model Years

Data Source	Initial EGR Failure Rate	Growth Rate
Emission Factors Program	2.77%	2.68%/10,000 miles
1978 Tampering Study	5.15%	0.92%/10,000 miles

The size parameters of the EGR category were obtained through combining the preceding sources of information with technical judgement. The 5.4 percent incidence of EGR category vehicles from the X-Body fleet combined with the MSED Tampering Survey figure of 5.15 percent were combined to establish a zero mile incidence of 5 percent for malfunctions in the EGR system itself. An additional 2 percent was added onto this base level to account for the effect of computer malfunctions on computer controlled EGR systems as was evidenced by the high incidence of this failure mode among the Ford 351 fleet. The growth rate of the EGR category was obtained by taking the average of growth rates indicated by the Emission Factors data and the MSED Tampering Survey data. The average of 1.8%/10,000 miles was rounded up to 2%/ 10,000 miles. The overlap of the EGR category with the Misfueling category was also taken into account as discussed in the following section. Thus, the size parameters of the EGR category are:

Initial Size = 6.44%
Growth Rate = 1.84%/10,000miles

b. Misfueling. As was discussed in Section V.2.b. which presented emission levels for the NOx Misfueling category, this category is further broken down into three sub-categories: EGR/Misfueling, Low/Misfueling, Secondary/Misfueling. These sub-categories represent the overlap of Misfueling with the other categories. Several helpful points can be made before presenting the growth rates of the individual subcategories.

First, this analysis assumes that a given portion of the fleet, 8%, is misfueled at zero-miles and remains misfueled throughout the analysis. (See Section IV.A.3.c. for a more complete discussion on why an 8% constant rate was chosen). The analysis also assumes that this 8% is spread proportionately throughout the fleet. That is, the number of cars which are misfueled and in the EGR category is directly proportional to the total number of EGR category vehicles in the overall fleet, and likewise for the Low and Secondary categories. It follows therefore that as the incidence of vehicles in the various NOx categories (EGR, Low, Secondary) changes with increasing mileage, that the sub-categories which represent the overlap situations also change in size in a parallel fashion. This concept can best be illustrated by considering the 8% of the fleet which makes up the Misfueling category as a separate fleet. The Misfueling fleet experiences the same internal changes in its sub-category sizes as does the total fleet with its categories, and in exactly the same proportion.

The following table presents the size parameters of each of the Misfueling sub-categories which were calculated in the manner described above.

Table V-3
Size Parameters of the Misfueling Sub-categories

	Initial Size	Growth Rate
Misfueled/EGR	0.56%	0.16%/10,000 miles
Misfueled/Low	0.16%	0.12%/10,000 miles
Misfueled/Secondary	7.28%	-0.28%/10,000 miles

c. Low.

The Low category represents those vehicles with Primary category HC/CO emission levels and a correspondingly low NOx emission level. Thus, the size of the Low category is inherently and directly related to the size of the Primary HC/CO category. One consideration that needs to be taken into account here, however, is the overlapping of the Primary HC/CO and the EGR NOx categories. That is, some vehicles can be expected to have both a Primary category failure mode and an inoperative EGR system, with resulting high or medium NOx levels. This phenomenon was observed in the X-Body fleet and is expected to limit the size of the Low category. This is especially so since it can logically be assumed that since tampering contributes to both the Primary and EGR categories, that there will be instances in which both the closed loop fuel system and the EGR system are tampered concurrently. Based on these considerations and accounting for the overlap of the Low category with the Misfueling category, the size parameters of the Low category are assumed to be:

Initial Size = 1.84%
Growth Rate = 1.38%/10,000 miles

d. Secondary.

As with the Secondary category for the HC/CO analysis, the Secondary category for NOx is simply assumed to represent the remainder of the fleet. Thus, its size parameters are:

Initial Size = 83.72%
Growth Rate = -3.22%/10,000 miles

4. Unit-of-Analysis Composite.

a. This section presents the composite emissions of Closed Loop vehicles designed to meet a 1.0 g/mi NOx standard. The NOx composite values are presented in units of g/mi at 10,000 mile intervals.

Table V-4
NOx Emissions for Closed Loop Vehicles

Miles	E(EGR)	S(EGR)	E(Low)	S(Low)	E(Secondary)	S(Secondary)	E(M/EGR)	S(M/EGR)	E(M/Low)	S(M/Low)	E(M/2nd)	S(M/2nd)	Comp.
0	1.58	0.06	0.27	0.02	0.58	0.84	4.69	0.01	0.80	0.00	1.72	0.07	0.74
1	1.71	0.08	0.40	0.03	0.71	0.80	4.82	0.01	0.93	0.00	1.85	0.07	0.88
2	1.84	0.10	0.53	0.05	0.84	0.77	4.95	0.01	1.06	0.00	1.98	0.07	1.03
3	1.97	0.12	0.66	0.06	0.97	0.74	5.08	0.01	1.19	0.01	2.11	0.06	1.18
4	2.10	0.14	0.79	0.07	1.10	0.71	5.21	0.01	1.32	0.01	2.24	0.06	1.33
5	2.23	0.16	0.92	0.09	1.23	0.68	5.34	0.01	1.45	0.01	2.37	0.06	1.48
6	2.36	0.17	1.05	0.10	1.36	0.64	5.47	0.02	1.58	0.01	2.50	0.06	1.62
7	2.49	0.19	1.18	0.12	1.49	0.61	5.60	0.02	1.71	0.01	2.63	0.05	1.77
8	2.62	0.21	1.31	0.13	1.62	0.58	5.73	0.02	1.84	0.01	2.76	0.05	1.92
9	2.75	0.23	1.44	0.14	1.75	0.55	5.86	0.02	1.97	0.01	2.89	0.05	2.07
10	2.88	0.25	1.57	0.16	1.88	0.51	5.99	0.02	2.10	0.01	3.02	0.04	2.21

This table of composite emissions yields a regression equation of:

$$NOx = 0.74 + (0.15)(m)$$

(m = miles/10,000)

B. Oxidation Catalyst vehicles designed to meet a 1.0 g/mi NOx standard.

1. Discussion of the analysis.

The development of the emission rates for this unit of analysis relies on the same methodology as that developed in Sections IV.C.1. and IV.D.1. for Oxidation Catalyst vehicles meeting various HC and CO standards. It will therefore not be presented in detail. In essence, the zero-mile emission levels and deterioration rates for 1980 Light Duty Vehicles (as developed in the 1980 revision of the Mobile Source Emission Factors Document (EPA-400/ 9-78-005)) were adopted after taking into account the effect of the Parameter Adjustment regulations and ratioing the zero mile emission level to account for the different design standard.

The "percent benefit" figures for NOx attributable to the Parameter Adjustment regulations are presented in Table 6. They were derived in the same way as were the HC and CO "percent benefit" figures as described in Section IV.C.1.

Table V-5
Percent Benefit from the Parameter Adjustment Regulations

	1981	1982+
NOx	-5.0%*	-7.6%*

These figures of "percent benefit" or, more precisely, "percent penalty" were then applied to the 1980 Light Duty Vehicle zero mile emission level (1.56 g/mi) and deterioration rate (0.10 g/mi/10,000 mile).

The final step consisted of applying a ratio of (1.0/2.0) to the zero mile emission level to account for the fact that the 1980 fleet is designed to meet a 2.0 g/mi NOx standard whereas the post-1980 fleet will be designed to meet a 1.0 g/mi NOx standard. The resultant zero mile emission levels and deterioration rates are presented in Table V-6.

* These figures are negative. They reflect what was observed in the data, that removing those vehicles with maladjustments which will most likely be prevented by the Parameter Adjustment regulations results in an increase in average NOx levels.

Table V-6
NOx Emission Factors for Oxidation Catalyst Vehicles

	1981		1982+	
	Zero Mile	Deterioration Rate	Zero Mile	Deterioration Rate
NOx	0.82	0.11	0.84	0.11

2. Unit-of-Analysis Composite.

This section presents the composite NOx emissions of Oxidation Catalyst vehicles designed to meet a 1.0 g/mi NOx standard. The NOx values are presented in units of g/mi at 10,000 mile intervals. Table V-7 simply tabulates the equations shown in Table V-6.

Table V-7
NOx Emission Composites for Oxidation Catalyst Vehicles

Miles	1981 NOx	1982+ NOx
0	0.82	0.84
1	0.93	0.95
2	1.04	1.06
3	1.15	1.17
4	1.26	1.28
5	1.37	1.39
6	1.48	1.50
7	1.59	1.61
8	1.70	1.72
9	1.81	1.83
10	1.92	1.94

References for Section V.

1. Internal EPA memorandum; July, 1980; from David Brzezinski/David Hughes, Inspection/Maintenance Staff to Tom Cackette, Chief, Inspection/Maintenance Staff. "EGR Tampering/Failure Rates: Comparison of 1978 MSED and FY77 Emission Factors Surveys".

VI. COMPOSITE EMISSION FACTORS FOR THE 1981 FEDERAL FLEET

A. Fraction of Total 1981 New Car Sales Contributed by Each Unit of Analysis.

The effect of the CO Waiver decisions of 1979 and 1980 for Light Duty vehicles was to allow certain engine families for some of the manufacturers to certify to a 7.0 g/mi CO standard in 1981 and 1982. (Not all engine families which were waived in 1981 were also waived for 1982.) The majority of the waived families are expected to employ Closed Loop technology in 1981 and 1982, however, several manufacturers are also expected to certify the waived portions of their Federal fleets with Oxidation Catalyst systems.

The model's predicted technology mix for the Federal fleet in 1981 and 1982 is 93 percent Closed Loop and 7 percent Oxidation Catalyst, based on confidential EPA Certification sales estimates and CO Waiver testimony.[1,2,3,4,5]* It is assumed that this technology split is essentially unaffected by the waiver decisions.

It is predicted that 28 percent of the 1981 Federal fleet has been waived to the 7.0 g/mi CO standard, based on EPA Certification sales estimates for 1980 and the CO Waiver decisions for specific engine families.[1,2,3,4,5] The emissions model is constructed so that the waived segment of the fleet is apportioned among the different units of analysis as predicted from technologies employed in 1981 Certification cars currently on record with EPA, and CO Waiver testimony.[1,2,3,4,5]

As was discussed in Section I.C.1, the portion of the Ford Motor Co. fleet which may be produced as an open loop system employing a Three-Way catalyst has been subsumed into the Closed Loop vehicle technology type.

Table VI-1 presents the percentage contribution of each unit of analysis to the 1981 fleet.

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* These references appear at the end of Section VIII.

Table VI-1
Percentage Contribution of the Various Units of Analysis to the 1981 Federal Fleet

Technology Type	Percent of Fleet Sales	CO Design Standard	Percent of Fleet Sales
Closed Loop	93	3.4	67.0
		7.0	26.0
Oxidation Catalyst	7	3.4	5.0
		7.0	2.0

B. Composite Emissions versus Mileage.

In the emissions model, the 1981 fleet composite at each mileage point from zero to 100,000 miles, in intervals of 10,000 miles, is calculated as a weighted average of the emission levels of each unit of analysis. Tables VI-2.a., VI-2.b. and VI-2.c. present the sales fractions and emission levels of each unit of analysis, and the fleet composites, at each 10,000 mile interval.

Table VI-2.a.

1981 Federal Fleet

HC Emissions by Units of Analysis and Fleet Composites

Mileage in Miles/10,000	Closed Loop at 3.4 CO		Closed Loop at 7.0 CO		Oxidation Catalyst at 3.4 CO		Oxidation Catalyst at 7.0 CO		Fleet Composite
	Emission level in g/mi	Sales frac.	Emission level in g/mi	Sales frac.	Emission level in g/mi	Sales frac.	Emission level in g/mi	Sales frac.	
0	0.40	0.67	0.40	0.26	0.24	0.05	0.24	0.02	0.39
1	0.59	0.67	0.59	0.26	0.48	0.05	0.48	0.02	0.58
2	0.77	0.67	0.77	0.26	0.72	0.05	0.72	0.02	0.77
3	0.96	0.67	0.96	0.26	0.96	0.05	0.96	0.02	0.96
4	1.15	0.67	1.15	0.26	1.20	0.05	1.20	0.02	1.16
5	1.34	0.67	1.34	0.26	1.44	0.05	1.44	0.02	1.35
6	1.53	0.67	1.53	0.26	1.68	0.05	1.68	0.02	1.54
7	1.72	0.67	1.72	0.26	1.92	0.05	1.92	0.02	1.73
8	1.91	0.67	1.91	0.26	2.16	0.05	2.16	0.02	1.93
9	2.10	0.67	2.10	0.26	2.40	0.05	2.40	0.02	2.12
10	2.29	0.67	2.29	0.26	2.64	0.05	2.64	0.02	2.31

Table VI-2.b.
1981 Federal Fleet
CO Emissions by Units of Analysis and Fleet Composites

Mileage in Miles/10,000	Closed Loop at 3.4 CO Emission level in g/mi	Closed Loop at 3.4 CO Sales frac.	Closed Loop at 7.0 CO Emission level in g/mi	Closed Loop at 7.0 CO Sales frac.	Oxidation Catalyst at 3.4 CO Emission level in g/mi	Oxidation Catalyst at 3.4 CO Sales frac.	Oxidation Catalyst at 7.0 CO Emission level in g/mi	Oxidation Catalyst at 7.0 CO Sales frac.	Fleet Composite
0	5.21	0.67	7.32	0.26	2.24	0.05	4.61	0.02	5.60
1	8.02	0.67	10.08	0.26	4.39	0.05	6.76	0.02	8.35
2	10.83	0.67	12.85	0.26	6.54	0.05	8.91	0.02	11.11
3	13.65	0.67	15.62	0.26	8.69	0.05	11.06	0.02	13.86
4	16.46	0.67	18.39	0.26	10.84	0.05	13.21	0.02	16.62
5	19.27	0.67	21.16	0.26	12.99	0.05	15.36	0.02	19.37
6	22.08	0.67	23.93	0.26	15.14	0.05	17.51	0.02	22.12
7	24.90	0.67	26.70	0.26	17.29	0.05	19.66	0.02	24.88
8	27.71	0.67	29.47	0.26	19.44	0.05	21.81	0.02	27.63
9	30.52	0.67	32.24	0.26	21.59	0.05	23.96	0.02	30.39
10	33.33	0.67	35.00	0.26	23.74	0.05	26.11	0.02	33.14

Table VI-2.c.
1981 Federal Fleet
NOx Emissions by Units of Analysis and Fleet Composites

Mileage in Miles/10,000	Closed Loop Vehicles: Emission level in g/mi	Closed Loop Vehicles: Sales frac.	Oxidation Catalyst Vehicles: Emission level in g/mi	Oxidation Catalyst Vehicles: Sales frac.	Fleet Composite
0	0.74	0.93	0.82	0.07	0.75
1	0.88	0.93	0.93	0.07	0.89
2	1.03	0.93	1.04	0.07	1.04
3	1.18	0.93	1.15	0.07	1.18
4	1.33	0.93	1.26	0.07	1.32
5	1.48	0.93	1.37	0.07	1.47
6	1.62	0.93	1.48	0.07	1.62
7	1.77	0.93	1.59	0.07	1.76
8	1.92	0.93	1.70	0.07	1.91
9	2.07	0.93	1.81	0.07	2.06
10	2.21	0.93	1.92	0.07	2.20

C. Regression Equations.

The fleet composites presented in Section VI.B need to be summarized in linear form for the purposes of emission factors programming. However, these emission levels do not constitute an exact linear function of the mileage points (although they are very close to a linear function). Therefore, these composite emissions have been linearized by regression analysis. Table VI-3 presents these linear equations by pollutant for the 1981 federal fleet. In all the emission equations, the constant equals the Zero-mile emission level in g/mi and the slope equals the regression-based composite deterioration rate in g/mi/10,000 miles.

Table VI-3
Regression Equations for 1981 Federal Fleet

Pollutant	Equation (g/mi)
HC	0.39 + (0.19)(m)
CO	5.60 + (2.75)(m)
NOx	0.75 + (0.15)(m)

m = miles/10,000

VII. COMPOSITE EMISSION FACTORS FOR THE 1982 FEDERAL FLEET

A. Fraction of Total 1982 New Car Sales Contributed by Each Unit of Analysis.

Some engine families which received CO waivers in 1981 received 2 year waivers; these families amount to an estimated 10% of the 1982 Federal fleet. No engine families received waivers for 1982 that had not previously received them for 1981. These engine families are accounted for in the model in the same way as are the waived families for 1981. The predicted technology split is the same (93% Closed Loop, 7% Oxidation Catalyst) and the waiver decisions are expected to have essentially no impact on this split.

Table VII-1 presents the contribution of each unit of analysis to the 1982 Federal fleet.

Table VII-1
Percentage Contribution of the Various Units of Analysis to the 1982 Federal Fleet

Technology Type	Percent of Fleet Sales	CO Design Standard	Percent of Fleet Sales
Closed Loop	93	3.4	83.6
		7.0	9.4
Oxidation Catalyst	7	3.4	6.4
		7.0	0.6

B. Composite Emissions versus Mileage.

Tables VII-2.a. through VII-2.c. present composite emissions and sales fractions for the various units of analysis and the 1982 Federal fleet composite, as explained in Section VI.B.

Table VII-2.a.
1982 Federal Fleet
HC Emissions by Units of Analysis and Fleet Composites

Mileage in Miles/10,000	Closed Loop at 3.4 CO Emission level in g/mi	Closed Loop at 3.4 CO Sales frac.	Closed Loop at 7.0 CO Emission level in g/mi	Closed Loop at 7.0 CO Sales frac.	Oxidation Catalyst at 3.4 CO Emission level in g/mi	Oxidation Catalyst at 3.4 CO Sales frac.	Oxidation Catalyst at 7.0 CO Emission level in g/mi	Oxidation Catalyst at 7.0 CO Sales frac.	Fleet Composite
0	0.40	0.836	0.40	0.094	0.24	0.064	0.24	0.006	0.39
1	0.59	0.836	0.59	0.094	0.48	0.064	0.48	0.006	0.58
2	0.77	0.836	0.77	0.094	0.72	0.064	0.72	0.006	0.77
3	0.96	0.836	0.96	0.094	0.96	0.064	0.96	0.006	0.96
4	1.15	0.836	1.15	0.094	1.20	0.064	1.20	0.006	1.15
5	1.34	0.836	1.34	0.094	1.44	0.064	1.44	0.006	1.35
6	1.53	0.836	1.53	0.094	1.68	0.064	1.68	0.006	1.54
7	1.72	0.836	1.72	0.094	1.92	0.064	1.92	0.006	1.73
8	1.91	0.836	1.91	0.094	2.16	0.064	2.16	0.006	1.93
9	2.10	0.836	2.10	0.094	2.40	0.064	2.40	0.006	2.12
10	2.29	0.836	2.29	0.094	2.64	0.064	2.64	0.006	2.31

Table VII-2.b.
1982 Federal Fleet
CO Emissions by Units of Analysis and Fleet Composites

Mileage in Miles/10,000	Closed Loop at 3.4 CO: Emission level in g/mi	Closed Loop at 3.4 CO: Sales frac.	Closed Loop at 7.0 CO: Emission level in g/mi	Closed Loop at 7.0 CO: Sales frac.	Oxidation Catalyst at 3.4 CO: Emission level in g/mi	Oxidation Catalyst at 3.4 CO: Sales frac.	Oxidation Catalyst at 7.0 CO: Emission level in g/mi	Oxidation Catalyst at 7.0 CO: Sales frac.	Fleet Composite
0	5.21	0.836	7.32	0.094	2.17	0.064	4.47	0.006	5.21
1	8.02	0.836	10.08	0.094	4.25	0.064	6.55	0.006	7.97
2	10.83	0.836	12.85	0.094	6.33	0.064	8.63	0.006	10.72
3	13.65	0.836	15.62	0.094	8.41	0.064	10.71	0.006	13.48
4	16.46	0.836	18.39	0.094	10.49	0.064	12.79	0.006	16.24
5	19.27	0.836	21.16	0.094	12.57	0.064	14.87	0.006	18.99
6	22.08	0.836	23.93	0.094	14.65	0.064	16.95	0.006	21.75
7	24.90	0.836	26.70	0.094	16.73	0.064	19.03	0.006	24.51
8	27.71	0.836	29.47	0.094	18.81	0.064	21.11	0.006	27.27
9	30.52	0.836	32.24	0.094	20.89	0.064	23.19	0.006	30.02
10	33.33	0.836	35.00	0.094	22.97	0.064	25.27	0.006	32.78

Table VII-2.c.
1982 Federal Fleet
NOx Emissions by Units of Analysis and Fleet Composites

Mileage in Miles/10,000	Closed Loop Vehicles: Emission level in g/mi	Closed Loop Vehicles: Sales frac.	Oxidation Catalyst Vehicles: Emission level in g/mi	Oxidation Catalyst Vehicles: Sales frac.	Fleet Composite
0	0.74	0.93	0.84	0.07	0.75
1	0.88	0.93	0.95	0.07	0.89
2	1.03	0.93	1.06	0.07	1.04
3	1.18	0.93	1.17	0.07	1.18
4	1.33	0.93	1.28	0.07	1.33
5	1.48	0.93	1.39	0.07	1.48
6	1.62	0.93	1.50	0.07	1.62
7	1.77	0.93	1.61	0.07	1.77
8	1.92	0.93	1.72	0.07	1.91
9	2.07	0.93	1.83	0.07	2.06
10	2.21	0.93	1.94	0.07	2.20

C. Regression Equations.

Table VII-3 presents the regression equations for the 1982 Federal fleet, as explained in Section VI.C. The CO equation is different than 1981 due to the effects of changing CO standards for certain engine families and due to the impact of the second step of the Parameter Adjustment regulations being implemented; the HC and NOx equations are different due only to the impact of the second step of the Parameter Adjustment regulations being implemented.

Table VII-3
Regression Equations for the 1982 Federal Fleet

Pollutant	Regression Equation (g/mi)
HC	0.39 + (0.19)(m)
CO	5.21 + (2.76)(m)
NOx	0.75 + (0.15)(m)

m = miles/10,000

VIII. COMPOSITE EMISSION FACTORS FOR THE 1983 AND BEYOND FEDERAL FLEET

A. Fraction of Total 1983 New Car Sales Contributed by Each Unit of Analysis.

Starting in 1983 the entire Federal fleet will be required to certify to the 3.4 g/mi CO standard. The predicted technology split is the same (93% Closed Loop, 7% Oxidation Catalyst). Table VIII-1 presents the contribution of each unit of analysis to the 1983 federal fleet.

Table VIII-1
Percentage Contribution of the Various Units of Analysis to the 1983 Federal Fleet

Technology Type	CO Design Standard	Percent of Fleet Sales
Closed Loop	3.4	93
Oxidation Catalyst	3.4	7

B. Composite Emissions versus Mileage.

Tables VIII-2.a. through VIII-2.c. present composite emissions and sales fractions for the various units of analysis and the 1983 and Beyond Federal fleet composite.

Table VIII-2.a.
1983 and Beyond Federal Fleet
HC Emissions by Units of Analysis and Fleet Composites

Mileage in Miles/10,000	Closed Loop at 3.4 CO		Oxidation Catalyst at 3.4 CO		Fleet Composite
	Emission level in g/mi	Sales frac.	Emission level in g/mi	Sales frac.	
0	0.40	0.93	0.24	0.07	0.39
1	0.59	0.93	0.48	0.07	0.58
2	0.77	0.93	0.72	0.07	0.77
3	0.96	0.93	0.96	0.07	0.96
4	1.15	0.93	1.20	0.07	1.16
5	1.34	0.93	1.44	0.07	1.35
6	1.53	0.93	1.68	0.07	1.54
7	1.72	0.93	1.92	0.07	1.73
8	1.91	0.93	2.16	0.07	1.93
9	2.10	0.93	2.40	0.07	2.12
10	2.29	0.93	2.64	0.07	2.31

Table VIII-2.b.
1983 and Beyond Federal Fleet
CO Emissions by Units of Analysis and Fleet Composites

Mileage in Miles/10,000	Closed Loop at 3.4 CO		Oxidation Catalyst at 3.4 CO		Fleet Composite
	Emission level in g/mi	Sales frac.	Emission level in g/mi	Sales frac.	
0	5.21	0.93	2.17	0.07	5.00
1	8.02	0.93	4.25	0.07	7.76
2	10.83	0.93	6.33	0.07	10.52
3	13.65	0.93	8.41	0.07	13.28
4	16.46	0.93	10.49	0.07	16.04
5	19.27	0.93	12.57	0.07	18.80
6	22.08	0.93	14.65	0.07	21.56
7	24.90	0.93	16.73	0.07	24.32
8	27.71	0.93	18.81	0.07	27.08
9	30.52	0.93	20.89	0.07	29.85
10	33.33	0.93	22.97	0.07	32.61

Table VIII-2.c.
1983 and Beyond Federal Fleet
NOx Emissions by Units of Analysis and Fleet Composites

Mileage in Miles/10,000	Closed Loop at 3.4 CO Emission level in g/mi	 Sales frac.	Oxidation Catalyst at 3.4 CO Emission level in g/mi	 Sales frac.	Fleet Composite
0	0.74	0.93	.84	0.07	0.75
1	0.88	0.93	.95	0.07	0.89
2	1.03	0.93	1.06	0.07	1.04
3	1.18	0.93	1.17	0.07	1.18
4	1.33	0.93	1.28	0.07	1.33
5	1.48	0.93	1.39	0.07	1.48
6	1.62	0.93	1.50	0.07	1.62
7	1.77	0.93	1.61	0.07	1.77
8	1.92	0.93	1.72	0.07	1.91
9	2.07	0.93	1.83	0.07	2.06
10	2.21	0.93	1.94	0.07	2.20

C. Regression Equations.

Table VIII-3 presents the regression equations for the 1983 Federal fleet, as explained in Section VI.C. The HC and NOx equations are unchanged from the 1982 equations; the CO equation is different due to the universality of the 3.4 g/mi CO standard for the 1983 and Beyond Federal fleet.

Table VIII-3
Regression Equations for 1983 Federal Fleet

Pollutant	Regression Equation (g/mi)
HC	0.39 + (0.19)(m)
CO	5.00 + (2.76)(m)
NOx	0.75 + (0.15)(m)

m = miles/10,000

References for Chapters VI-VIII.

1) Federal Register, Vol. 44, No. 179, 9/13/79, pp. 53376-53408.

2) Federal Register, Vol. 44, No. 233, 12/3/79, pp. 69416-69462.

3) Federal Register, Vol. 45, No. 22, 1/31/80, pp. 7122-7138.

4) Federal Register, Vol. 45, No. 55, 3/19/80, pp. 17914-17922.

5) Federal Register, Vol. 45, No. 107, 6/2/80, pp. 37360-37371.

IX. COMPARISON TO PREVIOUS EPA EMISSION FACTOR ESTIMATES

This section simply compares the emission factor equations obtained from this analysis with the equations developed in Appendix E to the Mobile Source Emission Factors Document (EPA-400/9-78-005). The attached figures (Figures IX.a.-c.) compare only the 1983-and-Beyond equations from this analysis with the Appendix E equations for HC, CO and NOx.

FIGURE IX.A.
HC

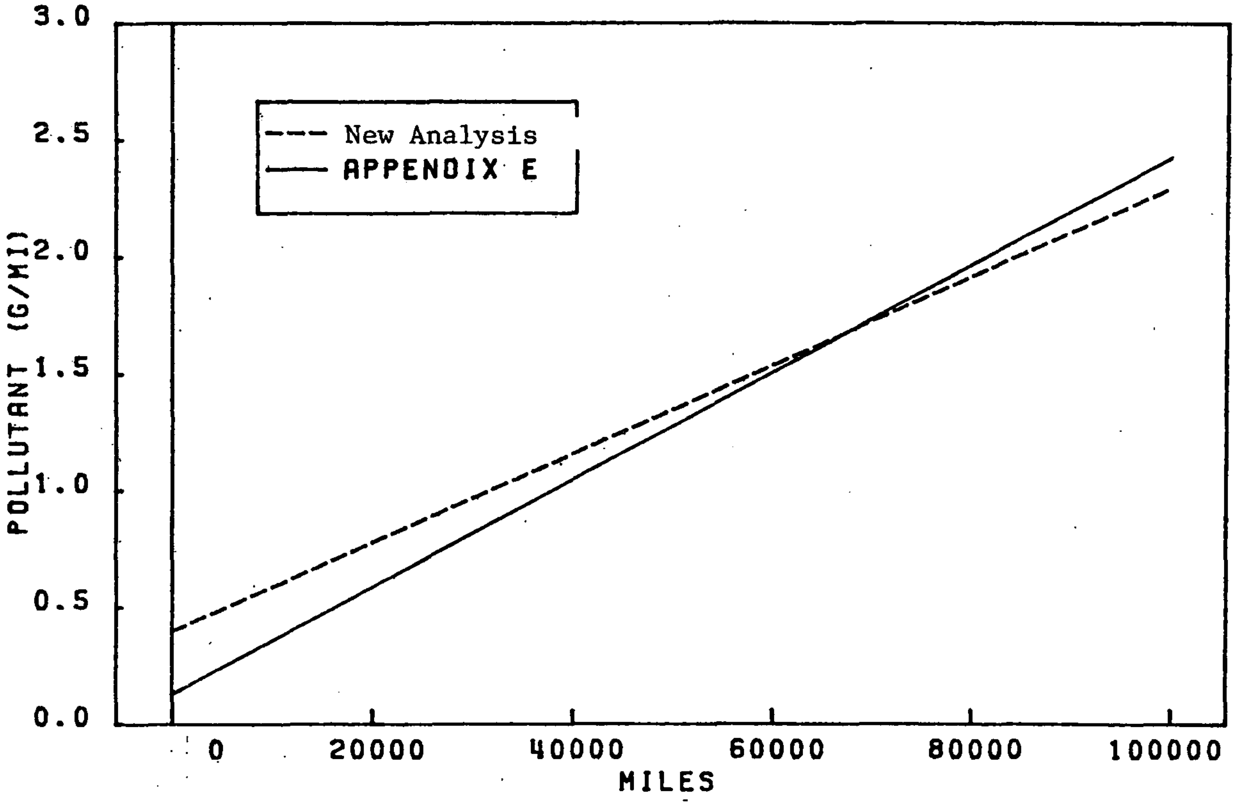

FIGURE IX.B.
CO

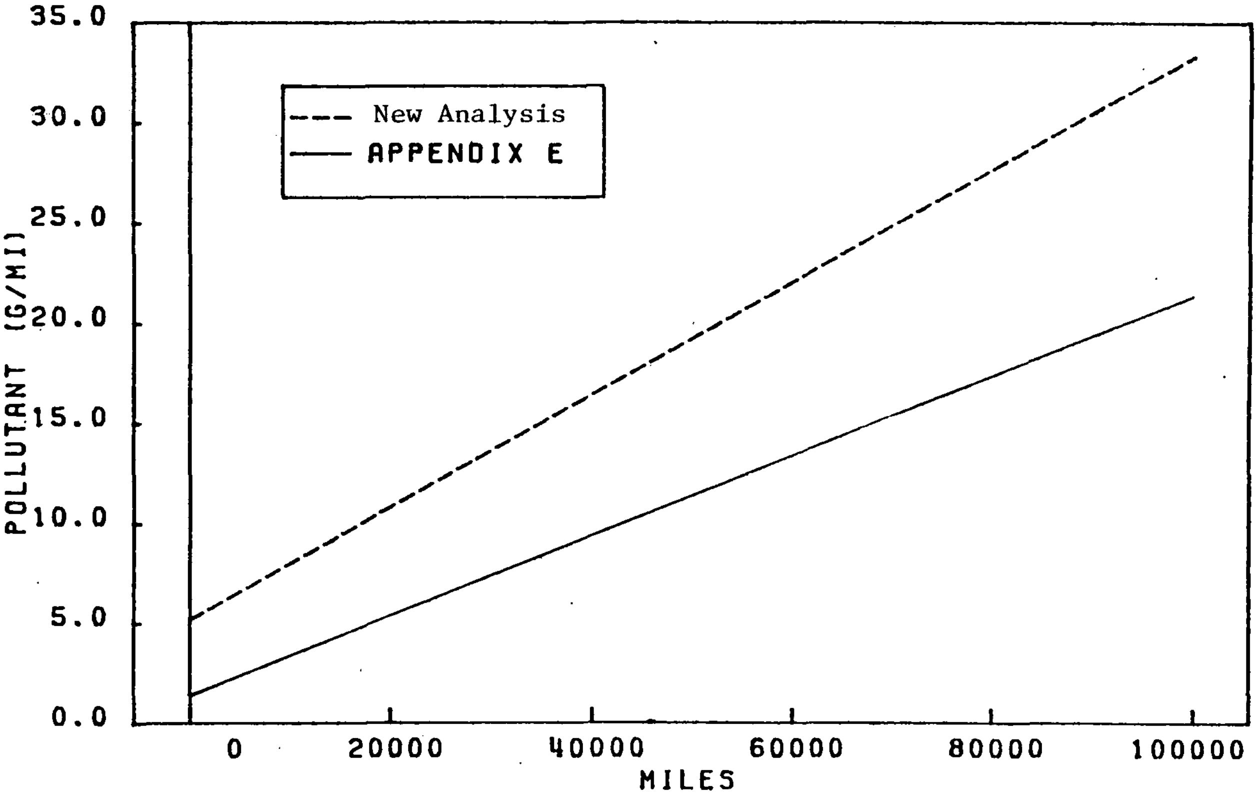

FIGURE IX.C.
NOX