Determination of Start Emissions as a Function of Mileage and Soak Time for 1981-1993 Model Year Light-Duty Vehicles

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1.0 INTRODUCTION

MOBILE6 will allocate vehicle exhaust emissions to either those associated with engine start (start emissions) or those associated with travel (running emissions). This split allows the separate characterization of start and running emissions for correction factors such as fuel effects and ambient temperature. It also allows a more precise weighting of these two aspects of exhaust emissions for particular situations such as morning commute, parking lots and freeways. This document describes the methodology used to calculate start emissions as a function of mileage and soak time for use in MOBILE6. The results for model year 1981-1993 light-duty cars and light-duty trucks are presented. The deterioration of running emissions will be addressed in a separate document (Report Number M6.STE.004).

Section 2 describes the FTP data sources and the model year and technology groups which are used. Section 3 describes the methodology and models for determining start emissions. It is divided into three sub-sections. The first sub-section describes the FTP cycle, the Hot505 cycle, and defines the basic unit of start emissions. The second sub-section describes the analysis of start emissions deterioration with mileage. The third sub-section describes the methodology used to predict start emissions as a function of soak time. Section 4 illustrates how start emissions will be estimated in MOBILE6 as a function of both deterioration and soak time.

2.0 DATA SOURCES USED

The datasets used to determine in-use deterioration are all based on FTP testing. No IM240 data or data collected by a state I/M program were used. Three data sources were used: 1) the test results from the EPA laboratory in Ann Arbor, Michigan, 2) the data received from AAMA...
(American Automobile Manufacturers Association) based on testing conducted in Michigan and Arizona, and 3) the API (American Petroleum Institute) data collected in Arizona. The model years in the dataset range from 1981 through 1993, and contain both cars and trucks. Table 1 gives a breakdown by vehicle type, model year, and technology for the three datasets combined.

In general, most of the 1990+ model year vehicle data were supplied by AAMA, and most of the pre-1990 data were supplied by the EPA laboratory testing. The API sample is a relatively small sample (99 cars and trucks). Its chief appeal is that the vehicles all have generally higher mileage readings that the rest of the sample (all over 100,000 miles). The other general trend in the data is toward PFI technology, and away from the others. This is seen in the 1990+ vehicles which are predominately PFI with some TBI still present. The 1981 to 1989 model years start with a high percentage of carbureted and some open loop, but end with mostly TBI and PFI technology. Although not explicitly shown in the tables, new catalyst technology was phased slowly into the fleet starting in the mid 1980's.

For analysis, the cars and trucks were placed into the model year/technology groups shown below.

<table>
<thead>
<tr>
<th>MY Group / Technology Type</th>
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<tr>
<td>1990-93 PFI</td>
</tr>
<tr>
<td>1990-93 TBI</td>
</tr>
<tr>
<td>1986-89 FI</td>
</tr>
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<td>1986-89 CL Carb</td>
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<tr>
<td>1983-85 FI</td>
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<td>1981-82 FI</td>
</tr>
<tr>
<td>1981-82 CL Carb</td>
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<tr>
<td>1981+ OPLP</td>
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</table>

The technology groups are closed-loop ported fuel injection (PFI), closed-loop throttle body injection (TBI), closed-loop carbureted (CARB), and open loop (OPLP). FI refers to a combination of PFI and TBI. These model year/technology grouping boundaries were selected in conjunction with the FACA In-Use Deterioration Workgroup on the basis of changes in emission standards or the development/refinement of new fuel metering or catalyst technologies. It is assumed that as of 1990, carbureted technology had negligible market share, and will not be modeled. Because of the relatively large amount of 1990-93 fuel injected data, the category was split into PFI technology and TBI technology for both cars and trucks. This produces separate deterioration functions based on this fuel delivery technology and allows the modeling of the future penetration of PFI technology into the in-use fleet.

3.0 DETERMINATION OF START EMISSIONS
3.1 Background

3.1.1 Overview of the Federal Test Procedure (FTP)

The Federal Test Procedure (FTP) is a test cycle which is used to certify new vehicles to emission performance standards (see 40 CFR Part 86, Subpart B, Section 86.144). The FTP consists of a cold start segment (Bag 1), a hot stabilized segment (Bag 2), and a hot start segment (Bag 3). Initially, the vehicle is stored for a minimum of 12 hours before testing to simulate a 12 hour overnight soak period. The vehicle is then driven over the cold start segment, which lasts 505 seconds over a length of 3.59 miles, and the emissions collected as Bag 1. Bag 2 emissions are then immediately collected from the hot stabilized segment, which lasts 867 seconds over a length of 3.91 miles. After a 10 minute soak, the 505 seconds of the start segment is then repeated and the emissions collected as Bag 3.

The FTP composite emission rate is a weighted combination of the three measured bags to represent two trips. The first trip is a cold start after a 12 hour soak, and the other is a hot start after a 10 minute soak. Each trip is a "LA4" cycle, which is a combination of the 505 cycle (either Bag 1 or Bag 3) and the Bag 2 cycle. In a typical FTP test, the Bag 2 is only measured once and the results are used for both trips. Since the 505 cycle is 3.59 miles long and the Bag 2 cycle is 3.91 miles long, each LA4 trip is 7.5 miles long. The cold start trip is weighted at 43% and the hot start trip weighted 57%. If the cold start trip is 43% of the driving, then the vehicle miles traveled (VMT) in Bag 1 (containing the cold start) is

\[
\text{FTP Bag 1 VMT Weighting} = 43\% \times (3.59 \text{ miles} / 7.5 \text{ miles}) = 0.206
\]

The hot start trip is 57% of driving, and the VMT weighting for Bag 3 (containing the hot start) is:

\[
\text{FTP Bag 3 VMT Weighting} = 57\% \times (3.59 \text{ miles} / 7.5 \text{ miles}) = 0.273
\]

The remaining VMT is from stabilized driving, represented by Bag 2. Since Bag 2 is used for both the cold start and hot start trips, it uses VMT weighting from both.

\[
\text{FTP Bag 2 VMT Weighting} = (43\% + 57\%) \times (3.91 \text{ miles} / 7.5 \text{ miles}) = 0.521
\]

The standard VMT weighting of the bags reported in grams per mile for the full FTP are:

\[
\text{FTP} = (\text{Bag 1} \times 0.206) + (\text{Bag 2} \times 0.521) + (\text{Bag 3} \times 0.273)
\]

where the fractions represent the amount of vehicle miles traveled within the three modes during the FTP trip in grams per mile (g/mi).

3.1.2 Overview of the Hot Running 505 and Its Use
The FTP testing method outlined above does not allow the precise separation of start and running emissions, since Bags 1 and 3 contain both start and running emissions. Bag 2 of the FTP does not contain an engine start, however, the driving cycle used in the second bag is significantly different from the cycle used for Bags 1 and 3. Thus, to estimate the amount of FTP emissions that can be allocated to engine start, the concept of the Hot Running 505 (HR505) is needed.

The HR505 is an extra 505 cycle performed immediately following Bag 3 of the FTP. It uses an identical driving cycle as the first and third bags of the FTP, but does not include an engine start. For more information, refer to the document “The Determination of Hot Running Emissions from FTP Bag Emissions”, report number M6 STE.002. With a HR505 emission result, it is possible to compare the results obtained from the HR505 to the results from Bags 1 and 3 of the FTP to determine the portions of Bags 1 and 3 attributable to start emissions following a 12 hour soak and start emissions following a 10 minute soak, respectively.

Since the HR505 has not historically been included in FTP test programs, a method of estimating the HR505 was developed, as described in report M6 STE 002. Briefly, HR505 emissions were measured from a sample of 77 vehicles tested under EPA contract. The results from this vehicle sample were used to develop a correlation between the HR505 and FTP bag data. This correlation was then used to estimate HR505 results for the FTP dataset used for this analysis.

### 3.1.3 Basic Start Emission Rate

For MOBILE6, the basic unit of engine start emissions is defined as a start after a 12 hour soak. The units for engine start emissions will be grams, instead of grams per mile, since start emissions will not be allocated by vehicle miles traveled. The engine start basic emission rate can be determined by subtracting the HR505 emission rate from the Bag 1 emission rate (in grams per mile) using the nominal distance traveled in the 505 driving cycle.

Basic Start Emission Rate (grams) = \[\text{Bag 1(g/mi)} - \text{HR505(g/mi)}\] * 3 59 miles

For illustration purposes, the average basic start emission rates (in grams) after a 12 hour soak were calculated for each model year and are shown in Tables 2a and 2b.

Start emissions after a 10 minute soak can also be estimated from the Bag 3 and HR505 emission rates, analogous to the basic start emission rate:

Start Emissions after 10 minute soak (grams) = \[\text{Bag 3(g/mi)} - \text{HR505(g/mi)}\] * 3 59 miles

The average start emissions after a 10 minute soak are also shown in Table 2a and 2b for each model year.
3.2 Basic Start Deterioration with Mileage

This section describes the methodology used to estimate start emission deterioration, and presents the basic deterioration rates versus mileage. The basic start (i.e., following a 12 hour soak) deterioration rates were obtained from simple linear regression of the Basic Start Emission Rate data (expressed as grams) versus mileage. The results are shown in Tables 3a, 3b, and 3c. Table 3a includes the deterioration rates for the fuel injected cars and Table 3b shows the rates for the fuel injected trucks. Table 3c shows the deterioration rates for the closed-loop carbureted and open-loop cars and trucks.

Separate deterioration rates were calculated for both cars and trucks, for each of the three pollutants, and for each model year/technology group. The exception is the 1981-82 fuel injected and closed-loop carbureted truck categories, which had zero data. Because of the lack of 1981-82 FI and CL Carb truck data, the deterioration functions for the corresponding 1981-82 car categories were used. The effect of this substitution in the MOBILE6 model should be negligible due to the scarcity of older model year fuel injected trucks in the in-use fleet.

Selected results from Table 3a (cars only) are also shown graphically in Figures 1 through 3 for HC, CO, and NOₓ for each model year/technology group. For HC, the results are generally as expected with the new model years having lower start emission levels and deterioration rates than the older model years. However, comparing PFI and TBI for the 1990-93 cars shows TBI cars having slightly lower emission levels than PFI cars. This is somewhat of an anomaly since it is believed that PFI is a superior technology to TBI. However, both regressions were generally statistically significant at least at a 90% confidence level, and further analysis of the sample using scatter plots (not shown) revealed that the differences were not the result of outliers greatly influencing the sample. Thus, the 1990-93 TBI vehicles will be projected to have slightly lower HC start emissions than the corresponding PFI vehicles.

Again for CO, the 1990-93 TBI category is slightly lower than the PFI category because of a lower ZML. Also, in this case, the 1986-89 model year group has slightly lower CO emissions than the 1990-93 PFI group. However, in this case, the deterioration rate is not statistically significant for the TBI or 1986-89 model year groups. Finally, the 1981-82 group is considerably higher than the other two groups with CO emissions at the 100,000 mile level almost twice as high as the other model year groups. This is not unexpected since much of the 1981-82 fuel injection technology was in early stages of development.

For NOₓ, the emission levels and deterioration rates for all model year groups are generally the same. The principal exception is the 1990-93 TBI group. For the 1990-93 TBI group, the deterioration rate is similar to the others, but the intercept is considerably higher.

3.3 Start Emissions Versus Soak Time
Start emissions will be a function of soak time so that MOBILE6 will be able to account for the entire distribution of soak times observed in the fleet. This ranges from a minimum soak time of zero minutes up to a 12 hour soak period (720 minutes). Soak periods exceeding 12 hours will be assumed to be the same as for a 12 hour soak.

To develop the relationship between start emissions and soak time, the FTP database was used only to determine the engine start emissions after a 10 minute soak and a 12 hour (720 minute) soak (these are the only data points available). To predict start emissions for the entire range of soak duration, a model was developed from the two FTP points, and from testing done by California of the effect of soak time on engine start emissions (see CARB report “Methodology for Calculating and Redefining Cold and Hot Start Emissions”)

The model which was developed uses the FTP start emission data from the two FTP soak times to adjust the curves presented in the California report. The start emission data points at 10 minutes and 720 minutes are derived from the FTP dataset described earlier and are a function of pollutant, technology, model year group, and mileage. The California interpolation curves (California Soak Function) is a function of pollutant and catalyst type.

Mathematically, the start emissions of a given pollutant (in grams) as a function of soak time is shown as:

Start Emissions (@ soak time) = Basic Start Emissions (@ 12 hour soak) * Soak Function

where the Soak Function is a multiplicative factor used to calculate start emissions for other soak times. The Soak Function is the grams for the soak time of interest divided by the grams for a soak time of 12 hours. At a 12 hour (720 minute) soak time, the Soak Function is equal to 1.

Mathematically, the Soak Function is defined as.

Soak Function = California Soak Function * [Ratio+(1-Ratio)*((SoakTime-10)/(720-10))]

where

California Soak Function. The values developed by the California Air Resources Board to adjust the start emissions for soak times other than 12 hours. This is a function of soak time in minutes. The coefficients for catalyst vehicles, non-catalyst vehicles, and electrically heated catalyst vehicles are given in Table 4. The coefficients for catalyst-equipped vehicles are for the model year/technology groups examined in this report. For example, for HC on a catalyst equipped vehicle at a soak time of 100 minutes, the value is

0.57130 + 0.00072*100 + (-1.76E-07)*(100)^2 = 0.64154
Ratio  This parameter is calculated by dividing the EPA ratio of start emissions at 10 minutes to start emissions at 12 hours by the California Soak Function at 10 minutes. Mathematically, it is given by:

\[
\text{Ratio} = \left( \frac{\text{Start @10 minutes}}{\text{Start @720 minutes}} \right) / \text{California Soak Function @10 minutes}
\]

The numerator in the above equation (Start @10 minutes/ Start @720 minutes) was developed from FTP data using the equations in Sections 3.1.3, and dividing the Start @10 minutes by the Start @720 minutes. One value for each pollutant was developed that included all technologies and vehicle types. These values, used in the numerator of the equation, are: HC= 0.160, CO = 0.112, and NOx = 0.204. The California Soak Function is the value obtained from the coefficients in Table 4 at a 10 minute soak point. The California Soak Function values at a 10 minute soak point for catalyst-equipped vehicles, used in the denominator of the equation, are: HC=0.1209, CO=0.1147, and NOx=0.3937. Therefore, the Ratios obtained are: HC=1.3234, CO=0.9718, and NOx=0.5182.

SoakTime: The time duration in minutes of the soak which is to be calculated (range zero minutes to 720 minutes)

The operation of the multiplicative Soak Function is illustrated in Figures 4, 5, and 6 for HC, CO, and NOx respectively. The Y-axis is the Soak Function (a unitless ratio) and the X-axis is the soak time in minutes. The California Soak Function is also shown for comparison.

For HC and NOx, the difference between the MOBILE6 soak function and the California soak function will be moderate for soak times between 30 minutes and 600 minutes. For CO, the two soak functions are very similar.

4.0 START EMISSION RESULTS

Start emissions are both a function of vehicle deterioration represented by mileage, and soak time. In previous sections the results were shown separately. In this section, examples of the results are shown with both effects combined. For example, Figures 7 through 9 show the HC, CO, and NOx start emissions as a function of soak time for three odometer levels (0, 50,000, and 100,000 miles) of 1990-93 PFI cars. For all three pollutants, the figures show low deterioration rates as mileage is increased at short soak times, and larger but constant deterioration rates at soak times after 120 minutes.

Shown below for illustration purposes is a sample calculation of start emissions. It illustrates the equations shown in Section 3.

Example: Calculate HC start emissions at a soak time of 90 minutes for a 1991 model year PFI-equipped car with 50,000 miles.
Start Emissions (@90min) = Basic Start Emissions (@12hr) * Soak Function

From Table 3a:
Basic Start Emissions = 2.0163 + (0.0074/1000 miles) * 50,000 miles = 2.3863g

Soak Function = California Soak Funct * [Ratio+(1-Ratio)*((SoakTime-10)/(720-10))]

From Table 4, using the coefficients for catalyst-equipped vehicles:
California Soak Funct = 0.57130 + (0.00072)*(90) + (-1.76E-07)*(90)^2 = 0.63467

Ratio = (Start@10min / Start@12hr) / California Soak Funct@10min
= 1.3234 for HC as given in Section 33

SoakTime = 90 minutes

Soak Function = 0.63467 * [1.3234 + (1-1.3234) * ((90-10) / (720-10))] = 0.81680

Start Emissions (@90min) = 2.3863 * 0.81680 = 1.9491g HC
Table 1
Distribution of Vehicles by Model Year and Technology*

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<thead>
<tr>
<th>MYR</th>
<th>Cars OPLP</th>
<th>Cars CL CARB</th>
<th>Cars TBI</th>
<th>Cars PFI</th>
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* No entry indicates no data available for that model year/technology type in the FTP dataset used for this analysis.
### Table 2a
**Mean Start and FTP Emission Levels by Model Year for Light-Duty Cars**

<table>
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<tr>
<th>MYR</th>
<th>HC</th>
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*In some isolated instances, a negative number for a start emissions estimate was obtained. This is possible when the simulated HR505 value is greater than the Bag 1 or Bag 2 value from the FTP.*
### Table 2b

Mean Start and FTP Emission Levels by Model Year for Light-Duty Trucks*

| MYR | HC  | CO   | NOx | MYR | HC  | CO   | NOx | MYR | HC  | CO   | NOx |
|-----|-----|------|-----|-----|-----|------|-----|-----|-----|------|-----|-----|
| 81  | 7.342 | 107.501 | 1.055 | 81  | 1.212 | 14.211 | 0.385 | 81  | 1.275 | 18.158 | 1.752 |
| 82  | 7.909 | 116.584 | -0.119 | 82  | 1.489 | 14.189 | 0.006 | 82  | 1.732 | 16.774 | 1.732 |
| 83  | 6.537 | 104.817 | 0.796 | 83  | 1.577 | 18.657 | -0.209 | 83  | 1.361 | 13.226 | 1.436 |
| 84  | 5.219 | 95.893 | 0.299 | 84  | 1.098 | 20.057 | 0.004 | 84  | 0.802 | 10.633 | 1.405 |
| 85  | 4.766 | 84.621 | 0.457 | 85  | 0.854 | 7.742 | 0.102 | 85  | 1.281 | 14.465 | 1.388 |
| 86  | 3.752 | 41.196 | 0.729 | 86  | 0.607 | 2.148 | 0.128 | 86  | 0.823 | 8.789 | 1.057 |
| 87  | 3.352 | 26.635 | 1.266 | 87  | 0.566 | 1.433 | 0.017 | 87  | 0.401 | 4.610 | 0.605 |
| 88  |     |     |     | 88  |     |     |     | 88  |     |     |     |
| 89  |     |     |     | 89  |     |     |     | 89  |     |     |     |
| 90  | 4.705 | 45.331 | 4.683 | 90  | 0.930 | 7.037 | 0.765 | 90  | 0.800 | 9.510 | 0.885 |
| 91  | 3.521 | 41.128 | 2.761 | 91  | 0.878 | 7.129 | 0.519 | 91  |     |     |     |
| 92  | 3.656 | 41.446 | 3.054 | 92  | 0.654 | 5.746 | 0.656 | 92  |     |     |     |
| 93  | 3.644 | 40.557 | 2.736 | 93  | 0.589 | 4.634 | 0.676 | 93  | 0.420 | 5.363 | 0.847 |

* No FTP data are available for 1988 and 1989 model year light-duty trucks.

In some isolated instances, a negative number for a start emissions estimate was obtained. This is possible when the simulated HR505 value is greater than the Bag 1 or Bag 2 value from the FTP.
Table 3a
Basic Start Deterioration with Mileage for Light-Duty FI Cars

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*The basic unit of engine start emissions is defined as a start after a 12 hour soak.
ZML and Det are the regression coefficients for the zero mile level (intercept) and the deterioration rate (slope) per one thousand miles, respectively.
The confidence levels shown are the upper and lower 95% confidence intervals. Significance values less than 0.05 are considered statistically significant at the 95% confidence level.
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* The basic unit of engine start emissions is defined as a start after a 12 hour soak. ZML and Det are the regression coefficients for the zero mile level (intercept) and the deterioration rate (slope) per one thousand miles, respectively. The confidence levels shown are the upper and lower 95% confidence intervals. Significance values less than 0.05 are considered statistically significant at the 95% confidence level.

** Due to lack of data for the 1981-82 FI truck category, the deterioration functions for the 1981-82 FI cars were used to represent this category.
### Table 3c

Basic Start Deterioration with Mileage for Light-Duty Open Loop and Closed Loop Carbureted Vehicles

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<td>1986-89</td>
<td>CL Carb</td>
<td>9</td>
<td>0 700</td>
<td>0.000</td>
</tr>
<tr>
<td>NOx</td>
<td>1983-85</td>
<td>CL Carb</td>
<td>54</td>
<td>0 700</td>
<td>0.000</td>
</tr>
<tr>
<td>NOx</td>
<td>1981-82</td>
<td>CL Carb</td>
<td>**</td>
<td>1 684</td>
<td>0.000</td>
</tr>
<tr>
<td>NOx</td>
<td>1981+</td>
<td>OPLP</td>
<td>250</td>
<td>0 753</td>
<td>0.000</td>
</tr>
</tbody>
</table>

* The basic unit of engine start emissions is defined as a start after a 12 hour soak. ZML and Det are the regression coefficients for the zero mile level (intercept) and the deterioration rate (slope) per one thousand miles, respectively. The confidence levels shown are the upper and lower 95% confidence intervals. Significance values less than 0.05 are considered statistically significant at the 95% confidence level.

** Due to lack of data for the 1981-82 CL Carb truck category, the deterioration functions for the 1981-82 CL Carb cars were used to represent this category.
Table 4
Coefficients for Adjusting Engine Start Emissions for Soak Time
(from “Methodology for Calculating and Redefining Cold and Hot Start Emissions”, CARB)

<table>
<thead>
<tr>
<th></th>
<th>HC Curve 1</th>
<th>HC Curve 2</th>
<th>CO Curve 1</th>
<th>CO Curve 2</th>
<th>NOx Curve 1</th>
<th>NOx Curve 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Constant</strong></td>
<td>0.38067</td>
<td>0.43628</td>
<td>0.43803</td>
<td>-0.08541</td>
<td>1.31568</td>
<td>2.48061</td>
</tr>
<tr>
<td><strong>minutes</strong></td>
<td>-0.00163</td>
<td>0.00078</td>
<td>-0.00998</td>
<td>0.00303</td>
<td>0.02752</td>
<td>-0.00018</td>
</tr>
<tr>
<td><strong>minutes²</strong></td>
<td>6.64E-05</td>
<td>0</td>
<td>7.01E-05</td>
<td>-2.11E-06</td>
<td>-0.00015</td>
<td>-2.6E-06</td>
</tr>
<tr>
<td><strong>domain(min)</strong></td>
<td>0-52</td>
<td>53-720</td>
<td>0-119</td>
<td>120-720</td>
<td>0-119</td>
<td>120-720</td>
</tr>
</tbody>
</table>

**Catalyst Equipped Vehicles**

<table>
<thead>
<tr>
<th></th>
<th>HC Curve 1</th>
<th>HC Curve 2</th>
<th>CO Curve 1</th>
<th>CO Curve 2</th>
<th>NOx Curve 1</th>
<th>NOx Curve 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Constant</strong></td>
<td>0</td>
<td>0.57130</td>
<td>0</td>
<td>0.70641</td>
<td>0.11796</td>
<td>1.12983</td>
</tr>
<tr>
<td><strong>minutes</strong></td>
<td>0.01272</td>
<td>0.00072</td>
<td>0.01195</td>
<td>0.00033</td>
<td>0.02967</td>
<td>2.21E-05</td>
</tr>
<tr>
<td><strong>minutes²</strong></td>
<td>-6.30E-05</td>
<td>-1.76E-07</td>
<td>-4.76E-05</td>
<td>1.00E-07</td>
<td>-0.00021</td>
<td>-3.04E-07</td>
</tr>
<tr>
<td><strong>domain(min)</strong></td>
<td>0-89</td>
<td>90-720</td>
<td>0-116</td>
<td>117-720</td>
<td>0-61</td>
<td>62-720</td>
</tr>
</tbody>
</table>

**Electrically Heated Catalyst Equipped Vehicles**

<table>
<thead>
<tr>
<th></th>
<th>HC Curve 1</th>
<th>HC Curve 2</th>
<th>CO Curve 1</th>
<th>CO Curve 2</th>
<th>NOx Curve 1</th>
<th>NOx Curve 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Constant (a)</strong></td>
<td>0</td>
<td>0.50641</td>
<td>0</td>
<td>0.44733</td>
<td>1.05017</td>
<td>1.37178</td>
</tr>
<tr>
<td><strong>minutes (b)</strong></td>
<td>0.00561</td>
<td>0.00069</td>
<td>0.00707</td>
<td>0.00162</td>
<td>0.00362</td>
<td>0.00027</td>
</tr>
<tr>
<td><strong>minutes² (c)</strong></td>
<td>-5.09E-06</td>
<td>0</td>
<td>-1.33E-05</td>
<td>-1.18E-06</td>
<td>-5.57E-06</td>
<td>-1.09E-06</td>
</tr>
<tr>
<td><strong>domain(min)</strong></td>
<td>0-117</td>
<td>118-720</td>
<td>0-107</td>
<td>108-720</td>
<td>0-113</td>
<td>114-720</td>
</tr>
</tbody>
</table>

California Soak Function = a + b * minutes + c * minutes²
(where minutes is time since last engine operation (i.e., soak time))

The Soak Function is the grams per soak time ÷ divided by the grams per overnight soak (720 minutes or 12 hours)
Figure 1
HC Basic Start Emissions for FI Cars by Model Year Group

HC Start Emissions (grams)

Mileage (in thousands)
Figure 2
CO Basic Start Emissions for FI Cars by Model Year Group

- 90-93 PFI
- 90-93 TBI
- 86-89 FI
- 83-85 FI
- 81-82 FI

CO Start Emissions (grams)

Mileage (in thousands)
Figure 3
NOx Basic Start Emissions for FI Cars by Model Year Group
Figure 5
CO Soak Function vs Soak Time for 1981+ Vehicles
Figure 6
NOx Soak Function vs Soak Time for 1981+ Vehicles
Figure 7
HC Start Emissions vs Soak Time for 1990-93 PFI Cars

Soak Time (in Minutes)

HC Start Emissions (grams)
Figure 8
CO Start Emissions vs Soak Time for 1990-93 PFI Cars
Figure 9
NOx Start Emissions vs Soak Time for 1990-93 PFI Cars

Soak Time (in Minutes)

NOx Start Emissions (grams)