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Modeling Hourly Diurnal Emissions and Interrupted Diurnal Emissions Based on Real-Time Diurnal Data

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Modeling Hourly Diurnal Emissions and Interrupted Diurnal Emissions Based on Real-Time Diurnal Data

M6.EVP.002

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U.S. Environmental Protection Agency

NOTICE

ABSTRACT

Evaporative emissions due to changes in ambient temperature are an important source of hydrocarbons. These full-day diurnal emissions were described as daily averages in a parallel report (M6.EVP.001). This report presents the method used in MOBILE6 for distributing these full-day emissions among the 24 hours of the day.

This document reports both on the methodology used to analyze the data from real-time diurnal (RTD) tests on 270 vehicles and on the results obtained from those analyses. The purpose of the analysis was to develop a model of the hourly diurnal emissions of the in-use fleet to be used in MOBILE6.

This report was originally released (as a draft) in May 1998, and then revised (and re-released) in July 1999. This current version is the final revision of the July 1999 draft (of M6.EVP.002). This final revision incorporates suggestions and comments received from stakeholders during the 60-day review period and from peer reviewers.

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Report Number M6.EVP.002

Larry C. Landman
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1.0   INTRODUCTION

In a recently released final report,[*] the Environmental Protection Agency (EPA) presented a model for estimating resting loss and diurnal emissions over the course of a full day (i.e., 24 hours). (The diurnal emissions are the pressure-driven evaporative HC emissions resulting from the daily increase in temperature, while the resting loss emissions are the evaporative HC emissions not related to pressure changes.) These estimates were based on the results of 24-hour real-time diurnal (RTD) tests during which the ambient temperature cycles over one of three similar 24-degree Fahrenheit ranges. The three ambient temperature cycles used in those RTD tests are illustrated in Figure 1-1; however, most of the testing was performed using the 72 to 96 degree cycle.[**] In that parallel report, EPA developed a method for estimating resting loss and diurnal emissions on a <u>daily</u> basis. Those estimates of <u>full-day</u> diurnal emissions will be used in MOBILE6.

However, many vehicles do not experience a full-day diurnal; they experience a partial-day (or interrupted) diurnal. In a parallel report, M6.FLT.006 (entitled "Soak Length Activity Factors for Diurnal Emissions"), EPA analyzes data from an instrumented vehicle study conducted in Baltimore, Spokane, and Atlanta to determine what percent of the fleet is undergoing either full-day or interrupted diurnals at each hour of the day.

Therefore, in this report, EPA developed a method for estimating both resting loss and diurnal emissions on an <u>hourly</u> basis. Using those hourly estimates, EPA calculates (in MOBILE6) both the emissions from full-day diurnal as well as the emissions from "interrupted" diurnal (i.e., diurnals that are delayed due to vehicle activity and do not start until after 6 AM when the daily temperature rise has already begun).

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[*] Report numbered M6.EVP.001, "Evaluating Resting Loss and Diurnal Evaporative Emissions Using RTD Tests."

[**] Many of RTD tests were actually performed for periods of more than 24 hours. The results after the 24-hour point are analyzed in M6.EVP.003, entitled "Evaluating Multiple Day Diurnal Evaporative Emissions Using RTD Tests."

As illustrated in Figure 1-1, these three temperature cycles
are parallel (i.e., have identical hourly increases/decreases).
The temperature profiles used in all of the RTD tests have the
ambient temperature rising gradually from the daily low
temperature to the daily high temperature nine hours later. Over
the course of the remaining 15 hours, the temperature slowly
returns to the daily low temperature. The three hourly
temperature cycles used in this study are given in Appendix A.
The most rapid increase in temperatures occurs during the fourth
hour. For RTD tests that exceed 24 hours, the cycle is simply
repeated for the necessary number of hours. (See Section 6.3 for
estimating the effects of alternate temperature profiles.)

Figure 1-1

Temperature Cycles for Real-Time Diurnal (RTD) Testing

Time (hours)
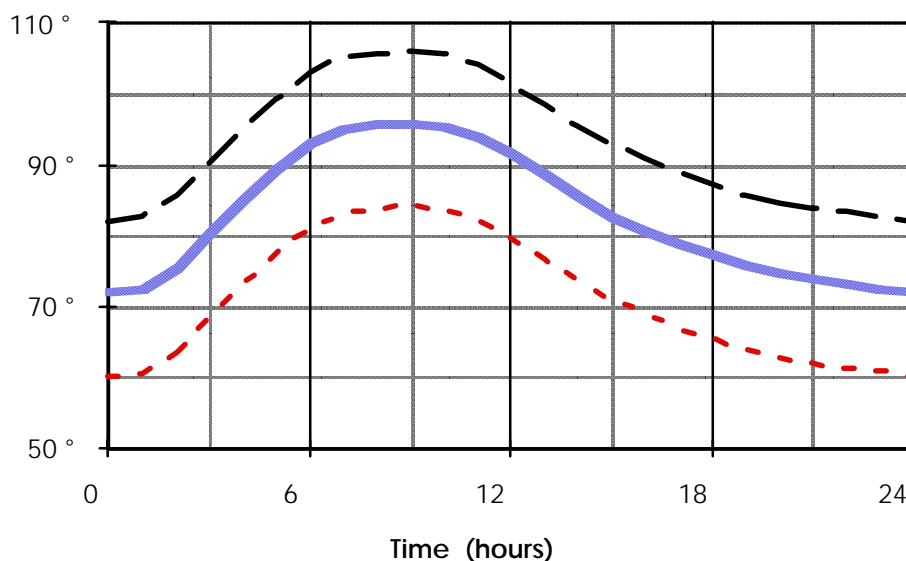
In a parallel document (M6.EVP.001), EPA analyzed full-day
RTD test results from 270 vehicles. In this document, we analyze
the hourly results from those same tests. This document reports
both on the methodology used to analyze the data from those same
RTD tests and on the results obtained from those analyses.

The cumulative hydrocarbon (HC) emissions were measured and
reported hourly. Subtracting successive cumulative results
produces the hourly emissions. However, using the hourly
emissions requires associating a clock time with each test hour.
The RTD test is modeled after a proposal by General Motors (GM).
(GM's proposal is documented in SAE Papers Numbered 891121 and
901110.) The temperature cycle suggested by GM had its minimum
temperature occurring at 5 AM and its maximum temperature at
2 PM. For MOBILE5, EPA analyzed 20-year averaged hourly

temperatures by month from Pittsburgh on high ozone days. EPA
found that the minimum daily temperature typically occurred
between 6 and 7 AM, while the maximum daily temperature typically
occurred between 3 to 5 PM. Obviously, the local temperature
curve depends on local conditions. However, for MOBILE6, EPA
will combine the GM and MOBILE5 time estimates and assign the
daily low temperature to 6 AM, and the daily high temperature to
at 3 PM. Applying this approach to the temperature cycles in
Appendix A results in having the time zero correspond with 6 AM.

2.0   STRATIFYING THE TEST FLEET

It was necessary to stratify the test fleet for two reasons.
First, different mechanisms are involved in producing the diurnal
emissions for different groups of vehicles, thus, necessitating
different analytical approaches. Second, the recruitment of test
vehicles was intentionally biased to allow testing a larger
number of vehicles that most likely had problems with their
evaporative control systems. The test data used for these hourly
analyses are the same data used in the aforementioned EPA draft
report. The data were obtained by combining RTD tests performed
on 270 vehicles tested by the Coordinating Research Council (CRC)
and EPA in separate programs. The distribution of the fleet is
given in Table 2-1.

Table 2-1

Distribution of Test Vehicles

Vehicle Type	Program	Cars	Trucks
Pre-80 Carbureted	CRC	38	13
	EPA	4	2
80-85 Carbureted	CRC	0	47
	EPA	13	5
80-85 Fuel-injected	CRC	0	3
	EPA	9	0
86-95 Carbureted	CRC	0	7
	EPA	8	0
86-95 Fuel-injected	CRC	0	43
	EPA	67	11

In that parallel report, EPA noted that the resting loss and
diurnal emissions from vehicles classified as "gross liquid
leakers" (i.e., vehicles identified as having substantial leaks
of liquid gasoline, as opposed to simply vapor leaks) are
significantly different from those of the remaining vehicles.
Based on that observation, those two groups were analyzed
separately in both reports.

The two <u>testing</u> parameters in the EPA programs that were found (in M6.EVP.001) to affect the 24-hour RTD test results are:

♦   the Reid vapor pressure (RVP) of the test fuel and

♦   the temperature cycle.

Similarly, the two <u>vehicle</u> parameters that were found to affect the 24-hour RTD test results are:

♦   the model year range:

    1)   1971 through 1979
    2)   1980 through 1985
    3)   1986 through 1995

♦   the fuel delivery system:

    1)   carbureted (Carb) or
    2)   fuel-injected (FI).

Also, since many of the EPA vehicles were recruited based on the pass/fail results of two screening tests (i.e., canister purge measured during a four-minute transient test and pressurizing the fuel system using the tank lines to the canister), each of those resulting stratum was further divided into the following three substrata:

♦   vehicles that passed both the purge and pressure tests,

♦   vehicles that failed the purge test, but passed the pressure test, and

♦   vehicles that failed the pressure test (including both the vehicles that passed the purge test as well as those that failed the purge test).*****

This stratification was used in both the analysis of the 24-hour diurnal emissions and in this current analysis (see Section 4.0).

2.1   **Evaluating Untested Strata**

As noted in M6.EVP.001, <u>no</u> pre-1980 model year, FI vehicles were recruited because of the small numbers of those vehicles in the in-use fleet (i.e., less than three percent).

Since the FI vehicles lack a carburetor bowl, they also lack the evaporative emissions associated with this component. This suggests that the resting loss and diurnal emissions of the pre-1980 FI vehicles are likely to be no higher than the

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*   For only <u>one</u> of the fuel delivery system/model year range groupings (i.e., pre-1980 carbureted vehicles) were there sufficient data to distinguish between the vehicles that failed both the purge and pressure tests and those that failed only the pressure test. Therefore, these two substrata were combined into a single ("fail pressure") stratum.

corresponding emissions of the pre-1980 carbureted vehicles. For
MOBILE6, EPA will estimate the RTD emissions of the (untested)
pre-1980 FI vehicles with the corresponding emissions of the pre-
1980 carbureted vehicles. This should be a reasonable assumption
since any actual differences between the emissions of these
strata should be balanced by the relatively small number of these
FI vehicles in the in-use fleet.

3.0   EVAPORATIVE EMISSIONS REPRESENTED BY THE RTD TEST

As described in M6.EVP.001, the results from the real-time
diurnal (RTD) tests actually measure the combination (sum) of two
types of evaporative emissions:

1)   "Resting loss" emissions are always present and related
to the ambient temperature (see Section 7.1 of
M6.EVP.001).

That report (M6.EVP.001) estimated the hourly resting
loss emissions as the mean of the RTD emissions from
hours 19 through 24 (i.e., midnight through 6 AM) at
the nominal temperature for the end of hour 24 (6 AM).

2)   "Diurnal" emissions are the pressure-driven emissions
resulting from the rising temperature in the daily
temperature cycle (Section 7.2 of M6.EVP.001).

The 24-hour diurnal emissions were calculated by first
adjusting the resting loss value for each hour's
ambient temperature, and then subtracting that
temperature-adjusted resting loss estimate from the
full 24-hour RTD test results.

A special case of each of these two categories consists of
evaporative emissions from vehicles that have significant leaks
of liquid gasoline. We defined these "gross liquid leakers" as
vehicles with resting loss emissions exceeding two grams per
hour. As stated in Section 2, these "gross liquid leakers" were
analyzed separately from the other vehicles. Alternative
definitions of these "gross liquid leakers" are possible;
however, with each such new definition, a new frequency
distribution and mean emission value would have to be determined.

The following graph (Figure 3-1) is an example of hourly RTD
emissions for vehicles that were not gross liquid leakers. For
this example, we averaged the RTD hourly results (in grams) from
69 1986-95 model year, FI vehicles that had passed both the
pressure and purge tests. All were tested over the 72° to 96°
cycle using a 6.8 RVP gasoline. We then plotted the temperature-
adjusted hourly resting loss and diurnal emissions.

Figure 3-1

An Example of Hourly RTD Emissions (grams) versus Time

Duration (hours)
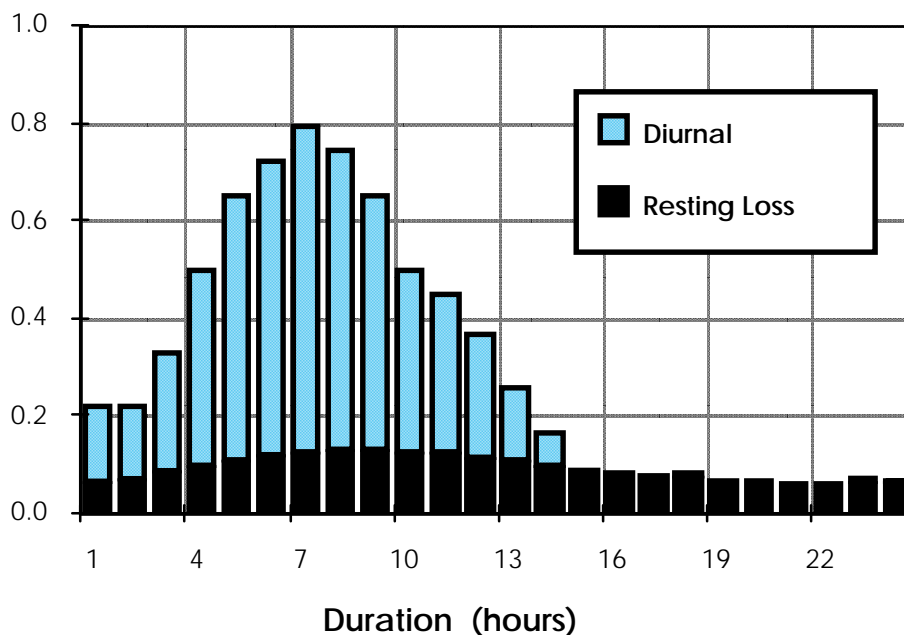
   This example represents the hourly resting loss and diurnal emissions of the mean of a <u>single</u> stratum. Each combination of the five parameters discussed in Section 2.0 can produce a different graph. In the database used for these analyses, there are:

♦   five combinations of fuel delivery system and model year range,

♦   six combinations of temperature cycle and fuel RVP, and

♦   three combinations of results of the purge and pressure tests.

Therefore, using the available data, we could construct 86 graphs for which there are any data (58 are based on the average of no more than four RTD tests). EPA chose to consolidate those strata into the smaller number of groups that were actually used. The selection of both the categorical variables (used to form the strata) and the analytical variables is discussed in the following section.

4.0　HOURLY DIURNAL EMISSIONS

4.1　<u>Characterizing Hourly Diurnal Emissions by Strata</u>

In Table 4-1 (on the following page), to normalize the
hourly diurnal emissions (which can vary substantially), we
divided each hour's diurnal emissions by the full (i.e., total
24-hour) diurnal emissions within each of the stratum described
in Section 3.0.　Twenty-four of those strata were represented by
at least ten tests.　Within each of those 24 strata, we estimated
(by interpolation) the time at which the cumulative hourly
diurnal emissions totaled 25, 50, and 75 percent of the full-
day's diurnal emission.　We also identified the test hour during
which the day's highest (i.e., peak) hourly diurnal emission
occurred.　(These values would correspond to the quartiles and
the mode.　These four clock times permitted us to distinguish
among strata without having to resort to using all 24 hourly
values.)　No attempt was made (in Table 4-1) to estimate the
overall mean values.

A visual inspection of these results in Table 4-1 suggests
that:

♦　These strata (containing at least 10 tests) do not yield a
　　complete representation of the various technologies (i.e.,
　　not all of the combinations of fuel delivery systems and
　　model year ranges are present), specifically:

　　♦♦　The only strata containing fuel-injected vehicles are
　　　　exclusively composed of the 1986-95 model year
　　　　vehicles.

　　♦♦　The only strata containing the Pre-1980 or the 1980-
　　　　85 model year vehicles are exclusively composed of
　　　　the carbureted vehicles.

　　Thus, we cannot treat as independent variables both the
　　type of fuel delivery system and the model year range.
　　Therefore, EPA selected the type of fuel delivery system
　　(i.e., carbureted versus fuel-injected) as the stratifying
　　variable (rather than model year range).

Table 4-1

Distribution of Hourly Diurnal Emissions
Within Each Stratum Containing at Least 10 Tests

Purge / Pressure Category	Temperature Cycle	MYR Range	Fuel Metering	Cnt	RVP	--- Hour During Which --- Cumulative Hourly Reaches Stated Percent of Full-Day 25%	50%	75%	Max Diurnal Occurs
Fail ONLY Purge	60.TO.84	86-95	FI	12	6.8	3.90	5.40	7.38	5
		86-95	FI	17	9.0	4.16	5.89	7.86	6
	72.TO.96	80-85	CARB	11	6.8	4.24	6.50	8.83	7
		86-95	FI	19	6.8	3.52	5.50	7.65	6
		86-95	FI	17	9.0	4.50	6.35	8.02	7
	82.TO.106	86-95	FI	16	6.8	3.99	5.74	7.70	6
		86-95	FI	12	9.0	5.01	6.71	8.58	7
Fail Pressure	60.TO.84	86-95	FI	11	6.8	4.06	5.73	7.54	7
		86-95	FI	19	9.0	4.08	5.60	7.15	6
	72.TO.96	Pre-80	CARB	33	6.8	4.39	6.28	8.35	6
		80-85	CARB	10	6.8	4.18	6.04	8.10	6
		86-95	FI	20	6.8	4.31	6.04	8.09	6
		86-95	FI	19	9.0	4.37	6.06	7.84	6
	82.TO.106	86-95	FI	17	6.8	4.26	5.98	7.79	7
		86-95	FI	12	9.0	4.57	6.29	7.90	7
Passing Both	60.TO.84	86-95	FI	16	6.8	4.06	7.10	9.73	8
		86-95	FI	32	9.0	5.49	7.88	10.36	8
	72.TO.96	Pre-80	CARB	11	6.8	6.32	8.46	10.85	8
		80-85	CARB	38	6.8	4.98	7.00	9.19	7
		86-95	CARB	10	6.8	5.36	7.72	10.10	9
		86-95	FI	70	6.8	4.62	6.73	8.98	7
		86-95	FI	31	9.0	6.43	8.36	10.46	8
	82.TO.106	86-95	FI	25	6.8	4.59	6.97	9.56	7
		86-95	FI	22	9.0	6.73	8.06	9.72	8

A further visual inspection of these results (in Table 4-1) also suggests that:

♦   The emissions distribution as indicated by these four clock times (i.e., the number of hours into the tests that the maximum hourly diurnal emissions occur as well as the number of hours into the tests necessary for the

cumulative hourly diurnal emissions to total 25, 50, and 75 percent of the full 24-hour diurnal) appear to be affected by both the temperature cycle and the fuel RVP, specifically:

♦♦ The higher temperature cycles usually (but not consistently) correspond with a delay in the occurrence of the four clock times in the distributions.

♦♦ For the strata of vehicles that passed the pressure test (either "Fail ONLY Purge" or "Passing Both"), a higher fuel RVP corresponds with delaying the occurrence of all four clock times in the corresponding distributions.

In the analyses of full-day diurnals (M6.EVP.001), EPA used the RVP to estimate the vapor pressure (VP) of the fuel at each point in the temperature cycle. The mean of the VP at the highest and lowest daily temperatures incorporates aspects of both the temperature cycle and the fuel RVP. EPA will use that (midpoint) value (in kiloPascals) as one of the potential variables. (This variable serves to more effectively distinguish among the three temperature cycles in Appendix A.)

♦ There appears to be differences among the three purge / pressure categories, specifically:

♦♦ As noted above, the four clock times in the distributions appear to be affected by the fuel RVP in the strata that passed the pressure test. However, for the strata of vehicles that failed the pressure test, those times are fairly insensitive to differences in fuel RVP.

♦♦ For the strata of vehicles that passed both the purge and pressure tests, the occurrence of all four clock times in the corresponding distributions are delayed (relative to the strata of vehicles that failed only the purge test).

Based on these observations, EPA estimated the hourly diurnal emissions separately for each of the three purge / pressure categories.

Therefore, EPA modeled the hourly diurnal emissions (as percentages of the full day diurnal):

♦ separately for the category of "gross liquid leakers" (see Section 4.2.3),

♦ separately for each of the six combinations of fuel
   delivery system (i.e., fuel-injected versus carbureted)
   and purge / pressure category,

♦ using (midpoint) VP to distinguish among the temperature
   cycles and the fuel RVP (for vehicles that are not "gross
   liquid leakers"), and

♦ using variables that describe the change in ambient
   temperature (discussed on the following page).

These decisions result in modeling the hourly diurnal emissions
separately within each of the following seven strata:

1) carbureted vehicles (**not** "gross liquid leakers") that pass
   both the purge and pressure tests,
2) carbureted vehicles (**not** "gross liquid leakers") that fail
   the pressure test,
3) carbureted vehicles (**not** "gross liquid leakers") that fail
   only the purge test,
4) FI vehicles (**not** "gross liquid leakers") that pass both
   the purge and pressure tests,
5) FI vehicles (**not** "gross liquid leakers") that fail the
   pressure test,
6) FI vehicles (**not** "gross liquid leakers") that fail only
   the purge test, and
7) the vehicles classified as "gross liquid leakers" (see
   Section 4.2.3).

NOTE: Since the diurnal emissions are pressure driven, and since
         the pressure in the fuel tank (while the vehicle is
         parked) is dependent on changes in ambient temperature,
         the choice of "changes in temperature" as the independent
         variable(s) is reasonable from a physical standpoint.
         This choice also yields more flexibility in estimating the
         diurnal emissions.

         If EPA's intent were simply to predict the hourly
         emissions over temperature cycles limited to only the
         three (parallel) cycles in Appendix A, then "clock time"
         might be an obvious choice for an independent variable.
         However, since the resulting equations must permit the
         modeling of different temperature cycles including
         interrupted cycles, the "changes in temperature" variables
         were used in lieu of a "time" variable.

Those seven strata can be illustrated in the following table.
The numbering of the cells (**1** through **7**) within the table

coincides with both the numbering in the preceding list as well as with the numbering of the seven equations in Section 4.2.

Fuel Delivery System	Passing Both Purge and Pressure	Failing the Pressure Test	Failing ONLY the Purge Test	Gross Liquid Leakers
Carbureted	(1)	(2)	(3)	(7)
Fuel-Injected	(4)	(5)	(6)	

As stated in Section 3.0, the diurnal emissions are the pressure-driven emissions resulting from the daily increase in the temperature of both the fuel and the vapor. Although the fuel temperature is not a readily available variable, it does follow the daily cycle of the ambient temperature. On 80 of the 119 vehicles that EPA tested using the RTD cycles, EPA measured both the ambient temperature and the fuel tank temperature. For hour of each of the three temperature cycles (illustrated earlier in Figure 1-1), we averaged the measured ambient temperatures and the measured fuel tank temperatures. These values are plotted below in Figure 4-1 (ambient temperatures as the solid lines and fuel tank temperatures as the dotted lines).

Figure 4-1

**Comparison of Ambient and Fuel Tank Temperatures
By Temperature Cycle**
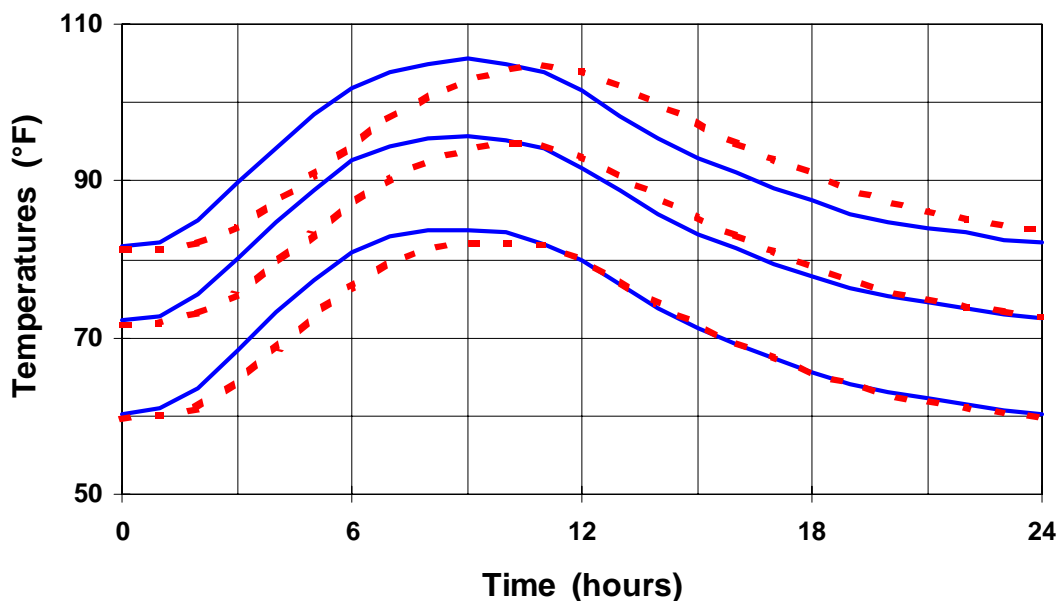
In Figure 4-1, the fuel tank temperatures lagged behind the corresponding ambient temperatures. We estimated a lag time for each of the three cycles by minimizing the sum of the squares of the temperature differences (ambient temperature less tank temperature). Those lag times (given below) are the times (in minutes) by which the fuel tank temperatures lagged behind the corresponding ambient temperatures.

| | Lag Time |
Ambient Temperature Cycle	(minutes)
60 to 84° Cycle	44.4
72 to 96° Cycle	67.0
82 to 106° Cycle	108.4

To validate those estimated lag times, each of the three curves in Figure 4-1 that represented the fuel tank temperatures (i.e., the dotted lines) were shifted left (i.e., translated) by the corresponding time lag. The result of shifting each of those three curves is illustrated below in Figure 4-2.

Figure 4-2

**Comparison of Ambient and "Shifted" Fuel Tank Temperatures
By Temperature Cycle**
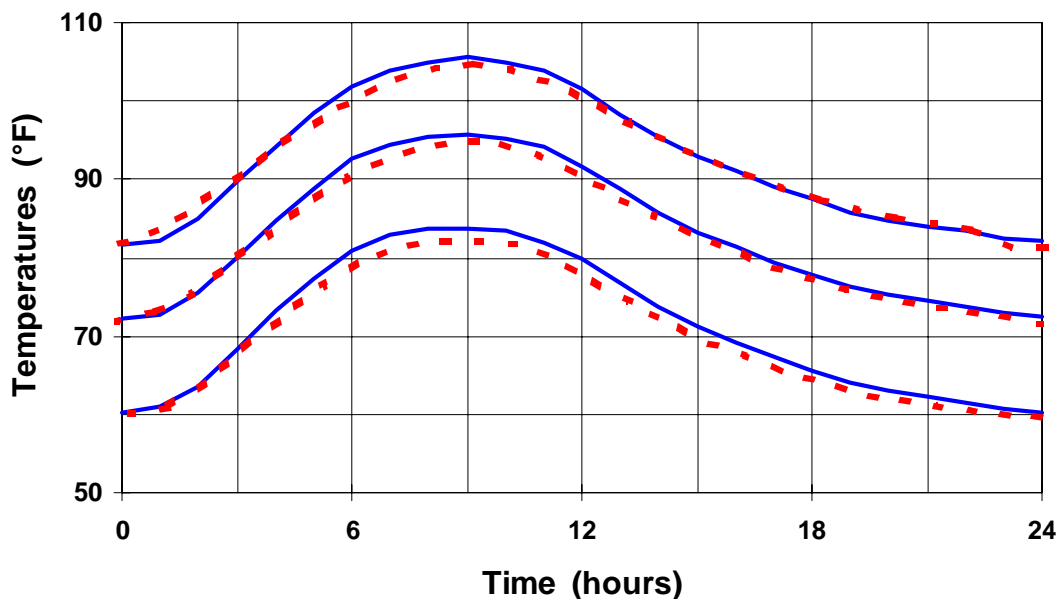
It is basic thermodynamics that the temperature changes recorded in the fuel tank will lag behind the temperature changes in the ambient. What is important is that the lag time of those temperature changes (which in turn produce the pressure changes driving the diurnal emissions) will vary depending upon the individual daily temperature cycle. Therefore, for some temperature cycles the most significant temperature change would be the one for the current hour, and for other temperature cycles the most significant temperature change would be one for an earlier hour. Thus, EPA considered the following three variables (and multiplicative combinations of them to allow for interactions) in modeling the hourly diurnal emissions:

- ♦ the change in ambient temperature during that specific hour,
- ♦ the change in ambient temperature during the previous hour, and
- ♦ the total change in temperature from the start of the cycle until the start of the previous hour.

Since all three of those temperature terms are actually differences of temperatures, it was not necessary to convert the temperature units from Fahrenheit to an absolute temperature scale. For the three temperature cycles used, these three temperature variables are given in Appendix A.

4.2   Calculating Hourly Diurnal Emissions by Strata

EPA will estimate the mean hourly diurnal emissions by multiplying the full day's diurnal emissions (estimated in the parallel report, M6.EVP.001, and reproduced in Appendix C) by the hourly percentages predicted in Sections 4.2.1 through 4.2.3 of this report.

4.2.1 Carbureted Vehicles

As noted in the discussion associated with Table 4-1, there is limited data on carbureted vehicles. The only combination of temperature cycle and fuel RVP represented by at least 10 tests was that of the 72 to 96 degree cycle using the 6.8 RVP fuel. That condition persisted even after eliminating the model year groupings as a stratifying factor. EPA, therefore, had the option of either performing analyses based on a small number of carbureted vehicles or applying the results of the analyses of the FI vehicles directly to the carbureted vehicles. EPA decided to proceed using the limited test results on carbureted vehicles. The distribution of the tests is given on the following page in Table 4-2.

Table 4-2

Distribution of RTD Tests of Carbureted Vehicles

Purge/Pressure Category	temperature cycle	RVP	Number of Tests
Fail ONLY Purge	60 to 84	6.8	4
		9.0	6
	72 to 96	6.8	19
		9.0	6
	82 to 106	6.8	5
		9.0	4
Fail Pressure	60 to 84	6.8	4
		9.0	8
	72 to 96	6.8	45
		9.0	8
	82 to 106	6.8	6
		9.0	4
Passing Both	60 to 84	6.8	4
		9.0	9
	72 to 96	6.8	59
		9.0	9
	82 to 106	6.8	6
		9.0	4

EPA chose to use stepwise* linear regressions to identify the variables that were the most influential in determining the shape of the graph of the hourly diurnal emissions when plotted against the hour (clock time). ("Time" itself is not actually the independent variable in the analysis. See the "Note" on page 10.) The mean hourly diurnal emissions were calculated within each of the 18 sub-stratum determined by the purge / pressure

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* The stepwise regression process first uses the Pearson Product-Moment to select the independent variable that has the highest correlation with the "**Ratio of Hourly Diurnal**." The difference between the best linear estimate using that variable and that "**Ratio of Hourly Diurnal**" (i.e., the residuals) is then compared with the set of remaining variables to identify the variable having the next highest correlation. This process continues as long as the "**prob**" values do not exceed (an arbitrary) 5 percent, thus, creating a sequence of variables in descending order of statistical correlation. The rank ordering produced by this process is dependent upon the independence of the variables. In this instance, there is some collinearity among the variables which may reduce the usefulness of this statistical tool.

category, the temperature cycle, and fuel RVP. The emissions
were positive for hours one through 18, and were zero for hours
19 through 24. The emissions for each hour were divided by the
full (i.e., total 24-hour) diurnal emissions to calculate the
percentage (ratio) of the total diurnal the percentage for hour
19 always zero). Therefore, each purge/pressure stratum
contained 19 hourly percentages for each of six combinations of
temperature cycles and fuel RVP (for a total of 114 results).
Within each purge/pressure stratum, a stepwise linear regression
of those 114 hourly diurnal ratios was performed to estimate the
"**Ratio of Hourly Diurnal**" as a linear function of the temperature
variables (from page 13) and multiplicative combinations of them,
as well as, multiplicative combinations of them with the VP term
(calculated as the midpoint of the VP at the highest and lowest
temperatures of the day in kiloPascals). The stepwise regression
process produced the following three equations that predict the
ratios of hourly diurnal emissions from **carbureted** vehicles:

For **Carbureted Vehicles Passing Both Purge and Pressure Tests:** **(1)**

    Ratio of Hourly Diurnal   **=**   **0.007032**

             + 0.000023 * [(Midpoint VP) *
                 (Change in Ambient During Previous Hr)
                 (Change in Ambient Prior to Previous Hr)]

             + 0.003586 * (Change Prior to Previous Hr)

             - 0.001111 * (Sqr of Change During Previous Hr)

For **Carbureted Vehicles Failing the Pressure Test:** **(2)**

    Ratio of Hourly Diurnal   **=**   **0.010549**

             + 0.001138 * [(Change During Previous Hr) *
                 (Change in Ambient Prior to Previous Hr)]

             + 0.001758 * (Change Prior to Previous Hr)

             + 0.001765 * (Sqr of Change During Current Hr)

For **Carbureted Vehicles Failing ONLY the Purge Test:**   **(3)**

    Ratio of Hourly Diurnal   =   0.006724

                    + 0.000023 * [(Midpoint VP) *
                                (Change in Ambient During Previous Hr)
                                (Change in Ambient Prior to Previous Hr)]

                    + 0.003966 * (Change Prior to Previous Hr)

                    - 0.001122 * (Sqr of Change During Previous Hr)

                    + 0.000019 * [(Midpoint VP) *
                                (Sqr of Change During Current Hr)]

                    - 0.000018 * [(Midpoint VP) *
                                (Change Prior to Previous Hr)]

More details can be found in Appendix D which contains the regression tables and graphs comparing the actual and predicted hourly ratios. The solid lines in each of the graphs in Appendix D are not regression lines. If the predicted values exactly matched the actual values, then the points of predicted versus actual pairs would exactly lie on those lines (i.e., unity lines).

EPA will use equations **(1)** through **(3)** to predict the ratios of hourly diurnal emissions of the carbureted vehicles that were not gross liquid leakers. EPA will then multiply those percentages by the full (24-hour) diurnals estimated by using the corresponding equations in Appendix C to obtain the hourly emissions (in grams of HC).

NOTE: In Appendix D, each "point" in the data is actually the average (mean) of all of hourly diurnal emissions from all of the tests within that stratum using the same fuel RVP and temperature cycle. This averaging permitted us to eliminate the vehicle-to-vehicle test variability; however, this also exaggerates (i.e., reduced the usefulness of) the "R-squared" statistic. Thus, that statistic is a measure of the amount of the variability in the <u>mean</u> (<u>not</u> the variability in the <u>individual</u> test data) that is accounted for by the resulting regression equation.

The preceding three equations for carbureted vehicles are actually written in a mixture of algebra and English. By adopting the following standard notation, these equations can be rewritten in a concise algebraic form.

Let:

VP = midpoint vapor pressure

N = index (subscript) indicating current hour

D_N = temperature change during current hour

D_{N-1} = temperature change during previous hour

D_S = total temperature change prior to previous hour

Using this notation, the previous equations become:

For Carbureted Vehicles Passing Both Purge and Pressure Tests: (1)

Ratio of Hourly Diurnal = **0.007032**

$$+ \ 0.000023 \ * \ VP \ * \ D_{N-1} \ * \ D_S$$
$$+ \ 0.003586 \ * \ D_S$$
$$- \ 0.001111 \ * \ D_{N-1} \ * \ D_{N-1}$$

For Carbureted Vehicles Failing the Pressure Test: (2)

Ratio of Hourly Diurnal = **0.010549**

$$+ \ 0.001138 \ * \ D_{N-1} \ * \ D_S$$
$$+ \ 0.001758 \ * \ D_S$$
$$+ \ 0.001765 \ * \ D_N \ * \ D_N$$

For Carbureted Vehicles Failing ONLY the Purge Test: (3)

Ratio of Hourly Diurnal = **0.006724**

$$+ \ 0.000023 \ * \ VP \ * \ D_{N-1} \ * \ D_S$$
$$+ \ 0.003966 \ * \ D_S$$
$$- \ 0.001122 \ * \ D_{N-1} \ * \ D_{N-1}$$
$$+ \ 0.000019 \ * \ VP \ * \ D_N \ * \ D_N$$
$$- \ 0.000018 \ * \ VP \ * \ D_S$$

For each combination of temperature cycle and fuel RVP, the 19 fractions (in each of the preceding three stratum) total exactly 1.0. However, the fractions produced by the three regression equations do not necessarily sum to 1.0. Therefore, to normalize these fractions in MOBILE6, the fractions for hours 1 through 18 are summed and divided into the individual results. The fractions for hours 19 through 24 are set to zero (on the assumption that the vehicles are producing only resting loss emissions for those six hours). This produces (for each of the seven strata) a distribution of hourly fractions that total exactly 1.0.

4.2.2 Strata of FI Vehicles

The distribution of the tests of fuel-injected vehicles is given below in Table 4-3. This table is similar to the previous table on the distribution of the tests of carbureted vehicles (Table 4-2).

Table 4-3

Distribution of RTD Tests of FI Vehicles

Purge/Pressure Category	temperature cycle	RVP	Number of Tests
Fail ONLY Purge	60 to 84	6.8	15
		9.0	21
	72 to 96	6.8	21
		9.0	21
	82 to 106	6.8	18
		9.0	16
Fail Pressure	60 to 84	6.8	13
		9.0	21
	72 to 96	6.8	23
		9.0	21
	82 to 106	6.8	18
		9.0	14
Passing Both	60 to 84	6.8	17
		9.0	33
	72 to 96	6.8	73
		9.0	33
	82 to 106	6.8	26
		9.0	22

For the strata of fuel-injected vehicles, the analytical approach was similar to that used for the carbureted vehicles. That is, the mean hourly diurnal emissions were calculated within each of the 18 sub-stratum determined by the purge/pressure category, the temperature cycle, and fuel RVP. The emissions were positive for hours one through 18, and were zero for hours 19 through 24. The percent of the total diurnal emissions represented by each hour was calculated for hours one through 19 (with the percentage for hour 19 always zero). Therefore, each purge/pressure stratum contained 19 hourly percentages for each of six combinations of temperature cycles and fuel RVP (for a total of 114 results).

Within each of the three purge/pressure stratum, a stepwise linear regression of those 114 hourly diurnal ratios was performed to estimate the "**Ratio of Hourly Diurnal**" as a linear function of the temperature variables (from page 13) and multiplicative combinations of them, as well as, multiplicative combinations of them with the VP term (calculated as the midpoint of the VP at the highest and lowest temperatures of the day in kiloPascals). The stepwise regression process produced the following three equations that predict the ratios of hourly diurnal emissions from **<u>fuel-injected</u>** vehicles:

For **Fuel-injected Vehicles Passing Both Purge and Pressure Tests:** **(4)**

Ratio of Hourly Diurnal **= 0.008001**

+ 0.001961 * (Change Prior to Previous Hr)

+ 0.000535 * [(Change During Previous Hr) * (Change in Ambient Prior to Previous Hr)]

- 0.000060 * [(Midpoint VP) * (Sqr of Change During Previous Hr)]

+ 0.005964 * (Change During Current Hr)

+ 0.000056 * [(Midpoint VP) * (Change in Ambient Prior to Previous Hr)]

For **Fuel-injected Vehicles Failing the Pressure Test:** **(5)**

Ratio of Hourly Diurnal **= 0.006515**

+ 0.001194 * [(Change During Previous Hr) * (Change in Ambient Prior to Previous Hr)]

+ 0.001963 * (Change Prior to Previous Hr)

+ 0.001329 * (Sqr of Change During Current Hr)

+ 0.000574 * (Sqr of Change During Previous Hr)

For **Fuel-injected Vehicles Failing ONLY the Purge Test:**   **(6)**

    Ratio of Hourly Diurnal   =   0.007882

                 **+ 0.000855 * [(Change During Previous Hr) *
                          (Change in Ambient Prior to Previous Hr)]**

                 **+ 0.000084 * [(Midpoint VP) *
                          (Change in Ambient Prior to Previous Hr)]**

                 + 0.006960 * (Sqr of Change During Current Hr)

                 **- 0.000160 * [(Midpoint VP) *
                          (Sqr of Change During Current Hr)]**

                 - 0.001172 * (Change Prior to Previous Hr)

                 **+ 0.000118 * [(Midpoint VP) *
                          (Change in Ambient During Current Hr)]**

                 + 0.000825 * (Sqr of Change During Previous Hr)

More details can be found in Appendix D which contains the
regression tables and graphs comparing the actual and predicted
hourly ratios. Again, the solid lines in each of the graphs in
Appendix D depict the case in which the predicted values exactly
matched the actual values. EPA will use equations **(4)** through **(6)**
to predict the ratios of hourly diurnal emissions of the fuel-
injected vehicles that were not gross liquid leakers.

    By adopting the same standard notation (as in Section
4.2.1), the preceding equations can also be rewritten in the
following concise algebraic form:

For **Fuel-injected Vehicles Passing Both Purge and Pressure Tests:**   **(4)**

    Ratio of Hourly Diurnal   =   0.008001

                 + 0.001961 * D_S
                 + 0.000535 * D_{N-1} * D_S
                 - 0.000060 * VP * D_{N-1} * D_{N-1}
                 + 0.005964 * D_N
                  + 0.000056 * VP * D_S

For **Fuel-injected Vehicles Failing the Pressure Test:**   **(5)**

    Ratio of Hourly Diurnal   =   0.006515

                 + 0.001194 * D_{N-1} * D_S
                 + 0.001963 * D_S
                 + 0.001329 * D_N * D_N
                 + 0.000574 * D_{N-1} * D_{N-1}

For **Fuel-injected Vehicles Failing ONLY the Purge Test:** **(6)**

Ratio of Hourly Diurnal **=** **0.007882**

$$+ \ 0.000855 * D_{N-1} * D_S$$
$$+ \ 0.000084 * VP * D_S$$
$$+ \ 0.006960 * D_N * D_N$$
$$- \ 0.000160 * VP * D_N * D_N$$
$$- \ 0.001172 * D_S$$
$$+ \ 0.000118 * VP * D_N$$
$$+ \ 0.000825 * D_{N-1} * D_{N-1}$$

As with the equations for the carbureted strata, these three equations are also normalized (for full-day diurnals) by dividing each of the predicted hourly fractions by the sum of predicted fractions for hours one through 18. The fractions for hours 19 through 24 are again set to zero.

In the observations following Table 4-1, it was noted that the shape of the hourly distribution curve (i.e., the ratios not the actual magnitude) for FI vehicles that failed the pressure test seemed to be insensitive to changes in the fuel RVP. The regression in Appendix D confirms that observation. The regression table indicates that more than 95 percent of the variability in the hourly diurnal emissions can be explained using only the variables involving changes in the temperature. (A similar condition holds true for carbureted vehicles that failed the pressure test.) Therefore, while changing the RVP of the fuel will affect the magnitude of the full-day's diurnal emission, it does not affect how those emissions are distributed over the day for the vehicles that fail the pressure test.

4.2.3 "Gross Liquid Leaker" Vehicles

In the parallel report (M6.EVP.001), vehicles classified as "gross liquid leakers" were analyzed separately from the other vehicles for the following two reasons:

- ◆ the large differences in both resting loss and diurnal emissions, as well as,

- ◆ the mechanisms that produce those high emissions.

For these vehicles, the primary source of the evaporative emissions is the leakage of liquid (as opposed to gaseous) fuel. Therefore, we would expect the diurnal emissions from these vehicles to be less sensitive to changes in ambient temperature than the diurnal emissions from vehicles that do not have significant leaks of liquid gasoline.

The analyses in Sections 4.2.1 and 4.2.2 were repeated for the vehicles identified as being gross liquid leakers. The hourly RTD results for those test vehicles are given in Appendix E. Several of these vehicles exhibited unusually high emissions during the first one or two hours of the test (relative to their emissions for the next few hours). One possible explanation is that during the first two hours of the RTD test, the analyzer was measuring gasoline vapors that resulted from liquid leaks that occurred prior to the start of the test. These additional evaporative emissions (if they existed as hypothesized) would have resulted in a higher RTD result than this vehicle would actually have produced in a 24 hour period. In the last column of Appendix E, we attempt to compensate (as explained in the footnote in Appendix E) for what appears to be simply an artifact of the test procedure. The modified RTD evaporative emissions were then converted to diurnals by assuming that the hourly resting loss for these vehicles is completely independent of ambient temperature, subtracting that amount (8.52 grams per hour which is the average RTD emissions of hours 19 through 24) from each hour's modified RTD emissions, and then dividing by the total diurnal to yield the hourly percentages below in Table 4-4.

Table 4-4

**Distribution of Hourly Diurnal Emissions
of Gross Liquid Leakers
(Hourly Emissions as Percent of 24-Hour Diurnal)**

Hour	Time of Day	Emissions	Hour	Time of Day	Emissions
1	6 - 7 AM	1.82%	13	6 - 7 PM	4.53%
2	7 - 8 AM	3.64%	14	7 - 8 PM	2.99%
3	8 - 9 AM	7.27%	15	8 - 9 PM	1.95%
4	9 - 10 AM	8.63%	16	9 - 10 PM	1.73%
5	10 - 11 AM	9.19%	17	10 - 11 PM	1.48%
6	11 AM - Noon	9.80%	18	11 PM - Midnight	1.28%
7	Noon - 1 PM	9.64%	19	Midnight - 1 AM	**0%**
8	1 - 2 PM	9.61%	20	1 - 2 AM	**0%**
9	2 - 3 PM	7.95%	21	2 - 3 AM	**0%**
10	3 - 4 PM	7.50%	22	3 - 4 AM	**0%**
11	4 - 5 PM	5.89%	23	4 - 5 AM	**0%**
12	5 - 6 PM	5.09%	24	5 - 6 AM	**0%**

A stepwise linear regression of those hourly diurnal ratios (for hours 1 through 19) was performed to estimate the "**Ratio of Hourly Diurnal**" as a linear function of the temperature variables (from page 13) and multiplicative combinations of them, as well as, multiplicative combinations of them with the VP term (calculated as the midpoint of the VP at the highest and lowest temperatures of the day in kiloPascals). The stepwise regression process produced the following equation that predicts the ratios

of hourly diurnal emissions from vehicles with **gross liquid leaks**:

For **"Gross Liquid Leaker" Vehicles:** (7)

Ratio of Hourly Diurnal **=** **0.021349**

+ 0.010137 * (Change During Previous Hr)

+ 0.002065 * (Change Prior to Previous Hr)

Just as the six equations for carbureted and fuel-injected vehicles (sections 4.2.1 and 4.2.2) were rewritten in concise algebraic forms, so too can this equation:

For **"Gross Liquid Leaker" Vehicles:** (7)

Ratio of Hourly Diurnal **=** **0.021349**

+ **0.010137** ***** D_{N-1}
+ **0.002065** ***** D_S

More details can be found in Appendix D which contains the regression table and graph comparing the actual and predicted hourly ratios. A second graph comparing the actual and predicted hourly ratios appears in Figure 4-3 in which equation **(7)** is plotted as a solid line and the data from Table 4-4 as a bar chart. Based on those two graphs depicting close matches between the predicted and actual ratios of hourly diurnal emissions, EPA will use equation **(7)** to predict the ratios of the hourly diurnal emissions of the gross liquid leakers.

Figure 4-3

**Distribution of Hourly Diurnal Emissions
from "Gross Liquid Leakers"**
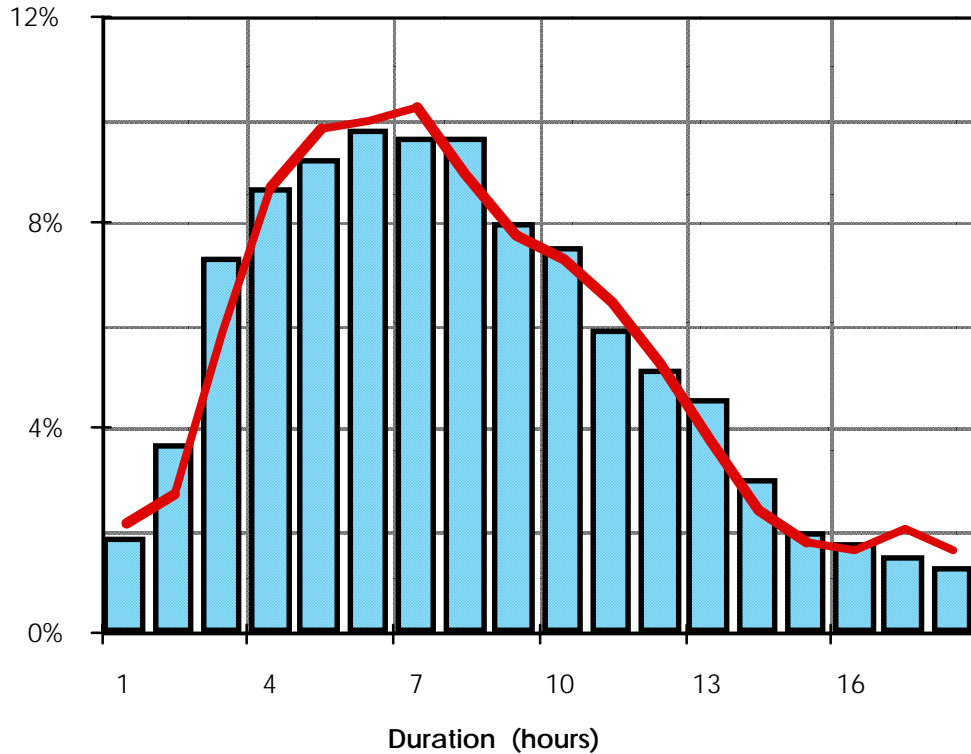
In the earlier report (from Section 10.2 of M6.EVP.001), it was determined that the mean 24-hour diurnal emissions from "gross liquid leakers" (for any of the three temperature cycles in Appendix A and independent of the fuel RVP) was 104.36 grams. Multiplying the hourly ratios in equation **(7)** by that value produces equation **(7a)** that predicts the mean hourly diurnal emissions (in grams of HC) for vehicles that are gross liquid leakers.

For **"Gross Liquid Leaker" Vehicles:**   **(7a)**

    Hourly Diurnal Emissions (grams of HC) =

          + 2.22798

               + 1.057897 * (Change During Previous Hr)

               + 0.215503 * (Change Prior to Previous Hr)

In that earlier report, we predicted the full 24-hour diurnal emissions from vehicles that were <u>not</u> gross liquid leakers for all temperature cycles in which the hourly changes in temperatures are proportional to the cycles in Appendix A. Unfortunately, the corresponding data on the "gross liquid leakers" were limited (i.e., practically all of the tests were performed using the same temperature cycle), and we did not make similar predictions for the gross liquid leakers. However, if we apply equation **(7a)** to each hour of any temperature cycle (with the hourly changes in temperatures proportional to the cycles in Appendix A) and then add these hourly predictions together, we obtain equation **(7b)**:

Total 24-Hour Diurnal Emissions (grams) **(7b)**

$$= 40.5533 + (2.658611 * Diurnal\_Temperature\_Range)$$

Where the **Diurnal_Temperature_Range** is the difference of the daily high temperature minus the daily low temperature.

Note, equation **(7b)** predicts a 24-hour total diurnal emission of 40.48 grams for a day during which the temperatures do not change. This is not reasonable since diurnal emissions result from the daily rise in ambient temperatures. Therefore, EPA will set the 24-hour diurnal equal to zero for a diurnal temperature range of zero degrees Fahrenheit. For diurnal temperature ranges between zero and ten degrees Fahrenheit, EPA will calculate the 24-hour diurnal for gross liquid leakers as increasing linearly from zero to 67.21 grams (i.e., the value predicted by the equation for a diurnal temperature range of 10 degrees).

Of the seven regression analyses performed (and displayed in Appendix D), the simplest equation (in terms both of number of variables and complexity of the variables) is the equation that predicts the hourly diurnal emissions of gross liquid leaking vehicles. This most likely results from the simplicity of the primary mechanism that produces the emissions for the vehicles in this stratum (i.e., a significant leakage of liquid fuel).

4.2.4   Summarizing All Strata

Examining the seven stepwise regression analyses in Appendix D (one for each of the stratum identified on page 10), we note that not every possible variable described on page 13 (along with their multiplicative combinations) were found to be statistically significant in one or more of those analyses; only 11 variables and products of variables were found to be statistically significant:

◆ Delta (change) in previous hour's temperature,

◆ Delta (change) in current hour's temperature,

- ◆ Total change in temperature prior to the previous hour (i.e., temperature at the start of the previous hour minus the daily low temperature),
- ◆ Square of the delta in previous hour's temperature,
- ◆ Square of the delta in current hour's temperature,
- ◆ Product of the delta in previous hour's temperature times the total (change in temperature) prior to the previous hour,
- ◆ Product of the "midpoint vapor pressure value" (VP) times the delta in current hour's temperature,
- ◆ Product of the VP times the total change prior to the previous hour,
- ◆ Product of the VP times the square of the delta in previous hour's temperature,
- ◆ Product of the VP times the square of the delta in current hour's temperature, and
- ◆ Product of the VP times the delta in previous hour's temperature times the total prior to the previous hour.

On further examination of Appendix D, we note that some of those variables are statistically significant in most of the strata:

- ◆ The total change in temperature prior to the previous hour, possibly combined with its product (i.e., interaction) with the midpoint VP, is statistically significant in all seven strata.
- ◆ The product of the delta in previous hour's temperature times the total change in temperature prior to the previous hour, possibly combined with its product with the midpoint VP, is statistically significant in the six strata that do not include gross liquid leakers.
- ◆ The square of the delta in the previous hour's temperature, possibly combined with its product with the midpoint VP, is statistically significant in the five strata that do not include either gross liquid leakers or carbureted vehicles that failed the pressure test.
- ◆ The square of the delta in the current hour's temperature, possibly combined with its product with the midpoint VP, is statistically significant in the four strata of vehicles that failed either the pressure or the purge test but which are not gross liquid leakers.

This "universality" of the variable "total change in temperature prior to the previous hour" will be the basis for a critical assumption in estimating interrupted diurnals (in Section 5.2).

5.0   INTERRUPTED DIURNAL

Many vehicles do not actually experience a full (i.e., 24-hour) diurnal. That is, their soak is interrupted by a trip of some duration. This results in what this report refers to as an "*interrupted diurnal*." The following example illustrates such an interrupted diurnal.

5.1   Example of an Interrupted Diurnal

For the purpose of this example, we will use the type of vehicle and conditions in Figure 3-1 (i.e., a 1986-95 model year FI vehicle that passes both the purge and pressure tests, uses a 6.8 RVP fuel, and experiences a daily temperature profile of the standard 72° to 96° F cycle from Appendix A). For those conditions, we will assume the following vehicle activity:

1.   The vehicle soaks overnight and into the early morning.

2.   Shortly after 9 AM (corresponding to the fourth hour of the RTD test), the vehicle is driven for 30 minutes. The vehicle reaches its destination and is parked by 10 AM. (That is, the entire drive takes place during the fourth hour of the RTD test.)

3.   The vehicle remains parked until the following morning.

The resting loss emissions would continue throughout the entire 24-hour period of this example. However, the other types of evaporative emissions would occur for only limited periods.

1.   The first segment of this example (from 6 AM through 9 AM) corresponds to the first three hours of the RTD test. Therefore, the diurnal emissions are represented by the first three hours in Figure 3-1.

2.   The evaporative emissions associated with the morning drive are the "running loss" emissions and the continuing resting loss emissions. Thus, the running loss emissions replace the diurnal emissions for the fourth hour (from 9 AM through 10 AM). We will allocate the entire hour interval (rather than fractional intervals) to running loss emissions even if the actual drive is much shorter than one hour. (Since running loss emissions are calculated as a function of distance, rather than of time, this approach will not change the total running loss emissions. Also, since MOBILE6 will not report emissions for intervals smaller than one hour, this approach will not change the calculated emissions.) The data used for the driving (running) activity and the data use for the soak (parked) activity are both based on the same data set and are, therefore, consistent.

3.   While the vehicle was being driven, the temperature in
     its fuel tank rose by about 20 degrees Fahrenheit**.
     After the vehicle stops and until this elevated fuel
     temperature drops to become equal to the ambient air
     temperature, the vehicle will be experiencing what is
     referred to as "hot soak" emissions.

     In MOBILE5 (and MOBILE4.1), EPA determined the time
     required to stabilize the temperatures was two hours.
     Therefore, the hot soak emissions replace the diurnal
     emissions for the fifth and sixth hours (from 10 AM
     through noon). For calculation purposes, in MOBILE the
     entire hot soak emissions will be credited to the first
     hour (see reports M6.EVP.004 and M6.FLT.004). Thus, in
     this example, from 11 AM to noon, only resting losses
     will be calculated.

4.   At noon, we assume the fuel temperature has cooled to
     the ambient temperature of 93.1° F (from the
     temperature profile). The hourly diurnal emission will
     resume but in the modified form of an "interrupted
     diurnal" due to the effects of the drive on canister
     loading and fuel temperature. To modify the hourly
     diurnal emissions, we will make the following
     assumptions:

     ♦ The pressure that is driving the interrupted
       diurnal emissions (starting at noon) results from
       the fuel being heated to above the temperature
       which occurred at the end of the hot soak (in this
       example, 93.1° F). Therefore, had the ambient
       temperature not risen above 93.1° F, there would
       have been no further diurnal emissions for the
       remainder of that day, only resting loss emissions.

     ♦ This suggests that the interrupted diurnal
       emissions will end once the ambient temperature
       returns to its starting point (i.e., 93.1° F in
       this example).

     ♦ From the temperature profile, the ambient
       temperature will return to 93.1 at 5:25 PM. We
       will assume that after 6 PM, there are only resting
       loss emissions.

** In SAE Paper Number 931991 (referenced in Appendix B), the authors discuss
    the increase in tank temperatures as a function of trip duration when the
    trips are longer than 5 minutes. Table 4 of that report illustrates this
    point. A 15 minute trip would be associated (on average) with an increase
    in tank temperature of about 12 to 13 degrees Fahrenheit. A 30 minute
    trip would be associated with an increase in tank temperature of about 20
    degrees Fahrenheit, while a one hour trip would be associated with an
    increase in tank temperature of about 30 degrees Fahrenheit.

Therefore, we need to modify the estimated hourly diurnal emissions so that the modified values are zero after 6 PM (i.e., from test hour 13 through 24). In the following section (Section 5.2), EPA presents a method of modifying the hourly diurnal emissions following such an interruption to the soak period.

5.2   Calculating Emissions of an Interrupted Diurnal

Based on the discussions in the preceding sections, EPA will make the following four key assumptions in estimating interrupted diurnals:

♦ The ambient temperature at the beginning of the interrupted diurnal (i.e., the end of the hot soak) will be used as the starting temperature for that interrupted diurnal.

♦ In Section 4.2.4, we commented on the "universality" of the variable "total change in temperature prior to the previous hour." In those analyses of diurnals that were not interrupted, that variable was calculated by subtracting the daily low temperature (i.e., the starting temperature of the full day's diurnal) from the temperature at the start of the previous hour. For interrupted diurnals, EPA will replace the "daily low temperature" in that subtraction with that new starting temperature.

♦ The estimate of hourly diurnal emissions from that interrupted diurnal will be modified so that they cease once the ambient temperature drops below that new starting temperature.

♦ In reality, when a soak period is interrupted by operating a vehicle, that operation may have the effect of purging (at least partially) the vehicle's canister (see GM's SAE paper number 891121, entitled "Measured Performance under Interrupted Diurnal Conditions"). That (partial) purge of the canister (if it occurs) has the potential to improve the ability of the vehicle's evaporative control system to reduce subsequent diurnal emissions. Due to the lack of data on this phenomenon, EPA has assume that any such improvement will be minimal and can be ignored.

In the preceding paragraphs, we analyzed one theoretical situation in which the diurnal emissions (following the morning drive) resumed at noon when the ambient temperature reached 93.1°F and, then, continued until the temperatures declined to that 93.1°F (at 5:25 PM). Using the 72° to 96° F temperature cycle given in Appendix A, we can repeat those calculations for

interrupted diurnals that begin at each hour of the day. Those results appear in Table 5-1 (below).

While the starting temperatures (the second column in Table 5-1) would vary with the daily temperature cycle, the time at which each (interrupted) diurnal ends would be unchanged for any of the three temperature cycles in Appendix A or for any cycle based on those three. Table 5-1, therefore, provides the time intervals during which diurnal emissions could occur following an interruption to the soak period.

Table 5-1

Starting and Ending Times and Temperatures
For Interrupted Diurnals
For the 72° to 96° Fahrenheit Cycle

Diurnal Begins		Time Diurnal Ends
Time	**Temperature**	
Midnight thru 6 AM*	72.0°	Midnight**
7:00 AM	72.5°	Midnight**
8:00 AM	75.5°	Midnight**
9:00 AM	80.3°	10:18PM
10:00 AM	85.2°	8:06PM
11:00 AM	89.4°	6:44PM
Noon	93.1°	5:25PM
1:00 PM	95.1°	4:17PM
2:00 PM	95.8°	3:24PM
3 PM thru Midnight	N/A***	N/A***

Therefore, EPA modified the predicted hourly emissions of full day's diurnals (from equations **(1)** through **(7)**) using the following four-step process:

_____

* In Section 4.2.1, it was noted that diurnal emissions are zero for hours 19 through 24 (i.e., midnight through 6AM). Thus, any diurnal that begins between midnight and 6AM effectively begins at 6AM, and that diurnal is actually a full 24-hour diurnal.

** In the previous footnote, it was noted that diurnal emissions are zero after midnight. Thus, even if the ambient temperature has not returned to the temperature at which the (interrupted) diurnal began, the diurnal effectively ends by the following midnight.

*** Any interrupted diurnal that begins while the ambient temperatures are declining (i.e., 3 PM or later) does not exist (has zero emissions).

1.)   In each of the seven regression equations (in Sections
        4.2.1 through 4.2.3), the variable "**Change Prior to Previous Hr**"
        appears. For an interrupted diurnal, that variable is
        calculated by subtracting the temperature at the start
        of the interrupted diurnal from the temperature at the
        beginning of the previous hour. This step will produce
        an estimate of the percent of the full day's diurnal
        occurring each hour of the interrupted diurnal.

2.)   Those hourly percentages would then be modified so that
        any negative estimates would be changed to zero, and
        any estimates for hours beyond the "**Time Diurnal Ends**"
        column in Table 5-1 would be replaced by zero.

3.)   The total 24-hour diurnal emissions are then predicted
        using the regression equations from Appendix C.

4.)   Finally, the hourly (interrupted) diurnal emissions are
        estimated by multiplying the predicted full 24-hour
        diurnal emissions by the individual hourly percentages.

To illustrate the use of this four-step process, we return
to the example in Section 5.1.

♦ Both Table 5-1 and the discussion at the end of Section
  5.1 indicate that the interrupted diurnal emissions would
  begin at noon and continue until 6 PM. For each of those
  six hours, we can use Appendix A to construct a table of
  hourly temperatures and changes in temperatures. (We will
  assume that the changes in temperature prior to noon are
  zero.) Those temperature values are given in Table 5-2 on
  the following page.

♦ Using the changes in temperature in Table 5-2 we use
  equation **(4)** (to estimate hourly emissions from FI
  vehicles that pass both the pressure and purge tests) to
  calculate the estimated percentages of the full 24-hour
  diurnal emissions that occur each hour of this interrupted
  diurnal. Those hourly fractions are given (as
  percentages) in the seventh column of Table 5-2.

♦ For the purpose of that example, we assumed a 1986-95
  model year, FI vehicle that passed both the purge and
  pressure tests, that used a 6.8 RVP fuel, and where the
  daily temperature profile was the standard 72° to 96° F
  cycle from Appendix A. The equation in Appendix C
  predicts the full 24-hour diurnal in this case would be
  2.55 grams (per day).

♦ Multiplying the predicted full 24-hour diurnal (2.55
  grams) emissions by the six hourly percentages then
  produces the estimated hourly emissions (in grams) which

appear as the eighth column of Table 5-2. (The negative
value for the second hour is then rounded up to zero.)

Table 5-2

Example of Calculating Hourly Diurnal Emissions
From an Interrupted Diurnal

Time Of Day	Initial Temp (°F)	Final Temp (°F)	Change in Previous Hr Temp	Change in Current Hr Temp	Change Prior to Previous	Hourly Diurnal (pct)	Hourly Diurnal (grams)
Noon - 1PM	93.1	95.1	0	2.0	0	0.80%	0.020
1PM - 2PM	95.1	95.8	2.0	0.7	0.0	-0.06%	0.000
2PM - 3PM	95.8	96.0	0.7	0.2	2.0	1.16%	0.030
3PM - 4PM	96.0	95.5	0.2	-0.5	2.7	1.35%	0.034
4PM - 5PM	95.5	94.1	-0.5	-1.4	2.9	1.23%	0.031
5PM - 6PM	94.1	91.7	-1.4	-2.4	2.4	0.66%	0.017

EPA believes that while this approach is not perfect (as
evidenced by the prediction of negative emissions during the
second hour that needed to be rounded up to zero), it does
provide a reasonable estimate of hourly diurnal emissions during
an interrupted diurnal; therefore, EPA uses this method in
MOBILE6.

For MOBILE6 to actually use estimates of interrupted diurnal
emissions, it is obvious that for each hour of the day (or for at
least the 18 hours between 6 AM and midnight) we must know the
percent of the fleet that has been soaking for "n" hours (n = 1,
2, 3, . . . , 72). The analysis that yields this distribution of
fleet activity can be found in report number M6.FLT.006 (entitled
"Soak Length Activity Factors for Diurnal Emissions").

6.0   ASSUMPTIONS RELATED TO HOURLY EMISSIONS

Several basic assumptions related to estimating hourly
emissions were made in this analysis due to the lack of test
data.

6.1   Distribution of Hourly Diurnal Emissions

In Section 4, the key assumption is that once the hourly
diurnal emissions are divided by the full 24-hour diurnal
emissions, the distribution (within each of the seven strata
identified on page 10) of those fractions is a function of the
temperature change variables and the midpoint VP.

As a direct result of that assumption, the hourly diurnal
emissions (in grams) can be predicted by simply multiplying the

estimated full 24-hour diurnal emissions (from Appendix C) by the fractions calculated in Section 4.2. EPA will use those products as estimates of the diurnal emission from each individual hour.

6.2   Assumptions for Interrupted Diurnals

The discussion of interrupted diurnals (in Sections 5.1 and 5.2) requires a number of assumptions. Four of these assumptions are stated at the beginning of Section 5.2.

The fifth assumption deals with estimating how much time must elapse following the driving cycle for the diurnal to resume. It is an accepted fact that interrupting the diurnal with a trip will result in a temporary increase in fuel tank temperature. The time required after the trip for the fuel temperature to return to (i.e., achieve equilibrium with) the ambient temperature depends on many factors (e.g., duration of the trip, fuel delivery system, fuel tank design, fuel tank materials, air flow, etc.). However, EPA will continue the approach used since MOBILE4.1 of assuming that exactly two hours is necessary to stabilize the temperatures. (Also, this approach of rounding off the vehicle activity periods to whole hours is also consistent with the vehicle activity data that will be used in MOBILE6.)

6.3   Temperature Ranges

All of the tests used in this analysis were performed using one of the three temperature cycles in Appendix A. Thus, all of the resting loss data were measured at only three temperatures (i.e., 60, 72, and 82 °F). In Appendix F, we present regression equations (developed in M6.EVP.001) to estimate hourly resting loss emissions at any temperature. We will limit that potentially infinite temperature range as we did in the previous version of MOBILE, specifically:

1) We will assume, for vehicles other than gross liquid leakers, there are no resting loss emissions when the temperatures are below or equal to 40°F. (This assumption was used consistently for all evaporative emissions in MOBILE5.)

    For temperatures between 40°F and 50°F, EPA will interpolate between an hourly resting loss of zero and the value predicted in Appendix F for 50°F.

2) We will assume, for vehicles other than gross liquid leakers, that when the ambient temperatures are above 105°F that the resting loss emissions are the same as those calculated at 105°F.

Since vehicles classified as gross liquid leakers were not handled separately in MOBILE5, we will now make a new assumption concerning the resting loss emissions of those vehicles as relates to temperatures. Specifically:

3) For the vehicles classified as gross liquid leakers, we will assume the resting loss emissions are completely independent of temperature, averaging 9.16 grams per hour. (from report number M6.EVP.009, entitled "Evaporative Emissions of Gross Liquid Leakers in MOBILE6").

In a similar fashion, the equations developed in this report to estimate hourly diurnal emissions theoretically could also be applied to any temperature cycle. EPA will limit those functions by making the following assumptions:

1) Regardless of the increase in ambient temperatures, there are no diurnal emissions until the temperature exceeds 40°F. (This assumption was used consistently for all evaporative emissions in MOBILE5.)

   For a temperature cycle in which the daily low temperature is below 40°F, EPA will calculate the diurnal emissions for that day as an interrupted diurnal that begins when the ambient temperature reaches 40 °F.

2) The 24-hour diurnal emissions will be zero for any temperature cycle in which the difference between the daily high and low temperatures (i.e., the "diurnal temperature range") is no more than zero degrees Fahrenheit. For temperature cycles in which the diurnal temperature range is between zero and ten degrees Fahrenheit, the 24-hour diurnal emissions will be the linear interpolation of the predicted value for the ten-degree cycle and zero.

6.4   Estimating Vapor Pressure

EPA will use the RVP of the fuel and the Clausius-Clapeyron relationship to calculate the vapor pressure of the fuel at each ambient temperature (see Figure B-1). This approach is the equivalent of attempting to draw a straight line based on only a single point since RVP is the vapor pressure calculated at a single temperature (100° F). Since two different fuels could have the same vapor pressure at a single temperature, it is possible for two fuels to have the same RVP but different relationships between the vapor pressure and the temperature. However, the two vapor pressure curves would yield similar results near the point where they coincide (i.e., at 100° F). Thus, at temperatures where ozone exceedences are likely to occur, this assumption (i.e., using Appendix B to estimate vapor pressure) should produce reasonable estimates of diurnal emissions.

6.5   Duration of Diurnal Soak Period

The analyses in this report were based on diurnals of 24 hours or less in length. In the real-world, vehicles could soak for longer periods of time. Estimating diurnal emissions when the soak period is a multiple of 24 hours are analyzed in report M6.EVP.003. For the purpose of this analysis, a full 24-hour diurnal takes place between 6 AM and 6 AM of the following day (with hourly diurnal emissions of zero between midnight and 6 AM). If a diurnal period extends beyond 6 AM, then the emissions during the hours beyond 6 AM will be calculated using equations **(1)** through **(7)** (in Sections 4.2.1 through 4.2.3).

EPA's approach of classifying a diurnal that follows a diurnal of less than 24 hours is based on EPA's hypothesis of why a single-day diurnal is different from a multiple-day diurnal. EPA believes that as the time progresses (during a multiple day diurnal), the vehicle's evaporative canister becomes more heavily loaded (with possible back purge occurring during the night hours). Therefore, if the first day's interrupted diurnal is almost equivalent to a full 24-hour diurnal, EPA will treat the subsequent days as if the first day's diurnal were a complete (i.e., a full-day) diurnal.

To determine the meaning of an interrupted diurnal being "almost equivalent" to a full 24-hour diurnal, we applied the equations **(1)** through **(6)** to various combinations of fuel RVP, temperature cycle, and starting time of an interrupted diurnal. This analysis determined that:

- ◆ Interrupted diurnals that began at 10 AM (i.e., the start of the fourth hour of the RTD test) exhibited only about one-third of the emissions of the full 24-hour diurnal.

- ◆ Interrupted diurnals that began at 9 AM (i.e., the start of the third hour of the RTD test) exhibited only about one-half of the emissions of the full 24-hour diurnal.

- ◆ Interrupted diurnals that began no later than 8 AM (i.e., at least by the start of the second hour of the RTD test) exhibited at least 80 percent of the emissions of the full 24-hour diurnal.

Based on these observations, if a vehicle's first day's incomplete (i.e., interrupted) diurnal begins no later than 8 AM, EPA will treat the subsequent days as if the first day's diurnal were a complete diurnal. Otherwise, we treat the subsequent day as the first day of the diurnal.

7.0   CONCLUSIONS

The conclusions (and assumptions) that EPA drew from this analysis and then incorporated into MOBILE6 are:

1) For the purpose of analyzing characteristics of hourly diurnal emissions, the in-use fleet can be divided into the following seven strata:

   ♦   the vehicles classified as "gross liquid leakers,"
   ♦   carbureted vehicles (**not** "gross liquid leakers") that pass both the purge and pressure tests,
   ♦   carbureted vehicles (**not** "gross liquid leakers") that fail the pressure test,
   ♦   carbureted vehicles (**not** "gross liquid leakers") that fail <u>only</u> the purge test,
   ♦   FI vehicles (**not** "gross liquid leakers") that pass both the purge and pressure tests,
   ♦   FI vehicles (**not** "gross liquid leakers") that fail the pressure test, and
   ♦   FI vehicles (**not** "gross liquid leakers") that fail <u>only</u> the purge test.

2) The full-day's diurnal emissions (for each of the preceding seven strata) can be distributed over 18 hours (from 6AM through midnight) using equations **(1)** through **(7)** (in Sections 4.2.1 through 4.2.3).

3) For emissions produced over an interrupted diurnal (in which "key-off" occurs after 4AM), those same equations can be used with the substitution of the "new starting temperature" (i.e., two hours after engine shut-off) in place of "daily low temperature."

Appendix A

Temperature Cycles (°F)

	Temperatures Cycling Between			Change in Previous Hr Temp (°F)	Change in Current Hr Temp (°F)	Change Prior to Previous Hr
Hour	60-84°F	72-96°F*	82-106°F			
0	60.0	72.0	82.0	---	---	---
1	60.5	72.5	82.5	0.0	0.5	0.0
2	63.5	75.5	85.5	0.5	3.0	0.5
3	68.3	80.3	90.3	3.0	4.8	3.5
4	73.2	85.2	95.2	4.8	4.9	8.3
5	77.4	89.4	99.4	4.9	4.2	13.2
6	81.1	93.1	103.1	4.2	3.7	17.4
7	83.1	95.1	105.1	3.7	2.0	21.1
8	83.8	95.8	105.8	2.0	0.7	23.1
9	84.0	96.0	106.0	0.7	0.2	23.8
10	83.5	95.5	105.5	0.2	-0.5	24.0
11	82.1	94.1	104.1	-0.5	-1.4	23.5
12	79.7	91.7	101.7	-1.4	-2.4	22.1
13	76.6	88.6	98.6	-2.4	-3.1	19.7
14	73.5	85.5	95.5	-3.1	-3.1	16.6
15	70.8	82.8	92.8	-3.1	-2.7	13.5
16	68.9	80.9	90.9	-2.7	-1.9	10.8
17	67.0	79.0	89.0	-1.9	-1.9	8.9
18	65.2	77.2	87.2	-1.9	-1.8	7.0
19	63.8	75.8	85.8	-1.8	-1.4	5.2
20	62.7	74.7	84.7	-1.4	-1.1	3.8
21	61.9	73.9	83.9	-1.1	-0.8	2.7
22	61.3	73.3	83.3	-0.8	-0.6	1.9
23	60.6	72.6	82.6	-0.6	-0.7	1.3
24	60.0	72.0	82.0	-0.7	-0.6	0.6

* The temperature versus time values for the 72-to-96 cycle are reproduced from Table 1 of Appendix II of **40 CFR 86**.

These three temperature cycles are parallel (i.e., identical hourly increases/decreases). The temperatures peak at hour nine. The most rapid increase in temperatures occurs during the fourth hour (i.e., a 4.9° F rise).

For cycles in excess of 24 hours, the pattern is repeated.

Appendix B

Vapor Pressure

Using the Clausius-Clapeyron Relationship

The Clausius-Clapeyron relationship assumes that the logarithm of the vapor pressure is a linear function of the reciprocal (absolute) temperature. This relationship is a reasonable estimate of vapor pressure (VP) over the moderate temperature ranges[*] (i.e., 60° to 106°F) that are being considered for adjusting the diurnal emissions.

In an earlier EPA work assignment, test fuels having RVPs similar to those used in EPA's RTD work assignments were tested, and their vapor pressures (in kilo Pascals) at three different temperatures were measured. The results of those measurements are given below in the following table:

Nominal RVP	Measured RVP	Vapor Pressure (kPa)		
		75° F	100° F**	130° F
7.0	7.1	30.7	49.3	80.3
9.0	8.7	38.2	60.1	96.5

** The VPs at 100° F are the fuel RVPs (in kilo Pascals).

Plotting these six vapor pressures (using a logarithm scale for the vapor pressure) yields the graph (Figure B-1) on the following page.

For each of those two RVP fuels, the Clausius-Clapeyron relationship estimates that, for temperature in degrees Kelvin, the vapor pressure (VP) in kPa will be:

Ln(VP) = A + (B / Absolute Temperature), where:

RVP	A	B
8.7	13.5791	-2950.47
7.1	13.7338	-3060.95

———————————————————————

[*] C. Lindhjem and D. Korotney, "Running Loss Emissions from Gasoline-Fueled Motor Vehicles", SAE Paper 931991, 1993.

Figure B-1

Comparison of Vapor Pressure (in kPa) to Reciprocal of Absolute Temperature

Reciprocal of Temp (1/°K)
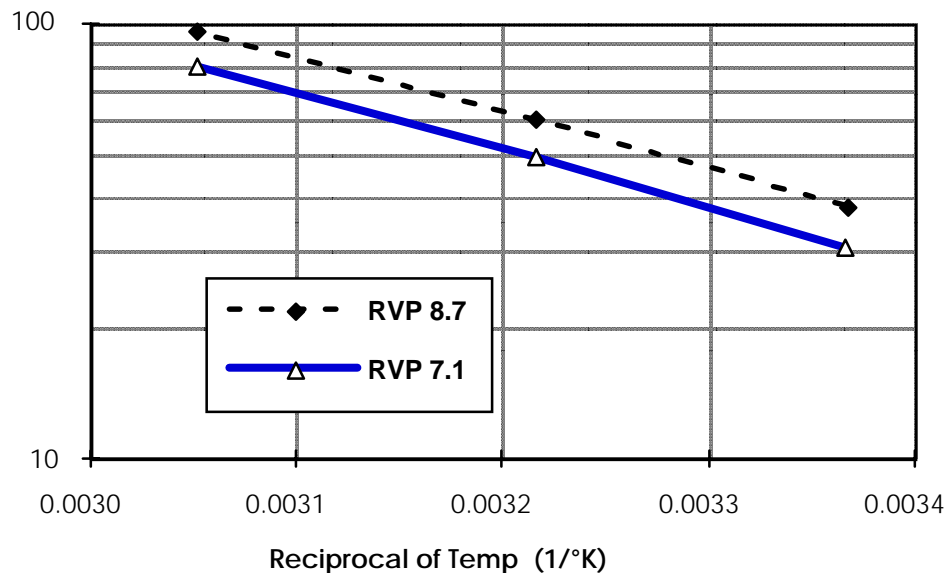
Since MOBILE6 will estimate diurnal emissions by using the vapor pressure of the typical (local) fuel at two temperatures (the daily low and high temperatures), we need to create a similar VP curve for any local fuel. Since that curve is a straight line (in log-space), all we need is the vapor pressure of the local fuel measured at two different temperatures. (That is, two points determine a straight line.) Unfortunately, **ALL** we usually have available is the Reid vapor pressure (RVP) which is the VP at 100 degrees Fahrenheit. To obtain a second point (to determine the VP curve), EPA will use the preceding graph (Figure B-1). In that graph the two lines are not parallel, they intersect at a point. (That point of intersection has meaning only in a mathematical context. In an engineering context, both the temperature (825.8 °F) and VP (12,679 kPA) at the point of intersection are so high as to be meaningless. This point could correspond to the "point at infinity" in perspective drawings.)

Combining the reported VP of the fuel at 100 degrees Fahrenheit (i.e., RVP) with this artificial VP value at 825.8 degrees Fahrenheit, we obtain the linear equation:

$$Ln(VP) = A + (B / \text{Absolute Temperature}), \text{ where:}$$
$$B = -3565.2707 + (70.5114 * RVP)$$
$$\text{and}$$
$$A = Ln(6.89286 * RVP) - (B / 310.9)$$

     Despite the artificial nature of that second point, this
equation accurately predicts the vapor pressure (in kPa) of the
two test fuels (in Figure B-1) as well as producing reasonable
estimates for the range of fuels and temperatures that are
modeled in MOBILE6. Therefore, EPA will use this equation to
estimate the values of VP (that are used as an intermediate step
in MOBILE6) to predict the hourly and full-day diurnal emissions.

Appendix C

Modeling 24-Hour Diurnal Emissions
As Functions of Vapor Pressure (kPa) and RVP (psi)

(Reproduced from M6.EVP.001)

In each of the following 18 strata, 24-hour diurnal emissions are modeled using four constants:

A ,B, C, D.   Where,

24-Hour Diurnal (grams) =

$$= A$$
$$+ B * RVP \text{ (in psi)}$$
$$+ C * [(Mean\ VP) * (Change\ in\ VP)]$$
$$+ D * [(Mean\ VP) * (Change\ in\ VP)]^2 / 1{,}000$$

For each of the 9 strata, the four constants used to model diurnal emissions are given below in the following table. Within each cell of this table, the four constants are listed vertically (i.e., with "A" at the top and "D" at the bottom).

Fuel Delivery	Model Year Range	Fail Pressure Test	Fail Only Purge Test	Pass Both Purge and Pressure
Carbureted	1972-79*	-0.29374	21.94883	21.13354
		-0.62160	-2.23907	-2.42617
		0.039905	0	0
		0	0.02990	0.024053
	1980-1985	-1.22213	16.69934	15.50536
		-0.62160	-2.23907	-2.42617
		0.039905	0	0
		0	0.02990	0.024053
	1986-1995**	18.97709	13.90647	8.37118
		-1.81237	-2.14898	-0.767027
		0	0.021368	0
		0.017098	0	0.005934

*   The **B**, **C**, and **D** values are based on 1980-85 carbureted vehicles.

**   The **B**, **C**, and **D** values are based on 1986-95 FI vehicles.

Appendix C (Continued)

Modeling 24-Hour Diurnal Emissions
As Functions of Vapor Pressure (kPa) and RVP (psi)

(Reproduced from M6.EVP.001)

In each of the following 18 strata, 24-hour diurnal emissions are modeled using four constants:

A ,B, C, D.   Where,

24-Hour Diurnal (grams) =

= A

+ B * RVP (in psi)

+ C * [(Mean VP) * (Change in VP)]

+ D * [(Mean VP) * (Change in VP)]^2 / 1,000

Fuel Delivery	Model Year Range	Fail Pressure Test	Fail Only Purge Test	Pass Both Purge and Pressure
Fuel-Injected	1972-79*	-0.29374	21.94883	21.13354
		-0.62160	-2.23907	-2.42617
		0.039905	0	0
		0	0.02990	0.024053
	1980-1985	7.11253	7.48130	5.62111
		-1.25128	-0.701002	-0.701002
		0.036373	0	0
		0	0.010466	0.010466
	1986-1995	14.19286	9.93656	5.85926
		-1.81237	-2.14898	-0.767027
		0	0.021368	0
		0.017098	0	0.005934

* The three untested strata of Pre-1980 FI vehicles were
represented using the Pre-1980 model year carbureted
vehicles (which were themselves based on the 1980-85 model
year carbureted vehicles).

Appendix D

Using Linear Regressions to Model Ratios of Hourly Diurnal Emissions

For <u>each</u> of the seven strata identified in Section 4.1 (pages 10 and 11), this appendix presents a two-page format that includes:

- ♦ the table of statistics produced by the regression described in Section 4.2,

- ♦ a scatter plot comparing the averaged (actual) hourly fractions with the corresponding values generated using the regression (note that the solid lines are not regression lines, they are "unity lines" indicating where perfect correlation would exist),

- ♦ a combination bar and line chart comparing the actual (averaged) hourly fractions with the predicted values for the <u>single</u> temperature cycle / RVP combination at which most of the vehicles in the stratum were tested (i.e., the 72 to 96 degree cycle using fuel with an RVP of 6.8 psi), and

- ♦ a combination bar and line chart comparing the actual (averaged) hourly fractions with the predicted values for a typical summer cycle (i.e., the 82 to 106 degree cycle using fuel with an RVP of 6.8 psi).

Note that for the seventh stratum (i.e., vehicles with gross liquid leaks of gasoline), all three temperature cycles (in Appendix A) and all fuel RVPs were assumed to produce the same diurnal emissions. Therefore, only a single combination bar and line chart graph is given.

Appendix D (continued)

Regression of Ratio of Mean Hourly Diurnal Emission Fractions
Carbureted Vehicles Passing Both Purge and Pressure Tests

Dependent variable is: **Ratio of Hourly Diurnal**
No Selector

R squared = 91.6%   R squared (adjusted) = 91.4%
s = 0.0146 with 114 - 4 = 110 degrees of freedom

Source	Sum of Squares	Df	Mean Square	F-ratio
Regression	0.257692	3	0.085897	400
Residual	0.023597	110	0.000215	

| Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	0.007032	0.0033	2.15	0.0336
VP * Previous * Total Prior to Previous	0.000023	0.0000	23.1	≤ 0.0001
Total Prior to Previous	0.003586	0.0002	20.7	≤ 0.0001
Sqr_Delta Previous	-0.001111	0.0002	-5.01	≤ 0.0001

Plotting Predicted versus Actual Hourly Ratios
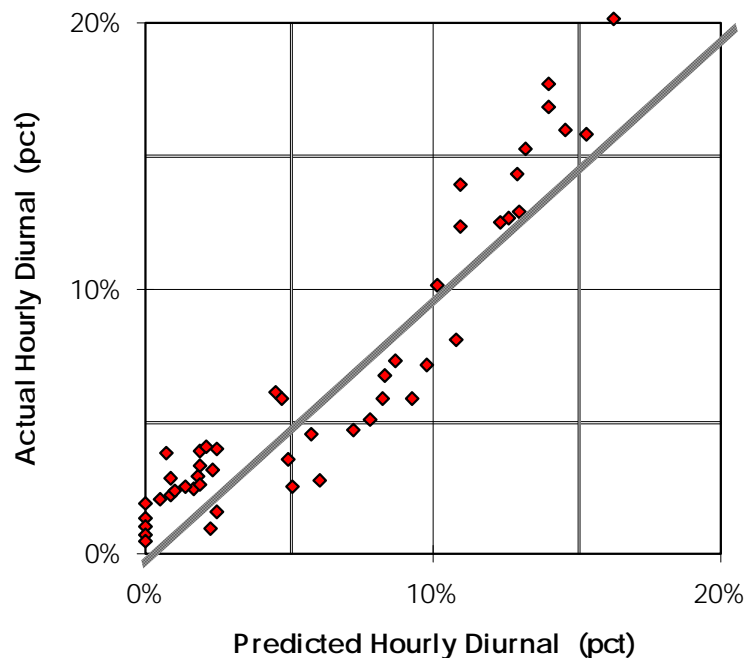
Appendix D (continued)

**Sample Comparison of Averaged Hourly Diurnal Emission Fractions v. Predicted
For Carbureted Vehicles Passing Both Purge and Pressure Tests**

Over 72-96 Degree Temperature Cycle -- Using 6.8 RVP Fuel
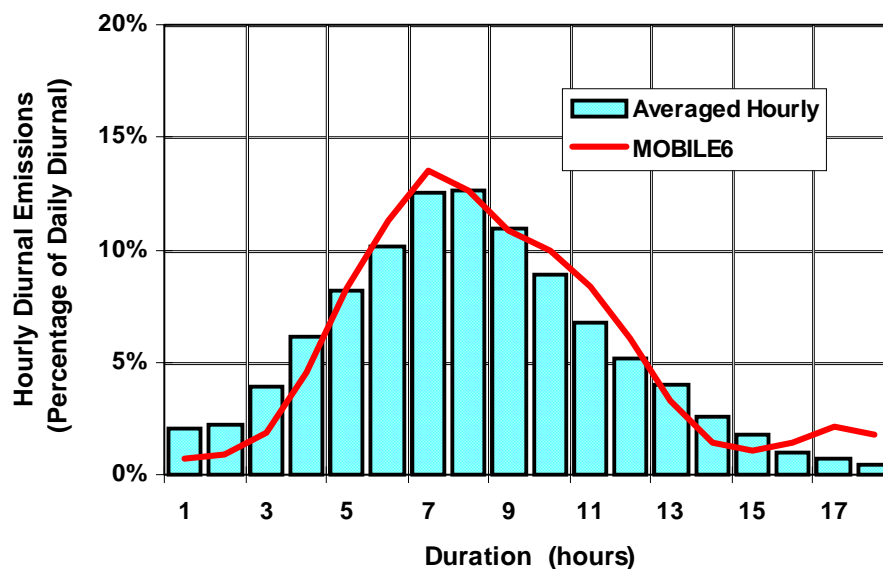
Over 82-106 Degree Temperature Cycle -- Using 6.8 RVP Fuel
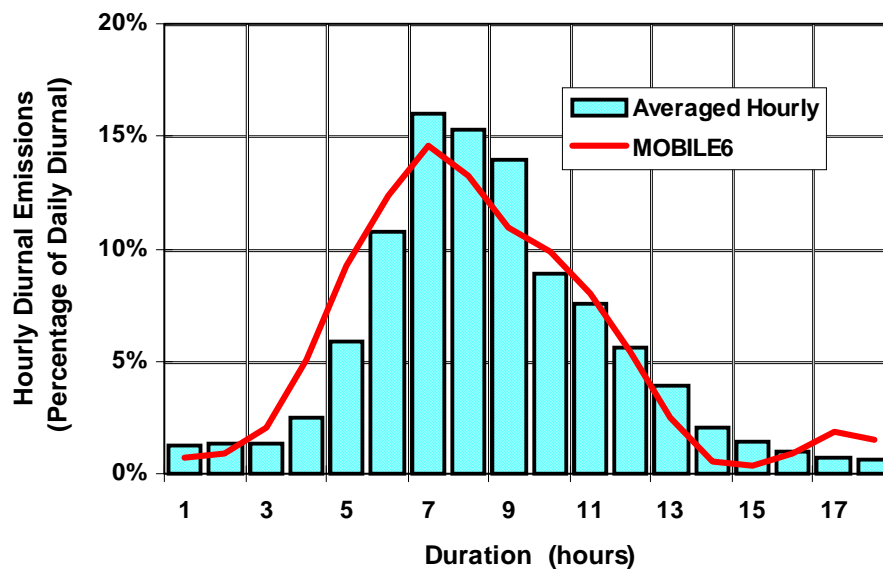
Appendix D (continued)

Regression of Ratio of Mean Hourly Diurnal Emission Fractions
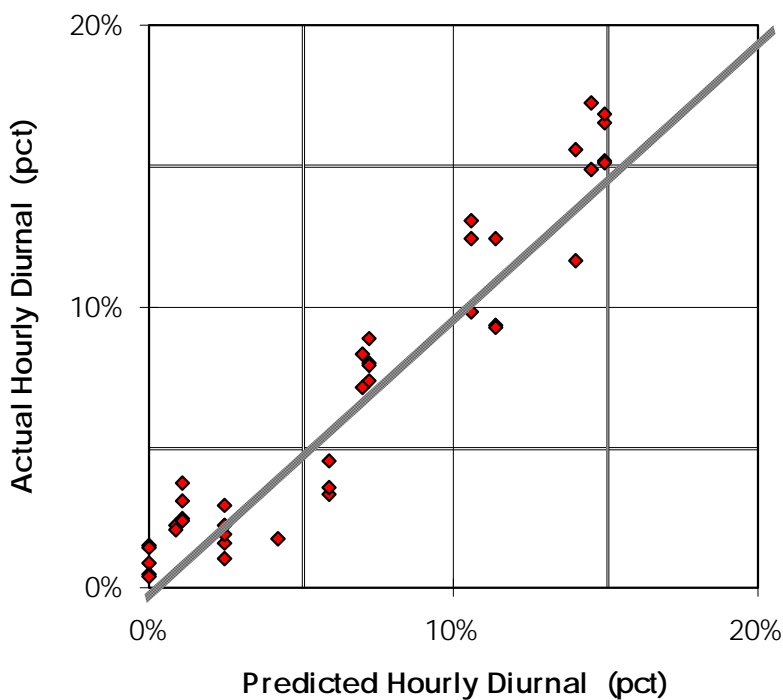### Carbureted Vehicles Failing the Pressure Test

Dependent variable is: **Ratio of Hourly Diurnal**
No Selector

R squared = 95.1%   R squared (adjusted) = 95.0%
s = 0.0119 with 114 - 4 = 110 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.300208	3	0.100069	710
Residual	0.015505	110	0.000141	

| Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	0.010549	0.0029	3.60	0.0005
Previous * Total Prior to Previous	0.001138	0.0000	37.4	$\leq$ 0.0001
Total Prior to Previous	0.001758	0.0001	11.8	$\leq$ 0.0001
Sqr_Delta Current	0.001765	0.0002	10.4	$\leq$ 0.0001

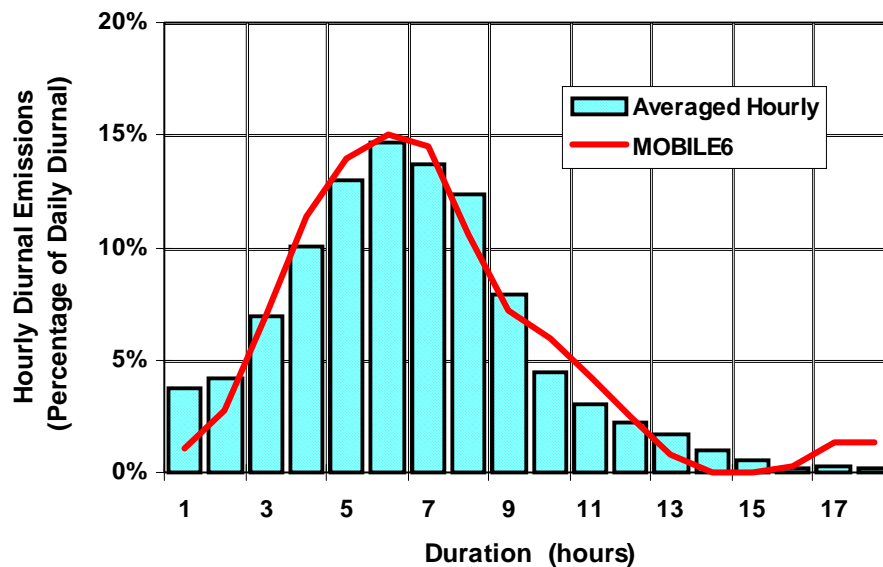### Plotting Predicted versus Actual Hourly Ratios

Appendix D (continued)

**Sample Comparison of Averaged Hourly Diurnal Emission Fractions v. Predicted
For Carbureted Vehicles Failing the Pressure Test**

Over 72-96 Degree Temperature Cycle -- Using 6.8 RVP Fuel
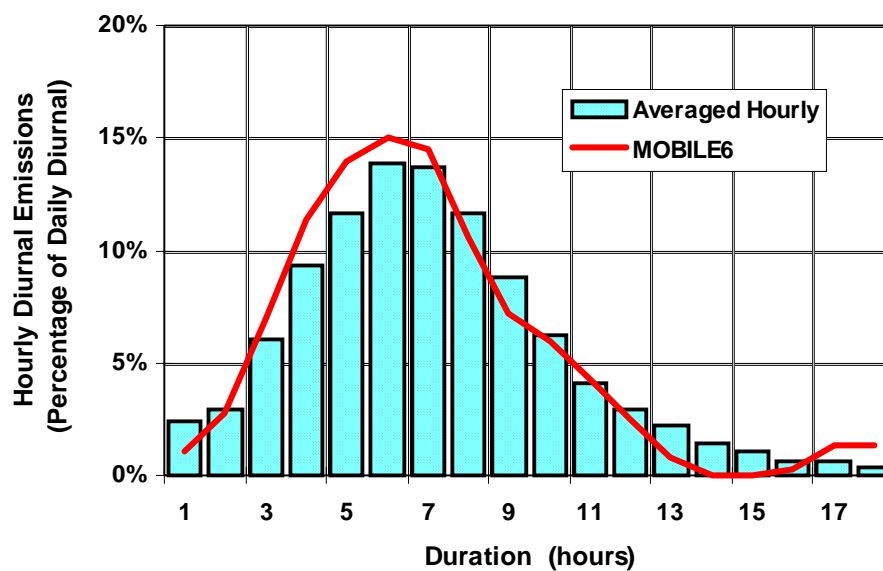
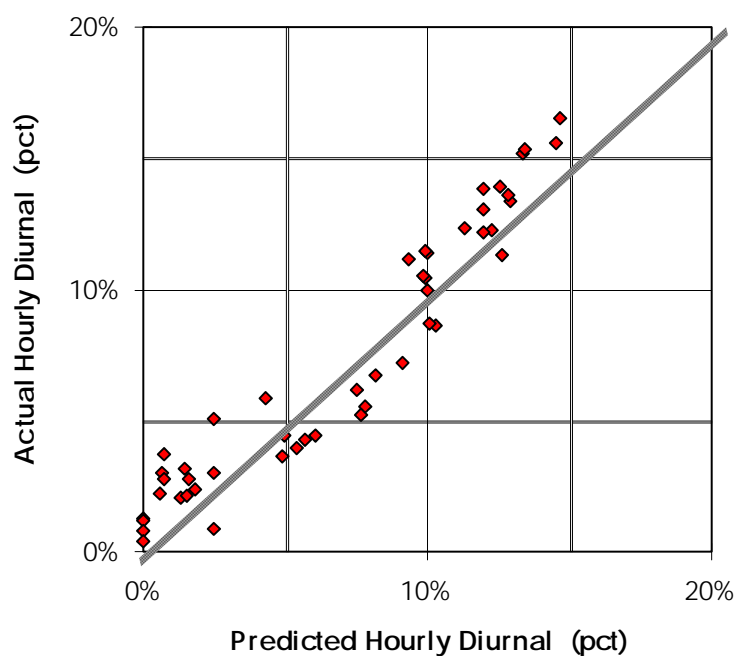**Over 82-106 Degree Temperature Cycle -- Using 6.8 RVP Fuel**

Appendix D (continued)

Regression of Ratio of Mean Hourly Diurnal Emission Fractions
Carbureted Vehicles Failing ONLY the Purge Test

Dependent variable is: **Ratio of Hourly Diurnal**
No Selector

R squared = 93.5%   R squared (adjusted) = 93.1%
s = 0.0124 with 114 - 6 = 108 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.236796	5	0.047359	308
Residual	0.01659	108	0.000154	

| Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	0.006724	0.0030	2.23	0.0276
VP * Previous * Total Prior to Previous	0.000023	0.0000	27.1	$\leq$ 0.0001
Total Prior to Previous	0.003966	0.0004	10.1	$\leq$ 0.0001
Sqr_Delta Previous	-0.001122	0.0003	-4.05	$\leq$ 0.0001
VP * Sqr_Delta Current	0.000019	0.0000	3.14	0.0022
VP * Tot Prior to Previous	-0.000018	0.0000	-2.24	0.0272

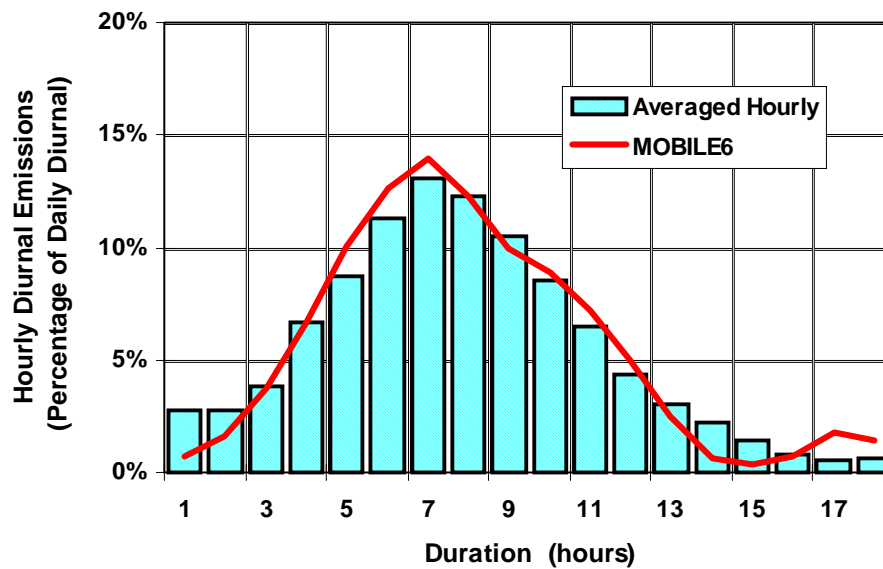### Plotting Predicted versus Actual Hourly Ratios

Appendix D (continued)

**Sample Comparison of Averaged Hourly Diurnal Emission Fractions v. Predicted
For Carbureted Vehicles Failing ONLY the Purge Test**

Over 72-96 Degree Temperature Cycle -- Using 6.8 RVP Fuel
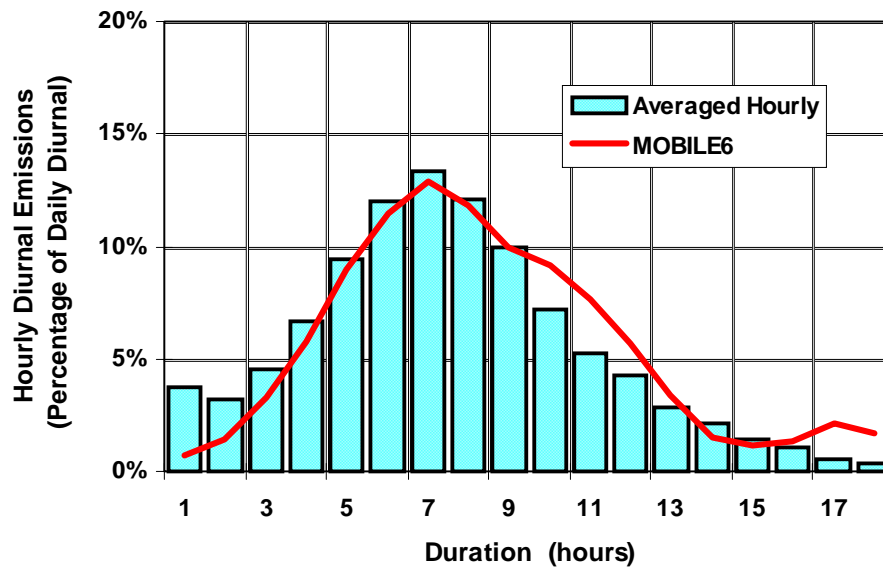
Over 82-106 Degree Temperature Cycle -- Using 6.8 RVP Fuel

Appendix D (continued)

Regression of Ratio of Mean Hourly Diurnal Emission Fractions
FI Vehicles Passing Both Purge and Pressure Tests

Dependent variable is: **Ratio of Hourly Diurnal**
No Selector

R squared = 85.2%   R squared (adjusted) = 84.5%
s = 0.0188 with 114 - 6 = 108 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.220626	5	0.044125	124
Residual	0.03832	108	0.000355	

| Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	0.008001	0.0046	1.75	0.0834
Total Prior to Previous	0.001961	0.0006	3.33	0.0012
Previous * Total Prior to Previous	0.000535	0.0000	5.61	$\leq$ 0.0001
VP * Sqr_Delta Previous	-0.000060	0.0000	-8.75	$\leq$ 0.0001
Delta Current	0.005964	0.0015	4.11	$\leq$ 0.0001
VP * Tot Prior to Previous	0.000056	0.0000	4.47	$\leq$ 0.0001

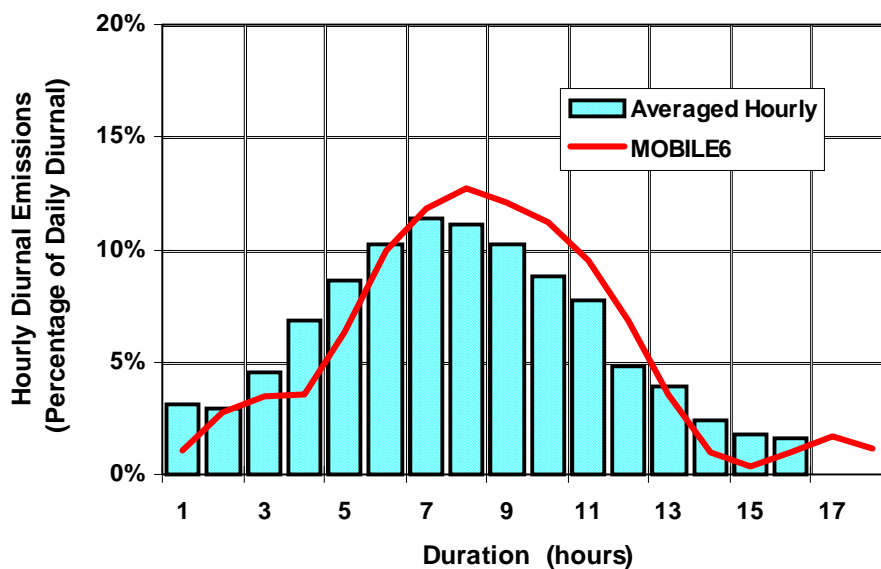## Plotting Predicted versus Actual Hourly Ratios
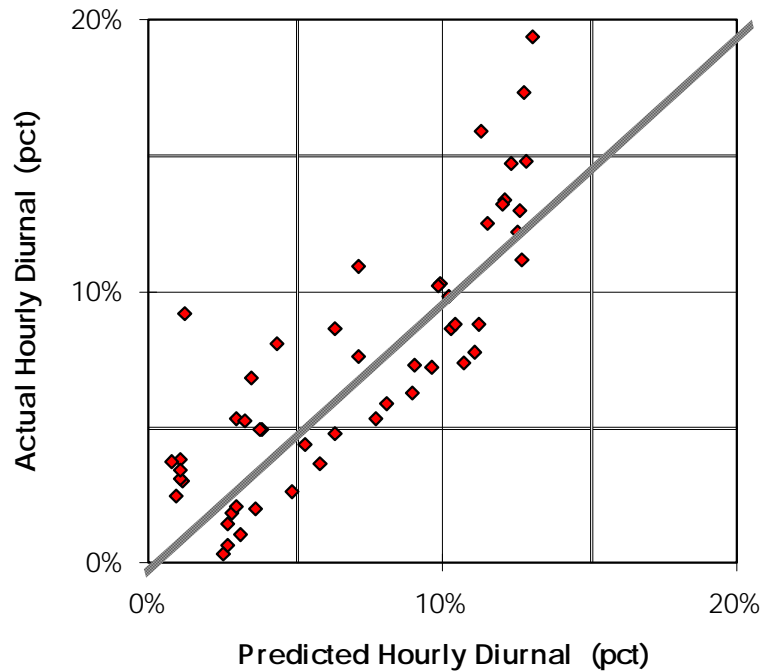
Appendix D (continued)

**Sample Comparison of Averaged Hourly Diurnal Emission Fractions v. Predicted
For FI Vehicles Passing Both Purge and Pressure Tests**

Over 72-96 Degree Temperature Cycle -- Using 6.8 RVP Fuel
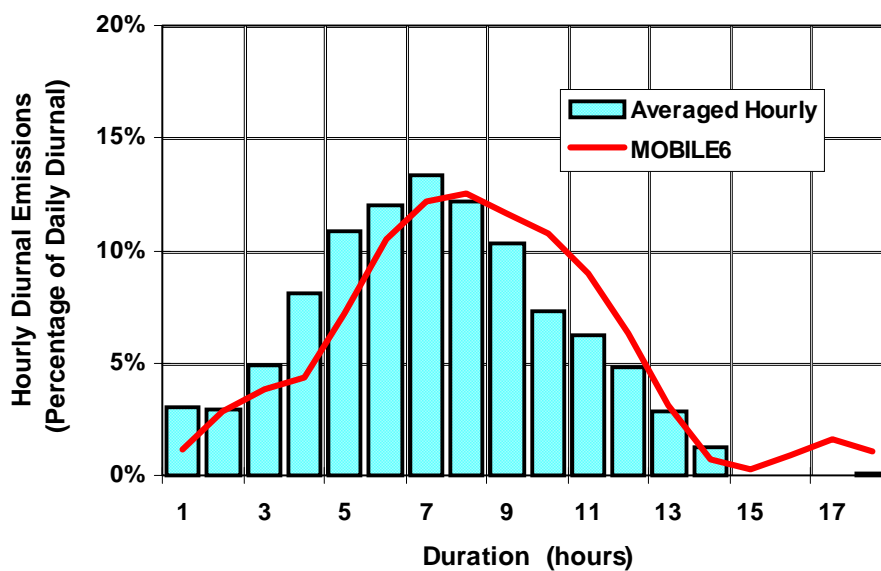
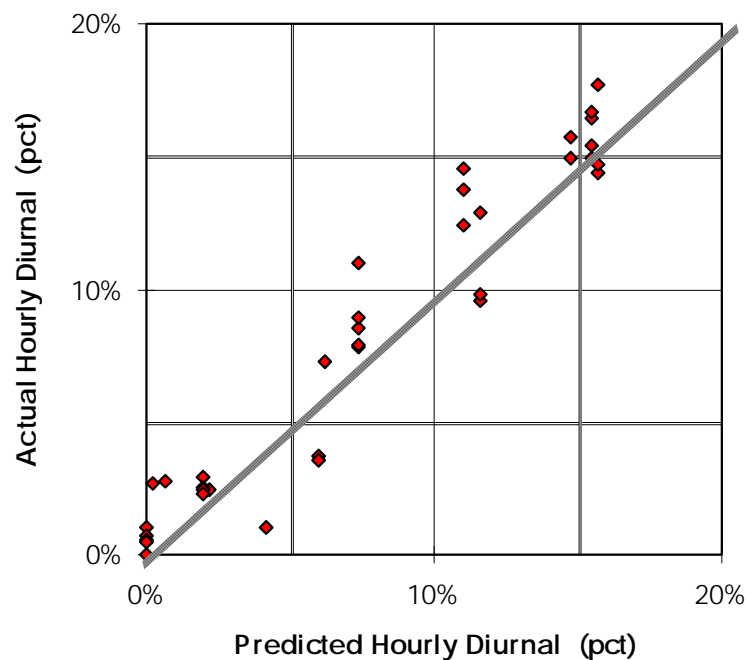**Over 82-106 Degree Temperature Cycle -- Using 6.8 RVP Fuel**

Appendix D (continued)

**Regression of Ratio of Mean Hourly Diurnal Emission Fractions
FI Vehicles Failing the Pressure Test**

Dependent variable is: **Ratio of Hourly Diurnal**
No Selector

R squared = 95.9%   R squared (adjusted) = 95.7%
s = 0.0118 with 114 - 5 = 109 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.350423	4	0.087606	634
Residual	0.015068	109	0.000138	

| Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	0.006515	0.0029	2.25	0.0267
Previous * Total Prior to Previous	0.001194	0.0000	33.9	≤ 0.0001
Total Prior to Previous	0.001963	0.0002	12.9	≤ 0.0001
Sqr_Delta Current	0.001329	0.0003	5.04	≤ 0.0001
Sqr_Delta Previous	0.000574	0.0003	2.03	0.0449

Plotting Predicted versus Actual Hourly Ratios

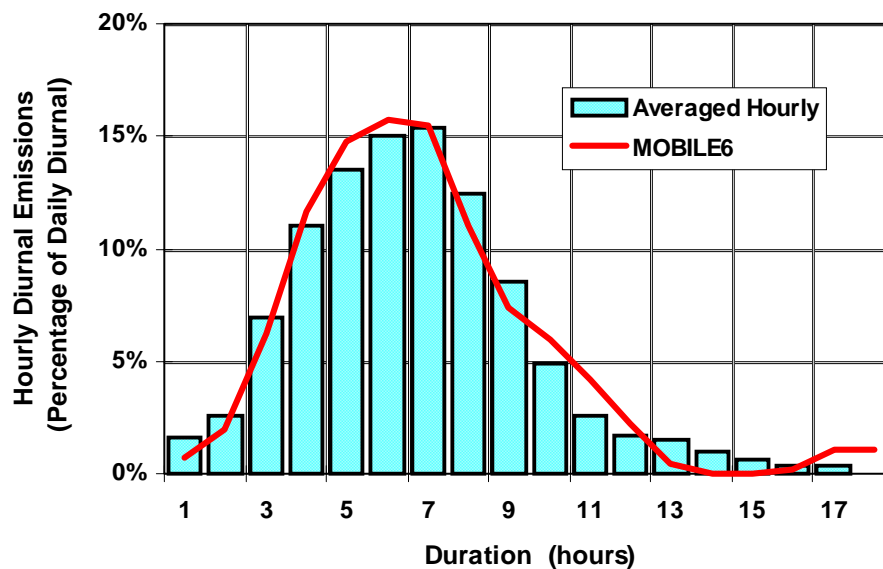**Appendix D** (continued)

**Sample Comparison of Averaged Hourly Diurnal Emission Fractions v. Predicted
For FI Vehicles Failing the Pressure Test**

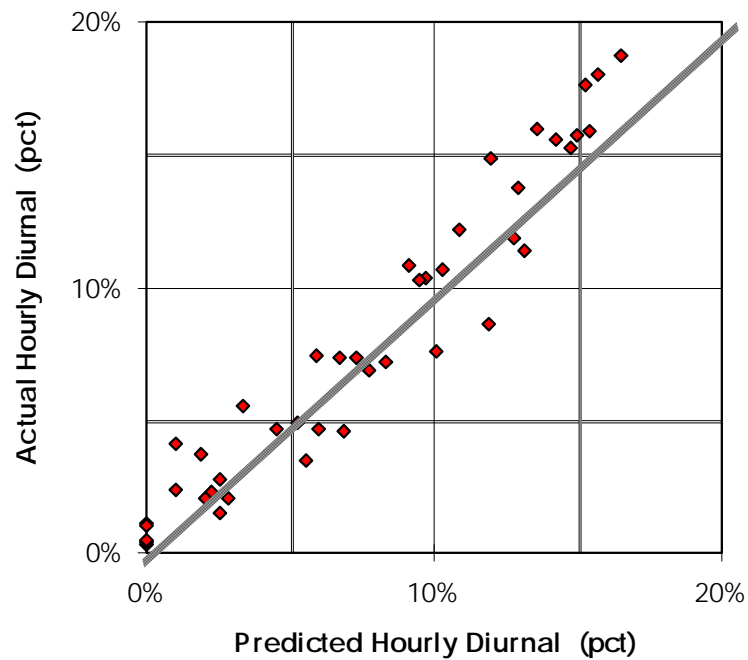**Over 72-96 Degree Temperature Cycle -- Using 6.8 RVP Fuel**
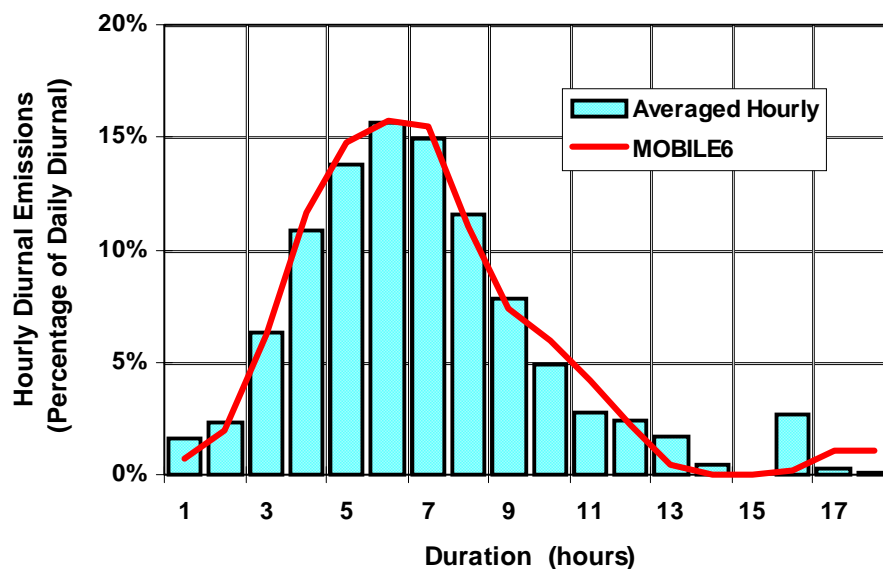
Over 82-106 Degree Temperature Cycle -- Using 6.8 RVP Fuel

Appendix D (continued)
FI Vehicles Failing ONLY the Purge Test

Dependent variable is: **Ratio of Hourly Diurnal**
No Selector

R squared = 95.6%   R squared (adjusted) = 95.3%
s = 0.0120 with 114 - 8 = 106 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.329042	7	0.047006	327
Residual	0.015255	106	0.000144	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	0.007882	0.0030	2.66	0.0090
Previous * Total Prior to Previous	0.000855	0.0001	7.87	$\leq$ 0.0001
VP * Tot Prior to Previous	0.000084	0.0000	8.82	$\leq$ 0.0001
Sqr_Delta Current	0.006960	0.0007	10.7	$\leq$ 0.0001
VP * Sqr_Delta Current	-0.000160	0.0000	-10.0	$\leq$ 0.0001
Total Prior to Previous	-0.001172	0.0004	-2.88	0.0048
VP * Delta Current	0.000118	0.0000	2.98	0.0036
Sqr_Delta Previous	0.000825	0.0004	2.06	0.0419

Plotting Predicted versus Actual Hourly Ratios

Appendix D (continued)

**Sample Comparison of Averaged Hourly Diurnal Emission Fractions v. Predicted
For FI Vehicles Failing ONLY the Purge Test**

Over 72-96 Degree Temperature Cycle -- Using 6.8 RVP Fuel
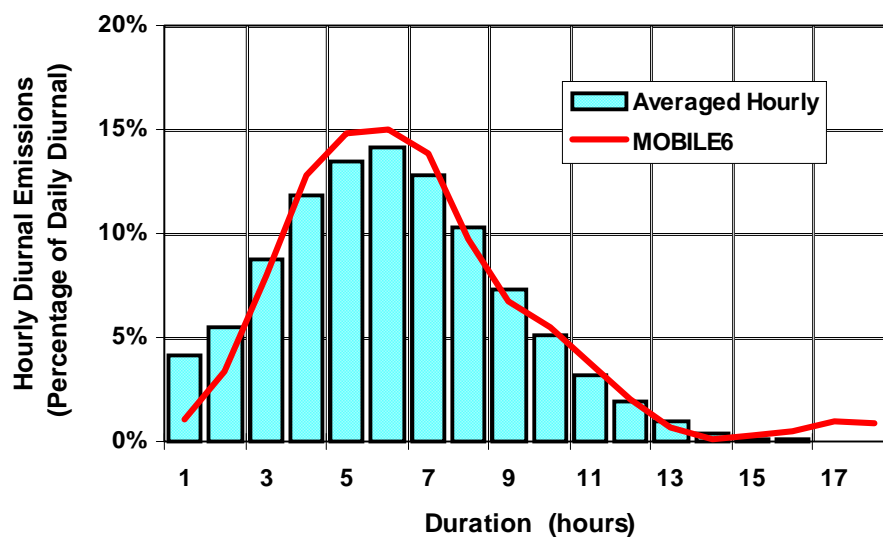
Over 82-106 Degree Temperature Cycle -- Using 6.8 RVP Fuel

Appendix D (continued)

Regression of Ratio of Mean Hourly Diurnal Emission Fractions
"Gross Liquid Leaker" Vehicles

Dependent variable is: **Ratio of Hourly Diurnal**
No Selector

R squared = 96.2%   R squared (adjusted) = 95.7%
s = 0.0070 with 19 - 3 = 16 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.019576	2	0.009788	200
Residual	0.000783	16	0.000049	

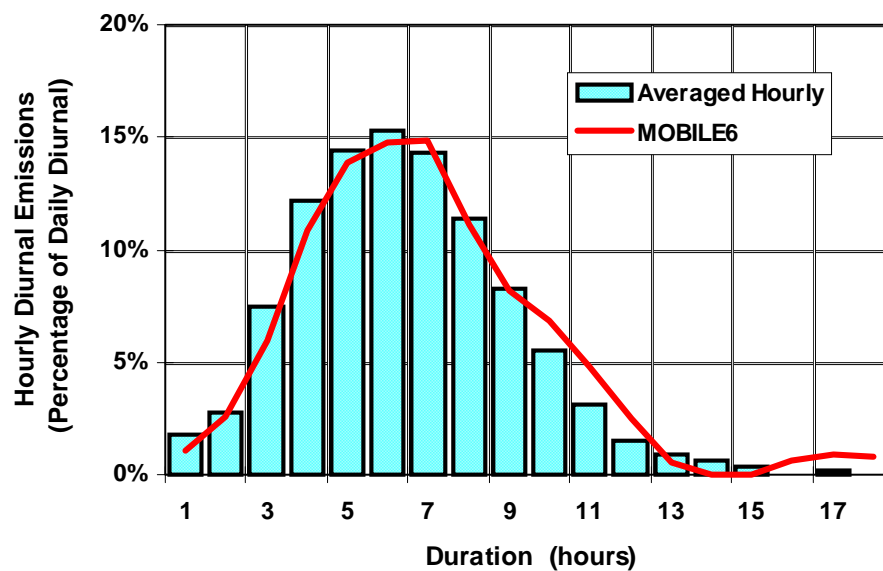| Variable	Coefficient	s.e. of Coeff	t-ratio	Prob
Constant	0.021349	0.0032	6.67	≤ 0.0001
Delta Previous	0.010137	0.0006	16.90	≤ 0.0001
Total Prior to Previous	0.002065	0.0002	10.30	≤ 0.0001

Plotting Predicted versus Actual Hourly Ratios
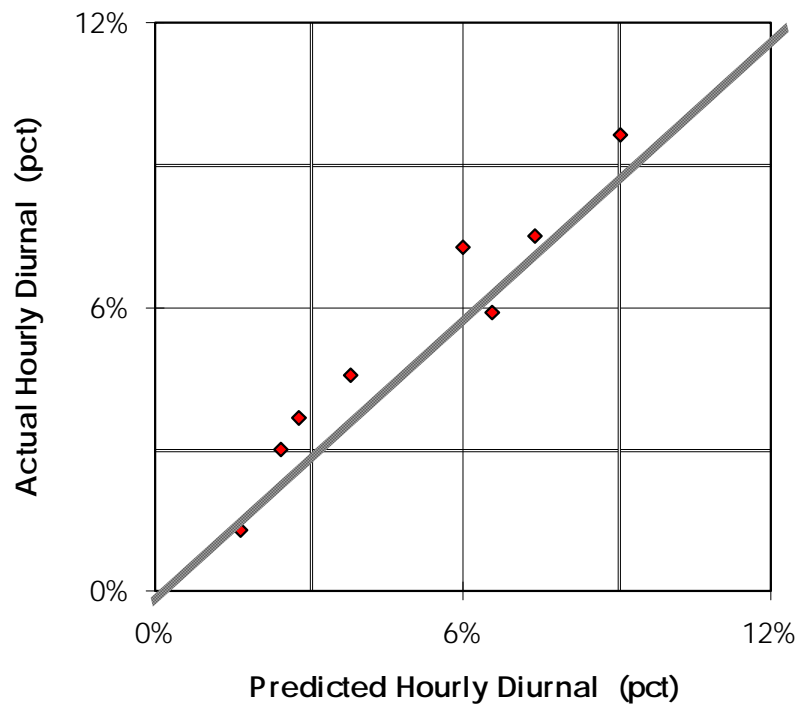
Appendix D (continued)

**Comparison of Averaged Hourly Diurnal Emission Fractions versus Predicted
For "Gross Liquid Leaker" Vehicles**

(Reproduction of Figure 4-3)
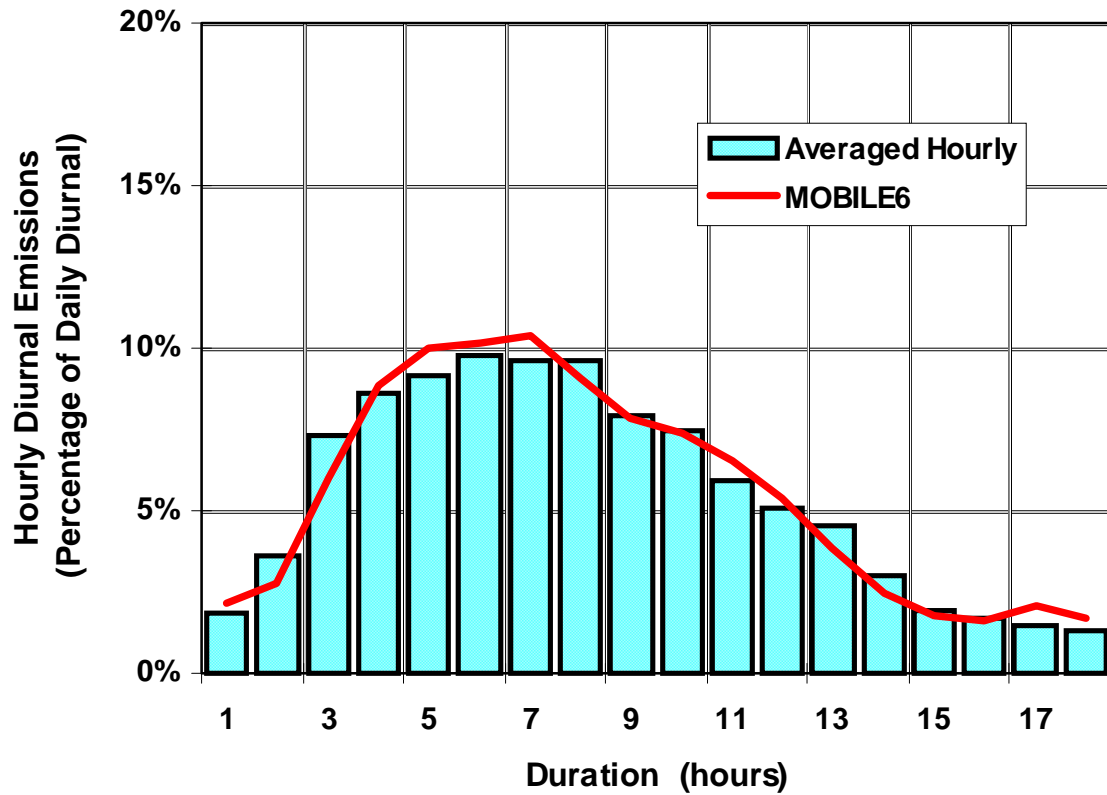
Appendix E

Hourly Real-Time Diurnal (RTD) Emissions (in grams)
From Six Gross Liquid Leakers

Hour	5002	5082	9049	9054	9087	9111	Mean	Modified*
			-------- Vehicle Number --------					
1	4.56	2.23	11.88	10.99	27.67	55.95	18.88	10.48
2	4.71	2.41	8.79	11.24	28.50	46.77	17.07	12.45
3	6.12	3.18	10.24	9.78	24.65	44.26	16.37	16.37
4	7.93	4.00	11.74	13.05	25.98	44.32	17.84	17.84
5	9.55	4.63	11.62	14.28	25.06	45.49	18.44	18.44
6	11.29	5.14	11.19	14.69	24.61	47.67	19.10	19.10
7	9.41	5.39	10.99	14.00	25.70	48.07	18.93	18.93
8	9.78	5.11	9.74	16.08	25.22	47.46	18.90	18.90
9	7.14	4.73	9.04	15.05	24.21	42.41	17.10	17.10
10	6.06	4.36	8.02	14.06	23.36	43.84	16.62	16.62
11	5.35	4.30	7.42	14.85	20.95	36.43	14.88	14.88
12	4.18	4.10	6.91	15.53	19.67	33.72	14.02	14.02
13	3.66	3.51	6.91	14.93	18.50	32.96	13.41	13.41
14	3.08	2.76	6.25	15.03	17.58	25.79	11.75	11.75
15	2.89	2.55	5.63	14.60	16.57	21.55	10.63	10.63
16	2.83	2.23	5.78	13.93	16.31	21.24	10.39	10.39
17	2.97	2.22	5.09	16.37	13.59	20.46	10.12	10.12
18	2.76	2.20	4.91	14.65	15.29	19.64	9.91	9.91
19	2.91	2.18	4.93	11.54	13.86	17.60	8.84	8.84
20	2.82	2.09	4.89	11.30	13.46	16.85	8.57	8.57
21	3.01	2.06	4.70	11.12	13.69	16.52	8.52	8.52
22	3.06	2.09	5.02	9.89	13.62	15.89	8.26	8.26
23	3.01	1.97	4.78	10.36	13.04	15.82	8.16	8.16
24	2.96	2.13	4.88	9.28	17.05	16.40	8.78	8.78

_____

* Mean emissions for the first two hours have been "**MODIFIED**" (see Section 4.2.3) to fit the following assumed pattern:

  ♦ The diurnal emissions (i.e., RTD minus the hourly resting loss of 8.52 grams) during the first hour were assumed to be one-half the diurnal emissions during the second hour.

  ♦ The diurnal emissions during the second hour were assumed to be one-half the diurnal emissions during the third hour.

Appendix F

Modeling Hourly Resting Loss Emissions
As Functions of Temperature (°F)

In each of the following 12 strata, resting loss emissions (in grams per hour) are modeled using a pair of numbers (A and B), where:

Hourly Resting Loss (grams) = A + (B * Temperature in °F)

B = 0.002812 (for ALL strata) and

"A" is given in the following table:

Fuel Delivery	Model Year Range	Pass Pressure Test	Fail Pressure Test
Carbureted	Pre-1980	0.05530	0.07454
	1980-1985	-0.05957	-0.02163
	1986-1995	-0.07551	0.05044
Fuel-Injected	Pre-1980*	0.05530	0.07454
	1980-1985	-0.09867	0.02565
	1986-1995	-0.14067	-0.10924

* The untested stratum (Pre-1980 FI vehicles) was represented using the Pre-1980 model year carbureted vehicles. (See report M6.EVP.001 for additional details.)

These equations can then be applied (in each stratum) to each of the hourly temperatures in Appendix A to obtain the resting loss emissions released in a 24 hour period. If we use an alternate temperature profile in which the hourly change in temperature is proportional to the cycles in Appendix A, we find that:

24-Hour Resting Loss (grams) = (24 * A) + (B * C)

Where **A** and **B** are given above, and where

C **= 0.002632 + (24 * Low Temperature)**

+ (11.3535 * Diurnal_Temperature_Range)

Where the **Diurnal_Temperature_Range** is the difference of the daily high temperature minus the daily low temperature.

Appendix G

Response to Peer Review Comments from H. T. McAdams

        This report was formally peer reviewed by two peer reviewers
(H. T. McAdams and Harold Haskew). In this appendix, comments
from H. T. McAdams are reproduced in plain text, and EPA's
responses to those comments are interspersed in indented italics.
Comments from the other peer reviewer appear in the following
appendix (Appendix H).

        This peer review included two appendices. These have been
renumbered as Appendix G-1 and Appendix G-2.

              ****

        Modeling Hourly Diurnal Emissions and Interrupted Diurnal
             Emissions Based on Real-Time Diurnal Data

                              By
                      Larry C. Landman

                  Report Number M6.EVP.001

                    Review and Comments
                           By
                      H. T. McAdams

1. INTRODUCTION

Report Number M6.EVP.002 is herein reviewed in accordance with a
letter postmarked May 25, 1999 from Mr. Philip A. Lorang,
Environmental Protection Agency (EPA) to Mr. H. T. McAdams,
AccaMath Services. The reviewer is instructed to address report
clarity, overall methodology, appropriateness of the data sets
used, statistical and analytical methodology and the
appropriateness of conclusions, with specific attention to data
stratification and predictive equations. The review follows
precedents set in the previous review of other, related MOBILE6
draft documents (see References 1 - 7).

Number M6.EVP.002 can be thought of as an extension, and to no
small degree a repetition, of material in the previously reviewed
reports M6.EVP.001 and M6.EVP.005. Accordingly, this review will
focus primarily on analytical deficiencies unique to the current
report, M6.EVP.002. These include what is considered to be a
flawed application of stepwise regression methodology and a
simplistic view of interrupted diurnals that stops short of its
objective.

It is admitted at the outset that there are significant philosophical differences between EPA's conception of modeling and the reviewer's conception, particularly in the present instance. It is hoped that these views may be reconciled, however, after both have been fairly presented and evaluated.

> *EPA believes that a major source of these "philosophical differences" is the reviewer's belief that he has a substantially superior approach to modeling these hourly diurnal emissions. That is, he suggests:*
>
> > *-- using (continuous) cumulative emissions rather than (discrete) incremental emissions and*
>
> > *-- using time as the primary independent variable rather than temperature differences.*
>
> *Even though these changes might produce estimates of diurnal emissions that more closely approximate the actual test data, they do not lend themselves to estimating the hourly emissions over <u>different</u> temperature cycles (<u>including interrupted cycles</u>). Therefore, both of these approaches were rejected by EPA.*

2. HOURLY DIURNAL EMISSIONS: TWO MODELING APPROACHES

Hourly diurnal emissions can be viewed as separate and discrete <u>events</u> associated with hour-long time intervals spanning a 24-hour period. Alternatively, they can be deduced from a continuum in which cumulative emissions <u>up to</u> a given time are expressed as a continuous function of time over 24 hours.

EPA chose the interval approach, as discussed in Section 2.1 below. Characteristic of the approach is its <u>discrete</u> representation of emissions and its reliance on <u>linear</u> stepwise regression.

That discussion will be followed by a presentation, in Section 2.2, of an alternative approach based on cumulative emissions. It is characterized by a <u>continuous</u> representation of emissions and its openness to either intuitive or analytical <u>nonlinear</u> curve fitting.

2.1 The EPA Perspective

Though extensively used in modeling a variety of processes, stepwise regression is not universally accepted by professional statisticians. This lack of enthusiasm is evidenced in the following quotation from the SYSTAT manual (see Reference 8).

> Stepwise regression is probably the most abused computerized statistical technique ever devised.

> If you think you need automated stepwise regression
> to solve a particular problem, it is almost certain
> that you do not. Professional statisticians rarely
> use automated stepwise regression because it does
> not find (a) the "best" fitting model, (b) the
> "real" model, or (c) alternative "plausible"
> models. Furthermore, the order in which variables
> enter or leave a stepwise program is usually of no
> theoretical significance. You are always better off
> thinking about why a model could generate your data
> and then testing that model.

Undaunted, however, EPA makes their position clear on page 12 of
Report M6.EVP.002:

> EPA chose to use stepwise linear regressions
> to identify the variables that were the most
> influential in determining the shape of the
> hourly diurnal emissions.

What is meant by "the shape of the hourly diurnal emissions" is
not clear, but the phrase is presumed to refer to the shape of a
plot of hourly diurnal emissions vs hour considered, as in Figure
4-1 *[renamed Figure here as 4-3]*.

> *That is correct. The text has been revised to eliminate*
> *that potential ambiguity.*

Stepwise regression can make its selections only from the set of
variables submitted to it as candidate variables. It is at this
point that the analyst must call upon whatever intellectual
resources are at his command pertinent to the response variable
and the factors that might influence it. Once a variable has been
put forward, the analyst then needs to consider whether that
variable might affect the response nonlinearly as well as
linearly and must postulate what he considers to be viable
options.

In resolving this question, too often one simply resorts to a
multinomial, power-series expansion of the response function on
the assumption that powers of a variable will accomodate
<u>nonlinearities</u> and that products of two or more variables will
accomodate what statisticians refer to as <u>interactions</u>. Though
not unique to <u>stepwise</u> regression, this practice can be more
insidious when the choice of terms is performed automatically by
a stepwise algorithm. The response variable for the seven
regression equations that evolved from this modeling exercise is
current hourly emissions expressed as a fraction (or percent) of
total daily emissions. Predictor variables are presumed to be of
two types, one related to fuel properties, the other to the
temperature cycle. These interact to determine vapor pressure,
the ultimate driving force for producing evaporative emissions.

In the previously reviewed document M6.EVP.001, EPA used fuel RVP
(Reid Vapor Pressure) to estimate the vapor pressure of the fuel
at each time in the temperature cycle. In the paper presently
under review, EPA chooses to use a quantity referred to as
"midpoint VP" derived as follows (see page 9 in M6.EVP.002):

> If we calculate the mean of the VP at the highest
> and lowest temperatures, then that midpoint value
> incorporates both the temperature cycle and the
> fuel RVP.

Other predictor variables consist of temperature changes (deltas)
that occur during specific hours in the emission time history.
Indeed, an equation may use the current hour's temperature delta,
the previous hour's temperature delta, and the sum of all hourly
temperature deltas before that.

The fact that there is a time lag between temperature rise and
corresponding emissions tends to support the inclusion of these
lagged terms. Also, it is reasonable to expect temperature deltas
to have a different effect on emissions for low and high midpoint
VP. However, it is difficult to justify some of the more complex,
temperature-related terms such as squared temperature deltas and
products of temperature deltas occurring at different points in
time. No reason for their inclusion in the model is offered by
Landman other than that these terms were found to be
"statistically significant" by the stepwise regression algorithm
"fishing expedition." Presumably he is relying on the time-
honored tradition of using higher-order terms to accomodate
nonlinearities and thus to adjust the "shape" of the emission
plot.

> *The product-terms (including second-degree terms) were*
> *included in the list of* <u>*potential*</u> *variables to account for*
> <u>*likely*</u> *interactions. Some of these product terms made it*
> *from the list of candidate variables to the list of actual*
> *variables because their presence significantly improved the*
> *ability of the resulting equations to predict the means of*
> *the actual hourly data.*

What is wrong with this picture?

First, all of the time-related predictor "variables" are attached
to a specific hour in the temperature cycle and conspire to
estimate emissions for the current hour <u>only</u>. Thus they can not
determine the "shape" of the curve in the usual sense because
they are fixed to a single point and have nothing to do with the
shape of the plot as a whole. If there is any doubt of this
conclusion, consider what it is <u>possible</u> for a square term to do.
Certainly an equation of second degree can not generate a plot as
complex as Figure 4-1 *[renamed Figure here as 4-3]*. In fact,
there is really no "shape," as such, to be dealt with, just a set

of discrete estimates for specific intervals in time, there being
no inputs for time intervals other than these.

> *On the contrary, these equations (from Appendix D) do, in
> fact, generate plots with the necessary complexity, as is
> illustrated in Figure 4-3 and the graphs newly added to
> Appendix D.*

Secondly, what is considered to be "statistically significant" is
an artifact of the choice of significance level. However we
resolve this age-old dilemma, an aura of uncertainty remains,
spawned by an unavoidable arbitrariness. Even more troubling,
though, is the realization that if other terms had been proposed
for inclusion in the model, they might have been just as likely
to succeed.

> *Granted, while the selected level of significance (i.e.,
> five percent) is arbitrary, it is also fairly standard.
> Also the set of candidate variables was chosen to include
> all of the relevant variables that were likely to be
> available (to MOBILE6). The "clock time" was not considered
> to be a relevant variable.*

These objections do not exhaust the list. It is the belief of
this reviewer that the approach used in M6.EVP.002 contains a
number of substantial flaws, that certain statistical procedures
are misused and/or misinterpreted, and that stepwise regression
has gone where stepwise regression has never gone before.

To illustrate some of these points, we shall first examine the
models as developed by Landman and shall comment on what is
considered to be their deficiencies. After that, we shall sketch
a different approach to the modeling of hourly evaporative
emissions - an approach that is believed to be more direct, less
complex and more readily interpreted in physical terms.

2.1 How EPA Applies Stepwise Regression to Time Series

Hourly diurnal evaporative emissions is an example of a time
series, for which there are specific applicable statistical
procedures. These analytical procedures almost universally
acknowledge the fact that the value of a time-series response
variable at a particular point in time is determined, to greater
or lesser degree, by the value of that variable at preceding
points in time. Serial correlation often plays an important role
in the analysis, as does also certain autoregressive procedures
such as ARIMA (AutoRegressive Integrated Moving Average) models.

> *For the three temperature cycles used in the testing
> programs (see Appendix A), all of the temperature
> differences (at a given time) are equal; thus, a time-series
> approach does seem reasonable. However, since the results
> must apply to other temperature cycles, EPA intentionally
> ignored "clock time" as a potential variable and*

*concentrated on temperature changes. The introductory
section of this report has been revised to emphasize this.*

In a garden-variety time series, responses at adjacent points in
time are usually most highly correlated. With increasing "lag,"
the correlation decreases until it approaches zero at a distance
known as the "decorrelation interval." This behavior works to
our advantage if we are attempting to compute current or future
responses in terms of past responses. If the decorrelation
interval is short, it would not be necessary to look back very
far in time in order to make reasonable predictions.

At first look, Landman's approach to the modeling of hourly
emissions seems to incorporate some of the predictive aspects of
time-series analysis. Instead of looking at prior <u>emissions</u>,
however, the EPA model looks at the prior temperature deltas that
<u>drive</u> the emissions.

Because the temperature deltas are <u>fixed</u>, they have the same
correlation structure regardless of the <u>emission response</u> to
those deltas. Viewed in this light, correlation between various
temperature deltas may work to our disadvantage because of
"creeping collinearity"(see Appendix I *[renamed here as Appendix
G-1]*). The correlation between current and previous deltas is
0.92, a fact that suggests that either one has almost as much
predictive power as both used together. Similarly, there is a
correlation of 0.92 between previous delta and its product with
the sum of all deltas prior to that. Indeed, it is shown that the
six lagged variables used by Landman in his models have the
effect of only three, or at most four, independent variables.

> *Although using "emission response" (or "prior emissions") as
> a variable could be useful in predicting <u>full-day</u> diurnals,
> their use would actually be counter productive when trying
> to estimate interrupted (partial-day) diurnals. Therefore,
> the regression analyses continue to focus on temperature
> changes rather than on prior emissions.*

> *The presence of collinearity among the several variables
> related to temperature differences is an unfortunate result
> of the nature of the three temperature cycles (from Appendix
> A). A future testing program might use substantially
> different temperature cycles, thus, producing additional
> data having reduced collinearity. However, until that
> additional data become available, we will continue to use
> this approach and live with the presence of collinearity.*

The page 12 footnote on how stepwise regression works is
misleading. If the predictor variables are orthogonal (that is,
independent), then of course the order of predictive
contributions would be consistent with the order of the
magnitudes of their correlation with the response variable. But,
of course, in that instance there would be no need for stepwise

regression. The intercorrelation of predictor variables and the non-additivity of sums of squares is the very reason stepwise regression came to be. The apparent contribution of predictor variables depends, computationally, on the order in which they are introduced into the model. Indeed, there may be two or more sets of variables that give essentially the same performance, so far as R-square is concerned.

> *The footnote has been revised.*

Clearly, therefore, the stepwise algorithm is not infallible in its effort to simplify a model by eliminating, from among the variables submitted, those that contribute little to the model's prediction capability. Another approach to model simplification is provided by a spin-off from random-balance experiment design (see Reference 12).

Not only is there correlation between near-neighbor values of a time series, but there may also be correlation between near-neighbor <u>residuals</u> from a fitted model. In spite of the fact that residuals should be examined in <u>any</u> regression analysis, Landman gives relatively little attention to this concern, and then in an unconventional manner.

> *The examination of the residuals might have been done in an "unconventional manner," but the residuals were examined. However, the examination did not check to determine if there was a time-related correlation. We had not considered checking this aspect since we were not (and still are not) interested in treating diurnal emissions as a function of clock time.*

For example, according to plots of "Predicted Versus Actual Values" (see Appendix D of the report), the implication is that model performance is quite good. The author is quick to point out, though, that his plots are not the usual "scatter plots," in which observed data are shown as points scattered about the computed curve. The actual values are not plotted in relation to the predicted curve but with regard to what Landman calls the "unity line."

> *The scatter plots are graphs of the actual hourly ratios versus the predicted ratios (not the "unity line"). The "unity line" is present only to illustrate how far off (or how close to) a "perfect" prediction the regression is.*

Such plots are highly suspect, because the sequential relation between actual and predicted emissions is lost. The "unity line" plot can look very symmetric, even though the usual scatterplot may show substantial "lack of fit." For example, consider the fact that the Landman models attempt to incorporate the effects of time and fuel vapor pressure. Suppose that predictions for RVP = 6.8 run mostly too high, whereas predictions for RVP = 9.0 run mostly too low. The situation is a classic case of <u>lack of</u>

fit. When the two cases are pooled, however, the magnitudes of the actual and predicted values may follow the "unity" line quite well, an observation that proves nothing in particular.

> *If one of the seven equations over-estimates the hourly fractions for one RVP and under-estimate for the other tested RVP, then the scatter plot would appear to be a "good fit" when, in fact, it is not. This is a valid concern. Fortunately, it does not occur.*

In another instance (see Figure 4-1 *[renamed Figure 4-3]*), a plot of "actual" vs "predicted" values is presented, this time in the usual way except that the "actual" values are plotted as a bar graph rather than as a scatter plot of points. The width of the bars tricks the eye into believing that the agreement is better than is actually the case. See Appendix II *[renamed here as Appendix G-2]* of this review document for further detail.

> *Each bar (in Figure 4-3) represents the total diurnal emissions occurring in each full hour. Therefore, each bar is approximately one hour in width.*

In addition to the matters of principle discussed above, there are questions that need to be raised about some of the computations and their numerical results.

Consider, for example, the following detailed results extracted from Appendix D.

Stratum	Page No.	Reg. d.f.	Resid. d.f.	Res. SS	R-square.
1	36	3	110	0.000215	0.916
2	37	3	110	0.000141	0.951
3	38	5	108	0.000154	0.935
4	39	5	108	0.000355	0.852
5	40	4	109	0.000138	0.959
6	**41**	**2**	**3**	**0.43039**	**0.956***
7	42	2	16	0.000049	0.962

* Discordant with table heading information indicating degrees of freedom (8 and 114) and s = 0.0120

Stratum #6, FI Vehicles Failing ONLY the Purge Test, is out of line with other strata, and the coefficients and analysis of variance obviously do not go together.

> *Correct. There was an error in "pasting" the data into the regression table template. The incorrect table (in Appendix D) has now been corrected.*

Evidently the highlighted case (Stratum #6) is just a computational or transcription error, but a more serious flaw pervades the data for the other strata as well.

The report states that the models for each stratum (except #7) is based on 114 <u>average</u> hourly emissions:

    2 RVPs x 3 temperature cycles x 19 hourly intervals = 114

In reality, an "honest" regression should be based on <u>individual</u> observations rather than averagers, in which case the number of degrees of freedom would be one less than:

    2 RVPs x 3 temperature cycles x 19 hourly intervals x N

where N is the Number of Tests as shown in Table 4-3. N ranges from 13 to 73. Thus there could be as many as 73 x 114 = 5402 and at least as many as 13 x 114 = 1482 data points in the scatter plot to be consolidated by a regression model. By averaging the data points, one removes the major source of variance in the data and exaggerates R-square, thereby making the model look much better than it actually is. Moreover, the averaging process makes it appear that the model for one group of observations is just as good as for another group, even though one might be based on several times as much data as the other.

> *Correct. A note/caution has been added to the end of Section 4.2.1 to emphasize this.*

Now recall that all the model does is to attempt to recapitulate the <u>individual</u> hourly average emissions, since the domain of the response function is discrete and there is no continuity from one hourly estimate to the next. Therefore, the <u>average</u> emissions for each hour is the best discrete estimate possible and already exists or is implied in Table 4-1.

> *Yes. If MOBILE6 needed only to estimate full-day (no interrupted) diurnals over these three temperature cycles (from Appendix A) using fuels with only RVPs of 6.8 or 9.0 psi, then we would simply code these averages into the model. However, since MOBILE6 must extrapolate over a wide range of fuel RVP and a wide range of temperature cycles (including interrupted cycles), some type of modeling (i.e., regression analysis) was necessary.*

Finally, one needs to give attention to some of the conclusions drawn with regard to what terms are "significant" and what terms are not. Of particular interest is the proclaimed "universality" of the variable "total change in temperature prior to the previous hour."

The fact that this term appears to be universally applicable to all seven strata should come as no surprise. If emissions for any given hour are dependent on emissions from the previous hour, and if this relation is recursive, then the current hour's emissions must be dependent on all previous hours, even though that dependence may decay exponentially as one looks back in

time. This lemma seems even more plausible when hourly emissions
are viewed cumulatively, as will be done in the following section
of this review.

To summarize, perhaps the most disturbing aspect of the
application of stepwise regression is that it can select
variables only as a subset of the set of variables submitted to
it as <u>candidates</u> for inclusion in the model. There is no
assurance that there may be other factors not dreamed of in our
philosophy and other pathways to follow in our search for the
Holy Grail.

> *The list of candidate variables was comprised of all the*
> *variables (and their products to account for interactions)*
> *that were likely to be included in MOBILE6 (either entered*
> *by the user or hard-coded). While other variables may, in*
> *fact, be significant in predicting hourly diurnal emissions,*
> *they would not be readily available to the users of MOBILE6.*
> *Thus, the analyses were limited to predicting the hourly*
> *emissions using only the information/data available to*
> *MOBILE6.*

2.2 A Road Less Traveled By: A Proposed Alternative

>   Two roads diverged in a wood, and I
>   I took the one less traveled by ...
>
>   -- Robert Frost

In view of the difficulties and circularities of the above
approach, it seemed legitimate to explore a different route to
modeling hourly emissions.

To begin, we ask the question, "What are we modeling, anyway?"

Evidently we seek a model that expresses hourly emissions as a
function of time:

                Hourly emission fraction = f(time)

More specifically, for any given hour in the test cycle, we want
to know what fraction (or percent) of the total daily emissions
is represented by the emissions given off during that (the
current) hour. Further, we want to know how this emission vs
time relation varies from stratum to stratum, and how it is
influenced by fuel vapor pressure.

> *As noted in comments at the end of the introduction of this*
> *review, predicting hourly diurnal emissions as a function of*
> *clock time would not lend itself to estimating the hourly*
> *emissions over interrupted cycles.*

Truth begins with Table 4-1 and could very well end there. In
the table, four "critical times" are presented for each of 24
groups of vehicles. Evidently these critical times were
interpolated from a plot of <u>cumulative</u> average emissions vs time
for each intersection of strata, RVP and temperature cycle. By
taking successive differences between times t_n **and t_{n-1}** for n = 1,
2, 3, ... , 24, one obtains, for each hour, an estimate of
hourly emissions as a ratio of total daily emissions.

But that is exactly what the modeling effort set out to do!

Why complicate the matter by a circuitous stepwise regression
that serves only to bring us back to the point of our beginning?

There are possibly two reasons for the regression effort. One
deals with the precision of the hourly averages and with whether
that precision is somehow improved by regressing the hourly
estimates on features of the temperature cycle and the midpoint
VP. The other concerns whether the model is to be used for
interpolation purposes - that is, for estimating hourly emission
ratios for situations for which there was no actual data. Table
4-1 offers data for RVP = 6.8 and RVP = 9.0. Is the model
expected to provide estimates at intermediate values of RVP, such
as 7.4 or 8.5? Presumably so, but the same can not be said for
"intermediate hours."

Evidently, according to the protocol set forth in M6.EVP.002,
interpolation at <u>times</u> other than hours 1, 2, 3, ... is <u>not</u>
contemplated. Accordingly, the <u>mean</u> of all measurements in a
given stratum and for a given midpoint VP is the least-squares
best estimate of emissions for that scenario. This assertion is
easily proved as an elementary statistical exercise.

In ordinary least-squares regression, it is true that the
precision of estimates at some points in the predictor space is
enhanced by information drawn from adjacent points in that space.
However, much depends on the form and validity of the model that
is <u>assumed</u> or possibly <u>forced upon</u> the data.

For example, if it is <u>known</u> that a response variable y is a
<u>strictly linear</u> function of a uniformly-spaced predictor variable
x, then a straight-line regression would make for a more precise
estimate of y at the midpoint of the range of x, and precision
would deteriorate as one moves toward the minimum or maximum
values of x.

In the case of emissions as a function of time, no such model is
known, especially when one attempts to model <u>incrementally</u> the
emissions for a given hour as a fraction of the total emissions
for the day. As will be shown later, the prospect is more
favorable if one models <u>cumulative</u> rather than <u>incremental</u>
emissions as a function of time.

All that can be said here is that the M6.EVP.002 models exhibit "reasonable" R-squares ranging from 0.852 to 0.962 but provide only segmented, "point" estimates of emissions at discrete hourly intervals in the time cycle. But that is exactly what the averaged "raw data" provides! What assurance is there that the Landman model is any better or that it is any closer to the "real" model? Certainly it is no less segmented than the representation obtained by plotting the averaged "raw data" against hours.

Now, suppose that the model, however it was developed, passes exactly through each of the hourly averages of all observations for that hour. Is it possible to conceive of a "better" model than that? The answer is left as an "exercise for the student." In any event, it can be argued that the mean hourly values are viable candidate estimates of the hourly fraction of daily emissions, subject, of course, to sample-size limitations.

Still unresolved, though, is the question of how to include vapor pressure VP into the model. Ostensibly, that variable could be incorporated into the "average raw data" model in much the same way as it is incorporated in Landman's model - that is, as an interaction. In Landman's models, the interactions are between midpoint VP and hourly temperature deltas or functions thereof. In the alternative model the interaction would be with the hourly averages as computed for some "base level" VP. Results for other values of VP would consist of adjustments to those base-level results.

2.2.1 Discrete vs Continuous Space

Much of the difficulty in modeling the hourly emission fractions of total daily emissions resides in the discrete nature of the Landman models. It is believed that the modeling effort would be considerably simplified if the problem were approached cumulatively. Instead of designing a model for estimating emissions within a given hour in the time cycle, why not design the model to estimate emissions up to a particular hour in the cycle. The relation would now be continuous, rather than segmented, and it is to be expected that the function or "curve" tying emissions to time would be much simpler and smoother than the curve based on incremental hourly observations. This continuum approach is the heart of the proposed alternative model.

> Actually, the hourly RTD emission measurements are cumulative (i.e., continuous), and they were then processed to obtain the incremental (discrete) measurements that we actually analyzed. Because MOBILE6 will estimate emissions (incrementally) for each hour, we chose to analyze the incremental hourly emissions rather than the smooth (continuous) cumulative emissions.

To illustrate, the models as presented in Report M6.EVP.002 are capable of estimating hourly fractions of total daily emissions only for time intervals from 6:00 AM to 7:00 AM, 7:00 AM to 8:00 AM, etc. but not from 6:30 AM to 7:30 AM or from 7:08 AM to 8:08 AM. The instant rebuttal to this criticism, of course, is that, under the testing protocol, there is no need for such a capability. Nonetheless, it can hardly be denied that such a revision would represent an extension or generalization of the model. But, what is more important, is the fact that the problem can be addressed in a continuum with tools not applicable in discrete space.

The key to the continuum approach is simply to view emissions cumulatively over time rather than in fixed time intervals. The point is well illustrated by Table 4-1 in the report. The table recognizes the cumulative aspect of diurnal emissions and makes it clear that there is a cumulative percent of total emissions associated with every point in time. Moreover, it is made evident that the relation between emissions and time is a positive-valued, non-decreasing function anchored to 0% and 100% at the beginning and ending times, respectively. These constraints narrow considerably the uncertainty to be dealt with in model development.

But there are further constraints that work to our advantage. All the cumulative curves are S-shaped and exhibit the greatest possibility for variation at the "belly of the curve," specifically near the inflection point of the curve, where its slope changes from increasing to decreasing, and the hourly emissions are at maximum.

2.2.2 Linear vs Nonlinear

With all of these "built-in" constraints, it would seem that relatively few parameters would be required to particularize a function to specific emission data. But S-shaped curves are nonlinear and not particularly responsive to linearization by transformation, as is so conveniently done when dealing with exponential response functions by transforming the response variable to logarithms.

A typical family of such S-shaped curves sometimes goes by the name "logistic" or "inhibited growth" curves. For example, in a town of limited population a few inhabitants become infected with a communicable disease. As time passes, other inhabitants become infected, and the epidemic grows at an increasing rate because of the increasing number of "carriers." After some time, however, the rate begins to decrease, simply because there are fewer people to become infected. The result: the ubiquitous S-shaped curve.

The resemblance of the cumulative emission curves to curves of inhibited growth is fairly evident. If one examines the factors

influencing emissions, it also becomes evident that similar driving mechanisms are at work in the two situations. Certainly emissions up to a certain point in time, when expressed as a fraction of the total day's emissions, depend to greater or lesser degree on emissions prior to that time. Once cumulative emissions reach, say, 25% of the day's total, subsequent emissions must bring the total cumulative to a higher (or at least equal) percent. On the other hand, the higher the cumulative becomes, the less "room" there is for further increase.

The general form of the logistic function is fairly simple:

$P(t) = a / (b + c \exp(-kt))$

The three parameters make it possible to match three points on the curve to available observations and, at the same time, to represent a relatively wide range of curves of this type.

For example, here is a simple logistic curve that could easily represent a diurnal test.

$P(t) = 1 / (1 + 100 \exp(-0.8 t))$

The 25% cumulative break point occurs at 4.38 hours, the 50% break point at 5.76 hours, the 75% break point at 7.13 hours and the maximum (inflection point) comes at 5.7 hours. Compare with strata tests #6 and #9 in Table 4-1 of the report.

It is not unreasonable to believe that this type of curve could model all the data available in M6.EVP.002 to sufficient precision for emission assessment. The curve could be approximated at the hourly points by group averages, as was previously pointed out, and could be smoothed manually (with the assistance of a French curve), or by the use of cubic spline interpolation. If the averaging procedure is not considered to be acceptable, the curve could be fitted by non-linear least squares or other procedures available for this purpose.

Further details pertinent to alternative approaches to modeling hourly diurnal emissions are given in Appendix 2 *[renamed here as Appendix G-2]* of this review. It is not too presumptive to say that by means of an extension of Table 4-1 a model already exists that would yield essentially the same information as the more involved pseudo-autogressive models provided in M6.EVP.002. If the times for 25%, 50% and 75% of full-day emissions are interpolable, then all other benchmarks should be interpolable. Cubic spline interpolation for this purpose should be explored, as well as the applicability of a logistic curve as a closed-form equation.

And don't forget human intuition. A model is not a model because it is mathematical but because it works. Slide rules are not "bad," just obsolete. The same can be said for French curves.

3. INTERRUPTED DIURNALS

The methodology proposed by EPA for estimating interrupted diurnals is heavily assumption laden, but that is not its most serious difficulty. Assumptions must necessarily be used when facts are not available, else we must abandon the chase. There is an aspect of interrupted diurnals, however, not addressed by either fact or assumption, and that is the characterization of the diurnal sample space and its attendant probability distribution.

Put more succinctly, the problem is this: how will the calculation of interrupted diurnals be used in MOBILE6? How many different interrupted profiles must be considered, and how can these be weighted to reflect their relative frequency in the space of all diurnals? Unless these questions are answered, it is not evident what purpose will be served by being able to compute interrupted diurnals, even if those estimates are error free. In short, it is not evident how the computation would help to inventory hydrocarbon emissions or assess their impact on air quality.

> *Correct. The frequency (or weighting) of the interrupted (along with the frequencies of full-day and multi-day) diurnals are not addressed in this report. They are all dealt with in the report entitled "Soak Length Activity Factors for Diurnal Emissions" (report number M6.FLT.006). Section 5.2 has been revised to reference that report.*

It appears that what is lacking is a "vehicle use cycle" comparable to the existing "standard driving cycle." Every vehicle user has his own driving cycle, dictated by his job commute, his Little League obligations and other factors, and it is not likely to duplicate the standard cycle. Still, it is not possible to take into account the behavior of each and every vehicle user.

Similarly, every driver has his own associated "use pattern" - that is, when he drives the vehicle, when he has it in the garage, and when it is "resting" in a parking lot. His driving cycle is just a subset of this more inclusive use pattern that determines the extent of diurnal emissions, running losses, resting losses, etc. Again, it is not possible to take into account the whims of every individual vehicle user. Ergo, the need for one or more standard "use cycles."

This reviewer is well acquainted with the limitations of the standard driving cycle, having been involved for several years in assessing the "shortfall" in real-world fuel economy relative to

the "sticker values" based on laboratory tests according to the
standard driving cycle (see References 9 and 11). His experience
also includes development of a "modal emission model" to estimate
emissions and fuel consumption for an arbitrary driving cycle,
given only modal estimates (see Reference 11). The teachings of
these exercises is that a compromise has to be made in the level
of detail that is practical and cost effective in addressing such
problems. It is not practical to include the experience of every
vehicle user in an inventory of pollutants or fuel consumption,
but it is also unreasonable to believe that all driving patterns
can be mapped into a single, characteristic driving cycle. A
suitable tradeoff must be found and the accompanying errors
accepted.

A very similar dilemma must be resolved in the assessment of the
"non-driving" aspects of vehicle use - that is, diurnal
emissions, resting losses, etc. In view of the multiplicity of
use patterns, perhaps interrupted diurnal computation is too
detailed. On the other hand, even further detail could be
considered.

For example, it is stated in M6.EVP.002 that interrupting the
diurnal with a trip causes a temporary increase in fuel tank
temperature. The time required to regain temperature equilibrium
depends, says the report, on "duration of the trip, fuel delivery
system, fuel tank design, fuel tank materials, air flow, etc."
One might also add location of the fuel tank, how full it is, and
other factors. However, rather than going into this level of
detail, EPA elected to use a fixed time of exactly two hours as
the time required to stabilize temperature. In a sense, for this
"micromodel" or "submodel" EPA invoked a "standard" response into
which all other responses are arbitrarily mapped.

It seems reasonable and necessary, therefore, that the
distribution of the total use cycle of automobiles be addressed
in considering the driving and non-driving contributions to
vehicle emissions.

4. SUMMARY AND OVERALL REPORT ASSESSMENT

Because of the significant departure of this reviewer's point of
view from EPA's perception of the modeling of hourly diurnal
emissions, this summary and overall assessment of M6.EVP.002 was
intentionally delayed until the two approaches could be
explicated, compared and put into perspective. We now present
our position.

   4.1 Clarity

The style of this report is quite similar to that of reports
M6.EVP.001 and M6.EVP.005 that were previously reviewed. The
writing is logically clear but somewhat pedestrian in places,

particularly where it is necessary to talk about such concepts
as:

> * Product of the delta in previous hour's temperature
>   times the total (change in temperature) prior to the
>   previous hour
>
> * Product of the VP times the delta in previous hour's
>   temperature times the total prior to the previous hour

Though there may be some advantage in avoiding mathematical
symbolism_wherever possible, here is a place where it might help
"keep the record straight." Why not use a convention of
subscripts to index points in time, where n denotes "now", n-1
denotes one step back, and s denotes summation over all time
intervals prior to that? Thus d_n means "change in current hour's
temperature," d_{n-1} denotes "change in previous hour's temperature,
and d_s denotes the sum of all temperature deltas prior to that
(see Appendix I *[renamed here as Appendix G-2]*).

> *Sections 4.2.1, 4.2.2, and 4.2.3 were revised to include
> this format for the seven equations.*

Other suggestions made in the reviews of M6.EVP.001 and
M6.EVP.005 are applicable here also.

4.2 Overall Methodology

Several modifications of overall methodology are suggested in the
discussion of interrupted diurnals. The specifics of diurnal
computation, however, serve only as a vehicle for addressing the
larger issues of appropriate level of detail in _any_ modeling
effort. Balance detail against gains in precision and cost.

4.3 Datasets Used

No comment is made with regard to the database, because this
topic has been treated previously in the review of M6.EVP.001 and
M6.EVP.005. As in those reports, we should make the most of what
data we have. This has not always been done; directions for
improvement are implicit in Section 2, Stepwise Regression, Its
Pros and Cons. A particular instance is that of modeling hourly
emissions cumulatively rather than incrementally. The cumulative
approach is capable of wringing more information from the data
than is the incremental approach.

4.4 Statistical Methodology / Conclusions

Some fairly sweeping changes in statistical methodology are
recommended. These directly impinge on the appropriateness of
the conclusions set forth in M6.EVP.002.

> * Forget about stepwise regression.

Regardless of the statistical approach being used, the analyst must identify:

-- the variables that are likely to have an effect on the result (i.e., hourly diurnal emissions) and

-- which of those variables will actually be available when running MOBILE6.

Once such a list of candidate variables has been created, some method must be used to limit that set to a smaller subset of the variables having a significant affect on diurnal emissions. If the data set of (hourly) test results were diverse enough, we could identify a subset of the set of variables that was linearly independent. Until we obtain that truly diverse data set, we will continue to use the stepwise regression method (in spite of its short comings) to help identify that subset of the set of significant variables.

* Re-structure the model: let the output be <u>cumulative</u> emissions as a function of time.

While a cumulative output would not be useful for the MOBILE model, some aspects of a cumulative model could be useful. Using a logistic growth curve to model the cumulative emissions as a function of time is an interesting concept. Just as using averaged test results (as in these analyses) can simplify the analysis by removing the vehicle-to-vehicle variability, using such a cumulative model would permit additional smoothing of the data.

If we can create logistic models that closely approximate the hourly (averaged) cumulative emissions, then those models would produced "processed" hourly incremental emissions. Those "processed" emissions could then be used to generate (hopefully) more accurate models of hourly diurnal emissions as functions of temperature cycle and fuel RVP. Granted, this is not what the reviewer had in mind when he suggested using cumulative emissions as a function of time.

In any event, using that approach must wait for a later analysis, possibly once more data become available.

* Re-examine the role played by sequential <u>hourly</u> temperature increments as predictor variables. Do they really serve any useful purpose?

Yes, they do.

* Try to minimize model complexity; seek a parsimonious model form consistent with the relatively simple form of the

cumulative emission vs time curves. Examine, e.g., logistic /
inhibited growth model.

> *Granted that a model of cumulative emissions as a function*
> *of time is much less complicated than the models used in*
> *these analyses, such a (simpler) model would not meet the*
> *needs of MOBILE6.*

* Reconsider the stratification of the data. Though
physical differences (e.g., carburetted vs FI) are logical bases
of classification, consider whether the models for candidate
strata differ enough to merit separate strata. This topic has
been discussed in more detail in the review of the parallel
reports M6.EVP.001 and M6.EVP.005.

> *The original draft version of this report, in fact, combined*
> *all six "non-Gross Liquid Leaking" strata into a single*
> *stratum on the assumption that the differences among the*
> *strata were small.*

5. REFERENCES

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H. T. McAdams

6-25-99

Editorial note: On page 8 of the report, third paragraph from the bottom, "appear to be effected" should read "<u>affected</u>." Also, there are places in the report where strata should read stratum and vice versa.

Those grammatical errors have been corrected.

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APPENDIX G-1

CORRELATION STRUCTURE OF TIME-DEPENDENT VARIABLES

Following are the six time-related, temperature-delta variables
that are used in the EPA models of hourly diurnal emissions.

A Prev. Hr. delta d_{n-1}	B Curr. Hr. delta d_n	C Sum of prior dels d_s	A Sqr. d_{n-1}^2	B Sqr. d_n^2	A * C $d_{n-1}*d_s$
0	0.5000	0	0	0.2500	0
0.5000	3.0000	0.5000	0.2500	9.0000	0.2500
3.0000	4.8000	3.5000	9.0000	23.0400	10.5000
4.8000	4.9000	8.3000	23.0400	24.0100	39.8400
4.9000	4.2000	13.2000	24.0100	17.6400	64.6800
4.2000	3.7000	17.4000	17.6400	13.6900	73.0800
3.7000	2.0000	21.1000	13.6900	4.0000	78.0700
2.0000	0.7000	23.1000	4.0000	0.4900	46.2000
0.7000	0.2000	23.8000	0.4900	0.0400	16.6600
0.2000	-0.5000	24.0000	0.0400	0.2500	4.8000
-0.5000	-1.4000	23.5000	0.2500	1.9600	-11.7500
-1.4000	-2.4000	22.1000	1.9600	5.7600	-30.9400
-2.4000	-3.1000	19.7000	5.7600	9.6100	-47.2800
-3.1000	-3.1000	16.6000	9.6100	9.6100	-51.4600
-3.1000	-2.7000	13.5000	9.6100	7.2900	-41.8500
-2.7000	-1.9000	10.8000	7.2900	3.6100	-29.1600
-1.9000	-1.9000	8.9000	3.6100	3.6100	-16.9100
-1.9000	-1.8000	7.0000	3.6100	3.2400	-13.3000
-1.8000	-1.4000	5.2000	3.2400	1.9600	-9.3600
-1.4000	-1.1000	3.8000	1.9600	1.2100	-5.3200
-1.1000	-0.8000	2.7000	1.2100	0.6400	-2.9700
-0.8000	-0.6000	1.9000	0.6400	0.3600	-1.5200
-0.6000	-0.7000	1.3000	0.3600	0.4900	-0.7800
-0.7000	-0.6000	0.6000	0.4900	0.3600	-0.4200

The associated correlation matrix is:

1.0000	**0.9320**	0.1282	0.6452	0.5652	**0.9202**
0.9320	1.0000	-0.1416	0.5822	0.6536	0.8030
0.1282	-0.1416	1.0000	0.1717	-0.0159	0.1349
0.6452	0.5822	0.1717	1.0000	0.7921	0.5312
0.5652	0.6536	-0.0159	0.7921	1.0000	0.2691
0.9202	0.8030	0.1349	0.5312	0.2691	1.0000

Note that the temperature deltas for the current and previous
hours are highly correlated (0.9320); also the previous hour and
the product of the previous hour and all hours prior to that

(0.9202). These high correlations and other sizable off-diagonal
entries suggest that the correlation structure of the variables
is such that the information afforded has dimensionality less
than the number of variables. How much less can be revealed by
computing the eigenvalues of the correlation matrix:

Eigenvalue	% of trace	Cumulative % of trace
3.7093	61.82	61.82
1.0825	18.04	79.86
0.9284	15.47	95.73
0.2529	4.21	99.94
0.0161	0.27	100.21
0.0100	0.17	100.38

The sum of the eigenvalues is 6; the largest eigenvalue indicates
that its associated eigenvector accounts for over 60% of the
trace and hence over 60% of the variance among the six variables.
Similarly, three eigenvectors account for all but about 4% of the
variation among the variables. Clearly, therefore, there is a
considerable amount of redundancy in the time-related variables
selected for inclusion in the EPA models.

If independent vectors, such as the eigenvectors of the
correlation matrix, were used as terms in the regression
equation, an orthogonal model would result, and there would be no
need for stepwise regression.

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APPENDIX G-2

SOME OBSERVATIONS ON GROSS LIQUID LEAKERS
AS AN EXAMPLE OF AN ALTERNATIVE APPROACH
TO THE MODELING OF HOURLY DIURNAL EMISSIONS

Since evaporative emissions are viewed in M6.EVP.002 as depending
on midpoint VP, via fuel RVP and temperature cycle, it it logical
that interaction of VP with time-related variables be included in
the model. Given a fixed fuel RVP and temperature cycle, though,
it is not clear that the time-related temperature deltas in
M6.EVP.002 actually _do_ anything, so far as providing better
estimates of hourly diurnal emissions are concerned.

Inasmuch as the emission response of gross liquid leakers is
independent of VP, the data for this stratum (#7) provides a
realistic opportunity to examine the consequences of time-related
temperature deltas in an environment free from other influences.

First, the models provide only discrete hourly estimates for the
first 18 hours of the emission cycle. They are based on
regression of the current hourly estimate on temperature deltas
for previous hours (and sometimes the current temperature delta)
as well as products of these temperature deltas. Data are
obtained from as many vehicles as possible in a given stratum.

As a result of the test data sequence, estimates are available
for each hour for each vehicle tested. Thus there are available
already multiple estimates of hourly diurnal emissions. All that
remains to be done, therefore, is to provide the best linear
unbiased estimate for each hour (the EPA model does no more than
this).

By the theory of least squares, quite apart from regression, the
mean of a set of observations _is_ the best estimate of the
expected value of the population from which the sample is drawn.
Regression analysis is invoked when one wants a model for
interpolating responses at predictor values for which there are
no observations. In the overall situation, estimation of the
response at a given point in x-space draws on information from
other points in that space in such a way that optimum estimates
are obtained.

In the present situation, however, it is only the original points
in x-space that are of interest - that is, the hourly
observations. It is a fair question to ask how emissions at the
second, third, ... etc. hours _improve_ the estimate for - say -
the sixth hour, when direct observations for that hour are
already available. Using a regression model based on antecedent
times, therefore, seems to carry an element of circularity. Also,
there seems to be no _real_ gain in succinctness. Though the number

of parameters in the equation may be less than the number of
hours in the day, information for each of those hours is drawn
upon in computing emissions for a given hour.

Nowhere in the report is there a genuine consideration of the
residuals for any of the models. The "unity line" plots do not
provide that information and yet mislead the reader into
believing that the models are "a good fit."

The closest approach to comparing observed and computed values is
in Figure 4-1*[renamed Figure here as 4-3]*, in which the computed
values for gross liquid leakers are plotted as a solid line. In
the usual scatterplot, one would expect the observed values to be
plotted as points to show how well the line cuts through the
observed data. Instead, a bar graph is used to represent the
observed hourly emissions. This bar-graph presentation tends to
obscure the relatively large differences between observed and
calculated responses.

Included in this Appendix is a duplicate of Figure 4-1 *[renamed
Figure here as 4-3]* (see Figure II-1), and, for comparison, a
second plot (Figure II-2) in which the data are presented in the
usual scatter-plot format. In view of the way in which the
calculated values are computed, it is fair to ask whether the
values computed from the model are any better than the values
computed as means of the observations.

There is another disturbing sense in which the models in
M6.EVP.002 depart from convention.   The line plot, though
continuous, is highly segmented and has discontinuous
derivatives. In fact, it should not be represented as a line at
all. The models provide estimates only on the discrete domain [1
2 3 ... 22 23 24] and are inapplicable at - say - 3.5 or 12.2.
It is here that some form of smoothing might be considered.
Figure II-3 employs cubic spline interpolation to provide a
continuous version of Figure 4-1 *[renamed Figure here as 4-3]* of
the report. The smoothed version offers no advantage, however,
and is included only to show that the terms in the EPA model
could not provide a curve as convoluted as Figure II-3.

It is the contention of this reviewer that the emission
observations should not have been discretized in the first place.
It is much easier to deal with emissions as a continuous function
of time rather than as 24 (or 19) discrete quantities, the hourly
emissions. A continuous model can be developed, and that model
can then be differentiated or subjected to a differencing
operation to provide hourly emission estimates.

Figure II-4 is a cumulative plot of the modified hourly diurnals
as given in Table 4-4 of the report. With the exception of a
slight kink in the curve at two hours, the cumulative is a smooth
S-shaped curve. If further smoothing were considered necessary,
one could invoke cubic splines for this purpose, or even

intuitive "fairing" of the curve. It is conjectured, however, that the cumulative curves from evaporative emissions will be smooth and relatively simple.

In Figure II-5 a second plot is added; that is a cumulative plot of the hourly emissions as computed from the equation 7a of the report. The fact that the two plots are very close together indicates that the delta terms in the EPA model are not necessary and that a smooth curve drawn through the cumulative mean hourly emissions would suffice as the time-dependent part of the model.

The argument becomes more convincing when it is realized that the model is just an artifice for reproducing the means of the hourly emissions. The closer the model-computed hourly emissions reproduce the <u>average</u> hourly emissions, the higher the R-square and the happier is the analyst. A model that <u>exactly</u> reproduces those averages is just a sequential list of those averages, inasmuch as the model, whatever its form, operates only in the finite domain [1 2 3 ... 19 ... 24].

In reality, the quoted R-square for the Landman model is highly exaggerated relative to what an "honest" regression model attempts to do. By averaging the emissions across tests, the analyst <u>removes</u> the major source of variation. If each hourly emission for each test had been regressed on the terms used in the model, R-square would have been about 0.13, as estimated from an Analysis of Variance separating the within-hour and between-hour sums of squares.

Because of its simplicity, gross liquid leaker data was used to demonstrate the possibility of this simpler approach to modeling hourly diurnal emissions. A similar approach can be applied to the other six strata. The effects of RVP and temperature cycle can be incorporated as dummy variables to further desegregate data within strata or as interactions capable of modifying a base-level cumulative curve.

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Appendix H

Response to Peer Review Comments from Harold Haskew

This report was formally peer reviewed by two peer reviewers (H. T. McAdams and Harold Haskew). In this appendix, comments from Harold Haskew are reproduced in plain text, and EPA's responses to those comments are interspersed in indented italics. Each of these comments refer to page numbers in the earlier draft version (dated July 1, 1999) that do not necessarily match the page numbers in this final version. Comments from the other peer reviewer appear in the preceding appendix (Appendix G).

This peer review included its own appendix identified in the review as Appendix F. It has been renumbered as Appendix H-1.

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Comments Concerning

M6.EVP.002,
"Modeling Hourly Diurnal Emissions and Interrupted Diurnal Emissions Based on Real-Time Diurnal Data"

By

Harold M. Haskew,P.E.

Overall

This report is difficult to read and comprehend.

A traditional Introduction and a Conclusions Section would help.

Why are we concerned with hourly emissions, or interrupted diurnals? Why is this information necessary? What new insight is gained by including this detail into the Mobile6 model? It would help the reader if this were established in the opening section.

Has the Baltimore-Spokane vehicle operation data been analyzed to see what the typical vehicle use patterns are? How many vehicles are driven at least twice before noon? The GM SAE paper suggests that these vehicles would have no "diurnal."

Those data have been analyzed (see report number M6.FLT.006). The analyses in this report suggest that the diurnal emissions from those vehicles would be small.

If there is a need to add additional fidelity into the inventory model, are there sufficient data available to make appropriate estimates at the detail level suggested? If not, should a recommendation be made for additional research?

Additional testing is being considered. However, analyses based on the results of any future testing will not be available for MOBILE6.

The report is strongly biased to another report (M6.EVP.001) which is not currently available in its updated form. Would it help to briefly repeat the conclusions and limitations of 001 in this report?

The final version of that report (M6.EVP.001) is now available. The primary conclusions/results in that report were the selection of the equations that MOBILE6 uses to model full-day diurnal emissions and hourly resting loss emissions. These equations are repeated in Appendices A-D in this report.

Has the author overanalyzed the data set? Statistics and coefficients are used extensively. Are the relationships appropriate? And will future data sets validate the same relationships?

These questions seem to be rhetorical in nature and require no answers.

Plots of the modeled relationships overplotted with the actual data points would help the reader to comprehend the success of the prediction.

Thirteen new bar charts (comparing the actual hourly diurnal to the predicted) were added to the existing seven scatter plots in Appendix D.

Specific Comments

The abstract contains notes and instructions to the reader that appear to be out of place. Should not Paragraphs 2 and 3 of the "Abstract" be in a separate section?

Those paragraphs (requesting comments from the reader) have been dropped from this "final" version of the report. They were present in the draft version of this report because EPA was still considering suggestions on how the MOBILE model should treat hourly diurnal emissions. Now that EPA has selected its approach, those paragraphs have been dropped.

The 1.0 Introduction leaps quickly to detail and discussions containing temperature cycles, etc., before establishing what the report is about. The right words are there, but need some rearrangement to help the reader understand the objective and order of presentation.

Would it help to rearrange the report using the outline below?

Page 6, Fig 3-1 illustrates the concept of hourly emissions with real data, but then at Table 4-1 goes on to present the time to 25%, 50%, and 75% of full day (the "four critical times"). Why did the author not stay with the hourly emissions concept? Have I mis-interpreted the way the model will handle the data?

> *No, the peer reviewer has not misinterpreted the way MOBILE6 handles diurnal emissions; the emissions are estimated on an hourly basis. Therefore, the analyses (in this report) are on that same hourly basis.*
>
> *In the section of this report in question (4.1), EPA selected a few "key" values (namely the hours that correspond to the three quartile values and the hour corresponding to the peak (mode) emissions) prior to performing the full (hourly) analyses. The selection of these "key" values was somewhat arbitrary. This preliminary approach was used to simply confirm that the characteristics of the hourly diurnal emissions of the individual strata were different. The analyses that resulted in the models actually used in MOBILE6 were based on hourly emissions.*

Section 4.2 (Calculating Hourly Diurnal Emissions by Strata) is very tough to follow. Given the small amount of data present, should the model use only carbureted and fuel injected as fuel type, normal and high as conditions, and a simple sliding adjustment for the temperature effect? Figure 4, at right, illustrates an analysis made for the CRC E-9 Diurnal program. Could this kind of correlation provide a better estimate than the 12 strata ? Why must one use "fail pressure", for example, if those tests are not being used in the field?

Diurnal Emissions vs. Model Year
**All Vehicles (less 8 carb. outliers)**
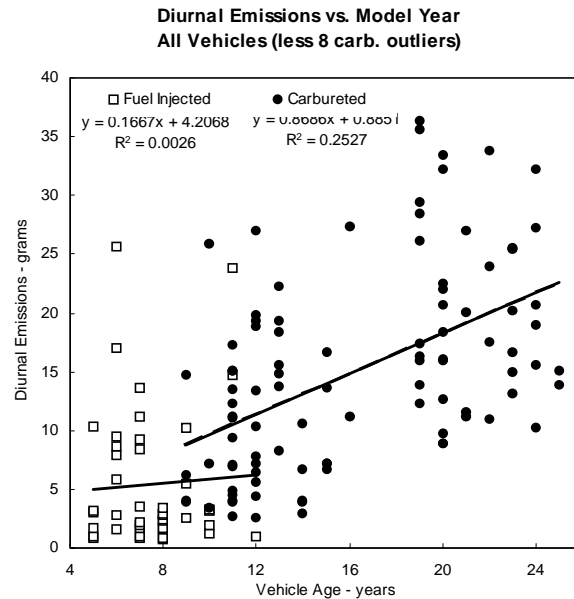
Figure 4

The reviewer makes a good point. In fact, this (suggested) approach is similar to what is used in the portion of MOBILE6 that estimates exhaust (i.e., tailpipe) emissions. However, in any approach that estimates the emissions within individual stratum (i.e., either the suggested or the one used in this report), it is necessary to eventually assemble the individual results by using weighting factors. We already have such factors based upon the purge and pressure tests; we do not have the necessary weighting factors based on emission levels (i.e., normal emitters, high emitters, . . .). In future analyses, we may have the data necessary to develop these recommended weighting factors.

4.2.3 "Gross Liquid Leaker" really begs a plot of measured emissions versus age, for FI and Carb vehicles, with the modeled result overplotted, much in the manner of the plot to the right.

The frequency and emissions of these "Gross Liquid Leakers" are analyzed in report M6.EVP.009, entitled "Evaporative Emissions of Gross Liquid Leakers in MOBILE6." In that report we note that the only vehicles identified on the RTD test as being gross liquid leakers were six carbureted vehicles. We point out that could mean either that carbureted and fuel-injected vehicles are different relative to their vulnerability to leaks or that there simply were not enough older fuel-injected vehicles in the sample. Until more data become available, EPA will use the second assumption. Therefore, we do not have separate graphs for carbureted and fuel-injected vehicles.

As to any graph of the magnitude of the emissions versus age, we believe that there simply are not enough data to support that type of analysis. (There are three age groupings, with the highest emissions coming from the single vehicle in the middle age group.)

At 5.1, <u>Interrupted Diurnal,</u>   A plot previously furnished to the Agency (See below) would help to illustrate the concept. A full set of these plots, and the text that explains them is included later in this report.

HOT URBAN DRIVING - THREE TRIPS
GM ENVIRONMENTAL CELL
1989 Cadillac Eldorado
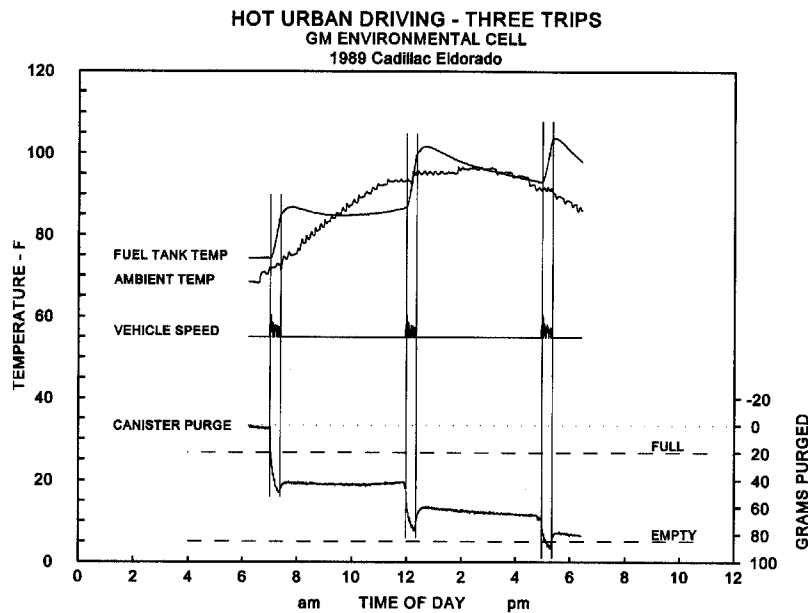
Electronic copies of the sample plot above were previously made available to the agency, and can be furnished again if requested.

Section 5.2 of this report has been revised to note this phenomenon. (See similar comment on page 95.)

Report Clarity

This report is difficult to read and comprehend. Plots, charts, and numeric examples would help.

The report has been revised by including more charts and plots.

Appropriateness of datasets selected

The real-time diurnal data analyzed appear to be the most appropriate (only) data available. The interrupted diurnal

analysis begs for a vehicle use factor. EPA has a large body of
data (e.g., Baltimore-Spokane) collected to study how, and when
during the day, vehicles are driven. Has this been analyzed? For
instance, what percentage of the vehicles driven today have one
or more trips before 10AM?

> *In a parallel report, M6.FLT.006 (entitled "Soak Length
> Activity Factors for Diurnal Emissions"), EPA analyzes data
> from an instrumented vehicle study conducted in Baltimore,
> Spokane, and Atlanta to determine what percent of the fleet
> is undergoing either full-day or interrupted diurnal at each
> hour of the day. The fact that the results of that study
> (of activity data) are necessary to weight the hourly
> diurnal emissions has been added to this report both in the
> introduction and at the end of Section 5.2 (pages 1 and 31,
> respectively).*

The Data Analysis

The report as written does not help the reader understand what
analysis was made.

One quarrel with the analysis described in this report comes from
the author's attempt to create relationships where little, or
inappropriate, data is available. A strong suggestion that more
tests are required would help.

> *We appreciate the reviewer's suggestion that more data are
> required. Hopefully, those additional data will be
> available when this analysis is revisited.*

Conclusions

There are no conclusions, or findings, offered.

> *A conclusion section was added to this version.*
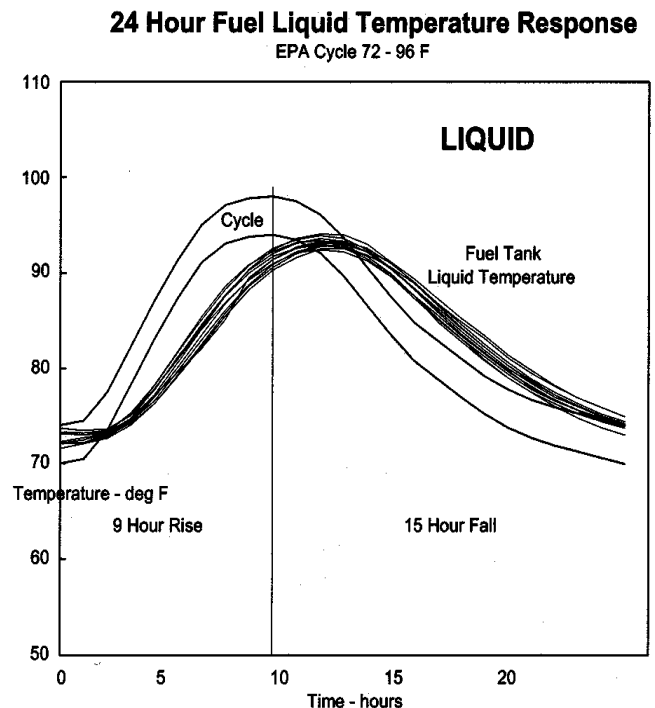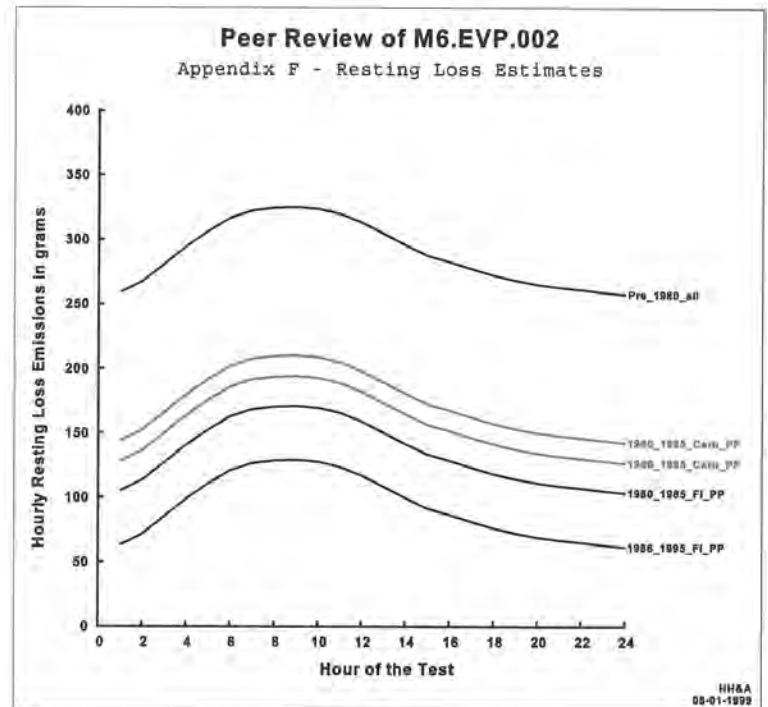
Appendix F *([renamed here as **Appendix H-1**])*

The estimates for hourly resting loss emissions mentioned in Appendix F **[renamed here as Appendix H-1]** appear to follow a simple correlation to the ambient temperature, with an initial value offset to reflect various technologies and conditions. The plot shown below and to the right presents plots of some of the combinations listed in Appendix F [renamed here as Appendix H-1], focusing on the "pass pressure" condition, and the 72 to 96°F diurnal cycle.

If "resting losses" are for the main part, permeation, why not pursue an exponential form of temperature correction? Is the simple form in Appendix F [renamed here as Appendix H-1] appropriate? Why?

> *Over the range of applicable temperatures, the linear form accurately predicted the actual resting loss emissions.*
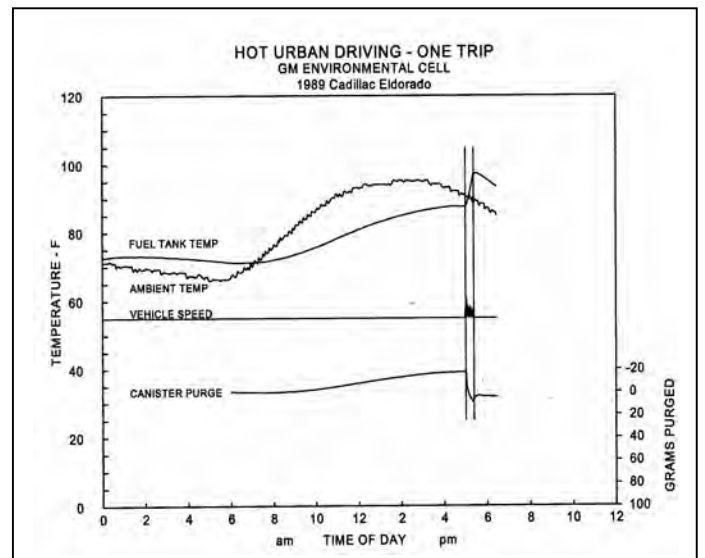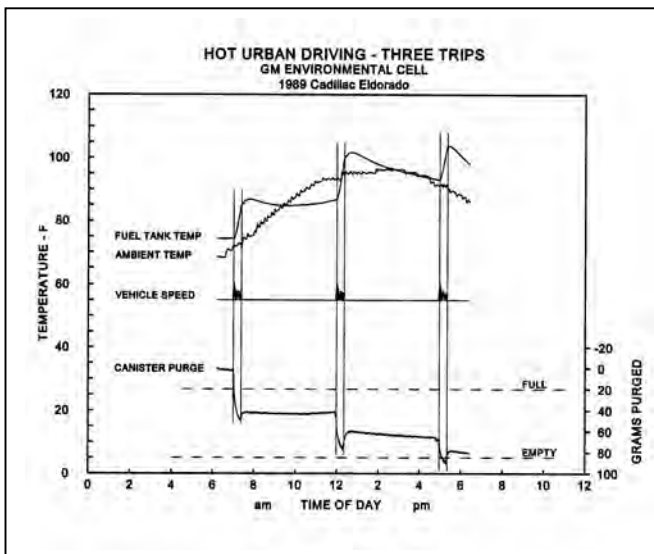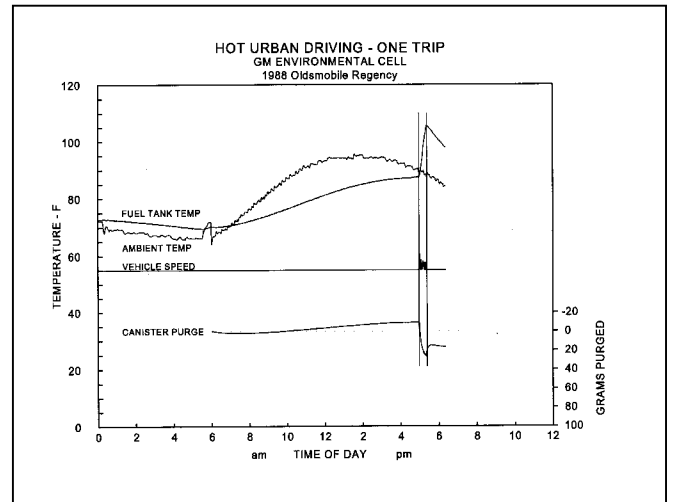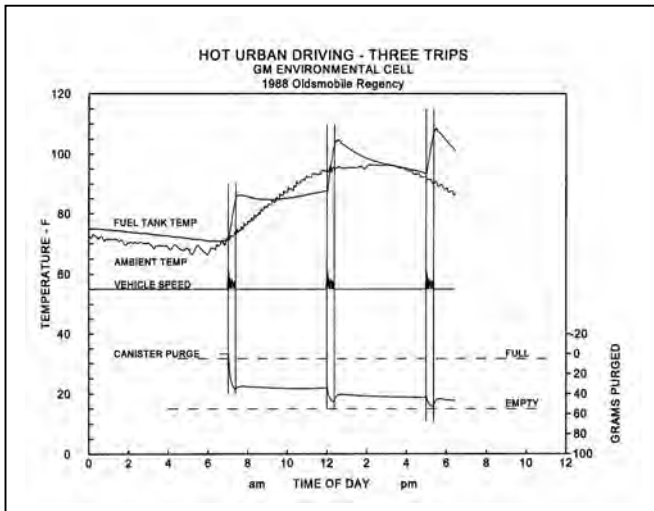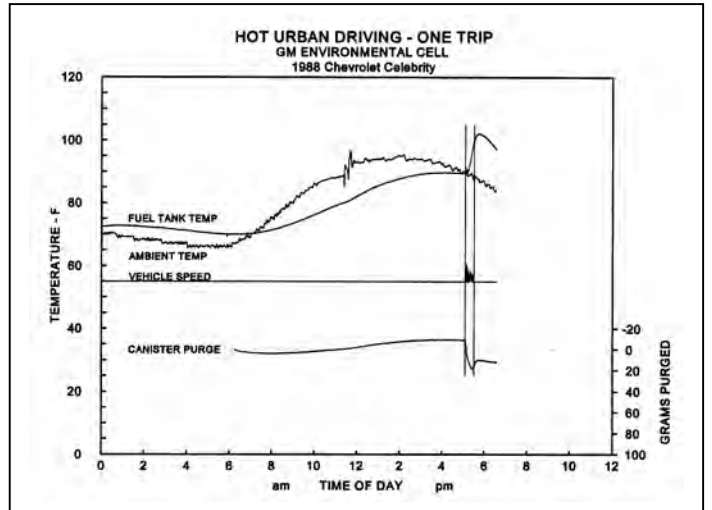
The figure on the right (taken from SAE 1999-01-1463) illustrates that the temperature of the liquid in the fuel tank lags the ambient temperature change during a real-time diurnal experience. The permeation from hoses and other materials must have a similar time lag response. Should the "resting loss" estimate emulate the lag factor seen here? If not, why?

> *If we assume that time lag (one to two hours) associated with the resting*

Peer Review of M6.EVP.002 — Appendix F – Resting Loss Estimates

24 Hour Fuel Liquid Temperature Response — EPA Cycle 72 - 96 F

loss emissions, then the temperature cycles (Appendix A) and resting loss models (Appendix F) combine to suggest that the effect on hourly resting loss emissions would be less than 0.02 grams per hour. (The sum of the 24 hourly resting losses, producing the estimate of the full-day's resting loss, would be virtually unchanged.) Since the overall effect of this hypothetical time lag on resting loss emissions appears to be almost negligible, EPA will not pursue it until more data become available.

Measured Performance under Interrupted Diurnal
Conditions -- SAE 891121

HOT URBAN DRIVING - THREE TRIPS
GM ENVIRONMENTAL CELL
1988 Chevrolet Celebrity

HOT URBAN DRIVING - ONE TRIP
GM ENVIRONMENTAL CELL
1988 Chevrolet Celebrity

HOT URBAN DRIVING - THREE TRIPS
GM ENVIRONMENTAL CELL
1988 Oldsmobile Regency

HOT URBAN DRIVING - ONE TRIP
GM ENVIRONMENTAL CELL
1988 Oldsmobile Regency

HOT URBAN DRIVING - THREE TRIPS
GM ENVIRONMENTAL CELL
1989 Cadillac Eldorado

HOT URBAN DRIVING - ONE TRIP
GM ENVIRONMENTAL CELL
1989 Cadillac Eldorado

(Excerpted from)
EVAPORATIVE EMISSIONS UNDER REAL-TIME CONDITIONS
SAE 891121

GM'S TEST PROGRAM - To conduct the real time test program, GM developed an ambient "high temperature" daily profile using published EPA data on Los Angeles [19] and maximum temperature limits from the June 30, 1988 workshop. [7]

The 90th percentile hourly temperature levels for the Los Angeles area during May-October, inclusive, are plotted as the lower curve in Figure 1. The lowest temperature occurs at 5 a.m., and is 63.2°F. The highest temperature is 91.9°F. at 2 p.m. The difference between the high and low is 28.7°F. The temperature rises from low to high in 9 hours, and cools in 15 hours.

Recent discussion of "excess" emissions has focused on a daily high temperature of 95°F. For the purposes of GM's test program, three degrees were added to each hourly reading to maintain the "Los Angeles" curve shape and reach a 95°F. maximum. The resulting test profile is shown as the upper curve in Figure 1. Rounding to the nearest degree, the low is 66°F. at 5 a.m., and the high is 95°F. at 2 p.m. The resulting 29 degree daily rise is more severe than the 24 degree rise in the FTP (60 - 84°F.).

Some pertinent features of the vehicles used in the GM test program are summarized in Table 1 below.

TABLE 1
VEHICLES USED IN
HIGH TEMPERATURE DRIVING TESTS

YEAR	ENG	TYPE	BODY TYPE	NOMINAL TANK SIZE (gal.)	PURGE OVER HOT LA-4 (ft^3)
1989	4.5L	V-8 TBI	Cadillac Eldorado	18.8	7.9
1988	3.8L	V-6 PFI	Oldsmobile Regency 98	18.0	11.2
1988	2.5L	L-4 TBI	Chevrolet Celebrity	15.7	4.2

All three were low mileage production vehicles equipped with automatic transmissions. Several specific modifications were made in the evaporative control hardware on each vehicle, for purposes of these tests.

First, the components of the evaporative emission control system of one vehicle, the Eldorado, were modified to ensure that tank headspace pressure was maintained near atmospheric levels throughout the testing. The modifications were performed specifically for this test program because: 1) some EPA policy statements have supported use of fuel and evaporative system designs that maintain tank headspace pressures near ambient levels, and 2) prior EPA users of the PT Model may have assumed that tank headspace pressures were at ambient levels. [16, 20, 21]

Secondly, each vehicle was equipped with an in-use 1500 cc canister. This was done to approximate the conditions under which, according to EPA's "excess" evaporative analysis, there would be no capacity left. An Agency spokesperson at the June 1988 workshop had stated that a "1.8 liter canister," which is presumably a canister having a nominal 1500 cc of activated carbon, would be predicted by the EPA staff not to have "any capacity at the end of the day." [22]

GM began the program with three trip days for each vehicle. For this series of tests, the vehicle canisters were fully loaded to "break- through" with butane the night before. A standardized definition of "breakthrough" loading does not exist in the engineering community. Industry representatives sometimes consider a canister "saturated" when it has reached a breakthrough level, typically two grams, under laboratory loading conditions. EPA at one time proposed that canisters be loaded with repeated vehicle diurnal heat builds in a SHED until the SHED concentration increased by a specified percentage. [8] These two methods may give different results.

Three Trip Test Results - The results of the three trip day tests are displayed on Figures 2, 3, and 4. The canister weight for each vehicle, measured at two second intervals, is displayed on the lower panel of each figure, while the ambient and fuel tank liquid temperatures appear in the upper panel. A trace in the middle of each figure identifies the driving periods.

The data show that each vehicle ended the three trip day having lost canister weight. In each instance, measurable new canister capacity was created during each LA-4, and the hot soaks at the end of the LA-4s used only part of the capacity created in the preceding drive. The Eldorado canister lost 76 grams, and the Regency 98 and the Celebrity canisters lost 45 and 51 grams,

respectively.

The fuel temperature and canister weight traces in Figures 2, 3 and 4 illustrate additional important concepts. One important point relates to the effect of the 7 a.m. drive on fuel system temperatures. The fuel is heated by vehicle operation, and the morning diurnal effect is mitigated or eliminated entirely.

On Figure 2, for example, the Eldorado's 23 minute trip at 7 a.m. increased the fuel liquid temperature from 74 to 84°F. The fuel temperature was 87°F. at the start of the noon trip. The measured canister weight increase following the initial 7 a.m. trip's hot soak was one gram. The "Partial Diurnal" (canister weight gain) for this day was one gram -- effectively zero. All three vehicles exhibited the same effects, although the Celebrity did not heat the fuel as much during the drives.

A second fundamental aspect of evaporative control shown by the Eldorado data is the "back-purge" effect. As Figure 2 shows, the canister weight decreased approximately 9 grams after the noon hot soak to 5 p.m., due to the "back-purge" effect caused by the fuel tank cooling. As the fuel tank cools, it draws air back through the canister in order to achieve an equilibrium condition in the vapor space, thus purging the stored vapors and restoring previous capacity.

One Trip Test Results - GM next ran real-time tests on each vehicle with only a single trip at 5 p.m. Prior to these tests, the canisters were loaded to approximately one third capacity, not unlike the weights at the end of the three-drive days. Figures 5, 6 and 7 show the results of these tests.

Each vehicle in the single trip tests saw a complete diurnal ambient temperature experience, and the canisters gained weight during the day. As Figures 5, 6 and 7 clearly show, however, the fuel temperatures did not experience the same temperature swing as did the ambient, and the canister weight increase was much less than would be predicted by using the ambient temperature swing. The weight loss resulting from the canister being purged during the 5 p.m. trip was considerably more than the weight gained during the day.

Appendix I

Response to Comments from Stakeholders

The following comments were submitted in response to EPA's posting a draft of this report on the MOBILE6 website. The full text of each of these written comments is available on the MOBILE6 website.

Comment Number: 68

   Name / Affiliation: David Lax / API

   Date: December 15, 1997

   Comment:

EPA should re-assess reliance on a single curve to allocate full-day diurnal emissions to each hour of the day for all vehicles other than gross liquid leakers."

   EPA's Response:

Done. This resulted in the most recent draft version of M6.EVP.002 (posted July 1999).

   Comment:

The methodology is flawed because it does not consider the state of vapor loading on the canister at the beginning of the interrupted diurnal.

   EPA's Response:

We agree that this was not incorporated. We have considered a testing program to test the hypothesis. Based on the results of that testing, we may later revise our approach.

   Comment:

More information on the statistical methodology used to develop the regression equations shown in M6.EVP.002 should be provided to the reader.

EPA's Response:

Appendix D was added to the report to provide those data.

Comment:

RVP should have some effect on diurnal emissions of Gross
Liquid Leakers.

EPA's Response:

*EPA believes that any effect of fuel RVP on diurnal
emissions is minimal compared to the actual (total) diurnal
emissions of these gross liquid leakers. We will consider
revising that hypothesis when sufficient test results over a
range of fuel RVPs are available.*

Comment Number:	**N/A.** The following question was asked during the third workshop for MOBILE6.
Name / Affiliation:	Harold Haskew / Consultant & Peer Reviewer
Date:	June 30, 1999

Question:

How does EPA's interrupted diurnal (from Slide 37 of that
presentation which corresponds to Section 5.2 of this
report) compare to Harold Haskew's SAE paper?

EPA's Response:

*That SAE report examines both diurnal emissions and canister
loading. Canister loading should be a factor in interrupted
diurnals. (For an interrupted diurnal to occur, the vehicle
must have been recently driven. However, driving the
vehicle would have resulted in the canister being purged.)
The data used in EPA's analysis (of interrupted diurnals)
was not obtained from vehicles with purged canisters. This
is a potential weakness in our analysis. We will consider
revising the analysis when sufficient test results (on
vehicles with purged canisters) are available.*

*This question is similar to one that this individual brought
up in his peer review (see page 88).*