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Evaluating Resting Loss and Diurnal Evaporative Emissions Using RTD Tests

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ABSTRACT

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 diurnal and resting loss emissions of the in-use fleet to be used in MOBILE6.

This report was originally released (as a draft) in October 1997, and then revised (and re-released) in July 1999. This current version is the final revision of the July 1999 draft (of M6.EVP.001). This final revision incorporates suggestions and comments received from stakeholders during the 60-day review period and from peer reviewers.

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Evaluating Resting Loss and Diurnal Evaporative Emissions Using RTD Tests

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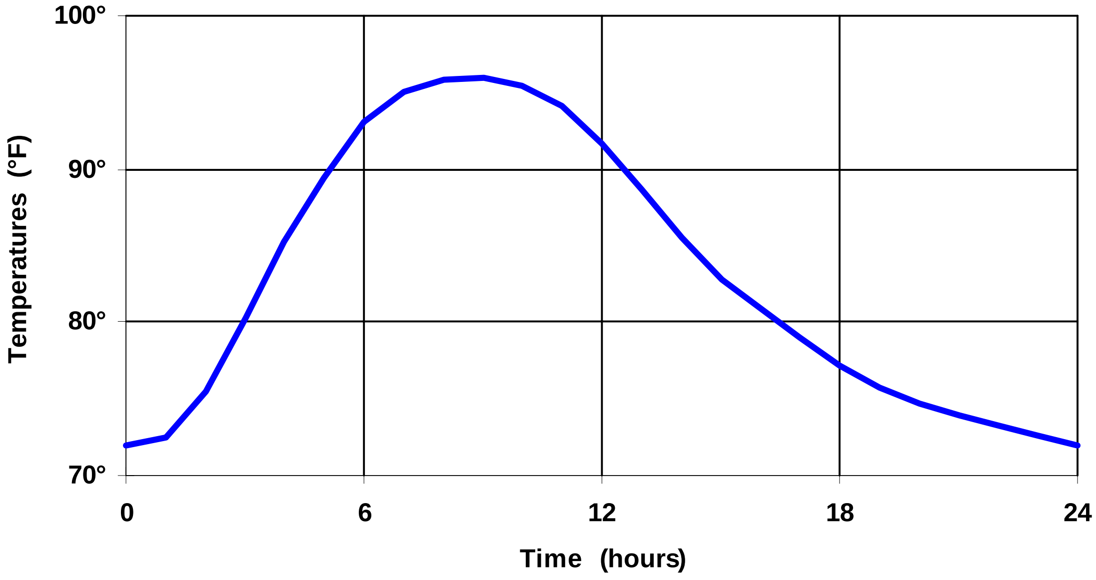
1.0 INTRODUCTION

In previous versions of the highway vehicle emission factor model (MOBILE), the estimates of the emissions resulting from the daily rise of the ambient air temperature were based on a one-hour test (adjusted to simulate an 8-hour test) in which the heating process was accelerated. As part of the MOBILE model revision, an effort has been undertaken to use the recently developed 72-hour real-time diurnal (RTD) test (or a shortened version) to more accurately estimate those temperature driven (i.e., diurnal) emissions, as well as the resting loss emissions.

In the RTD test, the ambient temperatures gradually cycle over a 24 degree Fahrenheit range during the course of each 24 hour period as illustrated below in Figure 1-1:

Figure 1-1

Nominal RTD Temperature Cycle
(Temperatures Cycling Between 72° and 96° F)



The three hourly temperature cycles used in this study are given in Appendix A. These three temperature cycles are parallel (i.e., identical hourly increases/decreases). Each temperature cycle peaks at hour nine (i.e., at 3PM). The most rapid increase in temperatures occurs during the fourth hour. For RTD tests that exceed 24 hours (i.e., 33, 38, or 72 hours), the cycle is simply repeated.

This document reports both on the methodology used to analyze the data from these RTD tests and on the results obtained from those analyses.

2.0 VEHICLE SAMPLE

In this analysis, EPA used real-time diurnal (RTD) test data from two sources:

1) from five (5) individual testing programs (i.e., work assignments) performed for EPA by its contractor, and
2) from a testing program performed for the Coordinating Research Council (CRC).

The RTD testing performed for EPA was done by its testing contractor (Automotive Testing Laboratories) over the course of five work assignments from 1994 through 1996 (performed under three different EPA contracts). A total of 119 light-duty vehicles (LDVs) and light-duty trucks (LDTs) were tested in these programs. In the following table (Table 2-1), the distribution of those 119 test vehicles is given:

1) by work assignment number,
2) by vehicle type (LDV versus LDT),
3) by model year range, and
4) by fuel metering system
    - carbureted (Carb)
    - port fuel injected (PFI)
    - throttle body injection (TBI).

Table 2-1

Distribution of EPA Test Fleet

Work Assignment No.	Vehicle Type	Model Year Range	Fuel Metering Carb	PFI	TBI
2-09	LDV	80-85	5	2	0
		86-95	7	15	10
1-05	LDV	80-85	3	4	3
		86-95	1	24	12
	LDT	86-95	0	0	2
0-05	LDV	71-77	3	0	0
		78-79	1	0	0
		80-85	5	0	0
		86-95	0	0	0
0-07	LDV	86-95	0	5	1
0-11	LDT	71-77	2	0	0
		78-79	0	0	0
		80-85	5	0	0
		86-95	0	5	4

The recruitment method used for most of the vehicles in the EPA sample was designed to recruit a larger number of vehicles that had potential problems with their evaporative control systems. Specifically, two tests of the integrity of each vehicle's evaporative control system (a purge test and a pressure test) were used to screen the candidate vehicles. This resulted, among the newer vehicles, in a larger proportion of the test vehicles failing either a purge test or pressure test (but not both) than did the corresponding vehicles in the in-use fleet. EPA excluded from its sample all those vehicles that failed both the purge and pressure tests. Any analyses performed on the EPA data must, therefore, account for this intentional bias toward problem vehicles. (See Section 4.0.)

It is important to note that neither the purge test nor the pressure test is a perfect identifier of vehicles that have problems with their evaporative control systems. While vehicles that passed both the purge test and the pressure test had, on average, lower RTD emissions than similar vehicles that failed either or both tests, there was a wide overlap of the RTD emissions of the vehicles that passed both tests with the RTD emissions of similar vehicles that failed one or both of those tests. The size of the overlap varied with the strata (see Section 6.4). But, on average, the cleanest (i.e., vehicles with the lowest RTD results) one-fourth of the vehicles failing the purge and/or pressure test(s) had lower RTD test results than the dirtiest (i.e., highest RTD results) similar vehicles that passed both the purge and pressure tests. In fact, the vehicle that had the highest RTD emissions (other than the seven gross liquid leakers discussed in section 7.3) was one that passed both tests.

The CRC program* involved performing RTD tests on a random sample of 151 vehicles (mostly LDTs) during 1996. The distribution of those 151 vehicles (by vehicle type, model year range, and fuel metering system) is given below in the Table 2-2:

Table 2-2

Distribution of CRC Test Fleet

Vehicle Type	Model Year Range	Carb	PFI	TBI
Car	71-77	38	0	0
Truck	71-77	13	0	0
Truck	80-85	47	2	1
Truck	86-91	7	24	19

3.0 VEHICLE TESTING

The testing in the EPA study consisted of performing one or more RTD tests on each vehicle in its "as-received" condition with the exception that the tank fuel was replaced with specified fuels. (To restore the vehicle to its "as-received" condition for subsequent tests, the canister was conditioned to return it to approximately the condition it was in prior to the first test.) Up to three temperature cycles were used. (In addition to the standard 72°-96° F cycle, 60°-84° and 82°-106° cycles were also used.) Similarly, up to four different fuel volatilities were specified; specifically, fuels having nominal Reid vapor pressure (RVP) of 6.3, 6.7, 6.9, and 9.0 pounds per square inch (psi). Since the actual RVP used in a given test may vary slightly from the specified target RVP, EPA felt that tests performed using the 6.7 or 6.9 psi RVP fuel could all be treated as equivalent to tests performed using a fuel with a nominal RVP of 6.8 psi.

The testing in the CRC study consisted of performing a single RTD test on each vehicle in its "as-received" condition. Each test used the standard temperature profile (i.e., temperatures cycling between 72° and 96° F) and was performed using the fuel already in each vehicle's fuel tank (typically having an RVP which ranged from 6.7 to 7.0 psi). EPA felt these

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* D. McClement, J. Dueck, B. Hall, "Measurements of Diurnal Emissions from In-Use Vehicles, CRC Project E-9", Prepared for the Coordinating Research Council, Inc. by Automotive Testing Laboratories, Inc., June 19, 1998.

tests could also be treated as equivalent to tests performed using a fuel with a nominal RVP of 6.8 psi.

For the purpose of the following analyses, we treated all testing performed using fuels with RVPs from 6.7 through 7.0 as if they were all performed using a fuel with a nominal RVP of 6.8 psi. Thus, all the EPA testing performed using fuels with nominal RVPs of either 6.7 or 6.9 will be combined and then used with all of the CRC tests.

4.0 Weighting the EPA Data

To correct for the intentional sampling bias toward "problem" vehicles in the EPA testing programs (described in Section 2.0), we first determined the number of vehicles in each stratum in both the recruited sample and the in-use fleet. Examining the purge/pressure data gathered in the I/M lanes in Arizona and Indiana, we found 16,637 as-received vehicles for which successful purge and pressure tests were performed. (These tested were conducted at the Phoenix, Arizona I/M lane from June 1992 through August 1994 and at the Hammond, Indiana I/M lane from January 1990 through February 1995.)

Modeling those preceding distributions with smooth (i.e., logistic growth) curves as functions of vehicle age* produced the distributions in Table 4-1. A full discussion of this process is given in Document Number M6.EVP.006, entitled "Estimating Weighting Factors for Evaporative Emissions in MOBILE6." The predicted purge failure rates (i.e., the sum of columns two and three in the above table) closely approximates those used in the MOBILE5 model for vehicles up to 12 years of age. The predicted pressure failure rates (i.e., the sum of columns three and five) also closely approximates those used in the MOBILE5 model for vehicles up to 12 years of age. Any differences between the estimates used in MOBILE5 and those in Table 4-1 should not affect the analyses in this report. A detailed analysis of the failure rates on the purge and pressure tests (and, hence on the appropriate weighting factors) is presented in document number M6.EVP.006.

This approach assumes that the purge/pressure results are functions only of age (i.e., independent of vehicle type, fuel metering system, model year, etc.). To use these distribution estimates within a given stratum (e.g., 1980-85 carbureted LDVs), we determined the numbers of vehicles in each of the purge/pressure categories that we would expect to find in a randomly selected sample of the in-use fleet. We then calculated the

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* Vehicle age was estimated by first subtracting the model year from the test year, and then adjusting so that the final value represents the age at January first (which is the standard date for the MOBILE model).

ratio of those expected category sizes to the number of vehicles actually recruited and tested within each of those four categories. Those ratios then became the weighting factors for the analysis of that stratum (only 1995 and older model years). The values in Table 4-1 will be adjusted to account for the presence of an I/M program (see document M6.IM.003, entitled "Estimating Benefits of Inspection/ Maintenance Programs for Evaporative Control Systems").

NOTE: Since no vehicles in the EPA testing programs were recruited from among those that failed both the purge and the pressure tests (the third column in the following table), EPA used the data from the CRC program to characterize the RTD emissions of that category. Since (as Table 4-1 indicates) this stratum is relatively small for newer vehicles, its exclusion had at most only a slight affect on the estimate of fleet emissions of those newer vehicles. (See Section 6.5.)

Table 4-1

Predicted Distribution of Purge/Pressure Results (By Vehicle Age -- Independent of Model Year)

Vehicle Age (years)	--- Results on Purge and Pressure Tests ---			
	Fail Purge Pass Pressure	Fail Purge Fail Pressure	Pass Purge Pass Pressure	Pass Purge Fail Pressure
0	1.77%	0.09%	95.00%	3.14%
1	1.80%	0.12%	94.93%	3.15%
2	1.88%	0.16%	94.72%	3.23%
3	2.02%	0.23%	94.36%	3.39%
4	2.23%	0.32%	93.81%	3.65%
5	2.53%	0.44%	93.03%	4.00%
6	2.95%	0.60%	91.96%	4.49%
7	3.51%	0.84%	90.51%	5.15%
8	4.25%	1.15%	88.57%	6.03%
9	5.23%	1.58%	85.99%	7.20%
10	6.47%	2.16%	82.62%	8.75%
11	8.00%	2.93%	78.30%	10.77%
12	9.76%	3.95%	72.94%	13.35%
13	11.61%	5.26%	66.60%	16.52%
14	13.29%	6.91%	59.58%	20.21%
15	14.51%	8.93%	52.42%	24.14%
16	15.06%	11.30%	45.76%	27.88%
17	14.95%	13.97%	40.14%	30.93%
18	14.41%	16.83%	35.84%	32.93%
19	13.70%	19.73%	32.80%	33.77%
20	13.03%	22.53%	30.81%	33.63%
21	12.50%	25.08%	29.58%	32.84%
22	12.13%	27.31%	28.85%	31.70%
23	11.89%	29.18%	28.45%	30.49%
24	11.74%	30.68%	28.23%	29.35%
25	11.65%	31.87%	28.11%	28.37%

5.0 TEST PARAMETERS

Since emissions from vehicles classified as gross liquid leakers (vehicles identified as having substantial leaks of liquid gasoline, as opposed to simply vapor leaks) are characterized separately from those of the remaining vehicles, the analyses in this section were also performed with those vehicles omitted (see section 7.3).

There are three testing parameters in the EPA programs that could affect the RTD test results. (The results of the RTD tests include both diurnal and resting loss emissions.) Those are:

1) the RVP of the test fuel,
2) the temperature cycle, and
3) the site from which each vehicle was recruited.

Since it is well known that both the ambient temperature and the fuel volatility will affect evaporative emissions, these two parameters were automatically included in the calculations. All of the analyses that used tests performed with fuels ranging from 6.7 to 7.0 psi RVP were conducted assuming the nominal RVP to be 6.8 psi, as noted previously.

The question of whether the "site" variable is significant was raised because EPA's testing contractor (ATL) recruited vehicles from two different parts of the country. Twenty-two (22) vehicles were recruited from and tested in Indiana; the remaining 97 vehicles were recruited from and tested in Arizona. Since the higher temperatures in Arizona might have resulted in higher canister loadings for those as-received vehicles, we compared the cumulative distributions of the 24-hour RTD results (weighted to correct for recruitment bias) of the 1986 and newer LDVs tested at both sites. In Figure 5-1, we compare the six PFIs tested in Indiana with the 35 in Arizona. In Figure 5-2, we compare the four TBIs tested in Indiana with the 17 in Arizona. All of these 24-hour RTD emissions were obtained using 6.7-6.9 psi RVP fuel over the 72°-96° Fahrenheit cycle.

Despite the small sample sizes in the Indiana data (only six PFIs and four TBIs), the closeness of the distribution curves (in Figures 5-1 and 5-2) is compelling and suggests that there is no reason to treat the test data separately. Therefore, the "site" parameter was dropped from the remaining analyses.

Figure 5-1

Weighted Cumulative Distributions at Two Sites
RTD Emissions of the 1986 and Newer PFIs

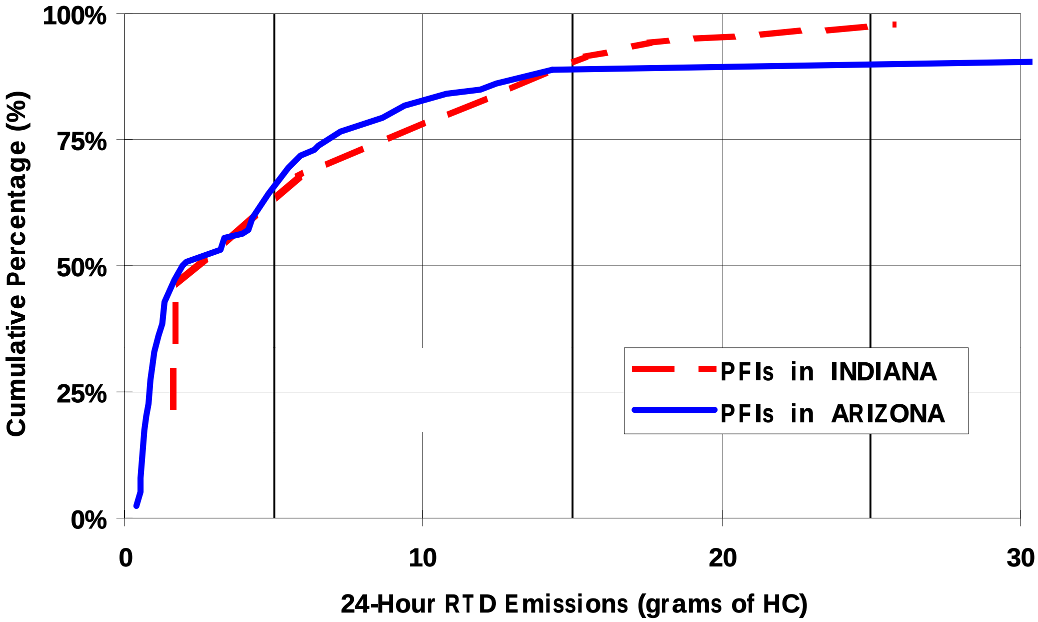
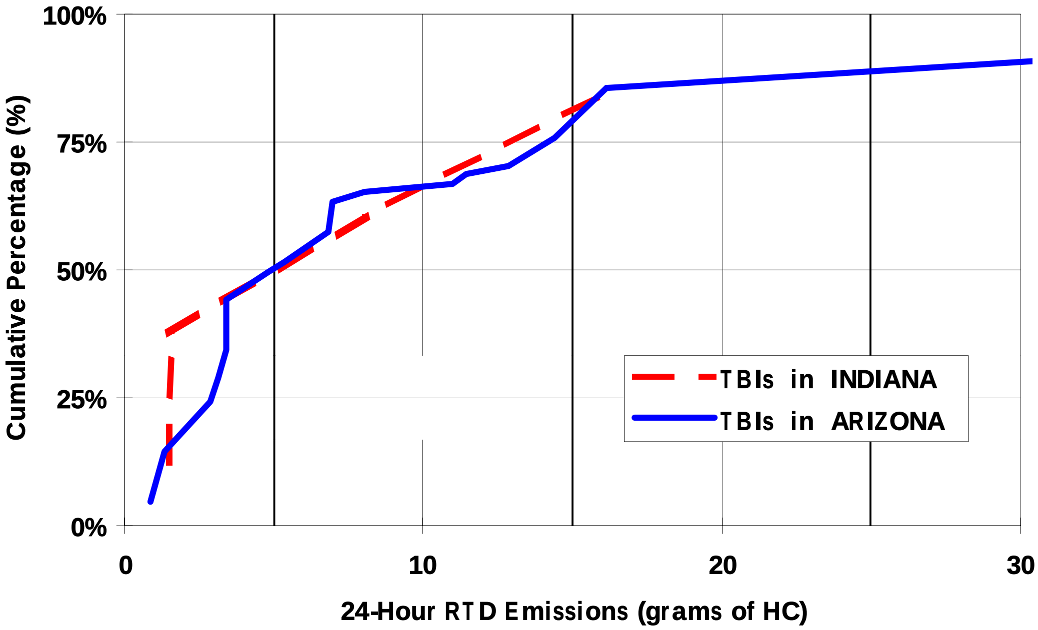


Figure 5-2

Weighted Cumulative Distributions at Two Sites
RTD Emissions of the 1986 and Newer TBIs



6.0 CONSOLIDATING VEHICLE PARAMETERS FOR 24-HOUR RTD

Since emissions from vehicles classified as gross liquid leakers (see section 7.3) are characterized separately from those of the remaining vehicles, the analyses discussed in this section were also performed with those vehicles omitted.

When analyzing exhaust emissions, we note that some vehicle technologies (sometimes identified by model year ranges) have distinct exhaust emission characteristics. Before beginning the primary analysis of these evaporative emissions, we examined the data to determine if analogous technology groupings exist for the RTD test results. Specifically, it was necessary to determine:

1) whether test results from different model year ranges (i.e., 1981-85 and 1986-93) can be combined,
2) whether test results from port fuel-injected vehicles (PFIs) can be combined with throttle body injected vehicles (TBIs) into a single stratum of fuel-injected vehicles,
3) whether test results from carbureted vehicles can be combined with fuel-injected vehicles, and
4) whether test results from cars and trucks can be combined (despite the differences in fuel tank size).

We stratified the test vehicles using the following three model year ranges:

1) 1972 through 1979,
2) 1980 through 1985, and
3) 1986 through 1995.

Based on the assumption that changes to the EPA certification requirements for evaporative emissions will result in changes to vehicles' evaporative control systems, we separated the RTD results on the pre-1980 vehicles from the results on the 1980 and newer vehicles. (For the same reason, data from the 1996 and newer model year vehicles will form a new stratum once we begin to test those vehicles.) While a similar argument can be made for an additional break at the 1978 model year point, we lacked the data to separately analyze the 1978-79 model year vehicles. A second break point was added between the 1985 and 1986 model years at the recommendation of some of the automotive manufacturers who based their suggestion on improvements in the control of evaporative emissions. Therefore, this second break point was not based on any changes in EPA test requirements or applicable standards nor on any analysis of the results of the RTD tests.

6.1 Comparing TBI and PFI Vehicles

To determine the appropriateness of combining the RTD test results of PFIs with those of TBIs, we found two samples containing otherwise similar vehicles:

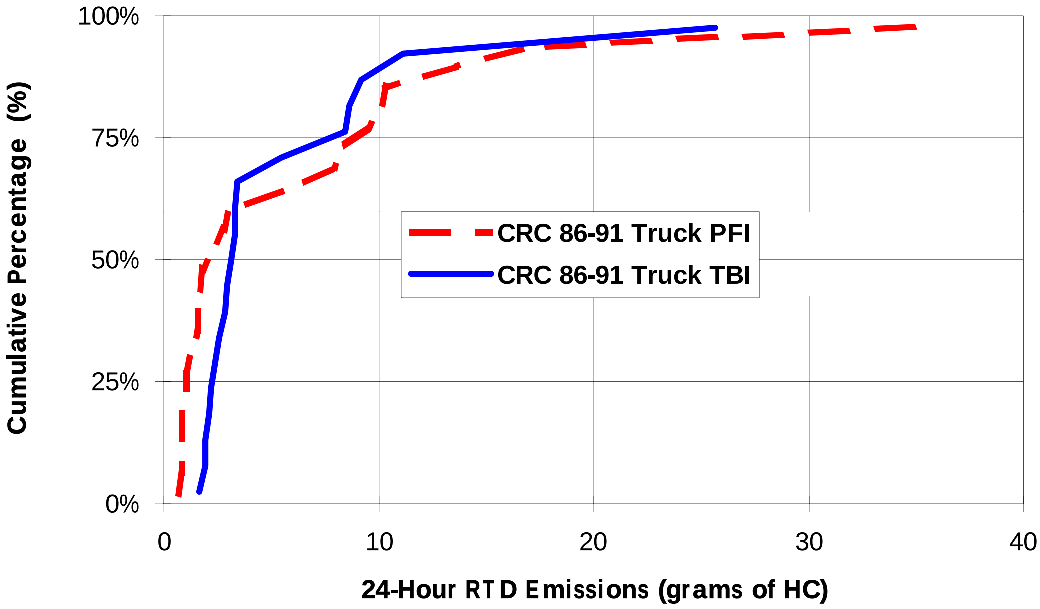
1) 1986 and newer trucks in the CRC testing program (see Figure 6-1) and

2) 1986 and newer LDVs in the EPA testing program (see Figure 6-2).

In each of those two samples, the testing was performed over the 72°-96° temperature cycle using fuel with an RVP ranging from 6.7 to 7.0 psi. The similarity between PFI and TBI among the 1986 and newer model year trucks in the CRC testing program is illustrated in Figure 6-1.

Figure 6-1

Cumulative Distributions of PFIs and TBIs RTD Emissions in the CRC Testing Program



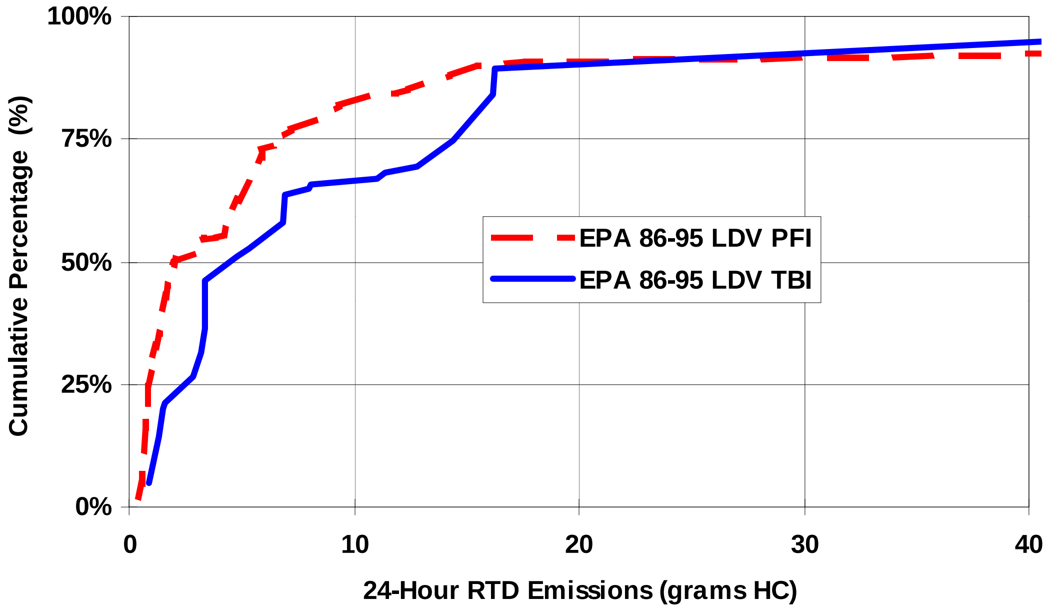
Characterizing those two CRC samples yields (in units of grams per day over the RTD test):

	Sample Size	Median	Mean	Standard Deviation
1986-91 CRC Truck TBIs	19	3.13	5.41	5.70
1986-91 CRC Truck PFIs	24	2.05	5.85	7.87

The similarity between PFI and TBI among the 1986 and newer model year LDVs in the EPA testing program is illustrated on the following page in Figure 6-2.

Figure 6-2

Weighted Cumulative Distributions of PFIs and TBIs RTD Emissions in the EPA Testing Program



Both the distributions shown in Figure 6-2 and the characterizations of those two EPA samples presented in the following table (in units of grams per day over the RTD test) have been weighted to correct for recruitment bias.

	Sample Size	Median	Mean	Standard Deviation
1986-95 EPA LDV TBIs	21	4.52	9.84	12.22
1986-95 EPA LDV PFIs	41	2.08	9.32	19.75

Based on the similarity of the cumulative distribution curves and on the close fit of the means relative to the respective standard deviations (in the strata illustrated in Figures 6-1 and 6-2), the PFI and TBI strata were merged into a single fuel-injected (FI) stratum for the remaining analyses.

6.2 Comparing Carbureted and Fuel Injected Vehicles

To determine whether test results from carbureted vehicles can be combined with those from fuel injected vehicles, we identified the only four samples containing otherwise similar vehicles:

1) in the CRC testing program, 43 1986-1991 FI trucks and 7 corresponding carbureted trucks (see Figure 6-3),
2) in the EPA testing program, 64 1986-1995 FI LDVs and 6 corresponding carbureted LDVs (see Figure 6-4),
3) in the CRC testing program, 3 1980-85 FI trucks and 46 corresponding carbureted trucks, and
4) in the EPA testing program, 6 1980-85 FI LDVs and 13 corresponding carbureted LDVs.

However, the two comparisons using the 1980-85 model year vehicles produced mixed results (possibly due to the small number of FI vehicles in the samples).

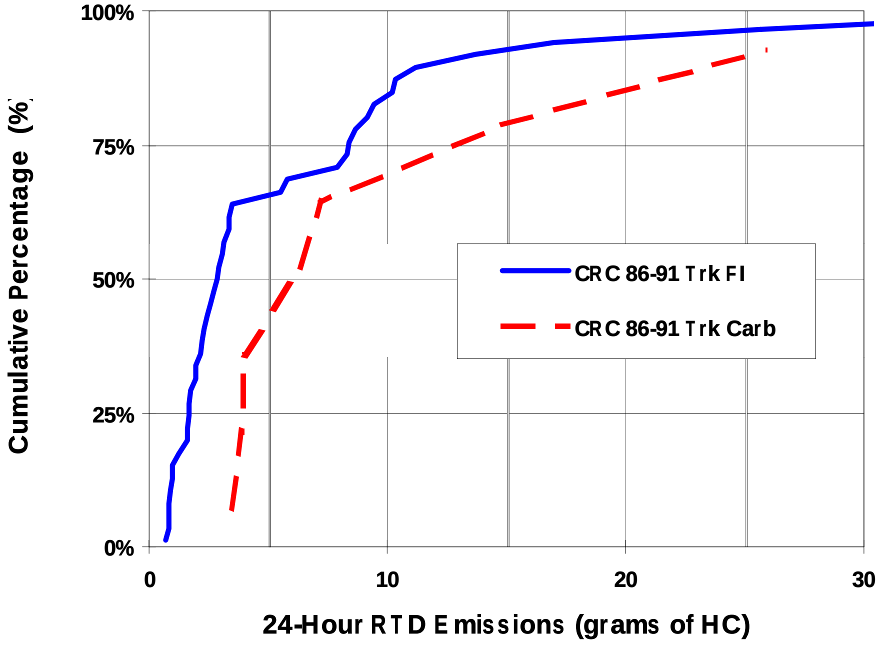
The difference in the distributions between carbureted (Carb) and FI trucks among the 1986-1991 model year trucks in the CRC testing program is illustrated in the following table (in units of grams per day over the RTD test) and in Figure 6-3.

Comparing Carbureted Trucks to Fuel-Injected Trucks

	Sample Size	Median	Mean	Standard Deviation
1986-91 CRC LDT Carbs	7	6.15	9.31	8.28
1986-91 CRC LDT FIs	43	2.85	5.65	6.92

Figure 6-3

Cumulative Distributions of FIs and Carb Trucks RTD Emissions in the CRC Testing Program



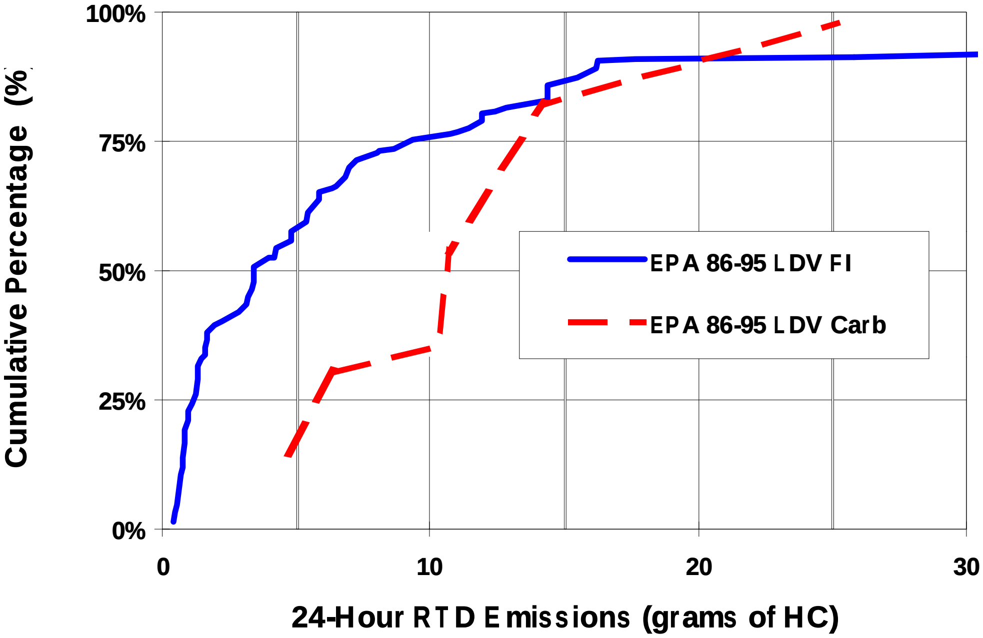
Similarly, the difference in the distributions between carbureted (Carb) and FI cars among the 1986-1995 model year LDVs in the EPA testing program is illustrated in the following table and in Figure 6-4. Both the distributions shown in Figure 6-4 and the characterizations of those two EPA samples represented in the following table (in units of grams per day over the RTD test) have been weighted (using Table 4-1) to correct for recruitment bias.

Comparing Carbureted LDVs to FI LDVs

	Sample Size	Median	Mean	Standard Deviation
1986-95 EPA LDV Carbs	6	10.56	10.34	6.73
1986-95 EPA LDV FIs	64	3.41	9.50	17.23

Figure 6-4

Weighted Cumulative Distributions of FIs and Carbs LDVs RTD Emissions in the EPA Testing Program



Statistical tests support the hypothesis that the means of the RTD test results are different for the 1986-1991 model year trucks. Also, the large standard deviation (relative to the difference of the means) for the sample of 1986-1995 model year passenger cars will not allow us to confirm that hypothesis using statistical tests. However, it is noteworthy that every carbureted vehicle in each sample had RTD test results higher than the median of the corresponding fuel injected vehicle sample. (An unlikely situation if the RTD emissions of the sample of fuel-injected and sample of the carbureted vehicles were to be indistinguishable from each other.)

Therefore, EPA will treat the carbureted vehicles and the FI vehicles as distinct strata for the remaining analyses.

6.3 Comparing Cars and Trucks

Determining the appropriateness of combining the RTD test results of LDVs with those of LDTs presented different problems. Specifically, the CRC sample was exclusively trucks except for the 1971-77 stratum, and the EPA sample (using 6.7-6.9 RVP fuel) was almost exclusively cars. The obvious solution was to compare the CRC trucks with the EPA cars. However, because of the difference in recruitment methods, we first had to omit from the CRC sample those vehicles which would not have been recruited in the EPA sample (i.e., those failing both purge and pressure), and we then re-weighted the remaining results (as we did with the EPA sample). This produced the following two strata with which to investigate the differences in RTD results between cars and trucks:

1) in the combined EPA and CRC testing programs, the weighted results of 13 1980-85 carbureted LDVs and 44 corresponding carbureted trucks (Figure 6-5), and

2) in the combined EPA and CRC testing programs, the weighted results of 62 1986 and newer FI LDVs and 42 corresponding carbureted trucks (Figure 6-6).

Figure 6-5

Weighted Cumulative Distribution of Cars and Trucks RTD Emissions in the EPA and CRC Testing Programs (1980-1985 Model Year Carbureted Vehicles)

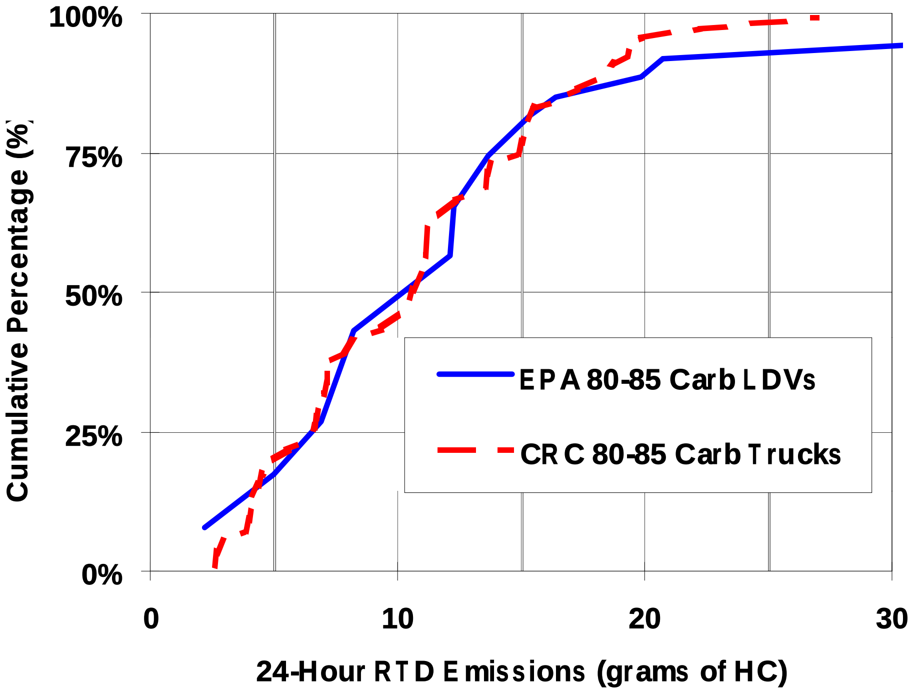
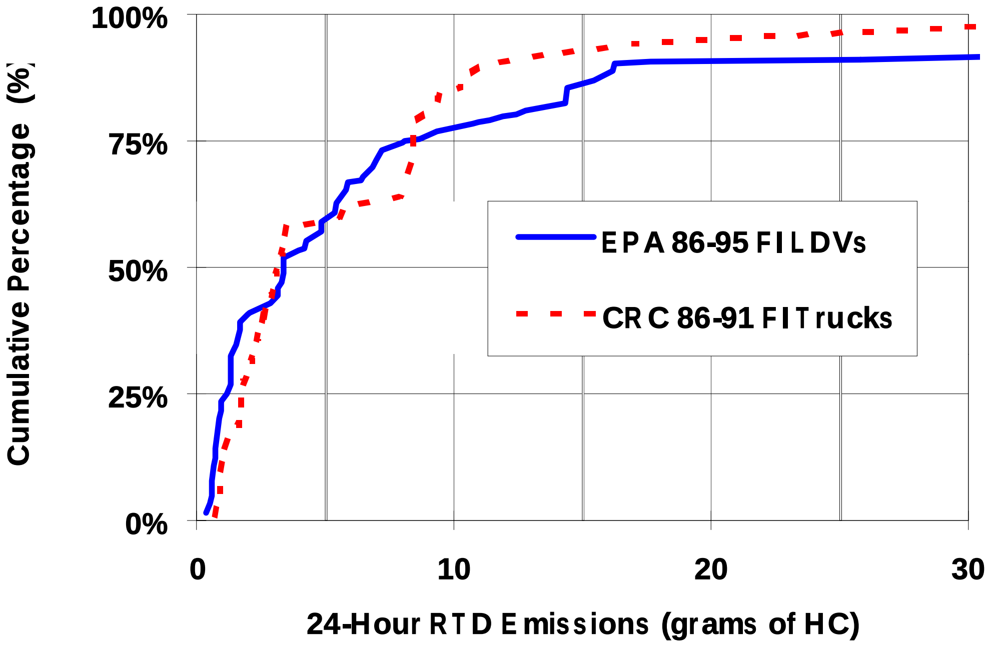


Figure 6-6

Weighted Cumulative Distribution of Cars and Trucks RTD Emissions in the EPA and CRC Testing Programs (1986 and Newer Model Year FI Vehicles)



The distributions in Figures 6-5 and 6-6 and the characterizations of those strata (in the following table, in units of grams per day over the RTD test) have been weighted to correct for the actual recruitment bias in the EPA sample and the simulated bias in the CRC sample.

	Sample Size	Median	Mean	Standard Deviation
1980-85 LDVs Carbureted	13	10.22	11.29	5.04
1980-85 LDTs Carbureted	44	10.55	10.58	6.44
86-95 FI LDVs	62	3.40	9.48	17.54
86-91 FI LDTs	42	3.11	5.99	7.67

In Figure 6-5, the distributions of the carbureted 1980-85 cars and trucks are virtually identical. Statistical tests, using the results from the first two rows in the above table, also support the hypothesis that the means of the RTD test results are the same for the carbureted 1980-85 cars and trucks (relative to the standard deviations). Therefore, EPA will treat the carbureted cars and trucks as a single stratum for the remaining analyses.

In Figure 6-6, the distributions of the FI 1986-95 cars and trucks appear virtually identical up to about the 75 percentile point, after which they diverge slightly. However, statistical tests (using the means, sample sizes, and standard deviations from the preceding table) do <u>not</u> support the hypothesis that the means of the RTD test results are the same. Regardless of the statistical tests, EPA decided to treat the fuel-injected 1986-95 model year cars and trucks the same for the following two reasons:

- the similarity of the cumulative distributions up through the 75 percentile point, and
- the shortage of the RTD testing of the 1986-95 model year FI trucks over a range of temperature cycles and fuel RVPs (which would be necessary to characterize the RTD emissions if trucks were to be treated differently than cars).

Therefore, EPA will combine the cars and trucks into a single stratum for the remaining analyses. This conclusion seems reasonable based on the fact that the larger fuel tanks (and hence potentially larger vapor volumes) of trucks are offset by the reportedly larger canister volumes.

6.4 Summarizing Stratification Parameters

For each combination of the pass/fail results on the (screening) purge test and pressure test (i.e., recruitment groups), we stratified the combined 119 vehicle EPA and 151 vehicle CRC data into the following five strata:

Model Year Range	**Number of Carbureted Vehicles**	**Number of Fuel Injected Vehicles**
1971-1979	57	*
1980-1985	65	12
1986 and Newer	15	121

* No data were available for this stratum. We simply applied the results of the 1971-79 carbureted vehicles to characterize this stratum.

These five (tested) strata, in the above table, were then subdivided to include the recruitment criteria and yielded the 20 substrata listed in Appendix C. Three of these 20 strata were not tested, and two of the remaining had only limited coverage. These five missing or poorly covered strata are comprised of vehicles that failed both the purge and pressure tests.

6.5 Evaluating Untested Strata

As noted in the previous section, the strata that are either missing or poorly represented in our sample fall into two categories:

1) No pre-1980 model year vehicles equipped with fuel injection were recruited because of the small numbers of pre-1980 model year vehicles in the in-use fleet.

2) The vehicles that failed both the purge and the pressure tests were:

    - systematically excluded from the EPA sample and

    - missing or poorly represented in CRC's sample of the newer model year vehicles due to their relative rarity among the newer vehicles (see Table 4-1).

For the MOBILE model, EPA will estimate the RTD emissions of the (untested) pre-1980 fuel injected vehicles as being identical to the corresponding emissions of the pre-1980 carbureted vehicles. This should be a safe assumption since any actual differences between these strata should be balanced by the relatively small number of these fuel injected vehicles in the in-use fleet. (In fact, MOBILE6 assumes that the pre-1980 vehicles are all carbureted.)

To characterize the vehicles that failed both the purge and pressure tests, we identified 14 such vehicles that were not gross liquid leakers (all tested as part of the CRC study). Thirteen (of those 14) were pre-1980 carbureted vehicles. For those 13 vehicles, the mean of the (24-hour) RTD emissions was 25.11 grams (with a standard deviation of 12.00). The corresponding stratum of pre-1980 vehicles that passed the purge test but failed the pressure test contains 20 vehicles (18 CRC and 2 EPA) has a mean (24-hour) RTD emissions of 24.39 grams (with a standard deviation of 7.77). Since the difference between those means is not statistically significant, we will combine those two strata into a single stratum of vehicles that failed the pressure test (regardless of their results on the purge test). (This approach permits us to avoid having to estimate emissions from the untested strata of newer vehicles that fail both the purge and pressure tests.)

7.0 EVAPORATIVE EMISSIONS REPRESENTED BY THE RTD TEST

The results from the real-time diurnal (RTD) tests can be used to model the following two types of evaporative emissions:

1) "Diurnal" emissions are the pressure-driven emissions resulting from the daily increase in temperature.

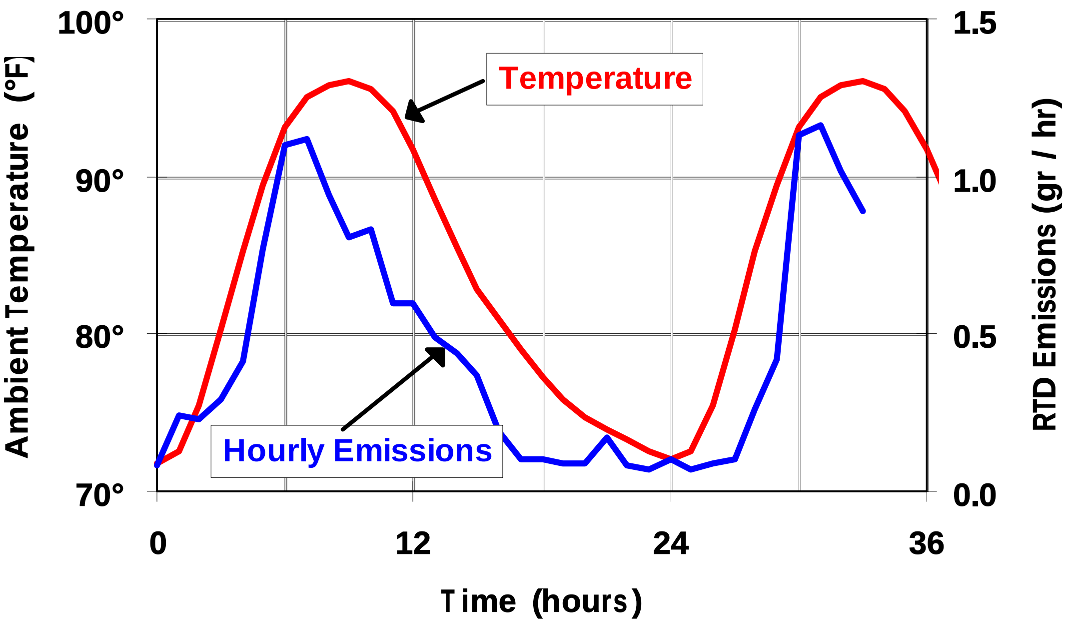
2) "Resting loss" emissions are the relatively stable emissions that are always present.

7.1 Resting Loss Emissions

Examinations of the RTD data suggest that, for virtually all of the tests (regardless of the temperature cycle, fuel RVP, or vehicle type), the hourly HC evaporative emissions had stabilized and were relatively constant for hours 19 through 24. (See Figure 7-1.) This suggests that the average hourly emissions during the final six hours of the 24-hour RTD cycle correspond to what this paper refers to (in the previous section) as hourly "resting loss" emissions.

Figure 7-1

Identifying Resting Losses
(Stable Portion of RTD Hourly Emissions)



The "resting loss" emissions component of each RTD test was calculated as the average (i.e., mean) hourly RTD emissions for hours 19 through 24, at the nominal temperature for the twenty-fourth hour. In this example, the average emissions for that 6-hour period (0.10 grams per hour) would represent this vehicle's hourly resting losses at a stable 72°F with a fuel having RVP of 6.8 psi. The mean hourly resting loss emissions (temperatures of 60°, 72° and 82°) for each of the strata in Section 6.4 are given in Appendix C.

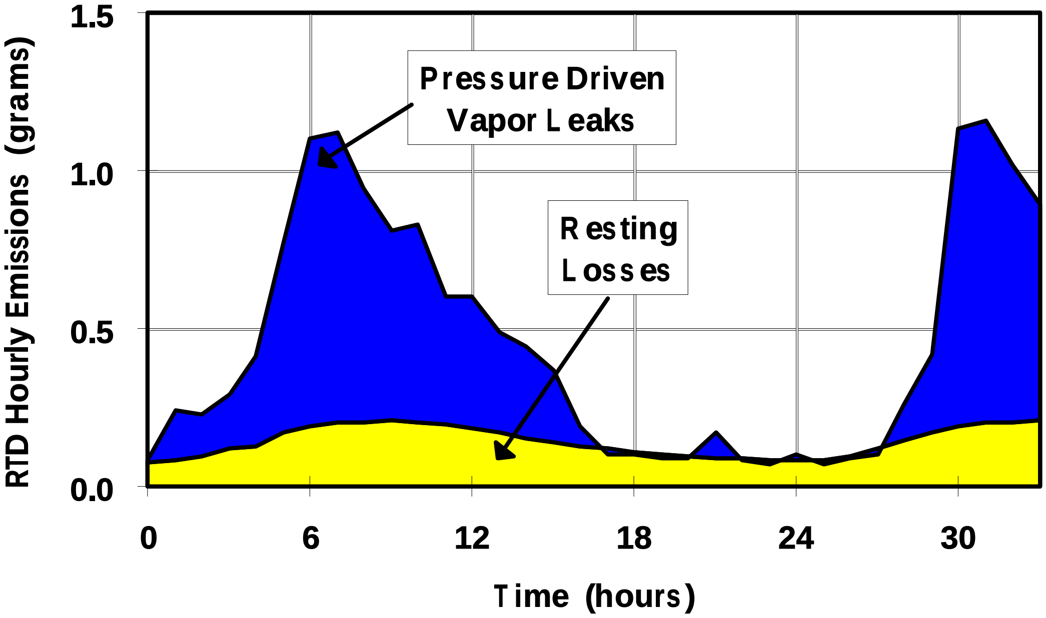
7.2 Diurnal Emissions

Subtracting the hourly resting loss emissions (calculated in Section 7.1) from the hourly RTD emissions should yield an estimate of the hourly emissions that result from the daily rise in temperature (i.e., "diurnal" emissions). Although the hourly resting loss emissions will vary as the ambient temperature cycles over the full range of the RTD test (see Section 8.0), the variation is small relative to the RTD hourly emissions. Using a "temperature adjusted" resting loss value will result in a slightly higher level of resting loss emissions over the day, and a corresponding lower level of diurnal emissions over that day. The total emissions will be unchanged.

In the following figure, the hourly resting loss emissions correspond to the unshaded area. The remaining (i.e., shaded) area then corresponds to the hourly diurnal emissions which are primarily pressure-driven vapor leaks. This approach produces calculated hourly diurnal emissions that approach zero as the SHED (i.e., "ambient") temperature drops to near the starting temperature.

Figure 7-2

Estimating Diurnal Emissions
(Pressure Driven Vapor Leaks)



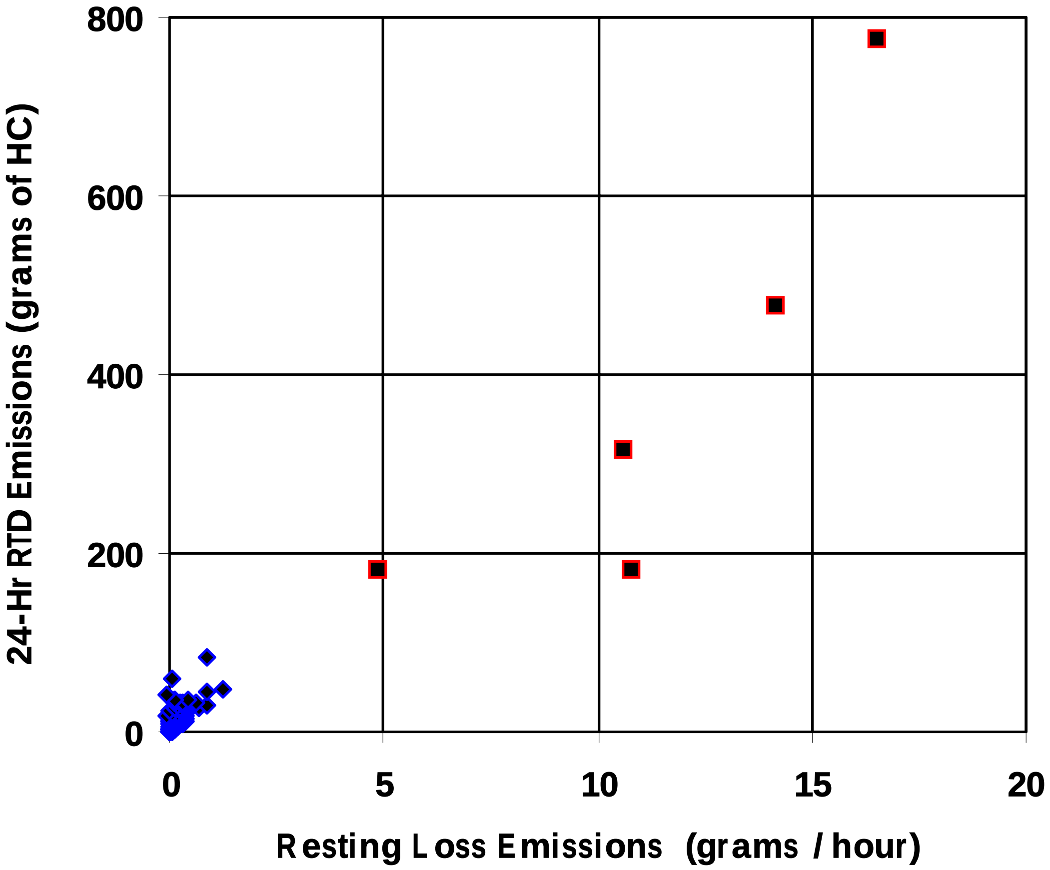
The average (mean) 24-hour RTD emissions for each of the strata in Section 6.4 are given in Appendix C.

7.3 Separating Out "Gross Liquid Leakers" (GLLs)

The largest quantity of RTD data (combining data from the EPA and CRC programs) was generated using fuel with an RVP ranging between 6.7 and 7.0 psi over the 72°-96° F temperature cycle. These test conditions were used by a total of 96 vehicles in the EPA program and all 151 vehicles in the CRC program. Using the preceding method to estimate hourly resting loss emissions (at 72°F) for each of those 247 vehicles, we then plotted the full 24-hour RTD emissions versus those hourly resting loss emissions (Figure 7-3).

Figure 7-3

Comparison of RTD versus Resting Loss Emissions (72°-96°F Cycle Using 6.7-7.0 RVP Fuel)



This graph clearly illustrates that the test results of all except five of the vehicles are tightly clustered with RTD results under 100 grams (per 24-hours) and with hourly resting losses under 1.5 grams per hour. The test results from each of the remaining five vehicles are quite distinct from those of the corresponding 242 tightly clustered vehicles. Each of these five extremely high emitting vehicles was also identified, by the mechanics who examined them, as having significant leaks of liquid gasoline (as opposed to simply vapor leaks).

The RTD data in Figure 7-3 suggest that the evaporative emissions from these five vehicles can exceed the emissions of corresponding vehicles by one to two orders of magnitude. For this reason, this report treats these "gross liquid leakers" as a separate category of evaporative emitters. It is important to note that this category (i.e., "gross liquid leakers") is not a new or previously unaccounted for source of emissions, since the emissions from these vehicles had previously been included with the resting loss and diurnal emissions in MOBILE5. Thus, modeling these vehicles separately (in MOBILE6) should have no impact on the total evaporative emissions.

To define this category of "gross liquid leakers," we first assumed that the effects of a significant liquid fuel leak should be evident during the resting loss portion of the RTD test. This report, therefore, defines a "gross liquid leaker" to be any vehicle whose resting loss emissions are at least two grams per hour. These five gross liquid leakers were all part of the CRC study. Using this definition, we classified two vehicles in the EPA study as likely gross liquid leakers. (These two are only "likely" gross liquid leakers because no mechanic's inspections were performed. We inferred their status based solely on their resting loss emissions.) These two additional gross liquid leakers do not appear in Figure 7-3 because they were tested only on 6.3 and 9.0 psi RVP fuels.

It is important to note that another type of liquid leaker is possible. Some leaks can occur only if the vehicle is operating (e.g., leaks associated with the fuel pump). Preliminary results from a running loss testing program being run by CRC suggests that vehicles with such leaks may have higher hourly evaporative emissions (in grams per hour) while they are operating than the hourly (RTD) emissions from the gross liquid leakers in this analysis. However, the gross liquid leakers identified in this analysis have high evaporative emissions every hour of the day; while, the other type of liquid leaker would probably have high evaporative emissions only during the hours the vehicle is actually operating. The effects of that other type of liquid leaker will be included in the running loss component of the evaporative emissions in the MOBILE model.

8.0 CHARACTERIZING RESTING LOSS EMISSIONS

Resting loss evaporative emissions are functions primarily of ambient temperature. There are several distinct mechanisms contributing to resting loss emissions:

- permeation of the liquid fuel through the walls of both hoses and (if applicable) plastic fuel tanks,
- seepage of vaporized fuel at connectors and through cracks in hoses, fuel tanks, etc.,
- permeation and seepage at the canister, and
- undetected (minor) liquid leaks of fuel.

Some of these components of resting loss emissions are strongly related to temperature changes while others such as the minor liquid leaks are relatively unaffected by temperature changes.

As the first step in characterizing the effects of changes in temperature and volatility on the hourly evaporative emissions, we identified 57 vehicles in the EPA program that were each tested:

- using both the 6.8 and the 9.0 RVP fuels and
- over all three temperature cycles.

Using this sample permitted us to have exactly the same vehicles being tested at each combination of fuel RVP and temperature; thus, avoiding many of the problems associated with vehicle-to-vehicle test variability. This sample of 57 vehicles consisted of:

- 12 1974-85 model year carbureted vehicles and
- 45 1985-94 model year fuel injected vehicles.

In the following graph (Figure 8-1), we plotted the mean hourly resting loss emissions for the carbureted vehicles and the fuel injected vehicles.

Based on the graphs in Figure 8-1 (on the following page), we can make the following observations:

- Hourly resting loss emissions increase with increasing ambient temperature.*
- For the fuel injected (i.e., the larger sub-sample), the graph appears to contain a slight non-linear component. However, with measurements at only three temperatures, there are insufficient data to confirm that observation.
- For the fuel injected (i.e., the larger sub-sample), the graph appears to contain a slight non-linear component. However, with measurements at only three temperatures, there are insufficient data to confirm that observation.

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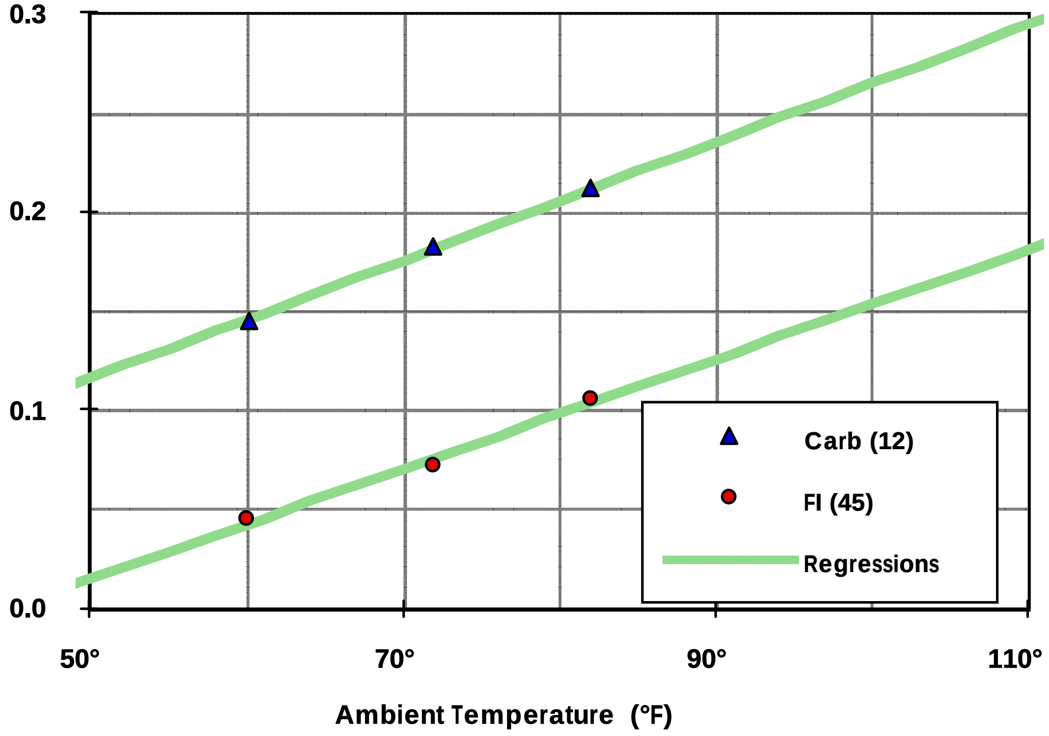
* An increase in hourly resting loss emissions corresponding to an increase in fuel RVP was also noted (especially for the FI vehicles). This apparent relationship is believed to simply be an artifact of the vehicles always being tested in the same (not randomized) order rather than being a true relationship between resting loss emissions and Reid vapor pressure. In the previous version of MOBILE, it was noted that resting loss emissions appear to be insensitive to the fuel volatility level, and EPA will continue to use that same assumption in this version of MOBILE.

Figure 8-1

Mean Hourly Resting Loss Versus Temperature
(averaged at each temperature)
(Sub-Sample of 57 Vehicles)



Therefore, for these 57 vehicles, the functions that most reasonably model the hourly resting loss emissions (within the tested range) are linear functions of temperature. That is:

Hourly Resting Loss = A + [B * Temperature (°F)]

Where:

"A"	"B"	
-0.032040	0.002973	For Carb Vehicles
-0.123027	0.002769	For FI Vehicles

The two slopes (i.e., the "**B**" values in the above table) are obviously close to each other in value. Since the difference between the slopes was not statistically significant, the regression was rerun, producing a single slope of 0.002812. Having a single value for the slope (regardless of the stratum) indicates that an increase in ambient temperature of ten degrees Fahrenheit will, on average, correspond to an increase of 0.028 grams in each hour's resting loss emissions.

While only the test results from the 57 vehicles that were tested over the full range of fuel RVPs and temperature cycles were used to calculate the coefficient ("**B**") which determines the slope of the lines, the full data set was used only to solve for the individual constant terms ("**A**").

For each of the strata identified in Section 6.4, we calculated the value of "**A**" that would minimize the difference between the predicted and the actual resting losses (i.e., the residuals). If more tests had been conducted at a given combination of temperature and fuel RVP (e.g., 72 °F using 6.8 psi RVP fuel), then the average resting loss emissions at that combination was then more heavily weighted in the process to calculate the value "**A**".

This process produced a regression equation for each of the 18 strata; however, the predicted results based on the vehicle's pass/fail status on the purge test were inconsistent. This inconsistency is not surprising since the types of mechanical problems that would cause a purge failure are not likely to contribute to resting loss emissions.* To address this situation, the population was stratified based simply on whether the vehicles pass or fail just the pressure test. The regression equations for each of the 12 resulting strata are given in Appendix D. The regression equations are unique for each stratum in which testing was performed. The untested strata of pre-1980 fuel-injected vehicles used the regression equations of the pre-1980 carbureted vehicles.

Using any one of these 12 equations (in Appendix D), we can estimate the hourly resting loss emissions for each hour of the day for the three temperature cycles (in Appendix A) for that stratum of vehicles. Adding those <u>hourly</u> estimates for the 24 hours of the day produces the <u>daily</u> resting loss emissions (for that stratum). Repeating that process for all the strata in Appendix D produces estimated resting loss emissions for all the 12 strata in Appendix D. Since all 12 of those equations are linear, with the same coefficient for temperature, they produce similar results: that the full day's resting loss emissions (in grams) would be 24 times the hourly resting loss (calculated at the lowest temperature of the day) plus 0.766.

These equations predict resting loss emissions of the carbureted vehicles to be higher than for the fuel injected vehicles. While these regressions can be used to calculate reasonable estimates of resting loss emissions within the range of temperature and fuel RVPs that were actually tested, we must determine (see Section 11) how to extrapolate beyond the limits of the test data.

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* This is consistent with the previous version of MOBILE, where it was noted that resting loss emissions are independent of the canister state (i.e., whether the canister is saturated or fully purged).

9.0 CHARACTERIZING 24-HOUR DIURNAL EMISSIONS

Diurnal evaporative emissions, like most other evaporative emissions, are functions of both fuel volatility and temperature which are themselves interdependent. The RVP is a measure of vapor pressure (VP) at a single temperature, 100°F. The Clausius-Clapeyron relationship was used to estimate the vapor pressure at each temperature and for each of the fuels (RVPs of 6.8 and 9.0 psi) used in this testing program. (In Appendix B, we illustrate how the Clausius-Clapeyron relationship can be used to estimate a fuel's vapor pressure at each temperature if the fuel's RVP is known.)

To characterize the diurnal emissions, we again (see Section 8.0) identified the 57 vehicles in the EPA program that were tested over a wide range of vapor pressures. These test vehicles were distributed among 12 strata (of the 18 potential strata identified in Section 6.5). Within each stratum, we then attempted to regress the diurnal emissions against combinations of fuel volatility and temperature.

A similar approach was attempted to characterize resting loss emissions (see previous section) but had not been successful. However, this approach produced more satisfactory results in characterizing the diurnal emissions even in strata that were sparsely tested. Most likely this difference was due to the effect that the test-to-test variability was substantially larger relative to the smaller resting loss emissions than to the larger diurnal emissions. Therefore, any test-to-test variability was less likely to hide patterns evidenced in the diurnal emissions measurements.

For each RTD test, the Clausius-Clapeyron relationship was used to estimate the vapor pressure at both the low and the high temperatures. Using these estimates, we calculated both the average of the low and the high vapor pressures, as well as the difference between the low and the high vapor pressures ($\triangle$VP) (both measured in kPa). Multiplying these two quantities together produced a single product term (VP*$\triangle$VP) that incorporates the parameters of the RTD test (i.e., both the temperature cycle and the RVP of the fuel).

The use of this vapor pressure product term (to estimate diurnal emissions) is a change from MOBILE5 that used as the independent variable an "uncontrolled diurnal index" (UDI). Comparing these two variables (as in the following table), we find that they are closely related (linearly). Regressing the values in that table gives us the equation:

$$\text{Vapor Pressure Product Term} = 260.774 + (409.919 * \text{UDI})$$

with an R-squared value of 98.9 percent. Thus, the use of this VP product term (as the independent variable in MOBILE6) not only incorporates the parameters of the RTD test, but it is also consistent with MOBILE5.

Sample Comparing Uncontrolled Diurnal Index (UDI) To Vapor Pressure (VP) Product Term

RVP (psi)	Low Temp	High Temp	UDI	VP Product
9.0	60	84	1.0000	655.07
10.5	60	84	1.4567	888.99
11.5	60	84	1.9581	1,063.50
11.7	60	84	2.0677	1,100.14
9.0	72	96	1.7448	968.66

The mean diurnal emissions (calculated in the previous section by subtracting a daily resting loss value from the RTD test results) were repeatedly regressed against a polynomial of that product term of vapor pressures within each stratum. The independent variable used in the regressions was either:

1) the product term (i.e., the average vapor pressures times the difference of the vapor pressures) or

2) the square or cube of that product term (to allow for possible non-linearity).

We also performed regressions using other combinations of variables (including RVP). Some of which had improved statistical "fits" to the test data. Although the equations that we developed in this analysis are empirical (i.e., data driven) models, we did impose two sets of restrictions. (The second set of restrictions is discussed on pages 31 and 32.) The first set contains the following three restrictions that were based on engineering experience with diurnal emissions. Many of the potential models were discarded due to their failure to meet this set of additional theoretical requirements:

- The diurnal emissions should decrease with a decreasing fuel RVP (with all other parameters held constant).
- The diurnal emissions should decrease with decreasing temperature cycles (with all other parameters held constant).
- For each combination of fuel delivery system (i.e., fuel injected versus carbureted) and purge/pressure category, the diurnal emissions should increase with each successively older model year grouping (for each combination of temperature cycle and fuel RVP).

In each of those 12 strata, we generated both a nonlinear (i.e., quadratic) model and a linear model*. A two step process was used to choose among those models:

1) We performed a visual inspection of the data. (This approach, in and of itself, is not very precise, but we wanted to make certain that the model selected would be both reasonable and accurately represent the test data.)

2) We compared the statistical parameters associated with each of those regressions. (That is, we identified the model that optimized: the F-ratio, the statistical significance of the independent variable, and the R-squared value.)

Seven separate strata required additional effort to meet these three criteria (that were based on engineering experience):

- the three strata of 1971-1979 model year carbureted vehicles,
- the 1980-1985 model year FI vehicles that passed the pressure test, and
- the three strata of 1986 and newer model year carbureted vehicles.

For the 1971-1979 model year carbureted vehicles, we used a modification of the equations that resulted from the analysis of the 1980-85 model year carbureted vehicles. Specifically, we used the same coefficients (i.e., the same corrections for changes in temperature and RVP), but we modified the constant terms so that the resulting equations would pass through the means of the actual (validating) data of the Pre-1980 vehicles.

The stratum of 1980-85 FI vehicle that passed both the purge and pressure tests was represented by only a single vehicle that was tested over the full range of temperature cycles and fuel RVPs. Thus, the results of those tests were combined with the tests on the three 1980-85 FI vehicles that failed the purge test but passed the pressure test into a single stratum of vehicles that passed the pressure test (represented by four vehicles). The regression of these data was used to determine the

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* Theoretically, in each of those models, a zero change in daily temperature (hence, in $\triangle$VP) should result in zero diurnal emissions. This physical necessity would result in the constant term in each regression being zero. However, this requirement was dropped due to:
(1) the resulting low r-squared values,
(2) the lack of test data having diurnal temperature ranges less than 24 degrees, and
(3) our requirement, that for any diurnal emissions to occur, a difference between the daily high and low temperatures was needed.

coefficients for both the stratum of 1980-85 FI vehicles that passed both the purge and pressure tests and the stratum of 1980-85 FI vehicles that failed only the purge test. The constant term for each stratum was the value that would make the resulting equations would pass through the respective means of the actual (validating) data of the 1980-85 FI vehicles (i.e., cause the sums of the residuals to equal zero).

The last three problem strata were the 1986 and newer carbureted vehicles. As is illustrated in Appendix C, only four combinations of temperature cycle and fuel RVP were tested (in each of the three purge/pressure substrata). The two untested combinations were the combinations that would have yielded results at the highest and the lowest VP values. Having test data over such a narrow range (i.e., only the four middle values) of vapor pressures made selecting the proper regression curve difficult.

We first, therefore, attempted to enlarge the scope of the data by estimating the diurnal emissions at the two missing extreme values. We did this by observing that the diurnal emissions of the 1986-95 carbureted vehicles (at the four tested combinations of fuel RVP and temperature cycle) were between the corresponding diurnal emissions of the 1986-95 FI vehicles and the 1980-85 carbureted vehicles for each tested combination of fuel RVP, temperature cycle, and purge/pressure result. If this pattern were to hold true for the two untested combinations, then the diurnal emissions of the 1986-95 carbureted vehicles would be:

- ♦ for tests using 6.8 RVP fuel over the 60-86 °F cycle:
    - ♦♦ between 4.815 and 9.519 for vehicles failing the pressure test,
    - ♦♦ between 4.372 and 5.100 for vehicles failing only the purge test, and
    - ♦♦ between 0.187 and 2.976 for vehicles passing both the pressure and the purge tests.
- ♦ for tests using 9.0 RVP fuel over the 82-106 °F cycle:
    - ♦♦ between 28.26 and 45.456 for vehicles failing the pressure test,
    - ♦♦ between 21.046 and 50.67 for vehicles failing only the purge test, and
    - ♦♦ between 9.932 and 36.565 for vehicles passing both the pressure and the purge tests.

We then experimented, using the tested values for the 1986-95 carbureted vehicles with the coefficients determined for the 1980-85 carbureted vehicles and for the 1986-95 FI vehicles to determine which set would more closely predict the preceding estimates of the untested configurations. While neither set was perfect, the coefficients developed for the 1980-85 carbureted vehicles came closer to the theoretical values and were selected.

The statistics associated with those regressions are given in Appendix E. Once the coefficient values of the equation were determined for each of the 15 strata, we again (as with the both the Pre-80 vehicles and the 1980-85 FI vehicles) modified the constant term (for <u>each</u> stratum) to minimize the sum of the differences between the predicted and calculated diurnal emissions. The resulting equations are given in Appendix F. (The coefficients, but not the constant terms, from Appendix E match those in Appendix F.) Graphical comparisons between the predictions of those models (i.e., resulting equations) and the means of the measured RTD test data are given in Appendix G.

In the five strata in which the vehicles passed both the purge test and the pressure test, the data strongly suggest a non-linear relationship (i.e., quadratic) between the diurnal emissions and that "vapor pressure product" term. In the various strata containing vehicles that failed either the purge or pressure (or both) tests, the relationship between diurnal emissions and the vapor pressure product term was sometimes linear and sometimes non-linear.

On page 28, we noted that two sets of restrictions were applied to the equations (in Appendix F) that predict diurnal emissions produced by the regressions in Appendix E. The second set of restrictions is intended to avoid having unrealistic predictions when the model extrapolates beyond the limits of the actual test data. (For example, although no RTD testing was conducted with a test fuel having an RVP over 9.0 psi, MOBILE6 will produce estimates for an RVP as high as 15.2.)

MOBILE6 attempts to avoid unrealistic estimates by limiting (i.e., setting "caps" for) the diurnal emissions. These limits are based on a theoretical approach that is validated by the means of the observational data in Appendix C. Specifically, we reasoned that (with all other conditions being the same):

- Among vehicles with defective evaporative control systems, those vehicles with severe leaks of liquid gasoline (GLLs) were likely to have the highest diurnal emissions. (This was the observed result for all of the actual tests. The restriction extended this to all combinations of temperature cycles and fuel RVPs.)

- The mean diurnal emissions from vehicles with properly functioning evaporative control systems ("Pass Both") were likely to be no higher than those from vehicles with defective control systems. (Again, this restriction extended this observation to all combinations of temperature cycles and fuel RVPs.)

- Among the non-GLL vehicles with defective evaporative control systems, those vehicles with pressure leaks (fail pressure) were likely to have higher diurnal emissions than those from vehicles with only defective purge system (fail purge). (Again, this restriction extended this observation to all combinations of temperature cycles and fuel RVPs.)

MOBILE6 implements these three additional restrictions (for each combination of temperature cycle, fuel RVP, model year, and fuel delivery system) by:

1) limiting the diurnal emissions from the vehicles that failed the pressure test to those from the GLLs

   "Fail Pressure" **=** Min ["Fail Pressure" , "GLL"]

2) limiting the diurnal emissions from the vehicles that failed the purge test to those from vehicles that failed the pressure test

   "Fail Purge" **=** Min ["Fail Pressure" , "Fail Purge"]

3) limiting the diurnal emissions from vehicles with properly functioning evaporative control systems to those from vehicles that failed the purge test

   "Pass Both" **=** Min ["Pass Both" , "Fail Purge"]

10.0 GROSS LIQUID LEAKERS

Three issues related to vehicles with gross liquid leaks need to be addressed:

1) the frequency of the occurrence of gross liquid leakers (possibly as a function of vehicle age),

2) the magnitude of the emissions from gross liquid leakers, and

3) the effects of changes in vapor pressure on the diurnal and resting loss emissions of these gross liquid leakers.

Analyses of these issues were hampered by a lack of a substantial number of identified gross liquid leakers. We anticipate revising the following initial estimates for future models based on additional data.

10.1 Frequency of Gross Liquid Leakers

In a parallel report (M6.EVP.009, entitled "Evaporative Emissions of Gross Liquid Leakers in MOBILE6"), EPA used the results from a test fleet of 270 vehicles (i.e., combined EPA and CRC samples) to estimate the occurrence of gross liquid leakers within each of the three model year ranges used in the recruitment process (the pre-1980, 1980-85, and 1986-95). The estimated rate of occurrence of the "gross liquid leakers" (at each of three given ages) is reproduced in the following table

(Table 10-1, below). The large confidence intervals are the result of the relatively small sample sizes.

Table 10-1

Frequency of Gross Liquid Leakers
(Based on RTD Testing)

Vehicle Age (years)	Sample Size	Frequency at Vehicle Age	Standard Deviation	90% Confidence Interval Lower	90% Confidence Interval Upper
6.12	85	0.20%	1.41%	0.00%	2.52%
13.00	50	2.00%	1.98%	0.00%	5.26%
21.79	51	7.84%	3.76%	1.65%	14.03%

* "**Vehicle Age**" was calculated by subtracting the model year from the test year and then adding one-half to simulate the rate as of early July (the median date for the testing).

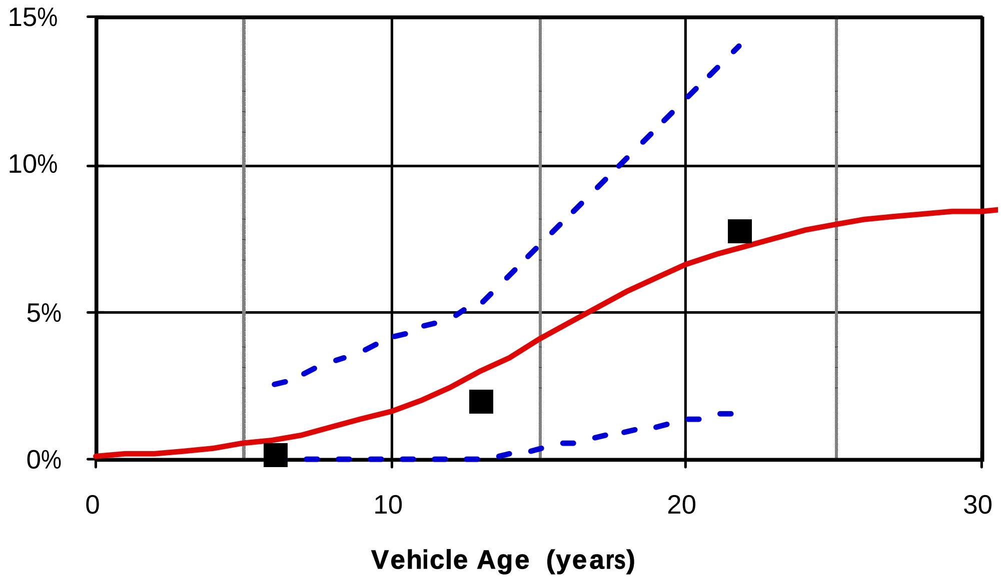
EPA then found (see Section 3.2 of M6.EVP.009) a logistic growth curve that closely approximates these three values while taking into account similar occurrences of "gross liquid leakers" identified using the hot soak test and the running loss test. The equation that EPA will use (in MOBILE6) to estimate the frequency of gross liquid leakers (on the RTD test) is:

$$\text{Rate of Gross Liquid Leakers Based on RTD/Resting Loss Testing} = \frac{0.0865}{1 + 55 * \exp[-0.259 * \text{AGE}]}$$

Plotting this curve and the preceding set of three failure rates (from Table 10-1) produces Figure 10-1 (on the following page). A logistic curve that produces an improved "fit" of the values in Table 10-1 can be obtained (see Section 3.1 of M6.EVP.009) by reducing (or eliminating) the interdependence with the "gross liquid leakers" identified using the hot soak test or the running loss test. However, EPA will use the preceding equation in MOBILE6.

Figure 10-1

Frequency of Gross Liquid Leakers (based on RTD testing)



The solid line in Figure 10-1 is the logistic growth function. Also graphed in that figure are the 90 percent confidence intervals (as dotted lines) from Table 10-1. Since the overall effect of the gross liquid leakers is the product (by model year) of the percentage of gross liquid leakers and the number of vehicles in the in-use fleet for that model year, the rapidly increasing proportion of gross liquid leakers in the in-use fleet tends to be offset by the decreasing number of older vehicles in the in-use fleet. This graph (as well as the preceding equation) predicts:

- Fewer than one-half a percent of vehicles (at each age) up to eight years of age will be "gross liquid leakers."
- "Gross liquid leakers" do not reach one percent of any age group of the in-use fleet until the vehicles exceed 10 years of age.
- "Gross liquid leakers" reach (or exceed) two percent of each age group of the in-use fleet for vehicles exceeding 13 years of age.
- The portion of the fleet that is "gross liquid leakers" then rises by vehicle age (almost linearly) to about eight percent for vehicles that are 22 years old.
- The increase in the frequency of "gross liquid leakers" then levels off and the frequency approaches just over eight and one-half percent (about age 30).

It is important to note that this model of the frequency of gross liquid leakers is based on the assumption that modern technology vehicles will show the same tendency toward gross liquid leaks as do the older technology vehicles at the same age. However, if the modern technology vehicles were to exhibit a lower tendency to leak (due to the more stringent demands imposed by the new evaporative emissions certification procedure as well as heightened attention to safety, e.g., fuel tank protection and elimination of fuel line leaks), the effect would be to replace that single logistic growth function with a family of two or more curves. (This assumed lower rate is used to create a different curve for the 1999 and newer vehicles. See Section 11.7.)

Since EPA has no data to indicate that the multiple curve scenario is the correct approach, EPA will use the single curve approach to estimate the occurrence in the in-use fleet of these vehicles that have substantial leaks of liquid gasoline (i.e., "gross liquid leakers").

10.2 Magnitude of Emissions from Gross Liquid Leakers

In that concurrent report on "gross liquid leakers" (Document Number M6.EVP.009), EPA used the RTD test results from ten (10) vehicles to estimate the mean diurnal emissions from the stratum of "gross liquid leakers." Each of these 10 vehicles:

- had diurnal emissions (RTD minus resting loss) of at least 15 grams per day
- had an observed liquid leak
- but, were not necessarily "gross liquid leakers."

EPA then assumed that the distribution of the diurnal emissions from these leaking (but not necessarily "gross liquid leakers") vehicles was lognormal (i.e., the logarithms of the emissions, rather than the emissions themselves, are assumed to be normally distributed). (Distributions other than the lognormal were examined, but none came as close to approximating the observed distribution.) That lognormal distribution was then used to estimate the frequency associated with each possible diurnal emission level. For a group of leaking vehicles whose diurnal emissions were between 25 and 1,000 grams per day, the lognormal distribution predicts that the mean diurnal emissions of that group of leakers would be 104.36 grams per day. (See Section 2.1 of M6.EVP.009 for details.)

EPA will use 104.36 grams per day as the average full-day's diurnal emissions from "gross liquid leakers" over a day for which the maximum daily temperature is exactly 24°F above the daily low temperature. In report number M6.EVP.002, EPA derives an equation to estimate full-day diurnal emissions over different temperature cycles (having a difference between the daily high and low temperatures of at least 10 degrees Fahrenheit) as:

Total 24-Hour Diurnal Emissions (grams)

= 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, that equation 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 a diurnal temperature range of exactly ten degrees Fahrenheit, the equation predicts the 24-hour diurnal for gross liquid leakers to be 67.011 grams. If daily temperature range is between zero and 10 degrees, then EPA will interpolate, producing:

Total 24-Hour Diurnal Emissions (grams) = 6.701075 * Diurnal_Temperature_Range

Earlier versions of MOBILE limited the pressure driven leaks (i.e., diurnal emissions) to times when the ambient temperature was at least 40°F. However, we suspect that, at temperatures below 40°F, the diurnal emissions would still continue. However, at those low temperatures, the likelihood of ozone exceedences would be small.

The preceding approach was repeated for resting loss emissions. (Again, see Section 2.1 of M6.EVP.009 for details.) For a group of leaking vehicles whose hourly resting loss emissions were between 2.0 and 50 grams, the lognormal distribution predicts that the mean resting loss emissions of that group of leakers would be 9.163 grams per hour.

EPA will use 9.16 grams per hour as the average hourly resting loss emissions from "gross liquid leakers."

On page 26, we noted that the daily resting loss emissions (assuming a daily temperature profile similar to those in Appendix A) would be 24 times the hourly resting loss (at the lowest temperature of the day) plus 0.766. Since including the 0.766 term will increase the day's total resting loss (from "gross liquid leakers") less than 0.4 percent, and since the mechanism responsible for the vast majority of the resting loss emissions from these vehicles is the fuel leaking out of the vehicle which is not dependent upon the ambient temperature or fuel volatility, we will assume the resting loss emissions from "gross liquid leakers" are completely independent of temperature (see Section 11.1). Therefore, based on the means in the preceding table, EPA will use, in MOBILE6, for the category of gross liquid leakers:

- DAILY RESTING LOSS = (24 * HOURLY RESTING LOSS)
  = (24 * 9.16) = 219.84 (GRAMS / DAY)

and

- Full-Day's Diurnal = Mean RTD - Daily Resting Loss
  = 104.36 (grams / day)

Thus, while the occurrence of these gross liquid leakers is relatively rare among newer vehicles (Section 10.1), their presence has a substantial effect on the total resting loss and diurnal emissions of the in-use fleet.

10.3 Effects of Vapor Pressure Changes on Gross Liquid Leakers

As previously discussed, the true vapor pressure is a function of both the ambient temperature and the Reid vapor pressure of the fuel. Since only two of the seven vehicles that have been identified as gross liquid leakers were tested over a range of fuel RVPs, there are not enough data to relate changes in diurnal and resting loss emissions to changes in fuel RVP. However, as noted in the preceding section, changes in fuel RVP are expected to have only minimal (proportional) effects on the total diurnal and resting loss emissions of vehicles whose primary mechanism of evaporative emissions is leaking liquid gasoline. Thus, until additional data are available, EPA will treat the diurnal and resting loss emissions of the gross liquid leakers as independent of fuel RVP.

In the previous section, EPA treated the hourly resting emissions of these gross liquid leakers as if they are independent of ambient temperature as well. In a concurrent report (document number M6.EVP.002, entitled "Modeling Hourly Diurnal Emissions and Interrupted Diurnal Emissions Based on Real-Time Diurnal Data"), EPA was able to use the hourly diurnal emissions to estimate the effects of temperature changes on the diurnal emissions of these gross liquid leakers. That report concludes that the full-day's diurnal emissions of gross liquid leakers is dependent only upon the daily temperature range (i.e., the difference between the daily high and low temperatures). Thus, for any of the three temperature cycles in Appendix A, the mean of the full-day's diurnal emissions of gross liquid leakers is the constant 104.36 grams (calculated in the previous section).

Therefore, EPA is proposing that both the hourly resting loss emissions and full-day's diurnal emissions of gross liquid leakers are independent of vapor pressure for each of the three temperature cycles in Appendix A.

11.0 Other Topics

Several topics were not discussed in the preceding analysis because either:

1) They will be discussed in forthcoming reports.

or

2) No changes are planned in how they were handled in MOBILE5.

11.1 Temperature Ranges

All of the tests used in this analysis were performed using one of the three temperature cycles in Appendix A. This results in all of the resting loss emissions being measured at only three temperatures (i.e., 60, 72, and 82 °F). In Section 8, we developed regression equations to estimate hourly resting loss emissions at theoretically 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 light-duty 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.)

2) We will assume, for light-duty 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 those vehicles' emission performance 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.

The equations developed in this report to estimate full-day diurnal emissions theoretically could also be applied to any temperature cycle. We will limit those functions by assuming that 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 zero degrees Fahrenheit (i.e., constant daily temperature). As with the "gross liquid leakers," if the daily temperature range is between zero and 10 degrees, we will interpolate.

11.2 Heavy-Duty Gasoline-Fueled Vehicles (HDGVs)

The analyses in this report were based on RTD tests of only light-duty gasoline-fueled vehicles (LDGVs) and light-duty gasoline-fueled trucks (LDGTs). Since the data did not indicate a significant difference between the RTD emissions from LDGVs and LDGTs, they were combined in a single group for analyses.

Since no RTD testing was performed on any HDGVs, we will use the same approach that was used in the earlier version of MOBILE. That is, the ratio of diurnal emissions of the HDGVs to those of the LDGTs is proportional to the corresponding ratios of the evaporative emission standards. For each strata of HDGV (2b, 3, 4, 5, 6, 7, 8a, 8b and heavy-duty gas busses) that are not "Gross Liquid Leakers," we will assume that their "full day" diurnal emissions will be a multiple of the "full day" emissions of the corresponding strata of LDGTs (or LDGVs since the emissions are the same). Therefore, the heavy-duty vehicles in classes IIb and 3 will have evaporative emissions of 1.5 times the evaporative emissions of the corresponding LDGT strata (determined by fuel metering and purge/pressure tests). And, the heavy-duty vehicles in classes 4 through 8 plus busses will have evaporative emissions of 2.0 times the evaporative emissions of the corresponding LDGT strata.

Translating these assumptions into equations yields the following cases:

- For model years prior to 1985, the diurnal emissions from HDGVs were uncontrolled. Therefore, for all model years prior to 1985, we will apply that multiplier to only the LDTs (of the appropriate fuel delivery system) that failed the pressure test (for each model year). That is, for all of the pre-1985 heavy-duty trucks that are not gross liquid leakers, we will assume that their full day diurnal emissions are a simple multiple (1.5 or 2.0) of the light-duty trucks of that model year that also fail the pressure test.

- For model years prior to 1979, trucks with gross vehicle weight ratings (GVWR) between 6,000 and 8,500 pounds were considered to be heavy-duty trucks. Therefore, MOBILE6 will set their evaporative emissions equal to those of the trucks with GVWR between 8,500 and 10,000 pounds (HDGV-2b). These vehicles are identified in MOBILE6 as LDGT-3 and LDGT-4.

- For the 1985 and newer model years, we will apply that multiplier to each purge/pressure fuel-delivery stratum of the LDTs (for each model year).

We will use the same formulas for resting losses (obviously changing to "diurnal emissions" to "hourly resting losses").

11.3 High Altitude Evaporative Emissions

We will continue to use the multiplicative adjustment factor of **1.30** (from previous version of MOBILE) to adjust both the resting loss and diurnal emissions for high altitude for all vehicles that are not "gross liquid leakers." For the "gross liquid leakers," we will assume that there is no difference in either resting loss or diurnal emissions between low and high altitude.

11.4 Motorcycles (MC)

RTD evaporative emission tests were not performed on motorcycles (MC). In MOBILE5, the resting loss and diurnal emissions from motorcycles were modeled using carbureted vehicles equipped with open-bottom canisters. That approach will continue with MOBILE6.

We first identified 109 RTD tests of carbureted vehicles equipped with open-bottom canisters (all 1988 or earlier model years), and calculated both the hourly resting loss (associated with the test's low temperature) and the full-day's diurnal for each of those 109 tests. The diurnal emissions were then regressed against both the vapor pressure product term (developed in Section 9) and the age of each test vehicle. As illustrated in Table 11-1, each of those variables is statistically significant. MOBILE6 will use the linear regression equation generated by that analysis to calculate the full day's diurnal emissions.

Table 11-1

Regression of Diurnal Emissions
(Simulated Motorcycle Fleet)

Dependent variable is: **Diurnal**
No Selector

R squared = 59.0%   R squared (adjusted) = 58.3%
s = 10.20 with 109 - 3 = 106 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	15892.9	2	7946.46	76.4
Residual	11024.5	106	104.005	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	-36.7971	4.5620	-8.07	≤ 0.0001
age	0.855491	0.1894	4.52	≤ 0.0001
VP_Product	0.058251	0.0051	11.5	≤ 0.0001

Translating that regression analysis into an equation yields:

24-Hour Diurnal Emissions (grams) of Motorcycles

= -36.7971 + (0.855491 * Vehicle_Age) + (0.058251 * VP_Product_Term)

EPA will use this equation to estimate the 24-hour diurnal emissions from motorcycles.

Similarly, the hourly resting loss emissions were regressed against both the temperature at which those values were calculated (i.e., the daily low temperature) and the age of each test vehicle. As illustrated in Table 11-2, only the vehicle age is statistically significant. It is possible that temperature was not found to be statistically significant simply due to the fact that most of the resting loss emissions were calculated at the same temperature (72 °F). Since resting loss emissions <u>should</u> be an increasing function of temperature, EPA will use for MOBILE6 the linear regression equation generated by the analysis (in Table 11-2) that uses <u>both</u> variables (despite the low statistical significance).

<u>Table 11-2</u>

Regression of Hourly Resting Loss Emissions (Simulated Motorcycle Fleet)

Dependent variable is: **Hourly Resting Loss**
No Selector

R squared = 5.6% R squared (adjusted) = 3.8%
s = 0.1346 with 109 - 3 = 106 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	0.114078	2	0.057039	3.15
Residual	1.92123	106	0.018125	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	0.044345	0.1572	0.282	0.7784
age	0.006134	0.0025	2.45	0.0159
Temperature	0.000859	0.0022	0.399	0.6909

Translating this regression analysis into an equation yields:

Hourly Resting Loss Emissions (grams) for Motorcycles

= 0.044345 + (0.006134 * Vehicle_Age) + (0.000859 * Hourly_Temperature)

EPA will use this equation to estimate the hourly resting loss emissions from non-leaking motorcycles at temperatures between 40 and 105 degrees Fahrenheit (see Section **11.1**).

11.5 <u>Pre-Control Vehicles</u>

Non-California vehicles prior to the 1971 model year were not required to meet an evaporative emission standard. These uncontrolled vehicles would simply vent vapors to the atmosphere as pressure built up. Since that situation is similar to that of a controlled vehicle with a vapor leak, we hypothesized that the resting loss and diurnal evaporative emissions of the pre-1971 vehicles would be comparable to the emissions of the pre-1980 vehicles that had failed the pressure test.

To characterize the hourly resting loss emissions from these pre-control vehicles, we proceeded in a similar fashion to the approach in Section 8. We first identified the two pre-1980 vehicles in our study that both had failed the pressure test and were tested over the full range of fuels and temperature cycles. Possibly due to that small sample size, a regression of those data produced a slope of resting loss versus temperature that was not statistically different from zero. We, therefore, decided to use the same slope (0.002812) that was developed in Section 8. Since most of the RTD tests (i.e., 37 of 47) that were performed on the 34 candidate vehicles were run over the same temperature cycle (i.e., 72 to 96 degrees), the variable "temperature" would not make a useful independent variable to analyze those 47 resting loss results. However, the variable "age" was found to be statistically significant. Combining the results of regressing the data against age with the previously calculated temperature slope yields the following equation:

$$\begin{aligned}\textbf{Hourly Resting Loss (grams)} = \quad & -0.768438 \\ & + (0.002812 * \text{Temperature in }^\circ\text{F}) \\ & + (0.040528 * \text{Vehicle Age in Years})\end{aligned}$$

EPA will use this equation to estimate the hourly resting loss emissions from pre-control vehicles with the restriction that the calculated value must be at least the estimated hourly resting loss of the (newer) 1971-79 model year vehicles (as calculated in Appendix D).

To characterize the full day's diurnal emissions from these pre-control vehicles, we proceeded in a similar fashion to the approach in Section 9. In the preceding paragraph we noted that only two of the candidate vehicles (i.e., pre-1980 vehicles that failed the pressure test) were tested over the full range of fuels and temperature cycles. Attempting to analyze the resting loss emissions of those two vehicles as a function of temperature produced only mediocre results. However, the corresponding analysis for diurnal emissions as a function of the vapor pressure product term produced satisfactory results, as shown in Table 11-3 (on the following page).

Table 11-3

Regression of Diurnal Emissions
(Simulated Pre-Control Fleet)
(Based on Two Vehicles)

```
Dependent variable is:                                              Diurnal
No Selector

R squared = 92.3%     R squared (adjusted) = 90.4%
s =  5.503  with  6 - 2 = 4  degrees of freedom

Source          Sum of Squares          df          Mean Square      F-ratio
Regression         1456.41               1            1456.41          48.1
Residual           121.136               4            30.284

Variable          Coefficient       s.e. of Coeff      t-ratio         prob
Constant            -6.52265           6.175             -1.06         0.3504
VP_Product           0.05115           0.0074             6.93         0.0023
```

Similar to the statements in the preceding material on the resting loss emissions from these test vehicles, the diurnal emissions from these tests are almost exclusively from tests performed over the 72 to 96 degree temperature cycle using a single fuel RVP. Thus, using a variable for vapor pressure for the full set of 47 tests would not be productive. However, as with the resting loss emissions, we used the preceding coefficient (0.05115) to estimate diurnal emissions (based on the vapor pressures) and then regress the calculated residuals against vehicle age. That regression analysis yields the following equation:

24-Hour Diurnal (grams) = -40.67512
+ (0.05115 * VP Product Term)
+ (1.41114 * Vehicle Age in Years)

EPA will use this equation to estimate the 24-hour diurnal emissions from pre-control vehicles with the restriction that the calculated value must be at least the estimated full-day's diurnal of the (newer) 1971-79 model year vehicles (as calculated in Appendix E).

11.6 Duration of Diurnal Soak Period

The analyses in this report were based on diurnals of exactly 24 hours in length. In the real-world, the soak period could run for longer or shorter periods of time.

Estimating diurnal emissions when the soak period is less than 24 hours are analyzed in report number M6.EVP.002 (entitled

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

Estimating diurnal emissions when the soak period is more than 24 hours are analyzed in report number M6.EVP.003 (entitled "Evaluating Multiday Diurnal Evaporative Emissions Using RTD Tests").

11.7 <u>1996 and Newer Model Year Vehicles</u>

Starting with the 1996 model year, EPA began certifying some of the new LDGVs, LDGTs, and HDGVs using an enhanced test procedure (ETP) which includes the RTD test. (The phase-in continued through the 1998 model year. By the 1999 model year, all the vehicles in the affected classes were ETP vehicles.) The methods used by EPA to estimate the resting loss and diurnal emissions from these vehicles are detailed in report number M6.EVP.005 (entitled "Modeling Diurnal and Resting Loss Emission from Vehicles Certified to the Enhanced Evaporative Standards"). Summarizing the results in that report, EPA found that (for ETP vehicles that are not "gross liquid leakers") the diurnal emissions predicted by those analyses:

- approximated the corresponding pre-enhanced (i.e., 1990-95), for the ETP vehicles that <u>failed</u> <u>either</u> the purge test or the pressure test and

- were approximately one-half the corresponding pre-enhanced (i.e., 1990-95), for the ETP vehicles that <u>passed</u> <u>both</u> the purge test and the pressure test.

These results support the assumptions made by EPA at the time the ETP rules were proposed; therefore, EPA will continue to use those assumptions in MOBILE6. That is, EPA will use a single set of equations to predict the <u>diurnal</u> emissions from the 1986 and newer vehicles that fail either the purge test or the pressure test, similarly for the gross liquid leakers. Also, for the ETP vehicles that pass both the purge and the pressure tests, EPA will estimate their diurnal emissions to be exactly one-half the diurnal emissions of the 1986-95 model year vehicles that also pass both the purge and the pressure tests and are <u>not</u> gross liquid leakers.

EPA will (in MOBILE6) also continue using the assumption that the <u>resting loss</u> emissions of the (ETP) vehicles that are <u>not</u> gross liquid leakers will be reduced by 75 percent.

11.8 <u>Tier-2 (2004 and Newer Model Year) Vehicles</u>

Beginning with the 2004 model year, vehicles that meet the more stringent Tier-2 standards will begin to be phased-in. Estimating the effects of those requirements for MOBILE6 is discussed in two parallel reports: "Modeling Diurnal and Resting Loss Emissions from Vehicles Certified to the Enhanced Evaporative Standards" (report M6.EVP.005) and "Accounting for the Tier 2 and Heavy-Duty 2005/2007 Requirements in MOBILE6" (report M6.EXH.007). MOBILE6 will estimate the diurnal emissions of those Tier-2 vehicles that are not "gross liquid leakers" and that <u>pass</u> <u>both</u> the purge and pressure tests:

- For passenger cars (i.e., LDGVs), we will assume that the diurnal emissions will be <u>reduced</u> <u>by</u> 0.75 (compared to the pre-Tier-2 ETP vehicles in Section 11.7).
- For LDGT-1 and LDGT-2 (GVWR $\leq$ 6000), we will assume that the diurnal emissions will be <u>reduced</u> <u>by</u> 0.675 (compared to the pre-Tier-2 ETP vehicles in Section 11.7).
- For LDGT-3 and 4s (6000 < GVWR $\leq$ 8500), we will assume that the diurnal emissions will be <u>reduced</u> <u>by</u> 0.525 (compared to the similar pre-Tier-2 ETP trucks in Section 11.7).
- For HDGTs with GVWR up to 14,000, emissions will be 1.474 times the corresponding emissions of the Tier-2 LDGTs with GVWR from 6,001 to 8,500 (i.e., proportional to the certification standards).
- For HDGTs (GVWR > 8500), we will assume that the diurnal emissions will be 2.000 times the corresponding emissions of the Tier-2 LDGTs with GVWR from 6,001 to 8,500 (i.e., proportional to the certification standards).

EPA will assume that for Tier-2 vehicles that fail <u>either</u> the pressure test or the purge test, their diurnal (and resting loss) emissions will be the same as the corresponding pre-Tier-2 vehicles.

EPA will (in MOBILE6) assume that the resting loss emissions of the affected (Tier-2) vehicles will exhibit the same percent reduction as the diurnal emissions.

Appendix A

Temperature Cycles (°F)

	---Temperatures Cycling Between ---			Change in
Hour	**60°-84°F**	**72°-96°F***	**82°-106°F**	**Temperature**
0	60.0	72.0	82.0	---
1	60.5	72.5	82.5	0.5
2	63.5	75.5	85.5	3.0
3	68.3	80.3	90.3	4.8
4	73.2	85.2	95.2	4.9
5	77.4	89.4	99.4	4.2
6	81.1	93.1	103.1	3.7
7	83.1	95.1	105.1	2.0
8	83.8	95.8	105.8	0.7
9	84.0	96.0	106.0	0.2
10	83.5	95.5	105.5	-0.5
11	82.1	94.1	104.1	-1.4
12	79.7	91.7	101.7	-2.4
13	76.6	88.6	98.6	-3.1
14	73.5	85.5	95.5	-3.1
15	70.8	82.8	92.8	-2.7
16	68.9	80.9	90.9	-1.9
17	67.0	79.0	89.0	-1.9
18	65.2	77.2	87.2	-1.8
19	63.8	75.8	85.8	-1.4
20	62.7	74.7	84.7	-1.1
21	61.9	73.9	83.9	-0.8
22	61.3	73.3	83.3	-0.6
23	60.6	72.6	82.6	-0.7
24	60.0	72.0	82.0	-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 third and fourth hours.

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:

$$\mathrm{Ln(VP)} = A + (B / \text{Absolute Temperature}), \text{ where:}$$

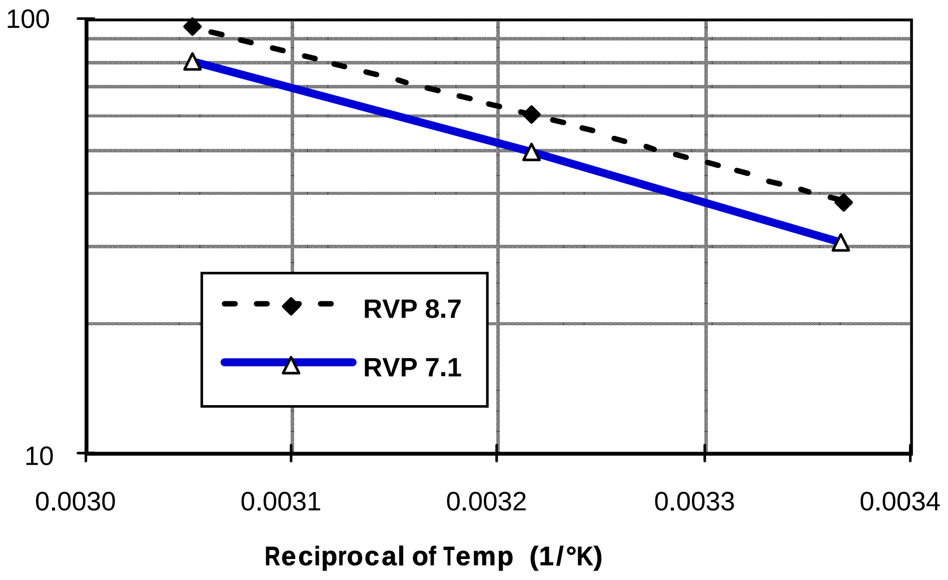
RVP	A	B
8.7	13.5791	-2950.47
7.1	13.7338	-3060.95

---

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

Figure B-1

Comparison of Vapor Pressure to Temperature



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) are so high as to be meaningless. This point would 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:

$$\text{Ln(VP)} = \mathbf{A} + (\mathbf{B} / \text{Absolute Temperature}), \text{ where:}$$

$$\mathbf{B} = -3565.2707 + (70.5114 * \text{RVP})$$

and

$$\mathbf{A} = \text{Ln}(6.89286 * \text{RVP}) - (\mathbf{B} / 310.9)$$

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 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 diurnal emissions.

Appendix C

Mean Evaporative Emissions by Strata By Vapor Pressure Products

Strata	Fuel RVP	Temp. Cycle	VP times △VP	Count	Mean RTD Test Results	Mean Hourly Resting Loss
Pre-1980 Carbureted Fail Purge/ Fail Pressure	6.8	72.TO.96	567.02	13	25.111	0.452
Pre-1980 Carbureted Fail Purge/ Pass Pressure	6.8	60.TO.84	374.77	1	16.229	0.250
	6.8	72.TO.96	567.02	7	21.055	0.307
	9.0	60.TO.84	655.07	1	17.511	0.218
	6.8	82.TO.106	789.30	1	36.321	0.204
	9.0	72.TO.96	968.66	1	44.222	0.250
	9.0	82.TO.106	1323.87	1	76.801	0.259
Pre-1980 Carbureted Pass Purge/ Fail Pressure	6.8	60.TO.84	374.77	2	21.284	0.238
	6.3	72.TO.96	489.32	1	17.426	0.140
	6.8	72.TO.96	567.02	20	24.385	0.227
	9.0	60.TO.84	655.07	3	21.572	0.103
	6.3	82.TO.106	683.98	1	24.328	0.175
	6.8	82.TO.106	789.30	2	42.799	0.174
	9.0	72.TO.96	968.66	3	35.331	0.107
	9.0	82.TO.106	1323.87	2	72.263	0.274
Pre-1980 Carbureted Pass Purge/ Pass Pressure	6.8	60.TO.84	374.77	1	7.861	0.167
	6.8	72.TO.96	567.02	11	13.240	0.263
	9.0	60.TO.84	655.07	1	17.423	0.239
	6.8	82.TO.106	789.30	1	32.292	0.293
	9.0	72.TO.96	968.66	1	38.297	0.204
	9.0	82.TO.106	1323.87	1	100.094	0.062
1980-85 Carbureted Fail Purge/ Fail Pressure	6.8	72.TO.96	567.02	1	27.401	0.265
1980-85 Carbureted Fail Purge/ Pass Pressure	6.8	60.TO.84	374.77	3	8.834	0.124
	6.3	72.TO.96	489.32	1	16.541	0.185
	6.8	72.TO.96	567.02	11	17.756	0.163
	9.0	60.TO.84	655.07	4	16.823	0.172
	6.3	82.TO.106	683.98	1	14.962	0.146
	6.8	82.TO.106	789.30	3	19.669	0.169
	9.0	72.TO.96	968.66	4	25.415	0.163
	9.0	82.TO.106	1323.87	3	55.324	0.162

Mean Evaporative Emissions by Strata By Vapor Pressure Products (continued)

Strata	Fuel RVP	Temp. Cycle	VP times △VP	Count	Mean RTD Test Results	Mean Hourly Resting Loss
1980-85 Carbureted Pass Purge/ Fail Pressure	6.8	60.TO.84	374.77	2	13.383	0.121
	6.3	72.TO.96	489.32	1	20.741	0.253
	6.8	72.TO.96	567.02	8	16.508	0.139
	9.0	60.TO.84	655.07	3	27.768	0.127
	6.3	82.TO.106	683.98	1	43.384	0.444
	6.8	82.TO.106	789.30	2	31.965	0.216
	9.0	72.TO.96	968.66	3	45.319	0.276
	9.0	82.TO.106	1323.87	2	53.615	0.308
1980-85 Carbureted Pass Purge/ Pass Pressure	6.8	60.TO.84	374.77	3	5.302	0.065
	6.3	72.TO.96	489.32	3	16.308	0.195
	6.8	72.TO.96	567.02	38	9.081	0.107
	9.0	60.TO.84	655.07	7	11.352	0.147
	6.3	82.TO.106	683.98	3	22.047	0.170
	6.8	82.TO.106	789.30	4	14.999	0.169
	9.0	72.TO.96	968.66	7	21.089	0.194
	9.0	82.TO.106	1323.87	3	43.900	0.274
1986+ Carbureted Fail Purge/ Fail Pressure	N/A	N/A	N/A	0	N/A	N/A
1986+ Carbureted Fail Purge/ Pass Pressure	6.8	72.TO.96	567.02	1	10.230	0.100
	9.0	60.TO.84	655.07	1	12.840	0.097
	6.8	82.TO.106	789.30	1	25.720	0.155
	9.0	72.TO.96	968.66	1	17.670	0.148
1986+ Carbureted Pass Purge/ Fail Pressure	6.8	72.TO.96	567.02	2	15.865	0.233
	9.0	60.TO.84	655.07	2	21.765	0.342
	6.8	82.TO.106	789.30	2	21.480	0.124
	9.0	72.TO.96	968.66	2	26.265	0.308
1986+ Carbureted Pass Purge/ Pass Pressure	6.8	72.TO.96	567.02	10	9.481	0.138
	9.0	60.TO.84	655.07	1	6.440	0.092
	6.8	82.TO.106	789.30	1	8.630	0.102
	9.0	72.TO.96	968.66	1	8.140	0.075
1980-85 Fuel Injected Fail Purge/ Fail Pressure	N/A	N/A	N/A	0	N/A	N/A
1980-85 Fuel Injected Fail Purge/ Pass Pressure	6.8	60.TO.84	374.77	3	4.329	0.010
	6.8	72.TO.96	567.02	3	7.910	0.011
	9.0	60.TO.84	655.07	4	6.556	0.045
	6.8	82.TO.106	789.30	3	10.744	0.041
	9.0	72.TO.96	968.66	4	11.506	0.086
	9.0	82.TO.106	1323.87	4	26.730	0.123

Mean Evaporative Emissions by Strata
By Vapor Pressure Products (continued)

Strata	Fuel RVP	Temp. Cycle	VP times △VP	Count	Mean RTD Results	Mean Hourly Rst Lss
1980-85 Fuel Injected Pass Purge/ Fail Pressure	6.8	60.TO.84	374.77	2	19.624	0.198
	6.8	72.TO.96	567.02	3	19.482	0.206
	9.0	60.TO.84	655.07	2	25.861	0.184
	6.8	82.TO.106	789.30	2	39.424	0.300
	9.0	72.TO.96	968.66	2	39.065	0.231
	9.0	82.TO.106	1323.87	2	50.255	0.252
1980-85 Fuel Injected Pass Purge/ Pass Pressure	6.8	60.TO.84	374.77	1	12.943	0.296
	6.8	72.TO.96	567.02	4	8.541	0.080
	9.0	60.TO.84	655.07	2	7.845	0.157
	6.8	82.TO.106	789.30	2	11.861	0.218
	9.0	72.TO.96	968.66	2	13.330	0.227
	9.0	82.TO.106	1323.87	1	25.503	0.348
1986+ Fuel Injected Fail Purge/ Fail Pressure	N/A	N/A	N/A	0	N/A	N/A
1986+ Fuel Injected Fail Purge/ Pass Pressure	6.3	60.TO.84	321.73	3	3.002	-0.009
	6.8	60.TO.84	374.77	12	5.413	0.011
	6.3	72.TO.96	489.32	5	6.027	0.024
	6.8	72.TO.96	567.02	18	9.083	0.060
	9.0	60.TO.84	655.07	17	7.802	0.034
	6.3	82.TO.106	683.98	5	11.068	0.064
	6.8	82.TO.106	789.30	15	14.498	0.073
	9.0	72.TO.96	968.66	17	11.734	0.056
	9.0	82.TO.106	1323.87	12	23.895	0.087
1986+ Fuel Injected Pass Purge/ Fail Pressure	6.3	60.TO.84	321.73	1	5.206	0.037
	6.8	60.TO.84	374.77	12	6.600	0.042
	6.3	72.TO.96	489.32	4	10.259	0.038
	6.8	72.TO.96	567.02	19	9.202	0.094
	9.0	60.TO.84	655.07	19	8.611	0.053
	6.3	82.TO.106	683.98	4	14.842	0.088
	6.8	82.TO.106	789.30	16	15.824	0.110
	9.0	72.TO.96	968.66	19	16.193	0.114
	9.0	82.TO.106	1323.87	12	32.116	0.129
1986+ Fuel Injected Pass Purge/ Pass Pressure	6.3	60.TO.84	321.73	2	0.602	-0.001
	6.8	60.TO.84	374.77	16	1.611	0.027
	6.3	72.TO.96	489.32	6	2.345	0.032
	6.8	72.TO.96	567.02	69	7.166	0.062
	9.0	60.TO.84	655.07	31	2.398	0.034
	6.3	82.TO.106	683.98	6	3.576	0.049
	6.8	82.TO.106	789.30	24	5.487	0.073
	9.0	72.TO.96	968.66	31	4.426	0.064
	9.0	82.TO.106	1323.87	21	13.640	0.123

Appendix D

Modeling Hourly Resting Loss Emissions From Light-Duty Gas Vehicles and Trucks 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)

Where

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.

Calculating the 24 hourly resting loss emissions using any temperature profile in which the hourly change in temperature is proportional to the corresponding hourly changes in the cycles in Appendix A, and then sum all of the 24 hourly results, we find:

24-Hour Resting Loss (grams) = (24 * Hourly_Resting_Loss_at_Lowest_Temperature)
+ (0.03193 * Diurnal_Temperature_Range)

Where the **Diurnal_Temperature_Range** is the difference of the daily high temperature minus the daily low temperature. This equation is used to predict the full-day's resting loss emissions that can then be subtracted from the RTD test results yielding the full-day's diurnal emissions.

Appendix E

Regression Analyses of Mean 24-Hour Diurnal Versus Vapor Pressure Product Term

1971-79 Carbureted Vehicles Passing the Pressure Test (based on 2 vehicles)

Dependent variable is: **Means of Diurnal**

No Selector

R squared = 97.4%   R squared (adjusted) = 96.7%

s = 5.175 with 6 - 2 = 4 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	3958.84	1	3958.84	148
Residual	107.107	4	26.7769	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	-3.971210	3.4920	-1.14	0.3190
Square of VP_Prod / 1,000	0.048250	0.0040	12.2	0.0003

1971-79 Carbureted Vehicles Failing the Pressure Test (based on 2 vehicles)

Dependent variable is: **Means of Diurnal**

No Selector

R squared = 94.1%   R squared (adjusted) = 92.6%

s = 4.824 with 6 - 2 = 4 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	1484.47	1	1484.47	63.8
Residual	93.0907	4	23.2727	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	12.65690	3.2560	3.89	0.0177
Square of VP_Prod / 1,000	0.029546	0.0037	7.99	0.0013

Appendix E (continued)

Regression of Mean Diurnal Emissions

1980-85 Carbureted Vehicles Passing Both Purge and Pressure Tests (based on 3 vehicles)

Dependent variable is: **Means of Diurnal**

No Selector

R squared = 97.2% R squared (adjusted) = 96.5%

s = 2.349 with 6 - 2 = 4 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	766.002	1	766.002	139
Residual	22.0621	4	5.51554	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	1.74328	1.299	1.34	0.2509
Cube of VP_Prod / 1,000,000	0.014639	0.0012	11.8	0.0003

1980-85 Carbureted Vehicles Failing the Pressure Test (based on 2 vehicles)

Dependent variable is: **Means of Diurnal**

No Selector

R squared = 95.5% R squared (adjusted) = 94.4%

s = 3.054 with 6 - 2 = 4 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	790.710	1	790.710	84.8
Residual	37.3085	4	9.32713	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	10.0859	2.061	4.89	0.0081
Square of VP_Prod / 1,000	0.021564	0.0023	9.21	0.0008

Appendix E (continued)

Regression of Mean Diurnal Emissions

1980-85 Carbureted Vehicles Failing ONLY the Purge Test (based on 3 vehicles)

Dependent variable is: **Means of Diurnal**
No Selector

R squared = 96.8% R squared (adjusted) = 96.0%
s = 3.262 with 6 - 2 = 4 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	1285.00	1	1285.00	121
Residual	42.5584	4	10.6396	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	5.18176	1.805	2.87	0.0454
Cube of VP_Prod / 1,000,000	0.018960	0.0017	11.0	0.0004

1980-85 Fuel-Injected Vehicles Passing the Pressure Test (based on 4 vehicles)

Dependent variable is: **Means of Diurnal**
No Selector

R squared = 98.2% R squared (adjusted) = 97.8%
s = 0.8350 with 6 - 2 = 4 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	154.859	1	154.859	222
Residual	2.78884	4	0.697209	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	2.40746	0.5635	4.27	0.0129
Square of VP_Prod / 1,000	0.00954291	0.0006	14.9	0.0001

Appendix E (continued)

Regression of Mean Diurnal Emissions

1980-85 Fuel-Injected Vehicles Failing the Pressure Test
(based on 2 vehicles)

Dependent variable is: **Means of Diurnal**

No Selector

R squared = 93.5%   R squared (adjusted) = 91.8%

s = 3.290 with 6 - 2 = 4 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	619.704	1	619.704	57.2
Residual	43.3046	4	10.8262	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	0.286889	3.692	0.078	0.9418
VP_Product	0.033366	0.0044	7.57	0.0016

1986-95 FI Vehicles Passing Both Purge and Pressure Tests
(based on 16 vehicles)

Dependent variable is: **Means of Diurnal**

No Selector

R squared = 91.6%   R squared (adjusted) = 89.5%

s = 0.9934 with 6 - 2 = 4 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	43.1082	1	43.1082	43.7
Residual	3.94721	4	0.986802	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	-0.834330	0.6704	-1.24	0.2813
Square of VP_Prod / 1,000	0.005035	0.0008	6.61	0.0027

Appendix E (continued)

Regression of Mean Diurnal Emissions

1986-95 Fuel-Injected Vehicles Failing the Pressure Test
(based on 11 vehicles)

Dependent variable is: **Means of Diurnal**
No Selector

R squared = 95.1% R squared (adjusted) = 93.8%
s = 2.221 with 6 - 2 = 4 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	380.824	1	380.824	77.2
Residual	19.7226	4	4.93065	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	1.75768	1.499	1.17	0.3059
Square of VP_Prod / 1,000	0.014965	0.0017	8.79	0.0009

1986-95 Fuel-Injected Vehicles Failing <u>ONLY</u> the Purge Test
(based on 12 vehicles)

Dependent variable is: **Means of Diurnal**
No Selector

R squared = 85.8% R squared (adjusted) = 82.3%
s = 2.492 with 6 - 2 = 4 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	150.611	1	150.611	24.3
Residual	24.8387	4	6.20969	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	4.14550	1.6820	2.46	0.0693
Square of VP_Prod / 1,000	0.009411	0.0019	4.92	0.0079

Appendix F

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

In each of the following strata, 24-hour diurnal emissions are modeled using four constants: A, B, C, and D. Where,

24-Hour Diurnal (grams) =

$$= A + B * [(\text{Mean VP}) * (\text{Change in VP})] + C * [(\text{Mean VP}) * (\text{Change in VP})]^2 / 1{,}000 + D * [(\text{Mean VP}) * (\text{Change in VP})]^3 / 1{,}000{,}000$$

For each of the 19 strata, the four constants used to model diurnal emissions are given below in the following table:

Fuel System	Model Yr Range	Purge / Pressure	A	B	C	D
Both FI & Carb	72-79	Fail Press	6.90895	0	0.029546	0
		Fail Purge	-4.58719	0	0.048250	0
		PASS Both	-8.09426	0	0.048250	0
Carb	80-85	Fail Press	9.71190	0	0.021564	0
		Fail Purge	6.88852	0	0	0.018960
		PASS Both	2.97845	0	0	0.014639
FI	80-85	Fail Press	-3.14389	0.033366	0	0
		Fail Purge	2.39612	0	0.009543	0
		PASS Both	-1.29432	0	0.009543	0
Carb	86-95	Fail Press	1.51716	0	0.02156	0
		Fail Purge	4.11975	0	0	0.01896
		PASS Both	1.42298	0	0	0.01464
FI	86-95	Fail Press	0.47846	0	0.014965	0
		Fail Purge	3.25800	0	0.009411	0
		PASS Both	0.38830	0	0.005035	0
Both FI & Carb	1999+	Fail Press	0.47846	0	0.01497	0
		Fail Purge	3.25800	0	0.00941	0
	1999-2003	PASS Both	0.19415	0	0.00252	0
	2007+	PASS Both	0.09222	0	0.00119	0

The ETP phase-in years (96-98) will be weighted averages of the pre-ETP and the ETP models. Similarly, for vehicles passing both purge and pressure, the Tier-2 phase-in years (2004-2006) will be weighted averages of the pre-Tier-2 and the Tier-2.

Appendix G

Plots Comparing Diurnal Models to Means of Measured Data

(Graphing of Appendix C versus Appendix F)

In the following 15 graphs, we plot on the same graph both the equations (from Appendix F) that are used in MOBILE6 to model diurnal emissions (as a function of the vapor pressure product term) as well as the corresponding mean diurnal emissions from Appendix C (after subtracting daily resting loss emissions from the RTD test results). To make the comparisons between graphs easier, the same scale is used on all 15 graphs.

Note: The three strata of 1986-95 model year carbureted vehicles were each tested at only four of the six possible temperature cycle / RVP combinations (see page 30).

Note: The points that are most distant from the curves (e.g., the single test at the highest VP on the pre-1980 vehicles passing both the pressure and purge tests) are those that are averages of only a small number of RTD test results.

Figure G-1

Carbureted 1971-79 – Failing Pressure Test

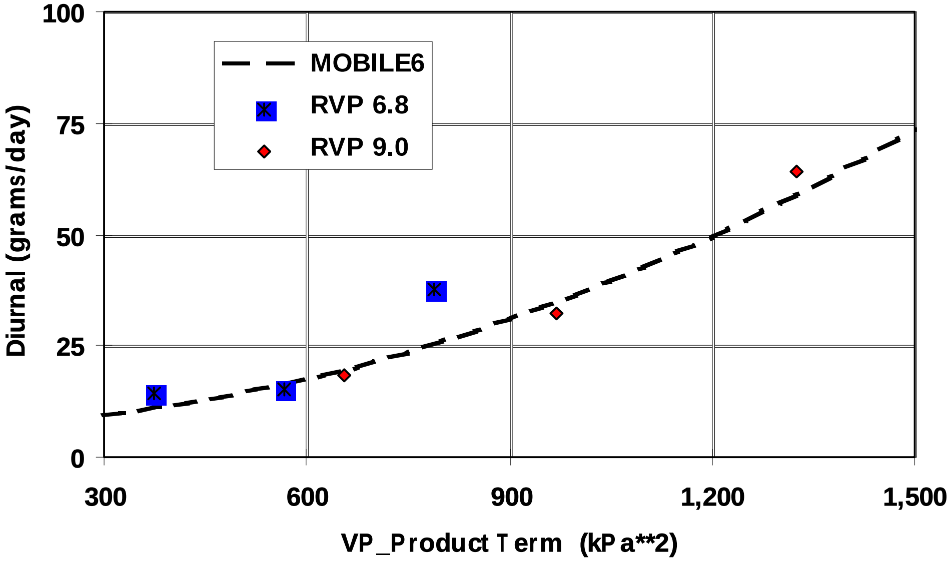


Figure G-2

Carbureted 1971-79 – Failing Purge Test

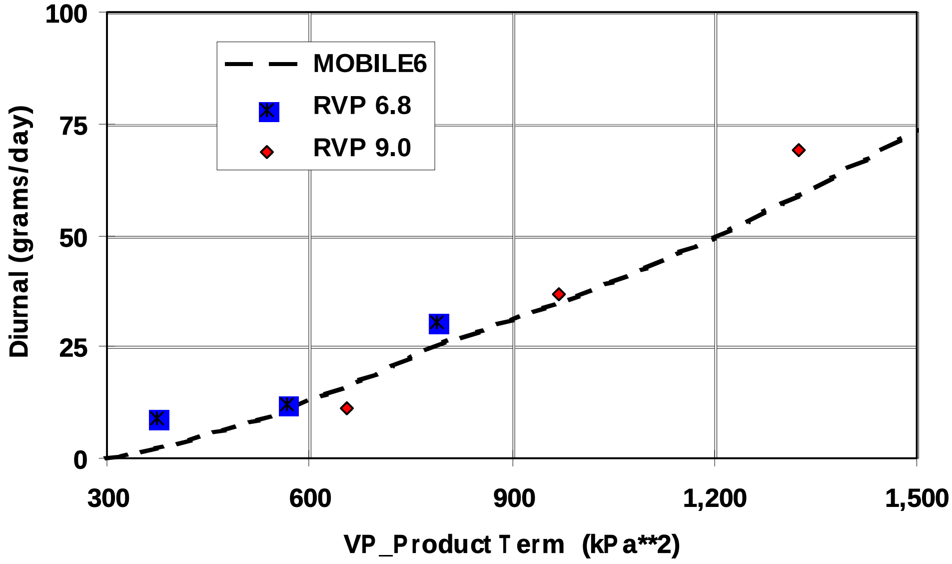


Figure G-3

Carbureted 1971-79 – Passing Both Pressure and Purge

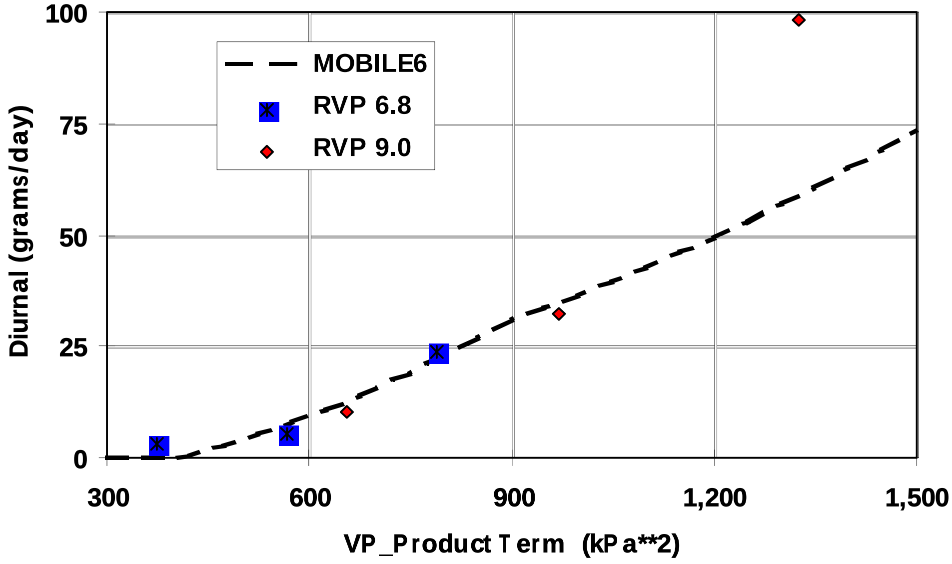


Figure G-4

Carbureted 1980-85 – Failing Pressure Test

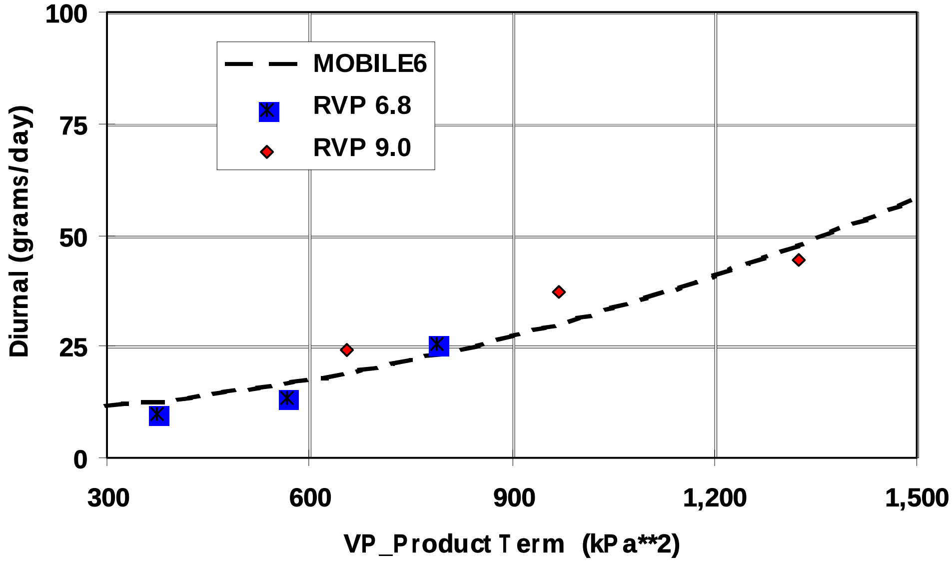


Figure G-5

Carbureted 1980-85 – Failing Purge Test

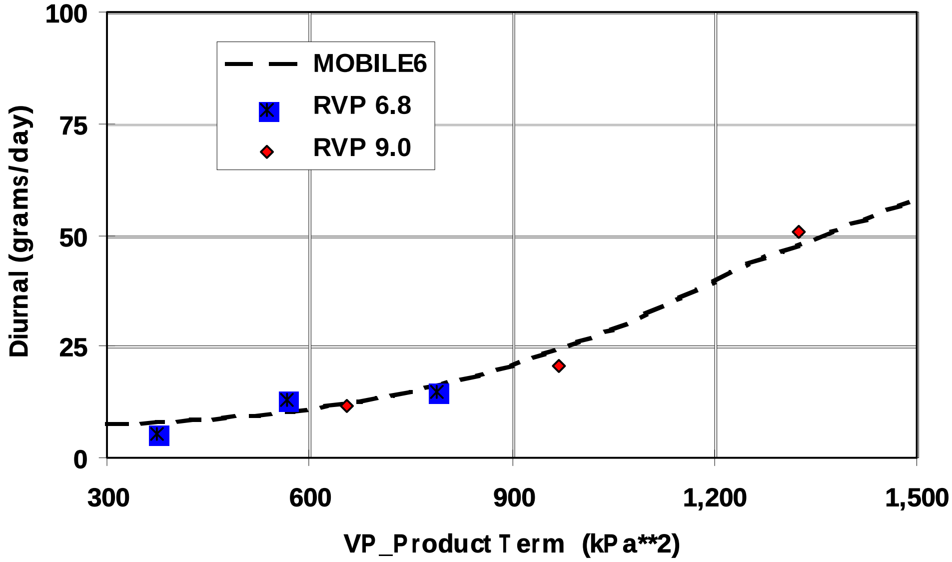


Figure G-6

Carbureted 1980-85 – Passing Both Pressure and Purge

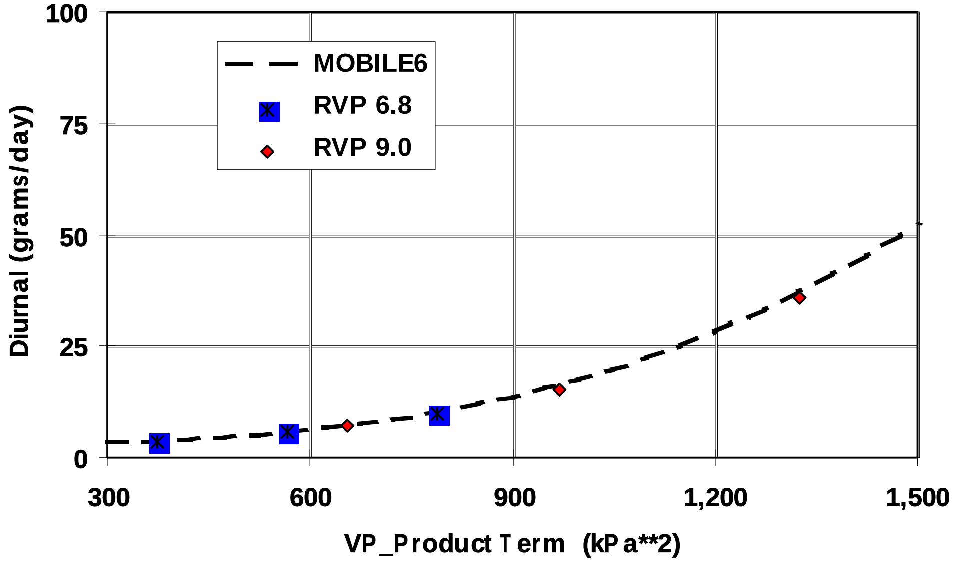


Figure G-7

Carbureted 1986-95 – Failing Pressure Test

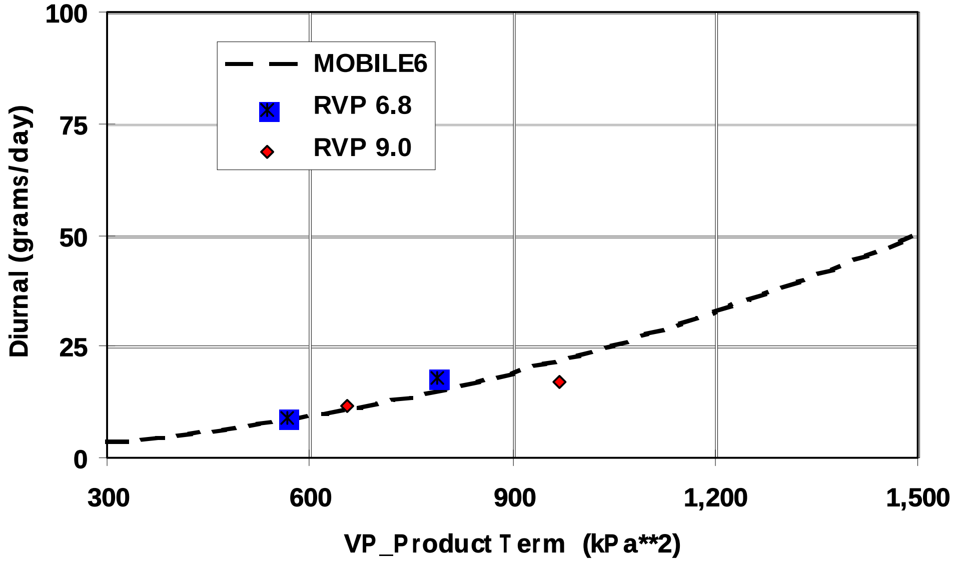


Figure G-8

Carbureted 1986-95 – Failing Purge Test

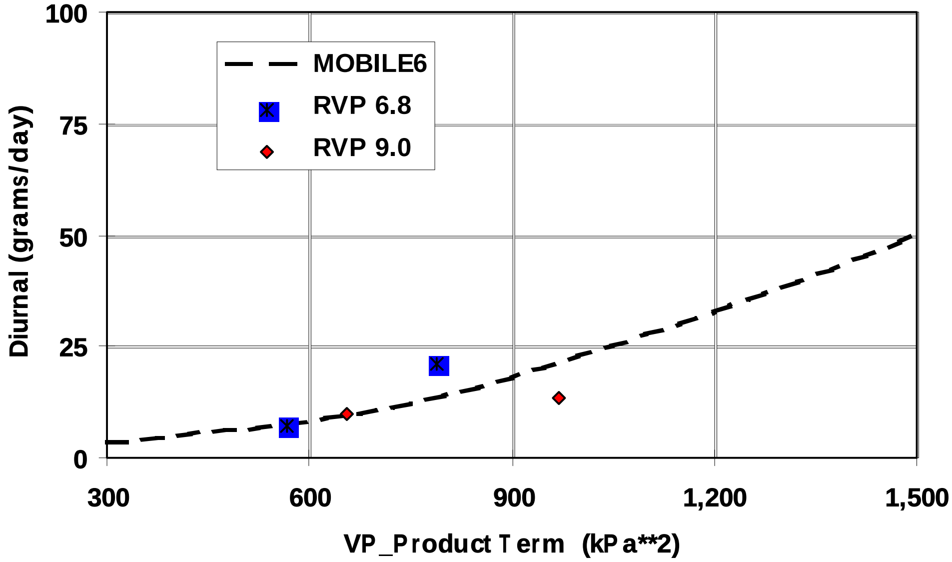


Figure G-9

Carbureted 1986-95 – Passing Both Pressure and Purge

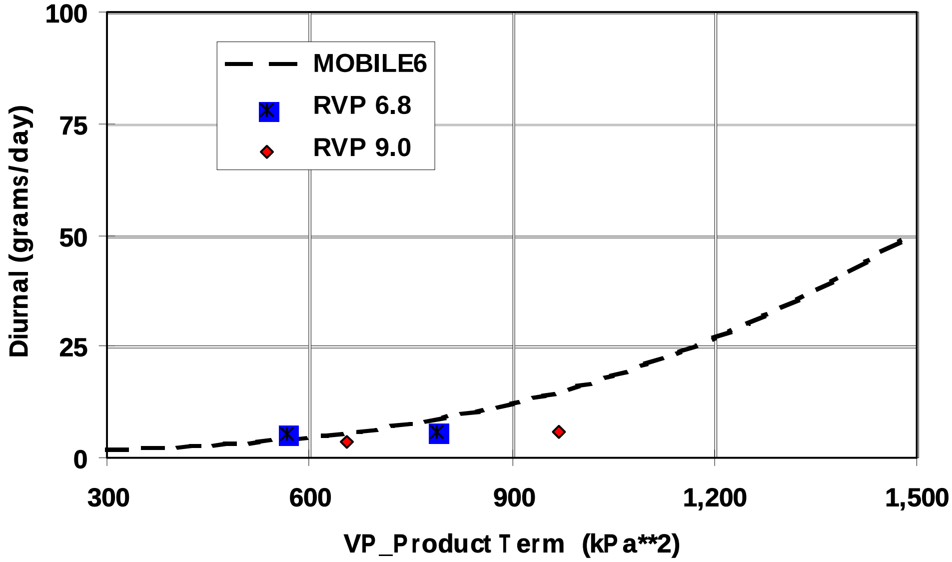


Figure G-10

Fuel-Injected 1980-85 – Failing Pressure Test

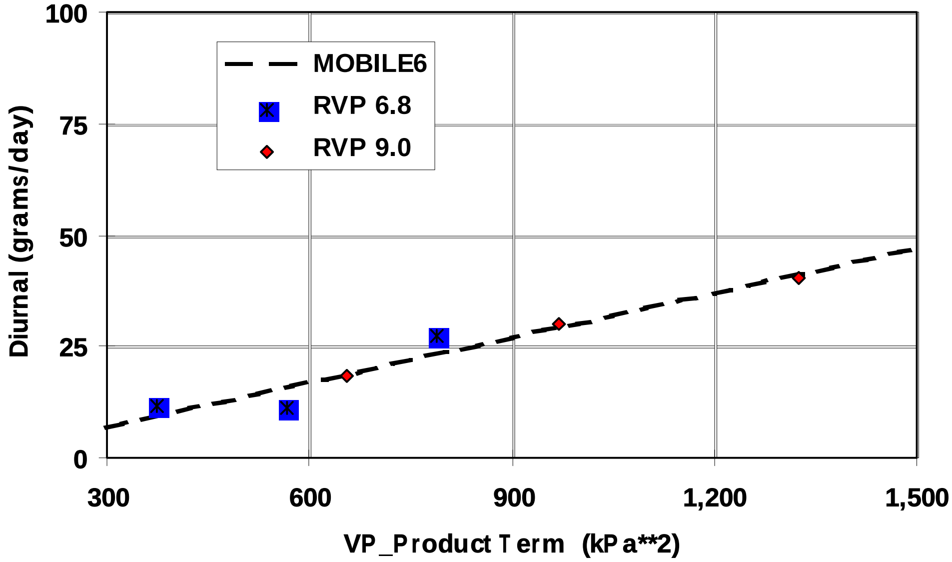


Figure G-11

Fuel-Injected 1980-85 – Failing Purge Test

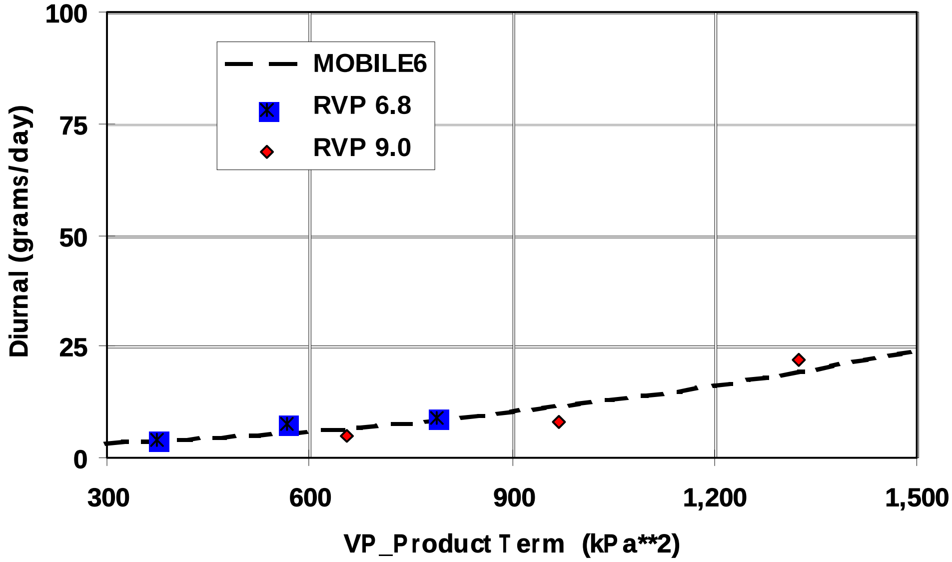


Figure G-12

Fuel-Injected 1980-85 – Passing Both Pressure and Purge

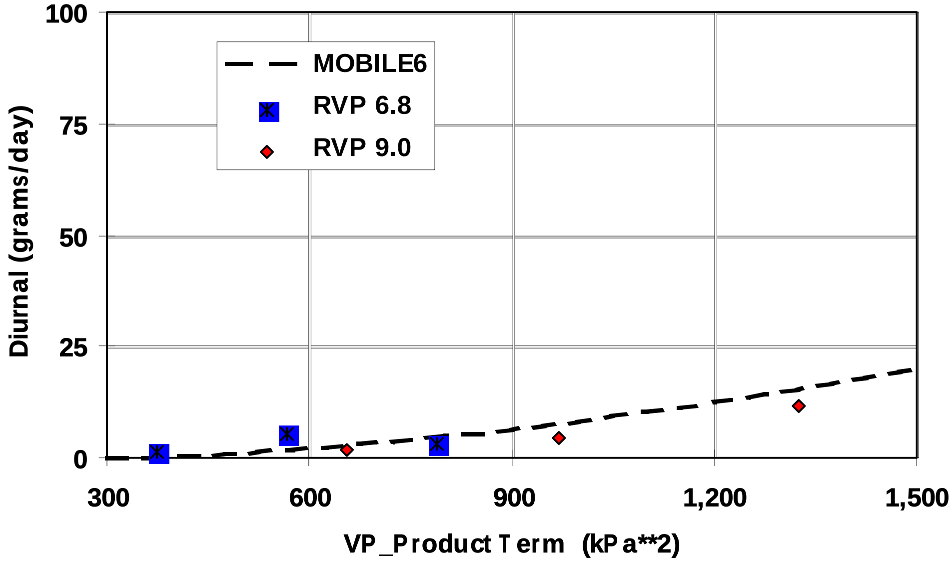


Figure G-13

Fuel-Injected 1986-95 – Failing Pressure Test

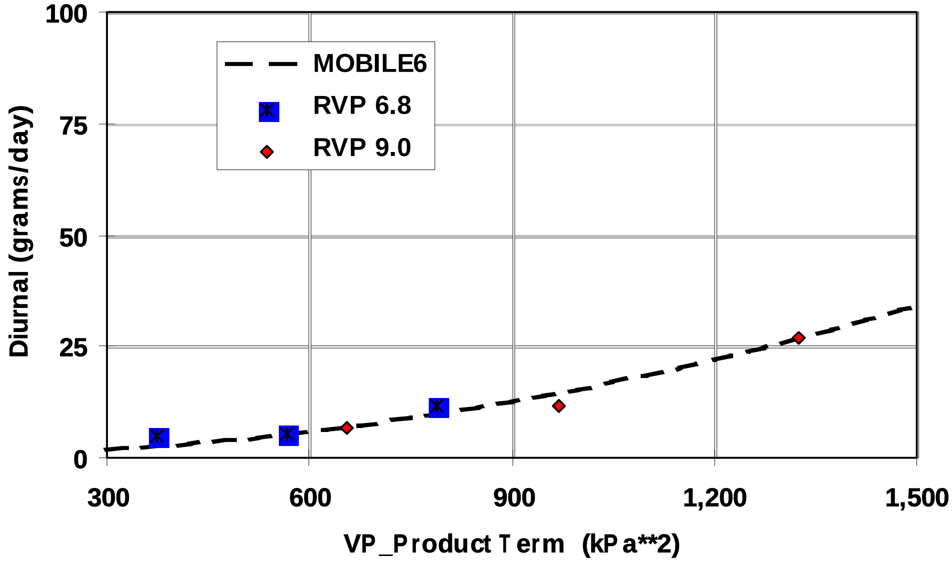


Figure G-14

Fuel-Injected 1986-95 – Failing Purge Test

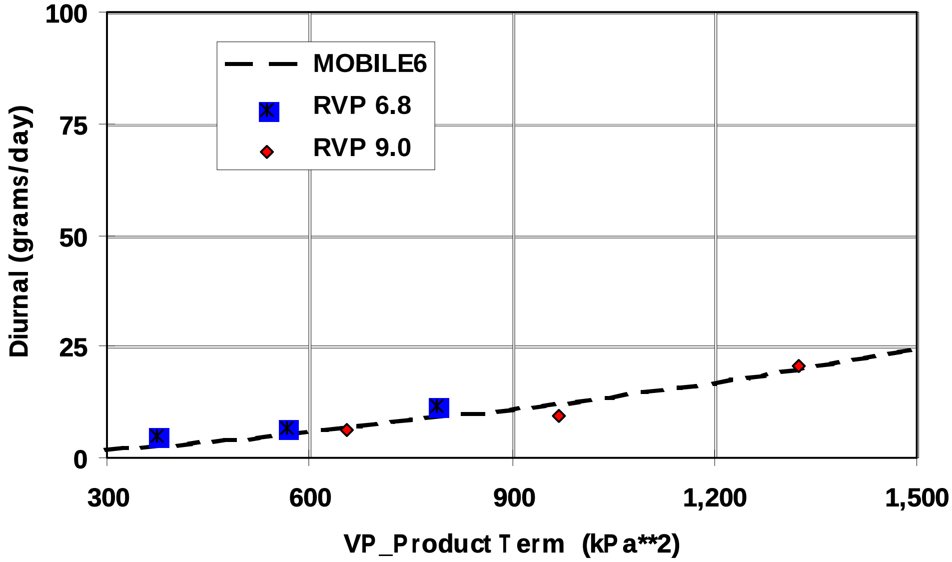
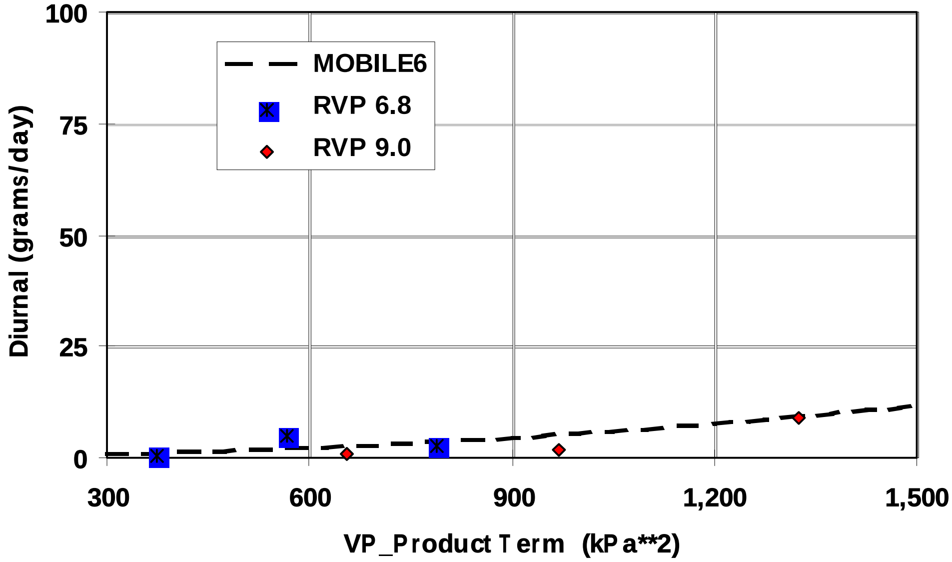


Figure G-15

Fuel-Injected 1986-95 – Passing Both Pressure and Purge



Appendix H

Response to Peer Review Comments from H. T. McAdams

This report was formally peer reviewed by two peer reviewers (H. T. McAdams and Sandeep Kishan). 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 I).

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Evaluating Resting Loss and Diurnal Evaporative Emissions Using
RTD Tests
By
Larry C. Landman

Report Number M6.EVP.001

Review and Comments
By
H. T. McAdams

1. REPORT CLARITY

Report clarity is determined by a number of factors, among them semantics, readability and logical rigor. The role played by semantics is multifaceted but can be roughly summarized as matching the report to the readership. Readability connotes directness and simplicity to the extent that the subject matter allows. Readability, therefore, is closely associated with style. Though it cannot alone guarantee clarity, most readers would probably agree that a report that is easily read is more likely to get its points across than a report that is weighted down with long, involved sentences and clumsy organization. Also clear writing does not insure sound logic, but it is difficult to envision one without the other.

In the review of Report M6.EVP.005, certain stylistic revisions were recommended in the interest of readability. Sometimes, however, grammar and syntax may be pristine but the writing conveys a mixed message. An example is found in Landman's discussion of the frequency of gross liquid leakers (Section 10.1, page 30 et seq.

On page 30 is the following table.

Vehicle Age	Frequency of Gross Liquid Leakers
5.62	0.28%
12.50	2.00%
21.29	7.84%

This table together with Figure 10-1 and comments on page 31 make it unclear whether the percentages refer to the fraction of vehicles <u>of a particular age</u> or to the fraction <u>of the entire fleet</u>. The table leads one to believe that 2.00%, for example, refers to 2% of vehicles that are 12.5 years old. The y-axis of the figure says simply "Frequency (%)" without identifying the sample space that the percentages are based on. Inasmuch as the x-axis denotes <u>age</u>, however, it would seem logical to assume that percent connotes percent of vehicles of a given age.

> *EPA revised this document to remove this source of possible ambiguity.*

Comments following the graph, however, are less than clear. For example, the statement is made that "the rapidly increasing proportion of gross liquid leakers in the in-use fleet tends to be offset by the decreasing number of older vehicles in the in-use fleet." The statement seems to be either contradictory or circular: the proportion can not both "increase rapidly" and yet "be offset" by the decreasing number of older vehicles.

The report should make it clear, however, that two functions have to be considered. One plots vehicle age along the x-axis and the proportion of vehicles <u>of that age</u> that are leakers along the y-axis. The other plots vehicle age along the x-axis and the fraction of the fleet represented by vehicles <u>of that age</u> along the y-axis. For any given vehicle age, it is the <u>product</u> of the two functions that must be considered. For example, if 1% of 8-year-old vehicles are leakers, but 8-year-old vehicles make up only 40% of the fleet, then only 0.4% of the fleet will consist of 8-year-old gross liquid leakers.

To estimate the portion of the fleet consisting of gross liquid leakers of <u>all</u> ages, one would have to make the same computation for all vehicle ages and sum the results. If vehicle ages are discrete, the computation would be simply the product of two vectors. If age is represented as continuous, then one would have to integrate the product function over time.

Revision of this part of the report is strongly recommended. It would also be prudent to look for similar situations where some simplification and clarification might be in order.

> *EPA agrees with those suggestions, and this report has been revised to incorporate those changes.*

2. OVERALL METHODOLOGY

The general methodology of this report essentially parallels that of Report No. M6.EVP.005. Both are driven by the objective to be realized: to model real-time diurnal (RTD) emission tests over a 72-hour period as a more realistic way to measure diurnal emissions. Separating resting loss emissions from diurnal emissions is a corollary aim. Resting loss emissions, the report says, are always present, whether there are any pressure-driven emissions or not.

We will examine, first, the mechanics of resting losses and secondly, the philosophy underlying the statistical approach.

2.1 Resting Losses: Real or Definitional?

Resting loss emissions are isolated by finding that region in the time series when emissions are essentially constant. According to the report, this time period encompasses hours 19 through 24. The hourly resting loss emissions are taken as the average of those losses over the 6-hour time period. This average is then subtracted from what was originally defined as diurnal losses to obtain a <u>new</u> measure of diurnal losses.

The methodology seems straightforward enough, but somehow not logically consistent. One senses that there are some aspects of the approach that need to be examined in more depth. In Report M6.EVP.005 one of the dictums laid down is that evaporative emissions over a zero time cycle (i.e., at constant temperature) are defined to be zero. Evidently, then, the resting loss emissions, as determined by the emissions during the 19th to 24th hours, <u>must</u> be pressure driven if only by the small pressure range associated with the small (5 degrees or so) temperature range.

> *This interpretation is not correct. Report M6.EVP.005 actually states: "The 24-hour <u>diurnal</u> emissions will be zero grams for any temperature cycle in which the diurnal temperature range is zero degrees Fahrenheit (i.e., a constant temperature throughout the entire day)." Thus, the reviewer's argument concerning <u>resting loss</u> emissions is not applicable.*

If that is so, why not run a 6-hour test over that temperature range and measure the resting loss directly? Should we expect to get the same results that we would get by isolating the 19th through 24th hours from the 24-hour cycle? Do the losses during the preceding 18 hours somehow have an effect on the next six hours? Is there, in fact, a <u>lag</u> effect?

To admit that possibility would mean that a pressure active at time t_0 might not take effect until some later time t_0 + delta. Actually, it would seem, pressure acting over zero time would have no effect on emissions. Moreover, if one were to look at pressure cumulatively over the pressure range, the pressure active at time t_0 + 1 hour would be effective over a considerably longer time than the pressure active at time t_0 + 5 hours.

Viewed in this light, resting losses are produced by the same mechanism as losses associated with any other small pressure interval and would seem to exist only by arbitrary definition.

More analysis needs to be addressed to this phenomenon. Computer modeling seems to be suggested and possibly serial correlation to determine the "decay time" for any given pressure.

> *While the suggestion may have merit; EPA is not able, at this time, to conduct a new vehicle testing program to validate this hypothesis (i.e., determining whether that approach would produce results different from those calculated by EPA in this report). Therefore, EPA will estimate resting loss emissions (in MOBILE6) by averaging the hourly evaporative emissions produced during the final six hours of the 24-hour RTD test.*

2.2 Philosophy Underlying the Statistical Approach

Special attention is directed to the statistical approach used to analyze RTD data, because it might seem to break with tradition. Vehicles are selectively recruited in such a manner that the sample is enriched with malfunctioning evaporative emission control systems. At first glance, it might appear that deliberately biasing the sample is against all sampling precepts. Actually, though, the procedure is just an ingenious adaptation of stratified sampling. The purge and pressure tests define the strata, each of which can be sampled as desired and the results weighted in accordance with the relative frequency of the strata in the fleet.

The choice of test parameters - e.g., fuel RVP and temperature cycle - is consistent with engineering knowledge. However, the way the temperature-related variables are redefined may merit further attention, as will become evident later in this discussion.

In addition to the variables that are known to affect evaporative emission, however, there are error sources that contaminate the emission measurements and complicate the construction of a predictive model. In the report, it is recognized that the same results may not be obtained at different test sites. It is also acknowledged that light-duty vehicles (LDV) may perform differently from light-duty trucks (LDT), and that carbureted vehicles may perform differently from fuel-injected (FI) vehicles. These differences, however, are the source of what statisticians call "fixed effects." Often they are treated as "dummy variables" having only two values, 0 and 1.

In the problem before us, it is likely that these fixed effects extend all the way to the level of individual vehicles. That is certainly true of exhaust emissions. In the development of the Complex Model for RFG, vehicle-to-vehicle variation was found to account for more than 90% of the total variation. A case was even cited in the reports under review in which the vehicle variation exceeded the variation accounted for by a predictor variable. As elsewhere noted, vehicle effects can often be isolated by way of dummy variables.

The hierarchy of errors are well described by this bit of doggerel verse.

Dogs have fleas,and fleas have fleas
Upon their backs to bite `em,
And they in turn have smaller fleas,
And so on ad infinitum.

So it is with emissions. Beyond the level of vehicle-to-vehicle variation arising from assignable causes, there are errors arising from unassignable causes. These are the error sources that give rise to the fact that repeated tests of a particular vehicle do not give the same results. Repeated tests such as these, known in statistical parlance as replications, can be used to estimate the magnitude of these random and unassignable errors. By proper experiment design, these errors can be determined by removing all identifiable effects and assigning the remainder to error, as is done in regression analysis. Any fixed effects not removed will inflate the error term and thereby weaken the ability of the test to detect effects that would otherwise be called statistically significant.

> *Running a testing program to characterize the variability of individual in-use vehicles as well as vehicle-to-vehicle variability will be a major undertaking. This is not something that can be done in time for MOBILE6.*

The methodology used in this investigation, for the most part, acknowledges this hierarchy of effects, but there are instances where error-management is less than optimum. In particular, error bounds are not specified except indirectly by statistical tests of significance used as the basis for including or excluding certain fixed effects. Though the approach used in the report is generally accepted under similar circumstances, the arbitrariness of significance tests leaves something to be desired.

> *Although Dr. McAdams believes this approach "leaves something to be desired," he does acknowledge that "the approach used in the report is generally accepted under similar circumstances," and he makes no specific recommendations. Therefore, EPA will continue to use the same statistical approach as in the draft version.*

3. APPROPRIATENESS OF DATASETS SELECTED

The available data comes from two very different sources, EPA "work assignments" and CRC tests. The EPA data is collected so as to be biased toward defective emission-control systems; that data is then "weighted" according to the frequency with which these defective vehicles are found in the real-world fleet. The CRC data is collected randomly but is biased toward trucks. Certainly this combination of data sets can not be said to be ideal.

For purposes of seeing just how far from ideal the combined sample is, it might be informative to list the characteristics of both side by side, as is done in the comparison of two products in the advertising media. Undoubtedly there would be many blank entries in the combined-sample column.

Landman has done a commendable job in adapting this less-than-optimum dataset to the purposes of his report. In some instances it was necessary to find a suitable surrogate for the missing data, and in other instances it was necessary to take a leap of faith. Though such tactics would not be admissible in a well-designed experiment, attention must be turned to "next best" options. Several are to be found in the report. The only suggestion that might be made here is to attempt to put bounds on the possible differences between what we have and what we would like to have.

4. DATA ANALYSIS AND STATISTICAL METHODOLOGY

Much of the concern in the report is with how to classify vehicles into appropriate subsets or strata. The methodology employed relies heavily on comparison of cumulative distribution plots for those data sets that are considered to be candidates for merging into a single set.

Landman starts with a list of classes or strata that are physically discernable, such as cars vs trucks, vehicles that pass certain tests vs vehicles that fail those tests, and so on. He then essentially arranges the RTD emissions for these vehicles into ascending order and constructs the sample cumulative probability distribution for each vehicle set. Finally, he plots the cumulative distributions for sets that are candidates for merging and relies on judgment to decide whether or not to combine these sets.

This procedure is subject to criticism on two counts. First, standard practice in the plotting of cumulative distributions is to plot measurements along the x-axis and cumulative probability along the y-axis.

> *The formats of the graphs have been revised.*

Secondly, judgemental decision making is highly subjective and, in this case, need not be, because a number of statistical tests are at hand for comparing two sets of measurements. These include contingency tables, discriminant functions and cluster analysis, as well as such simple procedures as a t-test for the difference between two means.

> *The discussion has been revised to include more objective methods.*

First, a word about the mechanics of plotting cumulative distributions. Though there is nothing wrong about Landman's way of plotting, it is unconventional and may cause the reader to reorient his thinking. Probability graph paper is designed so that the measurement axis is horizontal and the probability axis is vertical. Indeed, it might be interesting to plot Landman's data on such paper. Inasmuch as most data tends to follow a normal distribution, data tends to plot as a straight line, with the intercept and slope being measures of central tendency and dispersion, respectively. Accordingly, the linearized plots may be simpler to compare and interpret. (An alternative to probability graph paper is to transform cumulative percents to multiples of standard deviation in a normal [0,1] distribution.)

> *The software that we are using does not easily lend itself to graphing these cumulative distributions using a probability graph scale.*

Next, let us look at ways to compare two distributions. If the distribution of the data can be identified as being a sample from a known <u>theoretical</u> distribution, it suffices just to compare the estimated parameters of the theoretical distribution. For example, if data are known or suspected to be a sample from a normal distribution, it suffices to compare the means and standard deviations for the two distributions being compared.

Since the form of the data distribution is not actually <u>known</u>, Landman evidently seeks a comparison that circumvents any assumptions about the form of the underlying statistical distribution. That fact opens the door to an array of so-called <u>nonparametric</u> tests.

Plotting the cumulative distributions for the two samples being compared is a step in the right direction. From here, however, Landman's approach devolves to purely personal "eye-balling." In comparing Indiana and Arizona test sites, for example, he says "Despite the small sample size in the Indiana data ... the closeness of the distribution curves is compelling and suggests that there is no reason to treat the test data separately."

Elsewhere, in comparing the cumulative distributions for PFIs and TBIs, he says "Based on the similarity of the cumulative distribution curves and on the close fit of the means ... the PFI and TBI strata were merged into a single fuel-injected (FI) stratum for the remaining analyses." Though most analysts might agree with Landman on the above two cases, agreement becomes much less likely when we come to comparison of such pairs as cars vs trucks and EPA vs CRC testing programs.

Let us return to Landman's contentions with regard to the "close fit" of means and medians. The median is only one point on the cumulative distribution - namely the 50th percentile - and would seem to be redundant when comparing the entire cumulative distributions. If the entire cumulative distributions are "close fits," there are no "extra points" for the fact that the medians, also, essentially match. And, with regard to the means, how close is "close enough" to make the assertion that they are a "close fit?"

Comparison of the means of two sets of data is one of the first problems presented in elementary statistics courses. It is first addressed in comparing the means of two sets of data when the number of cases is the same for both sets. Later, a method is presented for the instance of unequal sample sizes. To implement the test, one needs the sample size, mean and standard deviation for both samples. From that, one computes the applicable value of t in the t-distribution. Even though the underlying distribution for the two samples might <u>not</u> be normal, the distribution of sample <u>means</u> tends to approach the normal by virtue of the Central Limit Theorem. This observation is true even for distributions as far from normal as a uniform distribution and for sample sizes as small as three or four.

> *Many of the comparisons used only the "eye-balling" approach since the curve "fits" appeared to be obvious; however, this report has been amended to include more objective methods.*

As illustrations, we present results for (1) comparison of PFI vs TBI (p. 10) and (2) carbureted vs FI trucks (p.12).

Sample Application of t-test to Coalesence of Sets

Sets Compared	Sample Size	Mean	Std. Dev.	t-ratio	Prob.
TBI Trucks	19	5.41	5.70		
PFI Trucks	24	5.85	7.87	-0.2047	0.8388
Carb.Trucks	7	9.31	8.28		
FI Trucks	43	5.65	5.92	1.2640	0.2113

The above test is based on the assumption that the two sets of data have the same standard deviation. When this assumption can <u>not</u> be made, we face a situation known in the statistical literature as the Behrens-Fisher problem, for which approximations are available.

Unfortunately, standard deviations are <u>not given</u> for most of the comparisons made in the report; among them are the more problematic cases, those that could benefit most from a statistical test of some kind. Although standard deviations are given for the CRC data, they are not given for the EPA data. If those statistics are <u>available</u>, it would be worthwhile to perform other t-tests to bolster the decision to merge or not to merge the strata.

> *The various tables have been expanded to include the standard deviations, and the discussions in the text have also been revised.*

It is to be pointed out that the t-test gives insight only with regard to the mean, into which all individual observations map. If one is interested in a more comprehensive measure, such as the cumulative distribution function, one might employ a non-parametric test, such as the Kolmogoroff-Smirnoff test or chi-square.

> *Since the goal of the MOBILE model is simply to estimate the <u>mean</u> of the emissions, EPA did not consider it necessary to employ other statistical methods to estimate the distributions.*

5. APPROPRIATENESS OF THE CONCLUSIONS

As in Report M6.EVP.005, conclusions are not stated explicitly. The thrust of the report, however, can be summarized as follows.

1) Real-time diurnal (RTD) tests of evaporative emissions make it possible to evaluate "resting losses" that are always present, even when there are no pressure-driven losses.

2) Resting losses per hour can be computed as the average RTD over hours 19 through 24 of the cycle.

3) Both diurnal and resting losses can be simply modeled by means of a set of regression equations in which the predictor variables are RVP and a VP-product term referred to as <u>prod</u> in this review.

4) The product term may enter equations as $prod^1$, $prod^2$ or $prod^3$ or some combination of these powers.

5) Whether two sets of data can be pooled can be judged by comparison of their cumulative distribution functions.

6. RECOMMENDATIONS FOR ALTERNATE DATASETS AND/OR ANALYSES

Several explicit recommendations are made with regard to the report being reviewed, Number M6.EVP.001. These recommendations stem mainly from the report's treatment of stratification and the manner in which it adjusts, or fails to adjust, for vehicle-to-vehicle differences. Of particular concern are those instances in which the standard deviation of the constant term approaches or exceeds its estimated value. It is likely that this inflation of the error of estimating the constant is caused by vehicle-to-vehicle differences in their overall level of evaporative emissions. Wherever feasible, these vehicle effects should be removed and the regression coefficients recomputed.

> *The effect of the statistical uncertainty in the constant term is most significant when the vapor pressure product variable is near zero. However, that situation will not occur in MOBILE6 because interpolation will be used for scenarios in which the daily temperature difference (daily temperature rise) is less than ten degrees Fahrenheit. Therefore, EPA is less concerned with the statistical uncertainty in the constant term than with the ability of the individual formulas to predict the emissions in the likely range of the vapor pressure product term.*

The following recommendations are made with regard to improvements that might be implemented within the time frame of finalization of this report.

1) Wherever possible, perform quantitative statistical tests to support the subjective decision made to pool or not to pool certain datasets.

> *The report has been revised to include the use of more objective statistical tests.*

2) Attempt to resolve the objection voiced earlier in this discussion with regard to the product term prod and its powers.

> *Investigating the uncertainty in the resulting regression equations produced by the vehicle-to-vehicle variability is beyond what can be done prior to completing MOBILE6.*

3) Wherever possible, use dummy variables to prevent the aliasing of vehicles or other extraneous variable with predictor variables.

> *The data were reanalyzed using categorical (dummy) variables instead of separate analyses for each stratum. However, the results were either unacceptable from an engineering perspective (i.e., predicting increasing emissions for decreasing fuel RVPs) or produced poorer "fits" within some strata to the actual test data.*

4) For representative cases, give error bounds for regression coefficients and for diurnal and resting loss emissions as computed by the applicable regression equation.

> *The regression tables (in Appendix E) include the standard error of the coefficient for the regressions of diurnal emissions.*

As pointed out earlier in this discussion, resting losses need to be defined more rigorously. To do so may require a better understanding of the loss process.

With regard to the modeling of diurnal and resting emissions, further attention needs to be directed to the reciprocity aspect of the product term prod and the "indifference" of powers of that term when selected as a predictor variable.

These are issues that might better be postponed for further systematic study. In that category, also, is a re-orientation of thinking with regard to more thoughtful application of statistical tests, regression analysis, and non-parametric procedures.

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Appendix I

Response to Peer Review Comments from Sandeep Kishan

This report was formally peer reviewed by two peer reviewers (H. T. McAdams and Sandeep Kishan). In this appendix, comments from Sandeep Kishan 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 November 20, 1998) that do not necessarily match the page numbers in this final version. Comments from the other peer reviewer appear in the preceding appendix (Appendix H).

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This memorandum provides peer review comments on two EPA documents: "Evaluating Resting Loss and Diurnal Evaporative Emissions Using RTD Tests", Document No. M6.EVP.001, November 20, 1998 and "Modeling Diurnal and Resting Loss Emissions" Report Number M6.EVP.005, October 1, 1998. Both of these are draft reports.

> *The original peer review covered two of the MOBILE6 documents. Only the portion of that review pertaining to this report is reproduced in this appendix. The remainder of the peer review is reproduced in report number M6.EVP.005 (Appendix G of that report).*

Overall, we think that the reports are good, and they present some new data analysis techniques that are attractive. Since, in the past, we have had to do similar data analyses and modeling for evaporative emissions from vehicle test data, we can appreciate many of the difficulties and data limitations you are subject to. We hope the comments below help you with this effort.

Document No. M6.EVP.001 (November 20, 1998)

We have the following questions, comments, and recommendations on this draft report. For each item we give the page number and paragraph that the comment refers to, if it is a specific comment.

Overall, this report was clearly written and the overall methodology seems alright. We were comfortable with the stratification based on purge and pressure tests results and the appropriateness of the datasets. We do not have any recommendations of any alternate datasets. We think that our most important comments involve the statistical analysis in which the average emissions of vehicles were regressed against input variables. We think that better results could be obtained by using a class variable to identify each vehicle in a regression. This would allow more experimental data to be used in each regression and it would provide better estimates of the regression coefficients. Additionally, we do not understand the background behind the vapor pressure product term especially since it seems to require patches for RVP functionality and for predictions of diurnal temperature increases shorter than those in the dataset.

The report has been revised to include additional background on this vapor pressure product term, as well as, comparisons between this term and the corresponding independent variable used in the previous version of MOBILE.

1. It would be helpful if the individual car data were provided in an appendix to the report. The data should provide the identity of the car and the evaporative emissions values obtained under each different test condition. This information provides the reader with a way to evaluate the raw data if he desires.

   The raw data is too extensive to easily fit within an appendix of this report. EPA will make it available electronically, upon request, in spreadsheet files.

2. Page 7, 4th paragraph – The phrase in parentheses weighted to correct for recruitment bias was not immediately clear. We presume that the weighting corrects for the recruitment bias of vehicles that failed purge and pressure tests. The abundance of vehicles that failed these tests in the population would be lower than they were in the vehicle test fleet.

   The reviewer's presumption is correct. (The phrase in question is in the fourth paragraph of Section 5.0.)

3. In Section 5.0, beginning on Page 7, comparisons for different strata of vehicles were made using RTD emissions. We think that the report should state somewhere near the beginning of this section, that these RTD comparisons really include both diurnal and resting loss emissions. The question then also arises as to whether the strata evaluations or strata comparisons would be the same if the RTDs had first been split into diurnal and resting losses first and then comparisons of diurnal emissions in strata made separately from comparisons of resting loss emissions in strata.

   A notation has been added to remind the readers that the results of the RTD tests include both resting loss and diurnal emissions. The alternative approach of splitting the resting loss and diurnal emissions prior to the comparisons may be considered in a future analysis (i.e., after the completion of MOBILE6).

4. Figures beginning with 5-1 on Page 8 – It would be helpful if the legends in these figures include the number of vehicles on which each curve in the plot is based. This

would give the reader a way to judge the confidence of the location of the curve on the plot.

The sample sizes are included in the text. Attempting to include the counts in the legends of each graph unfortunately reduces the readability (with the software packages we are using).

5. Page 9, Section 6.0, 2nd paragraph, Item 2 – One of the questions asked was whether PFI and TBI vehicles could be combined into a single stratum of fuel injected vehicles. Another possibility is to consider combining TBI with carbureted vehicles. Combining of vehicles in this fashion has been used in other studies and might be considered for this study.

   Since a major source of diurnal emissions is from the carburetor bowl, carbureted and fuel injected vehicles have historically be placed into separate strata. The reviewer did not indicate that this approach is flawed, only that an alternate approach may exist. Therefore, EPA will continue with this approach. The reviewers suggestion will be tested in future analyses.

6. Page 11, Section 6.1 – Comparison of strata statistics at the bottom of the page. This table no longer shows a value for standard deviation as was presented in the previous table of this sort in the report. In discussions with Larry Landman, Larry noted that the measures on page 11 were a combination of several strata of purge/pressure failures and that it was difficult to calculate a combined standard deviation. Also, it seems by examining these statistics, the purpose is to determine if the distributions are the same. Another possibility would be to perform a test to see if the distributions are significantly different given the sample sizes. It might be possible to perform a Komolgorov-Smirnoff test on each of these distributions to back up the visual appearance of the plots with a quantitative assessment.

   That table (and others) has been expanded to include the standard deviations, and the discussions in the text have been revised to also to include the standard deviations.

7. In Section 6.0 the comparisons of different strata are made as the report states after weighting the results to correct for recruitment bias. It would be helpful to have an appendix in the report describing how these weightings were accomplished. Larry pointed out that there was another EPA report that described this.

   The weighting method is the standard approach used when the sample is obtained using stratified random (targeted) recruitment.

8. Page 18, last paragraph of Section 6.5 – while it is probably true that this paragraph documents what has been done with the different strata, it is quite difficult to follow. Please consider modifying this paragraph to make it more clear to the reader.

   That paragraph has been revised.

9. Page 20, first paragraph of Section 7.2 – this section seems to say that we do not need to bother modeling the resting loss as a function of RVP and temperature but we can just make it constant and subtract off the constant value for every hour of the day from the RTD hourly emissions. This gives the impression that we are introducing errors in the deduced diurnal emissions values. Why don't you just model resting losses as a function of RVP and temperature and subtract them from the RTD emissions to get the diurnal emissions? In addition to comment #0, it may be helpful to include plots of several vehicles' RTD emissions versus time in an appendix. Considering the plots may bring a better understanding of the schematic of Figure 7-2.

   Actually, the analyses were performed using estimates of hourly resting loss emissions that were "corrected" to account for the changing temperatures. The paragraph has been revised.

   As to supplying more sample plots (of RTD emissions versus time), all of the individual (hourly) results will be provided electronically. Thus, if any reader who is interested can easily generate those plots.

10. Page 22, third full paragraph – while hot soak emissions are not being studied in this report, this paragraph might say, if you believe it is true, that leaks associated with the fuel pump might appear as high hot soak emissions.

    Yes, that is what is being suggested. While we have not tested such a vehicle, it seems possible that some of the leaked gasoline (e.g., from a leaky fuel pump) might still be present in liquid form after the engine has been shut off. That liquid gasoline would then be counted as part of the hot soak emissions.

11. Pages 22 and 23, first two paragraphs of Section 8.0 – We also expect that resting loss evaporative emissions are functions only of ambient temperature but it seems that you are immediately discarding the possibility of an RVP influence even though you have data that would seem to allow you to evaluate whether that influence is really present or not. So, why not test for the RVP effect? This could be done using the 57 vehicles in the EPA program that were tested with both 6.8 and 9.0 RVP fuels and three temperature cycles. Again, in discussions with Larry, he said that the sequence of the tests and RVP effects may be confounded due to the test procedure used. EPA should consider randomizing

the tests in future programs so that such effects can be properly investigated.

True. In future testing programs, we will consider randomizing the order of the testing so that the effects of RVP on resting loss can be investigated.

12. Page 23, middle of the page – at this point, we wanted to see the evaporative emissions data on these individual 57 vehicles. This desire leads to the next item.

    As note in the response to this reviewer's first comment, EPA will make the raw data available electronically, upon request, in spreadsheet files. One of those files will consist of the data on just these 57 vehicles.

13. Page 24, Figure 8-1 – the average values plotted in the table look quite good. However, consideration of just the average values can hide a lot of additional interesting information. We would like to be able to see the plot with individual vehicles or by the 12 strata used in the analysis in different symbols. Are the slopes different for the different strata? Are the slopes different for different RVP levels, purge and pressure failures, or model year groups? These issues potentially have a greater significance than the tiny amount of curvature seen in the figure. Larry pointed out that these relationships will be used in the MOBILE model which primarily considers averages so that inventories can be developed. However, we still think that at this stage of model development, it is important to consider vehicle to vehicle differences to get a better understanding of emission trends. In many datasets we have seen that the influence of a parameter on emissions is more subtle than vehicle-to-vehicle differences.

    As note in the responses to the first and twelfth comments, EPA will make the raw data will be available electronically for any additional graphs and analyses that the readers may wish to investigate. This approach (i.e., producing distinct regression equations of resting loss emissions for each tested stratum) was attempted and then discarded (as noted in the third paragraph of Section 9.0) because it produced predictions contrary to theoretical models.

14. Page 25, first paragraph – in the analysis values for B were calculated separately for carbureted and fuel injected vehicles. Did you look for different B's for the different strata in the dataset? This question is really just a restatement of question 12. However, it involves a regression type of solution rather than a graphical one. While there may insufficient data to detect significant differences, they might be significant. If it is found that the values are not significantly different, then this should be stated along with the error of the estimate in B.

    See previous response.

15. Page 25, paragraph 3 – at this point the report gives the reason for not considering the influence of purge failure with respect to resting loss emissions. While the engineering reason seems to make sense, it also seems that a regression of the data could reveal whether the presence of purge failures actually had a significant effect on resting loss emissions. This would confirm the elimination of purge failure from consideration and would make the case stronger for not using it to describe resting loss emissions.

    The sample sizes were <u>too</u> <u>small</u> (given the standard deviations) to permit us to distinguish the resting loss emissions of those substrata; thus, we relied upon engineering judgment.

16. Page 25, paragraph 4 – the last sentence ending in 0.766 leaves the reader wondering where that value came from. It would seem that either the value should not be mentioned or it should be explained. I think the source is in Appendix D, but I am not sure.

    More detail has been added to the explanation that was present.

17. Page 26, Section 9.0, paragraph 4 – the logic of using VP.Δ.VP eludes me. Is there some theory to back this up or some reference that can be referred to which contains theoretical development?

    The beginning of Section 9.0 (pages 26 and 27) has been revised to provide more background on this VP product term, including earlier uses of this variable as well as comparisons with the variable (UDI) used in MOBILE5.

18. Page 26, Section 9.0, paragraph 5 – the mean of the diurnal emissions were modeled. As soon as the mean of individual measurements are used, the error associated with those individual measurements is lost. In addition, because the number of tests performed at different conditions are unbalanced, the regression has no way of distinguishing the different uncertainties in the mean values. When individual values are used in a regression, the model will attempt to fit the measured data better for those conditions where there are more observations. Without using individual values, and instead using averages for each condition, a regression model will put equal emphasis on each mean whether that mean was calculated from one observation or 30. Use of means can also result in a functional form which may be actually unsupported by the individual vehicle data.

    In the sample being analyzed, the same test vehicles and the same number of test results were present at each point (i.e., at each of the six values of the VP product term). Thus, we avoided the potential problems that the reviewer *noted. (This was one of the reasons that EPA restricted this portion of the analyses to the 57 vehicles that were tested at each of the six combinations of temperature cycle and fuel RVP.)*

19. Page 26, Section 9.0 paragraph 9 – the diurnal emissions were <u>repeatedly</u> regressed against. What is meant by repeatedly is not clear. We assume that this means playing with the model statement until a satisfactory model is achieved.

    This assumption of the reviewer is correct.

20. Top of page 27 – doesn’t the fact that RVP helped the regression when the vapor pressure product was already in the regression indicate that the vapor pressure product doesn’t do a satisfactory job of modeling the emissions? This then causes us to wonder again what the theory of the vapor pressure product is.

    The vapor pressure product term <u>does</u> a satisfactory job of modeling the diurnal emissions; it does not do a perfect job. However, our attempts at improving those models produced equations that closely predicted the diurnal emissions at the six actual test conditions but erred at the intermediate points (e.g., at 8.0 RVP).

21. Top of page 27 – a third step which should be used to choose among the models is to validate or evaluate the alternative regression equations against the diurnal emissions of the vehicle data which were not used to build the models. The models for which the measured and modeled diurnal emissions data agree best would be top candidates for selection.

    Yes. That was how the final models were chosen.

22. Page 27, last paragraph – the text says that you imposed the following three restrictions. How did you impose these? Or did you really just check the predicted values of models for making sense based on engineering experience? The phrase "impose restrictions" suggests that you did something during model building rather than after model building.

    The candidate models that did not meet those restrictions were rejected. Therefore, we "imposed restrictions" after the models were built, <u>not</u> during the building process itself.

23. Footnote at the bottom of Page 27 – doesn’t the fact that the diurnal emissions should be zero when the temperature increase is zero and the fact that the models do not properly predict this boundary condition imply that the model statement could be improved upon? It seems that it would be possible to come up with a functional form for the model statement that included this zero/zero condition and

also describe reasonably well the measured emissions values when the temperature increase was not zero.

Since the model should predict zero diurnal emissions (for vehicles not "gross liquid leakers") when the daily temperature is constant, we first tested regressions that predict zero diurnal emissions when the temperature change is zero. (That is, regressions that simply connect the origin to the mean of the data.) None of those regressions (neither linear nor non-linear) were able to accurately predict the diurnal emissions at the six actual test conditions. As a compromise, we used the "best fit" equations for days in which the difference between the daily high and low temperatures is at least 10 degrees and, for days in which the temperature difference is less than 10 degrees, we simply interpolate between the prediction at 10 degrees and zero.

24. Page 28, second paragraph – we would like to see the regression results before the constant terms are adjusted. By the way, the use of the expression "altered the constant terms" sounds like you are fudging the models. We would suggest the use of a different expression and a little more explanation on the reason for the adjustments.

    Those regression results (prior to modifying the constant terms) are contained in the tables in Appendix E. Following the suggestion of the reviewer, the wording (concerning "altering" the constant terms) has been revised.

25. We recommend that the report contain a plot of measured data and model curves with appropriate symboling to describe the different strata and/or test variables. If this type of plot proves to be to busy or complex, at a minimum, we would recommend showing parity plots, that is predicted versus measured emissions, for each of the models. This will give the reader an indication of how accurately the models predict emissions and whether there are any major deviations across the range of emissions.

    Appendix G has been added to the report to illustrate the predicted versus the (means of the) measured data.

26. Page 29, third paragraph "we then transformed the constant term" – We think you don't really mean transformed but really mean adjusted as you have described earlier in the section. The word transformed, to us, means made a transformation. For example, a natural log transformation or a power law transformation. Also, two lines later, the report uses the term "calculated diurnal emissions". We assume you are referring to the fact that the diurnal emissions were deduced from the RTDs by subtracting off estimated resting losses. We would prefer to see the word "estimated" or "deduced" to replace the word "calculated."

    The wording has been revised similar to comment number 24.

27. Last paragraph on Page 29 – you state that sometimes the data suggests that a non-linear relationship for the diurnal emissions with respect to the vapor pressure product term, and sometimes it appeared to be linear. One approach to determining if a relationship is non-linear is to scale the inputs to have a mean of zero and then including in the model statement a linear term and a non-linear term such as a squared term. This scaling separates the linear and curvature effects so that the significance of the coefficient on the squared term can be used to answer the question is there significant curvature in the relationship between the inputs and the outputs. Was this technique used to answer the question of whether the relationship was linear or non-linear? Or was a different technique used?

    The significance of the non-linear term was calculated using the unscaled data.

28. Page 30, Section 10.1 – we suggest that you mention the number of vehicles used to determine the logistic growth curve for the frequency of gross liquid leakers.

    The details are given in report M6.EVP.009.

29. Appendix B, page 43 – The discussion of the Clausius-Clapeyron method. We can see how you calculate the values of A and B from the two RVP values from the previous EPA work assignment. However, we think that once the RVP, A, and B values are determined, it will then not be possible to ensure that the curves pass through the appropriate pressure at 100°F. The equation seems to be over specified.

    The discussion in Appendix B has been revised to improve clarity. The results are unchanged.

30. Appendix D, page 47 – We don't follow the equation at the bottom of the page or how it was obtained.

    An explanation of that equation was added to Appendix D.

Appendix J

Response to Written 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 comments is posted on the MOBILE6 website.

Comment Number: 18

Name / Affiliation: John Walsh / EPA Region 2

Date: April 3, 1997

Comment:

"We would assign this [diurnals, resting losses, & liquid leaks] a low priority unless significant differences as anticipated over estimates derived from current testing methods."

EPA's Response:

We could not determine in advance whether these new approaches would result in significant differences. These new approaches are being used because we believe they more closely represent the real world.

Comment Number: 28

Name / Affiliation: Chris Saricks / Center for Transportation Research (Argonne National Lab)

Date: April 29, 1997

Comment:

"The CTR is generally pleased to learn that corrections are planned in MOBILE6 ... for recalibrating the share of trip emissions attributable to diurnal and resting emission losses in recognition."

EPA's Response:

No response is necessary.

Comment Number: 30

Name / Affiliation: Dale Aspy / EPA Region 4

Date: April 30, 1997

Comment:

Acceptable methodology needs to be developed for testing of resting loss emissions.

EPA's Response:

The commentor appears to be concerned that the recruitment method(s) used be able to account for the rare, high-emitting outlier. We agree. We believe that the outliers will be represented.

Comment Number: 32

Name / Affiliation: John Walsh / EPA Region 2

EPA's Response:

This comment is simply an exact duplicate of Comment No. 18.

Comment Number: 49

Name / Affiliation: Marc Houyoux / North Carolina Supercomputing Center - Environmental Programs

Date: October 30, 1997

Comment:

Relative to analyzing resting loss emissions, the commentor does not like regression of means, he prefers to see scatter plots.

EPA's Response:

If we were trying to predict the distribution of resting loss emissions as a function of temperature, then we would agree. However, since we are attempting to estimate fleet (i.e., mean) emissions, we believe this approach is acceptable.

Comment Number: 54

Name / Affiliation: David Lax / API

Date: December 17, 1997

Comment:

API is "very concerned that the approach used in M6.RTD.001 to weight resting loss and diurnal evaporative emissions test data based on pressure / purge test result status may lead to biased representations of the in-use fleet."

EPA's Response:

EPA agrees that neither the purge test nor the pressure test is the best choice to use in order to stratify the fleet. Unfortunately, the vehicle recruitment process used them as recruitment criteria. But, since each purge / pressure bin is adequately represented, weighting the results should produce an unbiased representations of the in-use fleet.

Comment:

API wants the statistics that EPA used to characterize the resting losses so that they can confirm EPA's analyses.

EPA's Response:

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

Comment:

API wants the statistics for characterization of 24-Hour diurnal emissions to be able to confirm EPA's analyses.

EPA's Response:

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

Comment:

In the section of their comments entitled "Accounting for Liquid Leaks," API suggested that EPA "consider and evaluate more data before finalizing an algorithm for this component in the MOBILE model. In particular, ... the data on the liquid leaks observed in the running loss test program recently conducted by the CRC."

EPA’s Response:

We did consider those data (and others). As a result, we revised our estimates.

Comment:

In the section of their comments entitled "Accounting for Liquid Leaks," API suggested that EPA use the results of their recent survey program to detect leakers.

EPA’s Response:

We did use the results of their recent survey program to detect leakers. We were not able to follow up on their suggestion to study the effects of the behavior of the driver on real-world leaks.