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Evaluating Resting Loss and Diurnal Evaporative Emissions Using Real Time Diurnal Tests

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Assessment and Modeling Division
Office of Mobile Sources
U.S. Environmental Protection Agency

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Evaluating Resting Loss and Diurnal Evaporative Emissions Using RTD Tests

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ABSTRACT

This report is a revision of a draft that was released for stakeholder review on October 8, 1997. The report numbering convention was changed since the release of that earlier draft which carried the document number M6.RTD.001. Subsequent versions of that earlier draft (including this version) will all carry the document number M6.EVP.001 (i.e., the "RTD" was changed to "EVP"). All versions of this report are entitled "Evaluating Resting Loss and Diurnal Evaporative Emissions Using RTD Tests."

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 is to develop a proposal for a model of the diurnal and resting loss emissions of the in-use fleet. This revised draft report incorporates suggestions received from stakeholders during the 60-day review period.

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Evaluating Resting Loss and Diurnal Evaporative Emissions Using RTD Tests

Report Number M6.EVP.001

Larry C. Landman
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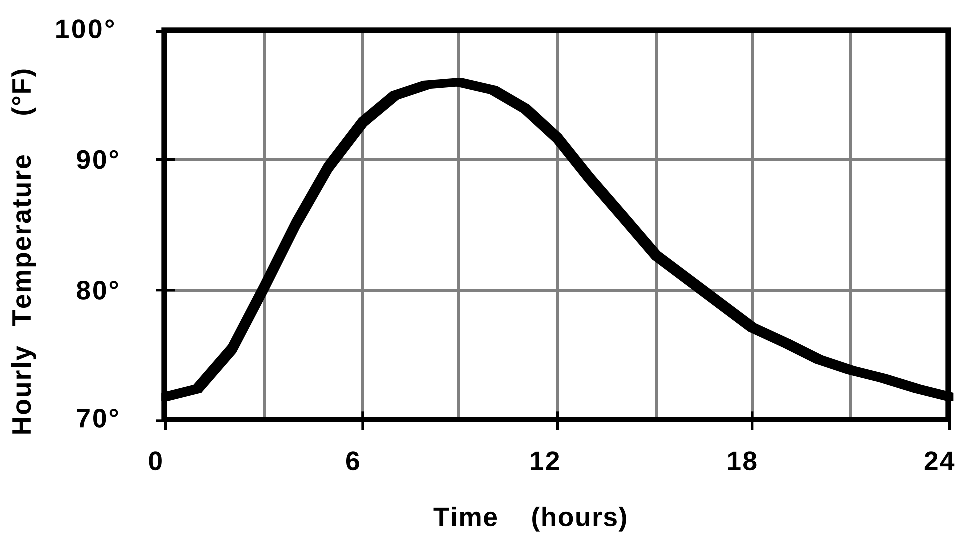
1.0 Introduction

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 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 (5) 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 on 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 in the following table:

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 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

* 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.

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 four) 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 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.

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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).

Table 4-1

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

	--- Results on Purge and Pressure Tests ---			
Vehicle Age	Fail Purge Pass Pressure	Fail Purge Fail Pressure	Pass Purge Fail Pressure	Pass Purge Pass Pressure
0	1.49%	0.05%	1.38%	97.1%
1	1.86%	0.08%	1.79%	96.3%
2	2.30%	0.14%	2.30%	95.3%
3	2.82%	0.23%	2.96%	94.0%
4	3.43%	0.36%	3.77%	92.4%
5	4.13%	0.55%	4.79%	90.5%
6	4.91%	0.82%	6.03%	88.2%
7	5.76%	1.20%	7.53%	85.5%
8	6.66%	1.72%	9.30%	82.3%
9	7.59%	2.40%	11.34%	78.7%
10	8.51%	3.26%	13.64%	74.6%
11	9.40%	4.32%	16.14%	70.1%
12	10.24%	5.57%	18.78%	65.4%
13	11.01%	6.99%	21.47%	60.5%
14	11.69%	8.53%	24.09%	55.7%
15	12.28%	10.14%	26.54%	51.0%
16	12.79%	11.77%	28.73%	46.7%
17	13.22%	13.35%	30.61%	42.8%
18	13.57%	14.86%	32.15%	39.4%
19	13.86%	16.26%	33.36%	36.5%
20	14.10%	17.55%	34.25%	34.1%
21	14.28%	18.71%	34.86%	32.1%
22	14.44%	19.77%	35.23%	30.6%
23	14.56%	20.73%	35.40%	29.3%
24	14.65%	21.61%	35.42%	28.3%
25	14.73%	22.41%	35.31%	27.6%

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 preceding 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 quite small for newer vehicles, its exclusion had a most a slight affect on the estimate of fleet emissions of those newer vehicles. (See Section 6.5.)

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. 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 24-hour RTD results (weighted to correct for recruitment bias) of the 1986 and newer PFI LDVs tested at both sites (Figure 5-1) and of the 1986 and newer TBI LDVs tested at both sites (Figure 5-2). All of these 24-hour RTD emissions were obtained using 6.7-6.9 psi RVP fuel over the 72°-96° F cycle.

Despite the small sample sizes in the Indiana data (only six PFIs and four TBIs), the closeness of the distribution curves 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

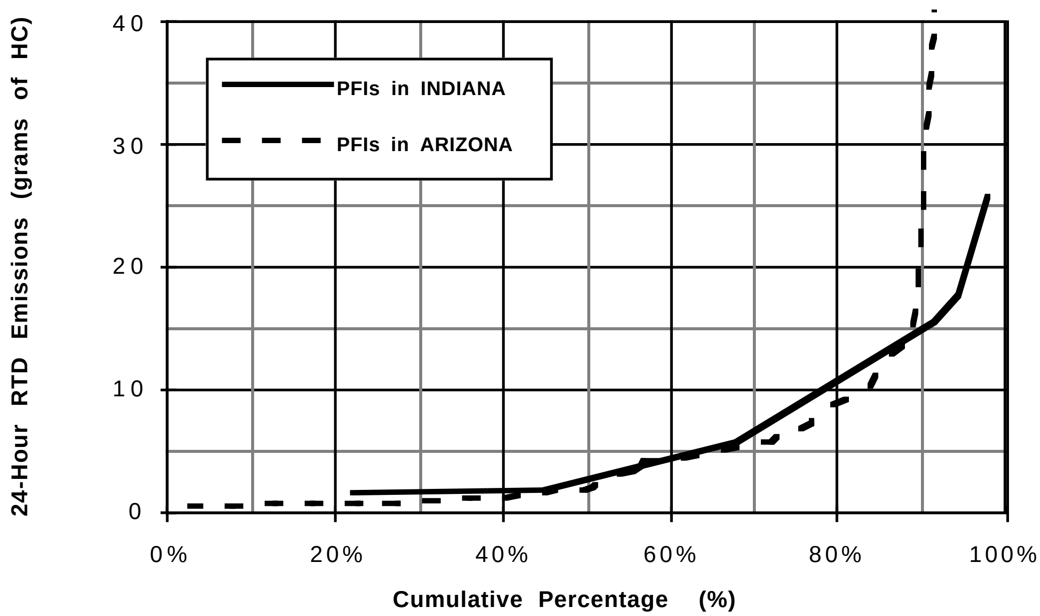
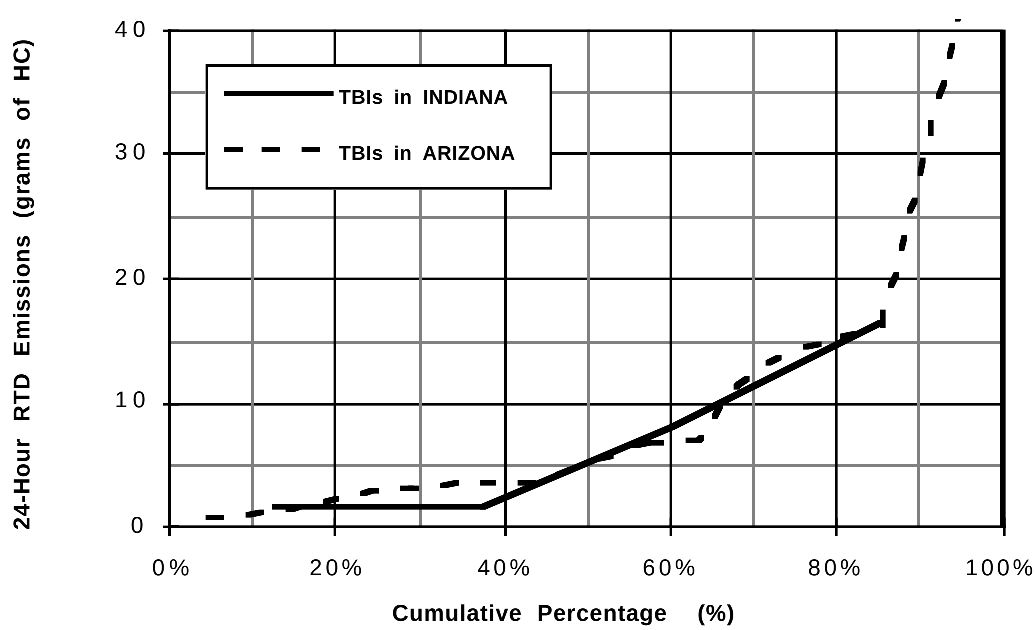


Figure 5-2

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 tests results from different model year ranges (i.e., 1981-85 and 1986-93) can be combined,

2) whether tests 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 tests results from carbureted vehicles can be combined with fuel-injected vehicles, and

4) whether tests results from cars and trucks can be combined (despite the differences in fuel tank size).

We stratified the test vehicles using the following three (3) 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:

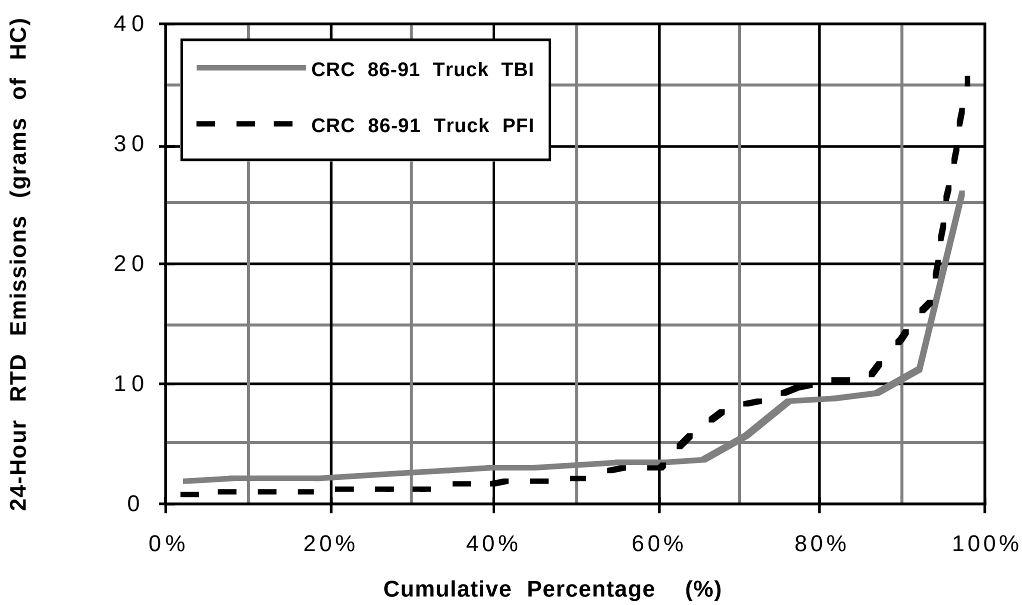
1) 1986 and newer trucks in the CRC testing program (see Figure 6-1) and

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



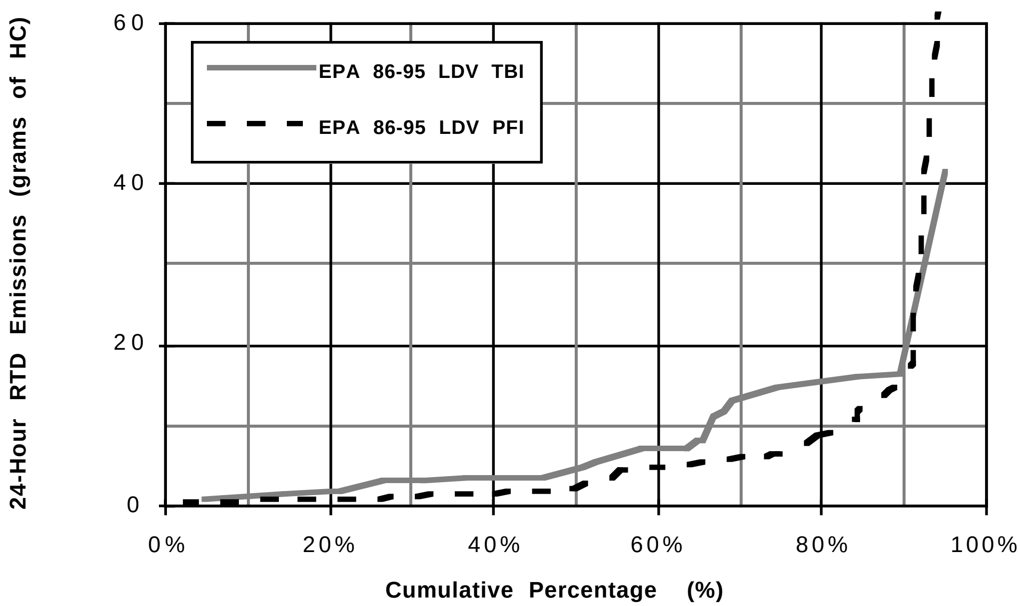
Characterizing those two CRC samples yields:

	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 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 have been weighted to correct for recruitment bias.

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

Based on the similarity of the cumulative distribution curves and on the close fit of the means (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 and newer FI trucks and 7 corresponding carbureted trucks (see Figure 6-3),

2) in the EPA testing program, 64 1986 and newer 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.

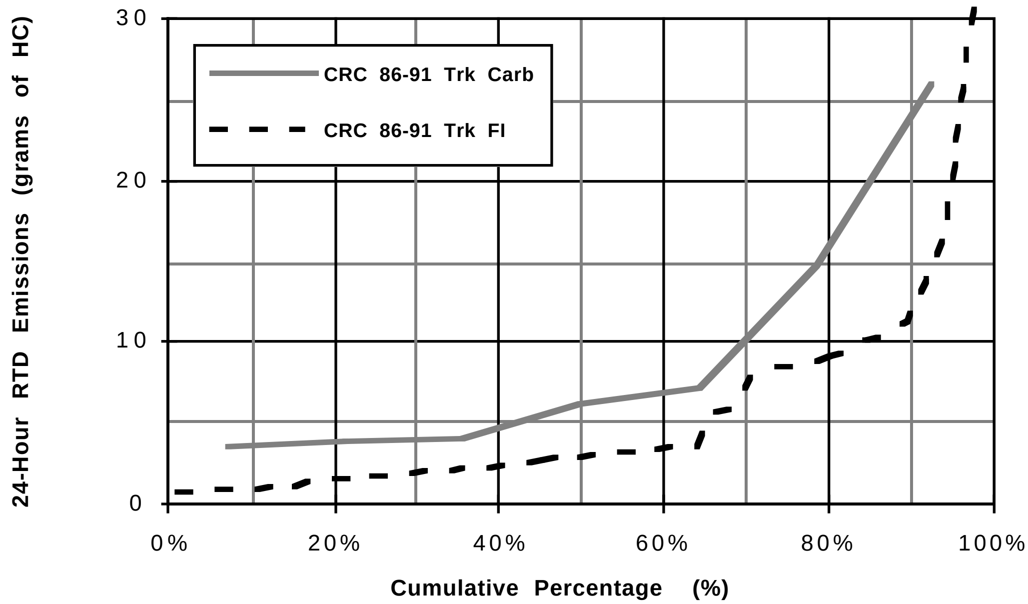
However, the two comparisons using the 1980-85 model year vehicles produced mixed results (possibly due to the small number of FI vehicles in the samples).

The differences in the distributions between carbureted (Carb) and FI among the 1986 and newer model year trucks in the CRC testing program is illustrated in the following table and in Figure 6-3.

Comparing Carbureted Trucks to FI Trucks

	Sample Size	Median	Mean	Standard Deviation
1986-95 CRC LDT Carbs	7	6.15	9.31	8.28
1986-95 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



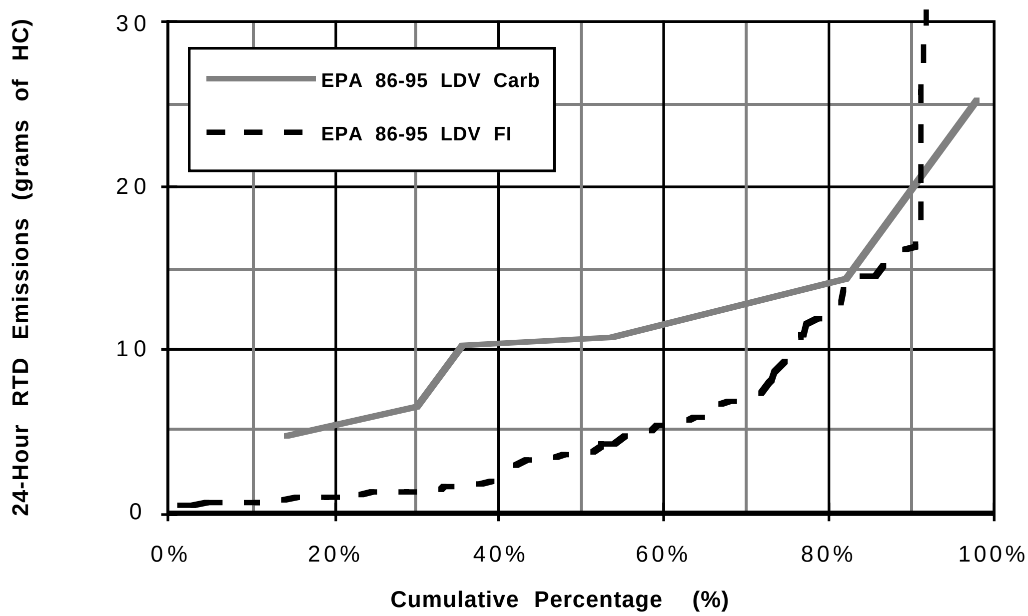
The differences in the distributions between carbureted (Carb) and FI among the 1986 and newer model year LDVs in the EPA testing program is illustrated in the following table and in Figure 6-4. Both the distributions shown in Figure 6-4 and the characterizations of those two EPA samples represented in the following table have been weighted (using Table 4-1) to correct for recruitment bias.

Comparing Carbureted LDVs to FI LDVs

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

Figure 6-4

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



In each of the two preceding figures, the sample sizes of the carbureted vehicles are relatively small. 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 fuel injected and carbureted vehicles were to be indistinguishable from each other.)

Therefore, EPA proposes to 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 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 <u>weighted</u> 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 <u>weighted</u> results of 62 1986 and newer FI LDVs and 42 corresponding carbureted trucks (Figures 6-6 and 6-7).

The distributions in Figures 6-5 and 6-6 and the characterizations of those strata (in the following table) 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
1980-85 LDVs Carbureted	13	10.22	11.29
1980-85 LDTs Carbureted	44	10.55	10.58
1986+ FI LDVs	62	3.40	9.48
1986+ FI LDTs	42	3.11	5.99

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)

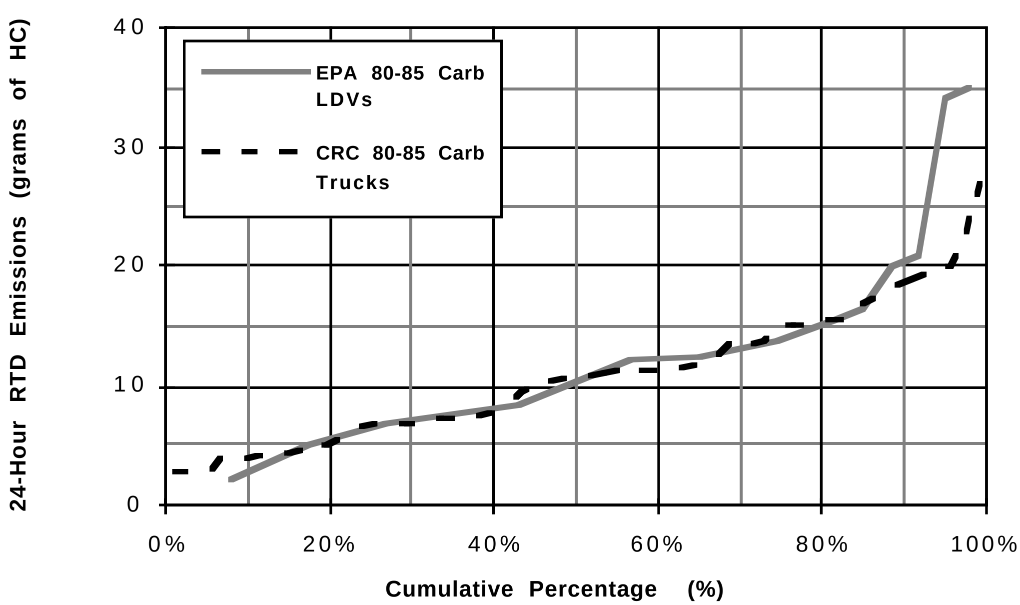
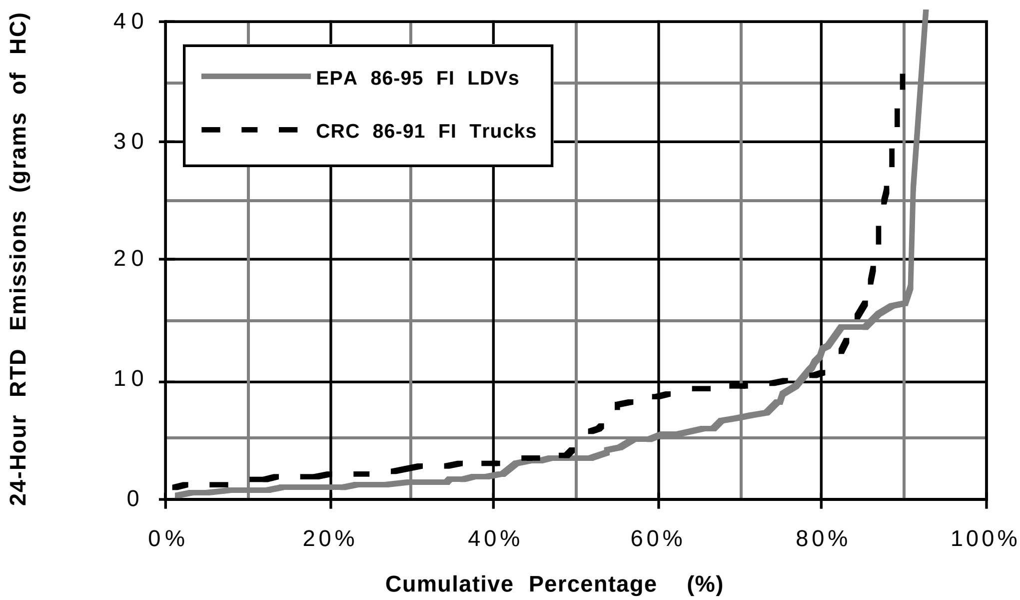


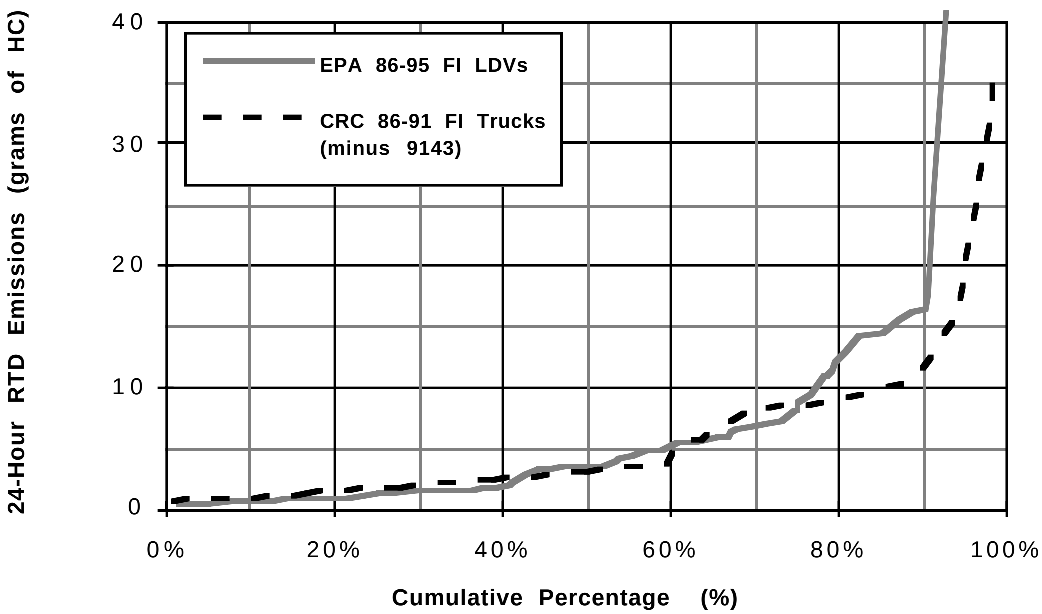
Figure 6-6

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



In Figure 6-6, the distributions of the FI 1986 and newer cars and trucks are virtually identical up to about the 50 percentile point, after which they diverge. However, much of that divergence is the result of a RTD test on a single truck in the CRC sample (vehicle 9143). If that single truck had not been recruited, then the (re-weighted) distribution of the remaining 41 FI trucks (given below in Figure 6-7) is quite similar to that of the corresponding 62 FI cars.

Figure 6-7
Weighted Cumulative Distribution of Cars and Trucks RTD Emissions in the EPA and CRC Testing Programs (1986 and Newer Model Year FI Vehicles) (Excluding CRC LDT No. 9143)



Based on the similarity of the cumulative distribution curves, the close fit of the means for the 1980-85 vehicles, and on the close fit of all of the medians, we merged 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

   - were 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 proposes that the RTD emissions of the (untested) pre-1980 fuel injected vehicles are 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 vehicles in the in-use fleet.

Eighteen vehicles that failed both the purge and the pressure tests were tested (all by CRC). Four of those were identified as gross liquid leakers and analyzed separately. Thirteen (of the remaining 14) were pre-1980 carbureted vehicles. For those 13 vehicles, the mean (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). Based on the similarity of those means, 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

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.

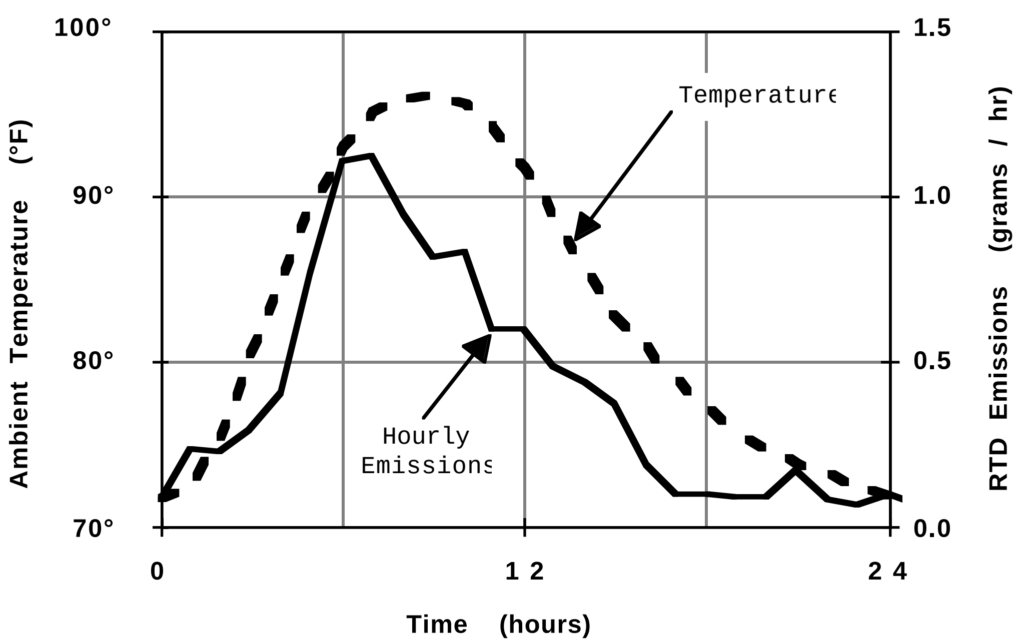
7.1 Resting Loss Emissions

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 (6) 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

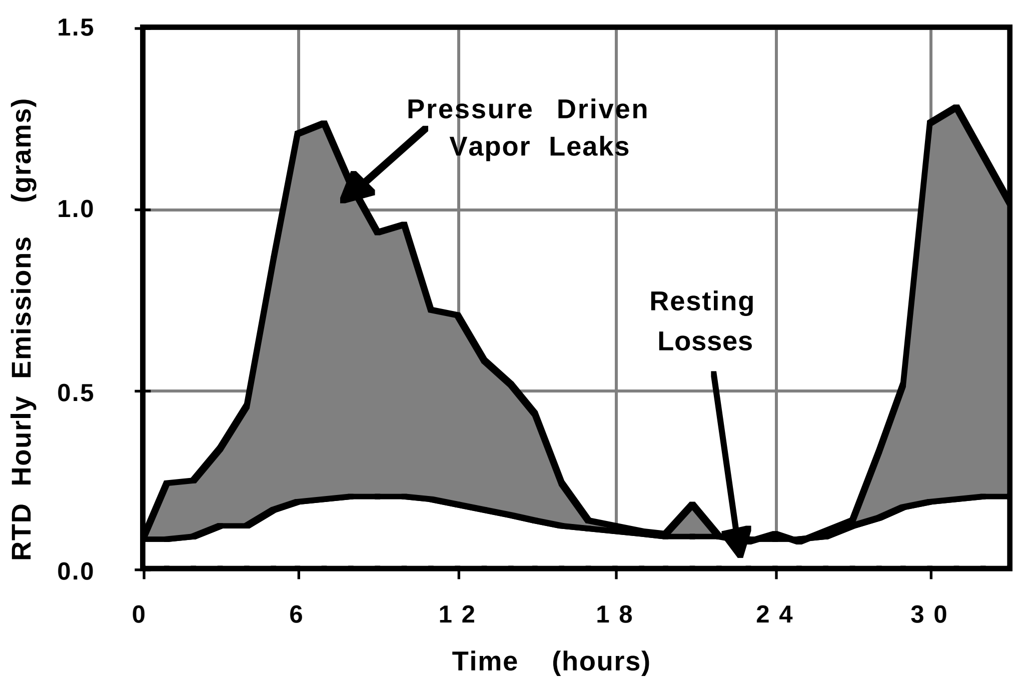
Subtracting the hourly resting loss emissions (calculated in Section 7.1) from the hourly RTD emissions, should yield an estimate of the hourly emissions that result from the daily rise in temperature (i.e., “diurnal” emissions). Although the hourly resting loss emissions will vary as the ambient temperature cycles over the full range of the RTD test (see Section 8.0), the variation is small relative to the RTD hourly emissions. Therefore, using a constant resting loss value rather than a “temperature adjusted” value will not affect the analysis. (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

Figure 7-2

Estimating Diurnal Emissions

(Pressure Driven Vapor Leaks)



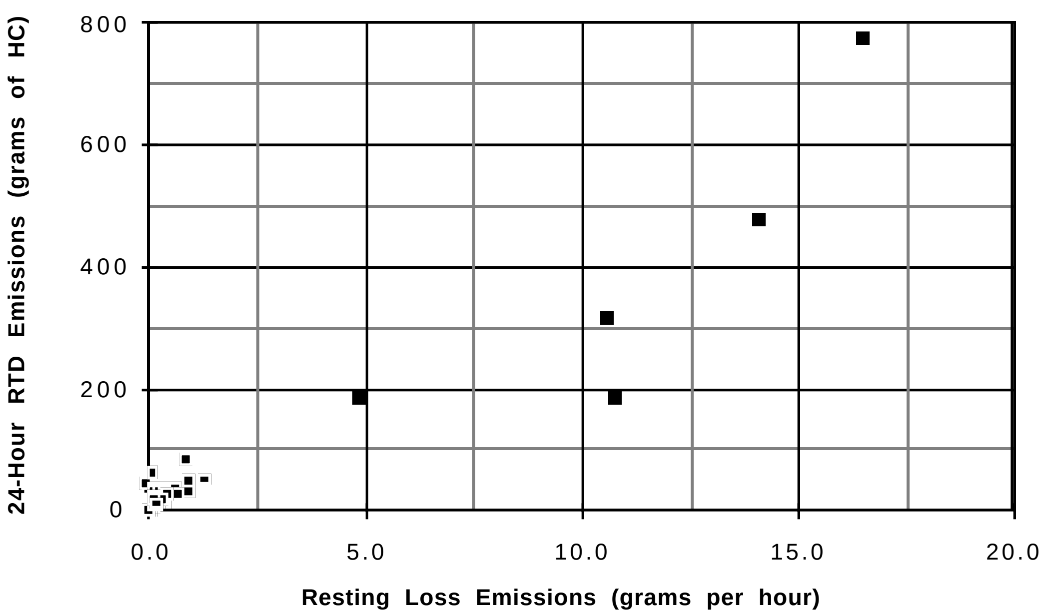
(i.e., "ambient") temperature drops to near the starting temperature.

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

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 but 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. Thus, modeling these vehicles separately 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.*
- The rate at which the resting loss emissions are increasing appears to be a linear function of the 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.

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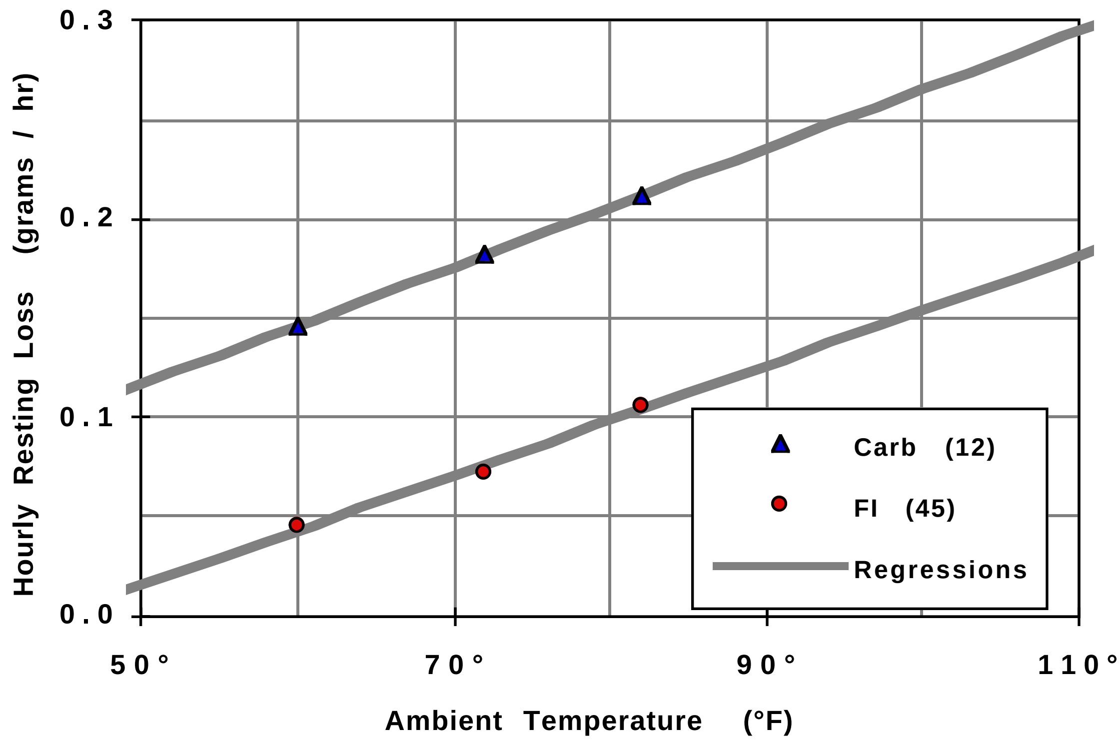
* An increase in hourly resting loss emissions corresponding to an increase in fuel RVP was also noted (especially for the fuel-injected vehicles). This apparent relationship is believed to simply be an artifact of the vehicles always being tested in the same (not randomized) order rather than being 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 proposes to 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:

$$\text{Hourly Resting Loss} = A + [\,B * \text{Temperature } (°F)\,]$$

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 determine 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 these 12 equations, we calculated an estimate of the hourly resting loss emissions at each hour of the three temperature cycles. Then, adding the <u>hourly</u> estimates for the first 24 hours of each test produced the <u>daily</u> resting loss emissions (for each of the 24 strata). These equations all predict that the full day's resting loss emissions (in grams) would be 24 times the hourly resting loss (calculated at the day's low temperature) 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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* In the previous version of MOBILE, 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. (See Appendix B.)

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 resting loss emissions than to the 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 (both in kPa). Multiplying these two quantities together produced a single product term (VP*?VP) that incorporates the parameters of the RTD test (i.e., both the temperature cycle and the fuel's RVP).

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 of that product term (to allow for possible non-linearity).

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* 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.

However, when we graphed the mean diurnal emissions against this "vapor pressure product" term, we noted that the affect of the RVP of the test fuel on diurnal emissions was not being completely accounted for by the "vapor pressure product" term. We, therefore, reran the previous regressions and included RVP as one of the independent variables. Thus, 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.)

The regression analyses performed did not always (i.e., in all 12 strata) identify the fuel RVP as a statistically significant variable. However, for consistency, RVP was used as an independent variable in all of the strata regardless of its significance level.

Although the equations that we developed in this analysis are empirical (i.e., data driven) models, we did impose the following three restrictions that were based on engineering experience with diurnal emissions:

- The diurnal emissions should increase with increasing fuel RVP (with all other parameters held constant).
- The diurnal emissions should increase with increasing 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).

---

* Theoretically, in each of those models, a zero change in daily temperature (hence, in ?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 because:
(1) of the resulting low r-squared values,
(2) of the lack of test data having diurnal temperature ranges less than 24 degrees, and
(3) we will require, for any diurnal emissions, a difference between the daily high and low temperatures of at least five degrees Fahrenheit.

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

- the three strata of 1972-1979 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.

Basing the estimates of diurnal emissions for the 1972-1979 model year carbureted vehicles resulted in predicted diurnal emissions (for some temperature cycle / RVP combinations) that were lower than for the newer (1980-85 model year) vehicles (possibly due to the small number of 1972-79 vehicles tested over different temperature cycles and with different fuel RVPs). As a result, 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, but we altered the constant terms so that when the modified equations were used to estimate the emissions of the Pre-1980 vehicles, the sum of the residuals (within each purge / pressure stratum) was zero.

The strata 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. Therefore, the results of those tests were combined with the tests on the three 1980-85 FI vehicles the 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 coefficients for both the stratum of 1980-85 FI vehicle the passed both the purge and pressure tests and the stratum of 1980-85 FI vehicle the failed only the purge test. The coefficient for each stratum was the value that would make each sum of residuals 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 makes selecting the proper regression curve difficult.

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* Theoretically, in each of those models, a zero change in daily temperature (hence, in ?VP) should result in zero diurnal emissions. This physical necessity would result in the constant term in each regression being zero. This requirement was dropped because of the resulting low r-squared values and because for any diurnal emissions we will require a difference between the daily high and low temperatures of at least five degrees Fahrenheit.

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 most closely predict the preceding estimates of the untested configurations. While neither set was perfect, the coefficients developed for the 1986-95 FI vehicles came closer and were selected.

Once the coefficient values of the equation were determined for each of the 15 strata, we then transformed the constant term (for each stratum) to minimize the sum of the differences between the predicted and calculated diurnal emissions. The resulting equations are given in Appendix E. The statistics associated with the eight regressions are given in Appendix F.

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.

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 MOBILE7 based on additional data.

10.1 Frequency of Gross Liquid Leakers

In a concurrent report (Document Number M6.EVP.006, entitled "Estimating Weighting Factors for Evaporative Emissions in MOBILE6"), EPA first uses data from EPA testing programs, CRC testing programs, and an American Petroleum Institute (API) testing program to estimate the occurrence of the gross liquid leakers at three different vehicle ages:

Vehicle Age	Frequency of "Gross Liquid Leakers"
5.62	0.20%
12.50	2.00%
21.29	7.84%

EPA then found a logistic growth curve that closely approximates these three values:

$$\text{Gross Liquid Leaker Rate} = \frac{0.09063}{1 + 337.2*\exp[-0.3625 * AGE]}$$

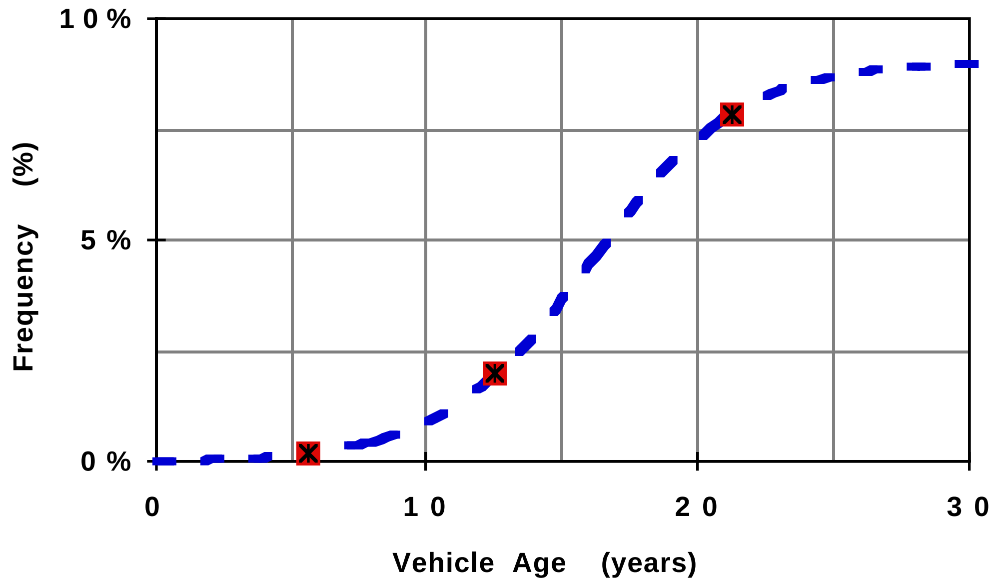
In this analysis, vehicle age was estimated by subtracting the model year from the test year. Since the test dates averaged (both mean and median) early July, the preceding equation actually estimates the occurrence of gross liquid leakers as of July of each given calendar year. However, the MOBILE models base their estimates as of January 1 of each calendar year. Therefore, EPA proposes to modify the preceding equation so that its predictions are based on January first:

$$\text{Gross Liquid Leaker Rate} = \frac{0.09063}{1 + 337.2*\exp[-0.3625 * (AGE - 0.5)]}$$

Plotting both the unmodified curve (i.e., based on ages as of July) and the preceding set of three failure rates produces Figure 10-1 below:

Figure 10-1

Frequency of Gross Liquid Leakers



The dotted line in Figure 10-1 is the logistic growth function. 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 (or 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 the fleet until the vehicles exceed 10 years of age.
- "Gross liquid leakers" reach two percent of the fleet for vehicles exceeding 13 years of age.
- The portion of the fleet that is "gross liquid leakers" then rises (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 nine 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 three curves.

Since EPA has no data to indicate that the multiple curve scenario is the correct approach, EPA proposes to 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 Section 10.1, we concluded that the frequency of gross liquid leakers is a function of vehicle age. The question as to whether the magnitude of the emissions are also a function of age cannot be answered with the available data.

Seven vehicles (five in the CRC study and two in the EPA study) have been identified as gross liquid leakers. However, two of the five CRC vehicles exhibited questionable results. Specifically:

1) For vehicle number 9111, the RTD test was aborted after only 16 hours due to the high evaporative emissions. CRC used the emissions measured during the first 16 hours to estimate the emissions during the final eight hours. (The cumulative HC through 16 hours was 616.71 grams which was extrapolated to 777.14 for the full 24 hours.) Therefore, the calculated resting loss emissions (i.e., the mean of the untested hours 19 through 24) might be in error.

2) Vehicle number 9129 exhibited relatively normal emissions for the about the first nine hours of the RTD test, after which the hourly emissions quickly rose then stabilized at about 11 grams per hour. This suggests that the leak actually developed during the RTD test (around the tenth hour). Therefore, while this vehicle's resting losses (i.e., the mean of hours 19 through 24) were representative of other gross leakers, the calculated diurnal emissions are likely <u>not</u> representative of other gross leakers. (The calculated resting loss emissions at 72°F from this vehicle were 10.77 grams per hour. Had that level of emissions simply continued for the full 24 hours, the total resting loss emissions would have been 258.48 grams compared to the 181.79 grams actually measured for the

entire 24-hour RTD test. Computationally, this would result in a substantial negative estimate of diurnal emissions.)

An additional difficulty is caused by the two vehicles in the EPA sample not being tested with the same fuel as the five CRC test vehicles. However, since the major mechanism driving the emissions of these vehicles is the leaks of liquid gasoline, the effects of changes in temperature or fuel RVP should be relatively small (see Section 10.3). If we, therefore, simply average the emissions of these two vehicles, we obtain the following table:

Veh No	RVP	Temp Cycle	RTD	Hourly RstL
5002	9.0	72.to.96	91.09	1.88
	9.0	82.to.106	158.80	3.81
	Means:		124.95	2.85
5082	6.3	72.to.96	54.80	1.45
	6.3	82.to.106	99.35	2.88
	9.0	72.to.96	87.26	2.07
	Means:		80.47	2.13

If we then average the preceding two means with the results from the five vehicles in the CRC sample (omitting the non-resting loss data from vehicle 9129), we obtain:

Veh No	RTD	Hourly RstL
9049	181.35	4.87
9054	316.59	10.58
9087	478.16	14.12
9111	777.14	16.51
9129	**Ignore**	10.77
5002	122.01	2.96
5082	77.58	2.09
Means:	325.47	8.84
Std Dev:	264.96	5.62

A third complication becomes apparent when the hourly emissions for these tests are examined.* Several of the tests exhibit high and decreasing hourly emissions for the first three hours. (We expected the tests to exhibit increasing emissions for the first few hours.) EPA believes that the unexpectedly high emissions for the first two hours resulted from the evaporation of

* A more thorough analysis of the hourly emissions is contained in report M6.EVP.002.

gasoline that had leaked prior to the start of the test. Compensating for that (hypothesized) problem results in reducing the above mean of the RTD emissions from 325.47 grams per day down to 312.45 (a decrease of 13.01 grams).

On page 25, 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 day's low temperature) plus 0.766. Since including the 0.766 term will increase the day's total resting loss less than 0.4 percent, , we will assume the resting loss emissions are completely independent of temperature (see Section 11.1). Therefore, based on the means in the preceding table, we propose to use, in MOBILE6, for the category of gross liquid leakers:

- DAILY RESTING LOSS = (24 * HOURLY RESTING LOSS)
  = (24 * 8.84)
  = 212.16 (GRAMS / DAY)

and

- Full Day's DIURNAL = MEAN RTD - DAILY RESTING LOSS
  = 312.45 - 212.16
  = 100.29 (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 proposes to treat the diurnal and resting loss emissions of the gross liquid leakers as independent of fuel RVP.

In the previous section, EPA proposed to treat 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 100.29 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 any 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 data being 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 8.84 grams per hour.

The equations developed in this report to estimate hourly 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 less than five degrees Fahrenheit.

11.2 Heavy-Duty Vehicles (HDGVs)

The analyses in this report were based only on RTD tests of light-duty gasoline-powered vehicles (LDGVs) and light-duty gasoline-powered 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 of 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 both the corresponding ratios of the evaporative emission standards and the corresponding market shares (under each of the emission standards). Translating that sentence into an equation yields:

$$DI_{HDGV} = DI_{LDGT} * [(1.5 * 0.875) + (2.0 * 0.125)]$$
$$= 1.5625 * DI_{LDGT}$$

Where, DI_{HDGV} is the full day's diurnal emissions from the HDGVs.

DI_{LDGT} is the full day's diurnal emissions from the corresponding LDGTs.

We will use the same formula for resting losses (obviously changing **DI** 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.

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 proposes to 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 temperature should be an important factor in determining resting loss emissions, EPA proposes to use for MOBILE6 the linear regression equation generated by the analysis (in Table 11-2) that uses both variables.

Table 11-2

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
Daily_Low Temp	0.000859	0.0022	0.399	0.6909

Translating that regression analysis into an equation yields:

Hourly Resting Loss Emissions (grams) of Motorcycles

= 0.044345 + (0.006134 * Vehicle_Age)

+ (0.000859 * Daily_Low_Temperature)

EPA proposes to use this equation to estimate the hourly resting loss emissions from motorcycles.

11.5 Pre-Control Vehicles

Non-California vehicles prior to the 1972 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-1972 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:

Hourly Resting Loss (grams) = -0.768438
+ (0.002812 * Temperature in °F)
+ (0.040528 * Vehicle Age in Years)

EPA proposes to 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) 1972-79 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:

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 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 proposes to 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) 1972-79 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 1996 and Newer Model Year Vehicles

Starting with the 1996 model year, EPA began certifying some of the new LDGVs and LDGTs using the RTD test. Estimating the resting loss and diurnal emissions from these vehicles will be analyzed in report number M6.EVP.005.

Appendix A

Temperature Cycles (°F)

Hour	---Temperatures Cycling Between --- 60°-84°F	72°-96°F*	82°-106°F	Change in 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 is a reasonable estimate of vapor pressure over the moderate temperature range (i.e., 60° to 106°F)* being considered for adjusting the diurnal emissions. This relationship assumes that the logarithm of the vapor pressure is a linear function of the reciprocal (absolute) temperature.

In a previous EPA work assignment, similar RVP fuels were tested, and their vapor pressures (in kilo Pascals) at three temperatures were measured. The results of those tests are given 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 fuels' 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:

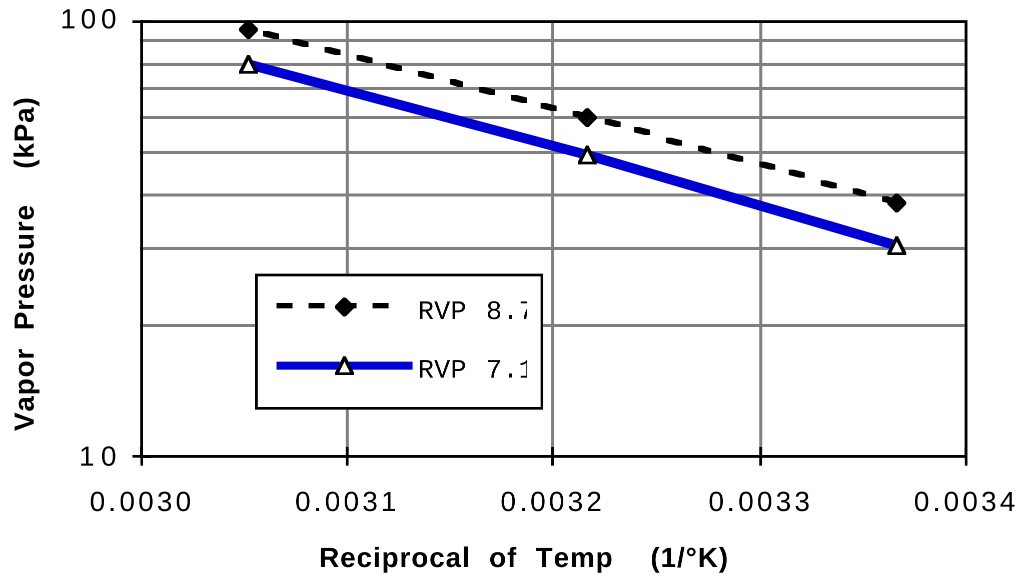
$$\mathrm{Ln(VP)} = A + (B / \text{Absolute Temperature}),$$ where:

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



We will assume that the specific fuels used in the vehicles that were tested in this analysis had vapor pressure versus temperature curves similar to the curves for these to two test fuels. Extrapolating the trends in either the "A" or "B" values to fuels with nominal RVPs of 6.3, 7.0, and 9.0 psi; and then requiring the lines (in log-space) to pass through the appropriate pressures at 100°F, yields the linear equations with coefficients:

RVP	A	B
6.3	13.810	-3121.05
6.8	13.773	-3085.79
9.0	13.554	-2930.67

We will use the above to estimate vapor pressures for the 6.3, 6.8, and 9.0 psi RVP fuels.

In general, given the fuel RVP, we can approximate **A** and **B** with these equations:

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

and

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

Appendix C

Mean Evaporative Emissions by Strata By Vapor Pressure Products

Strata	Fuel RVP	Temp. Cycle	VP times ?VP	Count	Mean Diurnal	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
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

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

Strata	Fuel RVP	Temp. Cycle	VP times ?VP	Count	Mean Diurnal	Mean Hourly Resting Loss
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
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

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

Strata	Fuel RVP	Temp. Cycle	VP times ?VP	Count	Mean Diurnal	Mean Hourly Resting Loss
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 As Functions of Temperature (°F)

In each of the following 12 strata, resting loss emissions (i 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.

If we use any temperature profile in which the hourly change in temperature is proportional to the cycles in Appendix A, we find:

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

Where **B** is given above, and where the **Diurnal_Temperature_Range** is the difference of the daily high temperature minus the daily low temperature.

Appendix E

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

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

A ,
B,
C, and
D. Where,

24-Hour Diurnal (grams) =

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

For each of the 18 strata, the four constants used to model emissions are given below in the following table:

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

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

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

Appendix E (continued)

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

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

A ,B, C, D. Where,

24-Hour Diurnal (grams) =

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

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

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

Appendix F

Regression Analyses of 24-Hour Diurnal versus Fuel RVP and Vapor Pressure Product Term

Regression of Mean Diurnal Emissions Based on Three 1980-85 Carb Vehicles Passing Both Purge and Pressure Tests

Dependent variable is: **Diurnal**
No Selector

R squared = 97.1% R squared (adjusted) = 95.2%
s = 2.754 with 6 - 3 = 3 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	765.294	2	382.647	50.4
Residual	22.76	3	7.58666	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	14.3895	9.439	1.52	0.2248
VP_Product Sqrd / 1,000	0.024053	0.0027	8.78	0.0031
Fuel RVP	-2.42617	1.326	-1.83	0.1648

Regression of Mean Diurnal Emissions Based on Two 1980-85 Carb Vehicles Failing the Pressure Test

Dependent variable is: **Diurnal**
No Selector

R squared = 99.4% R squared (adjusted) = 99.0%
s = 1.307 with 6 - 3 = 3 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	822.877	2	411.438	241
Residual	5.12862	3	1.70954	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	-1.00903	4.18	-0.241	0.8250
VP_Product Term	0.039905	0.0023	17.0	0.0004
Fuel RVP	-0.621600	0.650	-0.956	0.4096

Appendix F (continued)

Regression of Mean Diurnal Emissions Based on Three 1980-85 Carb Vehicles Failing ONLY the Purge Test

Dependent variable is: **Diurnal**
No Selector

R squared = 94.7%   R squared (adjusted) = 91.1%
s = 4.853 with 6 - 3 = 3 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	1256.90	2	628.449	26.7
Residual	70.6578	3	23.5526	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	15.3041	16.6300	0.920	0.4253
VP_Product Sqrd / 1,000	0.029900	0.0048	6.19	0.0085
Fuel RVP	-2.23907	2.3370	-0.958	0.4087

Regression of Mean Diurnal Emissions Based on Four 1980-85 FI Vehicles Passing the Pressure Test

Dependent variable is: **Diurnal**
No Selector

R squared = 99.6%   R squared (adjusted) = 99.3%
s = 0.4728 with 6 - 3 = 3 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	156.976	2	78.4882	351
Residual	0.670742	3	0.223581	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	7.29846	1.620	4.50	0.0204
VP_Product Sqrd / 1,000	0.010466	0.0005	22.2	0.0002
Fuel RVP	-0.701002	0.2277	-3.08	0.0542

Appendix F (continued)

Regression of Mean Diurnal Emissions Based on Two 1980-85 FI Vehicles Failing the Pressure Test

Dependent variable is: **Diurnal**
No Selector

R squared = 94.4% R squared (adjusted) = 90.7%
s = 3.511 with 6 - 3 = 3 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	626.019	2	313.009	25.4
Residual	36.9725	3	12.3242	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	7.82649	11.23	0.697	0.5361
VP_Product Term	0.036373	0.0063	5.77	0.0104
Fuel RVP	-1.25128	1.746	-0.717	0.5253

Regression of Mean Diurnal Emissions Based on 16 1986-95 FI Vehicles Passing Both Purge and Pressure Tests

Dependent variable is: **Diurnal**
No Selector

R squared = 97.1% R squared (adjusted) = 95.2%
s = 0.6560 with 6 - 3 = 3 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	43.7687	2	21.8844	50.8
Residual	1.29117	3	0.43039	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	4.70657	2.248	2.09	0.1273
VP_Product Sqrd / 1,000	0.005934	0.0007	9.09	0.0028
Fuel RVP	-0.767027	0.3159	-2.43	0.0935

Appendix F (continued)

Regression of Mean Diurnal Emissions Based on 11 1986-95 FI Vehicles Failing the Pressure Test

Dependent variable is: **Diurnal**
No Selector

R squared = 98.9% R squared (adjusted) = 98.1%
s = 1.206 with 6 - 3 = 3 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	382.227	2	191.113	131
Residual	4.36316	3	1.45439	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	14.5718	4.1330	3.53	0.0388
VP_Product Sqrd / 1,000	0.017098	0.0012	14.2	0.0007
Fuel RVP	-1.81237	0.5807	-3.12	0.0524

Regression of Mean Diurnal Emissions Based on 12 1986-95 FI Vehicles Failing ONLY the Purge Test

Dependent variable is: **Diurnal**
No Selector

R squared = 95.7% R squared (adjusted) = 92.8%
s = 1.578 with 6 - 3 = 3 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	164.793	2	82.3963	33.1
Residual	7.47312	3	2.49104	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	11.0427	5.050	2.19	0.1166
VP_Product	0.021368	0.0028	7.54	0.0048
Fuel RVP	-2.14898	0.7849	-2.74	0.0715