MOBILE6 Model Development
Stakeholder Review Document

- Draft -

Evaluating Resting Loss and Diurnal Evaporative Emissions Using RTD Tests

Larry C. Landman

Document Number M6.RTD.001

October 8, 1997

U.S. EPA
Assessment and Modeling Division
National Vehicle Fuel and Emissions Laboratory
2565 Plymouth Road
Ann Arbor, Michigan 48105-2425
313-741-7939 (fax)
mobile@epamail.epa.gov

ABSTRACT

The Office of Mobile Sources, Assessment and Modeling Division, announces the release of "Evaluating Resting Loss and Diurnal Evaporative Emissions Using RTD Tests" for stakeholder review and comment. This document M6RTD001.PDF is available at the MOBILE6 section of the OMS Web Site:

http://www.epa.gov/omswww/models.htm

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. Since this draft report is a proposal, its analyses and conclusions may change to reflect comments, suggestions, and new data.

Please note that EPA is seeking any input from stakeholders and reviewers that might aid us in modeling any aspect of resting loss or diurnal evaporative emissions.

Comments on this report and its proposed use in MOBILE6 should be sent to the attention of Larry Landman. Comments may be submitted electronically to mobile@epamail.epa.gov, or by fax to (313)741-7939, or by mail to "MOBILE6 Review Comments", US EPA Assessment and Modeling Division, 2565 Plymouth Road, Ann Arbor, MI 48105. Electronic submission of comments is preferred. In your comments, please note clearly the document that you are commenting on including the report title and the code number listed. Please be sure to include your name, address, affiliation, and any other pertinent information.

This document is being released and posted on October 8, 1997. Comments will be accepted for sixty (60) days, ending December 7, 1997. EPA will then review and consider all comments received, and will provide a summary of those comments and how we are responding to them in the form of a follow-up document within 30 days after the close of the comment period.

TABLE OF CONTENTS

*** Draft ***

Evaluating Resting Loss and Diurnal Evaporative Emissions Using RTD Tests

Report Number M6.RTD.001

Larry C. Landman
U.S. EPA Assessment and Modeling Division

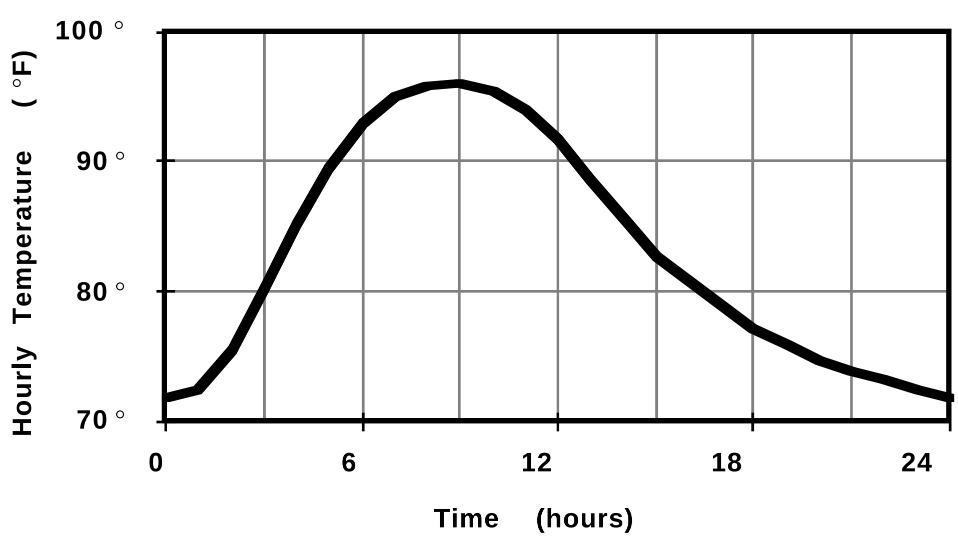
1.0 Introduction

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). The temperatures peak at hour nine. 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 <u>Vehicle Sample</u>

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 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., 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, see 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 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 11,832 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.) The distributions of those tests results are given in the following table:

Table 4-1

Observed Distribution of Purge/Pressure Results (by Vehicle Age)

Vehicle	--- Purge / Pressure Test Results ---			
Age	F/F	F/P	P/F	P/P
0	1	2	12	125
1	5	24	48	986
2	6	24	48	819
3	12	30	44	889
4	20	25	62	822
5	19	54	76	972
6	26	68	84	1,075
7	32	91	82	1,092
8	42	70	79	899
9	31	89	68	752
10	19	63	67	461
11	30	47	105	304
12	46	55	92	264
13	30	38	77	191
14	13	13	35	98
15	3	3	11	28
16	3	1	3	14
17	3	0	2	6
18	0	0	1	1

Modeling the preceding distributions with smooth curves produced the distributions in Table 4-2. Similar results can be obtained by using the CRC data. For example, of the 28 1989 through 1991 model year vehicles (average age of 6) in the CRC sample, 24 passed both the purge and pressure tests (85.7%), compared to 85.5 percent in Table 4-2. For the 1983-85 model year vehicles in the

CRC program (averaging 11.74 years of age), Table 4-2 predicts that 23 vehicles pass both the purge and pressure tests (90 percent confidence interval from 18 through 27) which is consistent with the 26 actually in the CRC sample.

Table 4-2

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

Vehicle	--- Purge / Pressure Test Results --- (Pass/ Fail)			
Age	F/F	F/P	P/F	P/P
0	0.7%	0.6%	3.9%	94.8%
1	0.7%	1.6%	4.1%	93.5%
2	0.8%	2.6%	4.4%	92.2%
3	1.0%	3.5%	4.8%	90.7%
4	1.3%	4.4%	5.1%	89.1%
5	1.7%	5.3%	5.5%	87.5%
6	2.2%	6.1%	6.2%	85.5%
7	2.7%	6.9%	7.4%	83.0%
8	3.4%	7.6%	8.8%	80.2%
9	4.2%	8.3%	10.7%	76.9%
10	5.1%	8.9%	12.9%	73.1%
11	6.1%	9.5%	15.4%	69.0%
12	7.2%	10.0%	18.4%	64.4%
13	8.3%	10.5%	21.7%	59.5%
14	9.6%	11.0%	25.3%	54.0%
15	11.0%	11.4%	29.4%	48.2%

Extrapolating these estimates beyond vehicles of 15 years of age (i.e., beyond the data) produces unrealistic results (e.g., negative pass/pass rates for vehicles more than 21 years old). Therefore, for vehicles more than 15 years of age, we simply used the estimated rates for 15-year old vehicles. Limiting these estimated identification rates to the predictions at the 15-year point would affect only the analyses of the pre-1980 vehicles, and then only when comparing the proportion of vehicles which past both the purge and pressure tests with those that failed either test. And, that situation never occurred in these analyses.

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.

NOTE: Since no vehicles in the EPA testing programs were recruited from among those that failed both the purge and the pressure tests, we used the data from the CRC program to characterize the RTD emissions of that category. Since (as Table 4-2 indicates) this stratum is quite small for newer vehicles, its exclusion had only 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 the test data are comparable. 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**

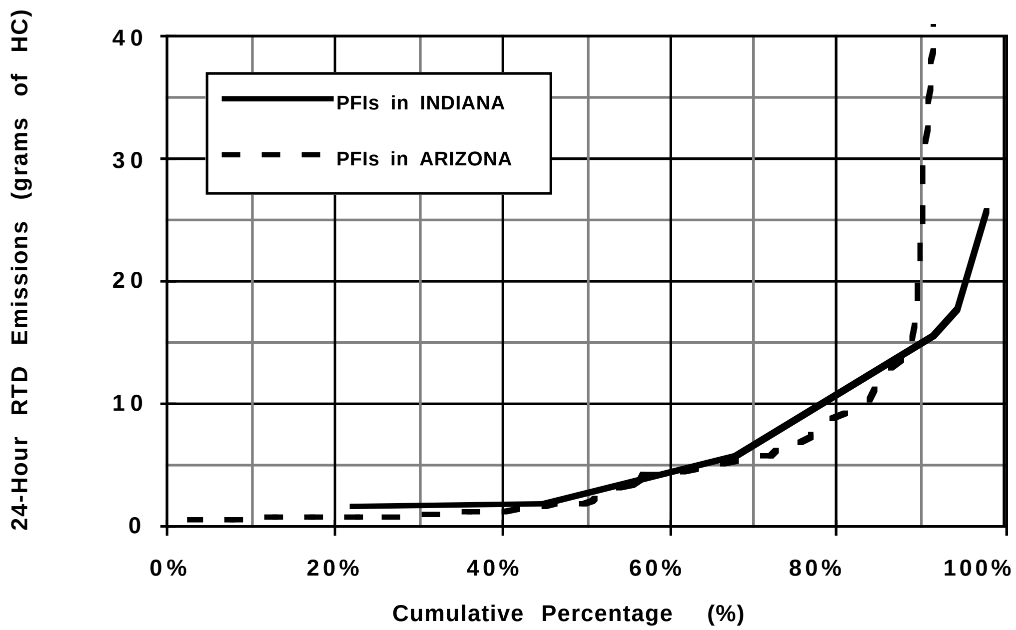
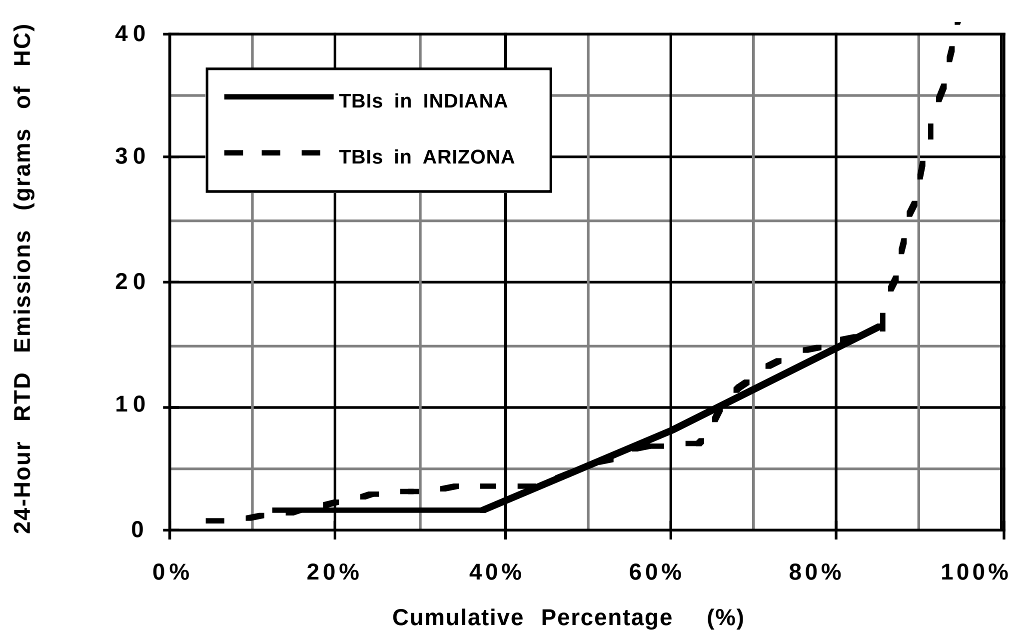


Figure 5-2

**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) 1971 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:

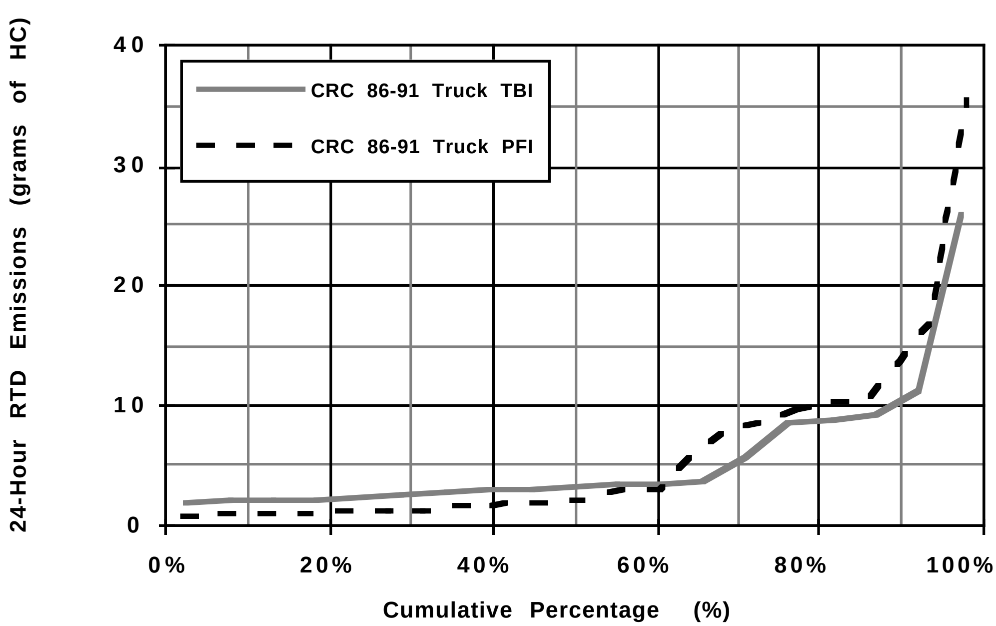
1) 1986 and newer trucks in the CRC testing program (see Figure 6-1) and

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



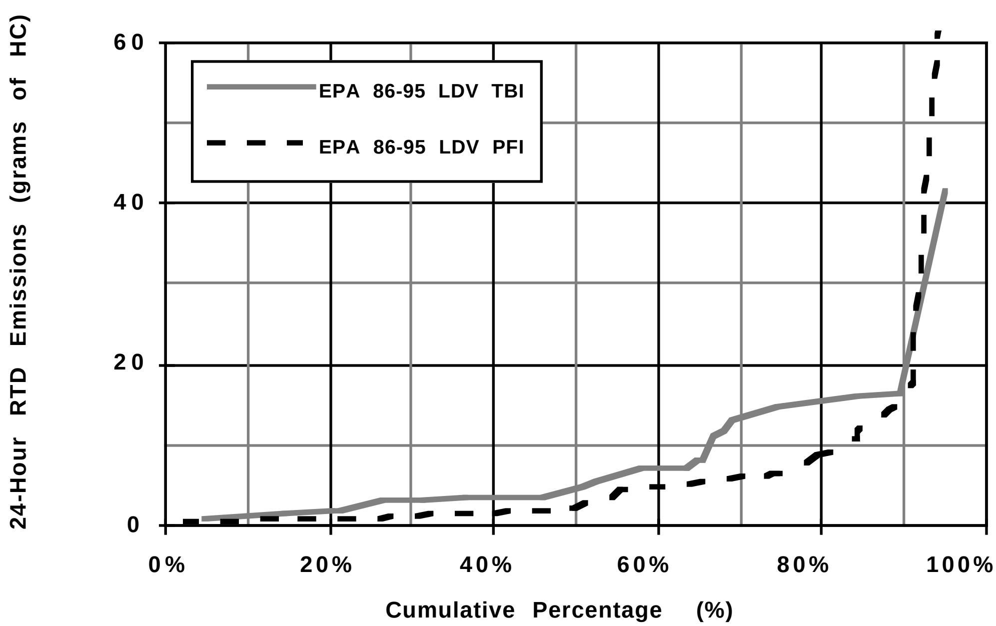
Characterizing those two CRC samples yields:

	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),

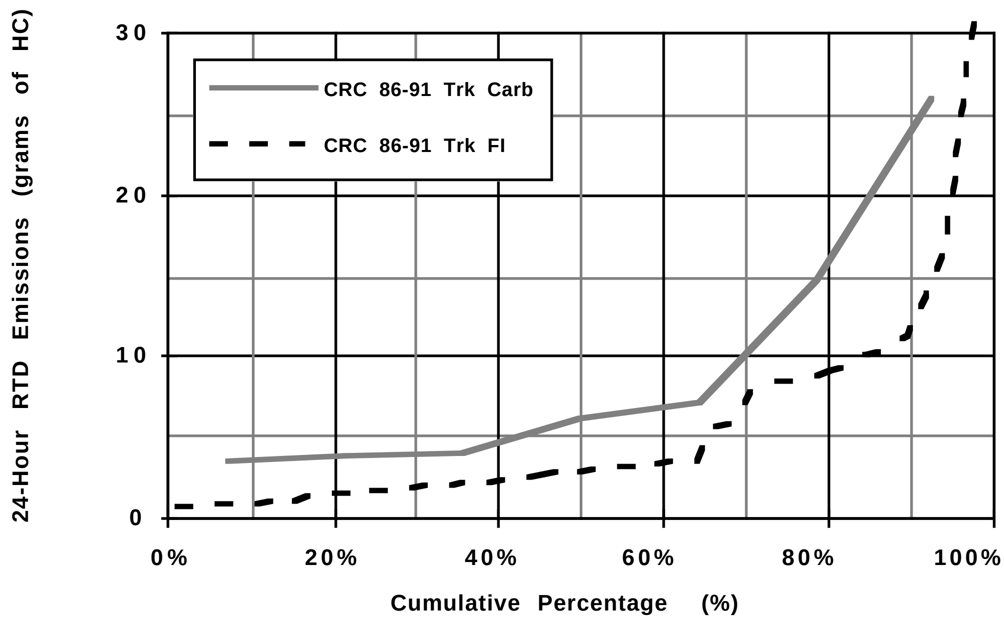
3) in the CRC testing program, 3 1980-85 FI trucks and 46 corresponding carbureted trucks, and

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 Figure 6-3.

Figure 6-3
Cumulative Distributions of FIs and Carb Trucks RTD Emissions in the CRC Testing Program



Characterizing those two CRC samples yields:

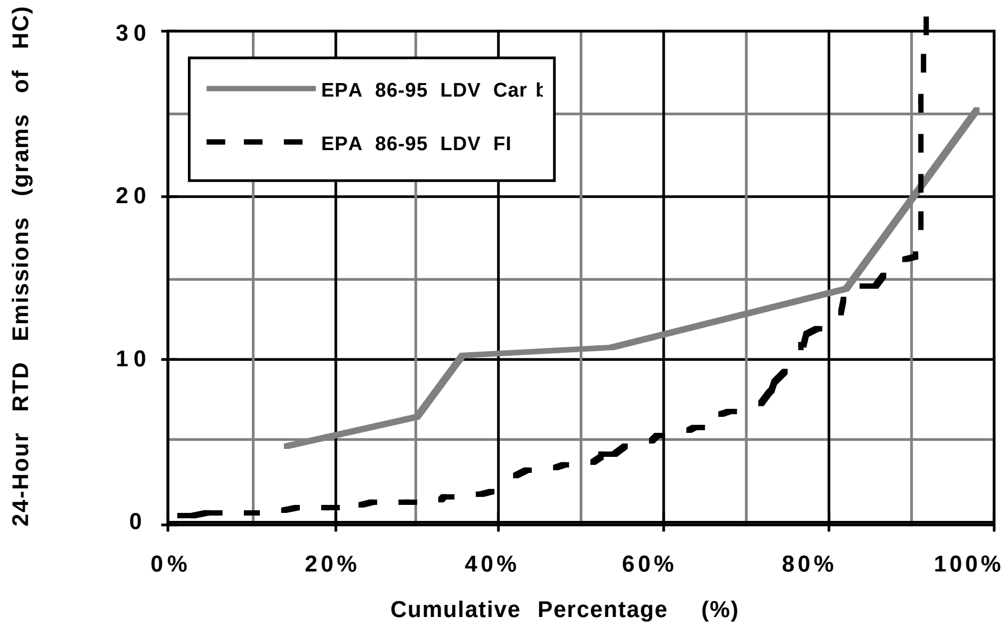
Comparing Carbureted LDTs to FI LDTs

	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

The cumulative distributions of the carbureted (Carb) and the FI among the 1986 and newer model year LDVs in the EPA testing program is illustrated in Figure 6-4.

Figure 6-4

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



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 4-2) 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

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.

Therefore, the carbureted vehicles and the FI vehicles were treated 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:

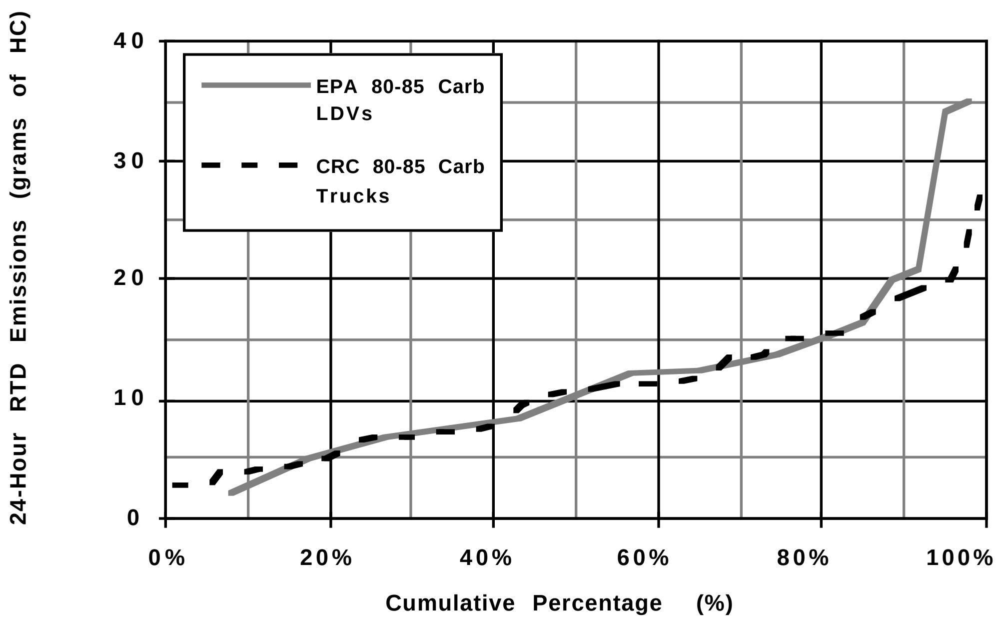
1) in the combined EPA and CRC testing programs, the weighted results of 13 1980-85 carbureted LDVs and 44 corresponding carbureted trucks (Figure 6-5), and

2) in the combined EPA and CRC testing programs, the weighted results of 62 1986 and newer FI LDVs and 42 corresponding carbureted trucks (Figures 6-6 and 6-7).

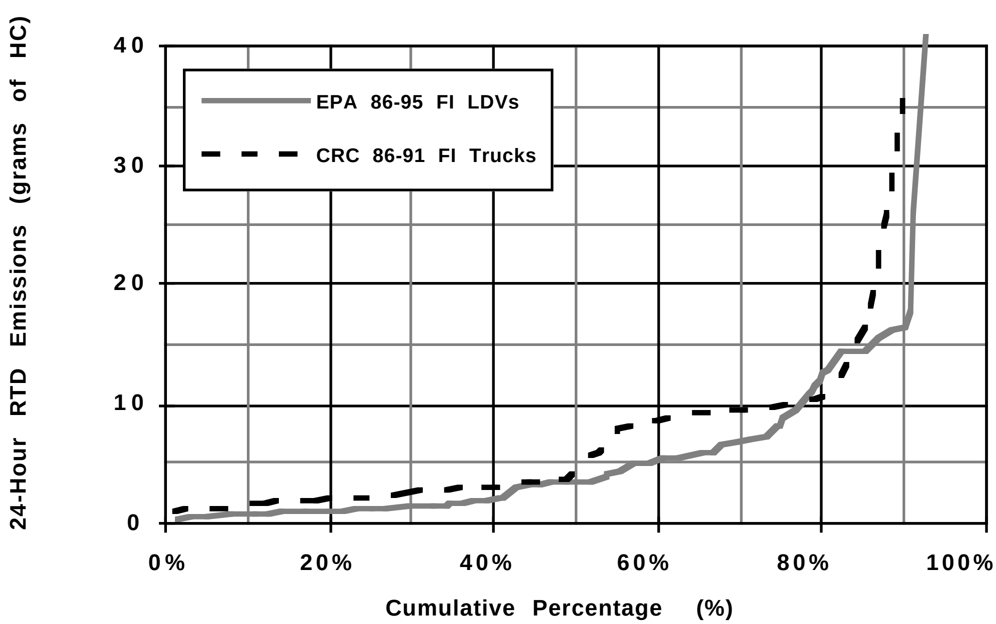
The distributions in Figures 6-5 and 6-6 and the characterizations of those strata (in the following table) have been weighted to correct for the actual recruitment bias in the EPA sample and the simulated bias in the CRC sample.

	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

<u>Figure 6-5</u>
Weighted Cumulative Distribution of Cars and Trucks RTD Emissions in the EPA and CRC Testing Programs (1980-1985 Model Year Carbureted Vehicles)

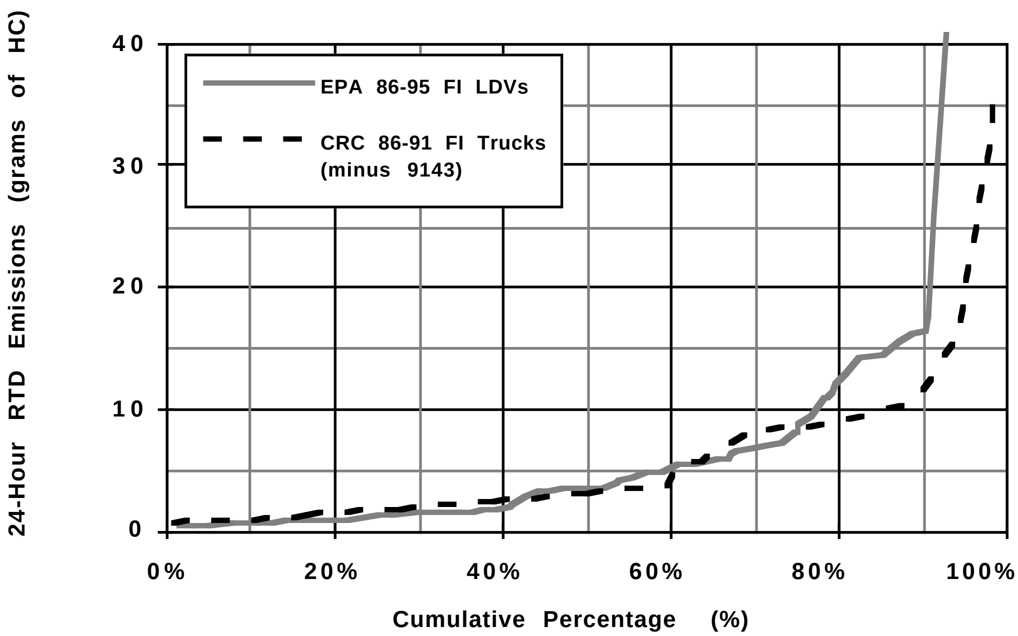


<u>Figure 6-6</u>
Weighted Cumulative Distribution of Cars and Trucks RTD Emissions in the EPA and CRC Testing Programs (1986 and Newer Model Year FI Vehicles)



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 large 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 (see Table 4-2).

For the MOBILE model, we will assume 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 use the test results of vehicles that failed the pressure test but passed the purge test to represent the corresponding untested strata of vehicles that failed both screening 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.

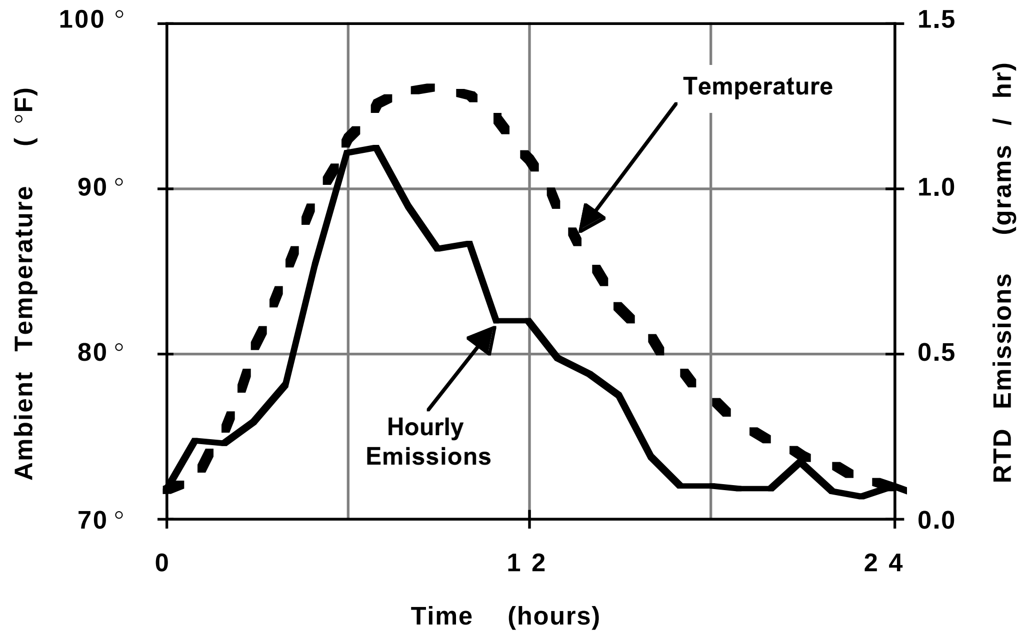
7.1 Resting Loss Emissions

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.

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.

<u>Figure 7-1</u>

Identifying Resting Losses
(Stable Portion of RTD Hourly Emissions)



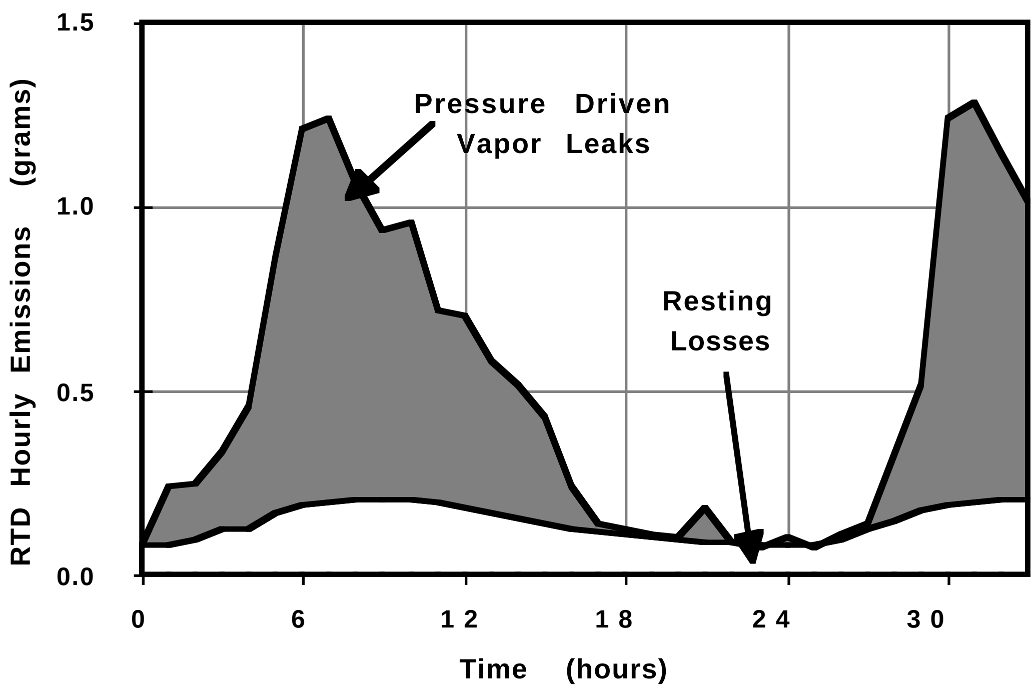
7.2 Diurnal Emissions

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

Figure 7-2

Estimating Diurnal Emissions
(Pressure Driven Vapor Leaks)



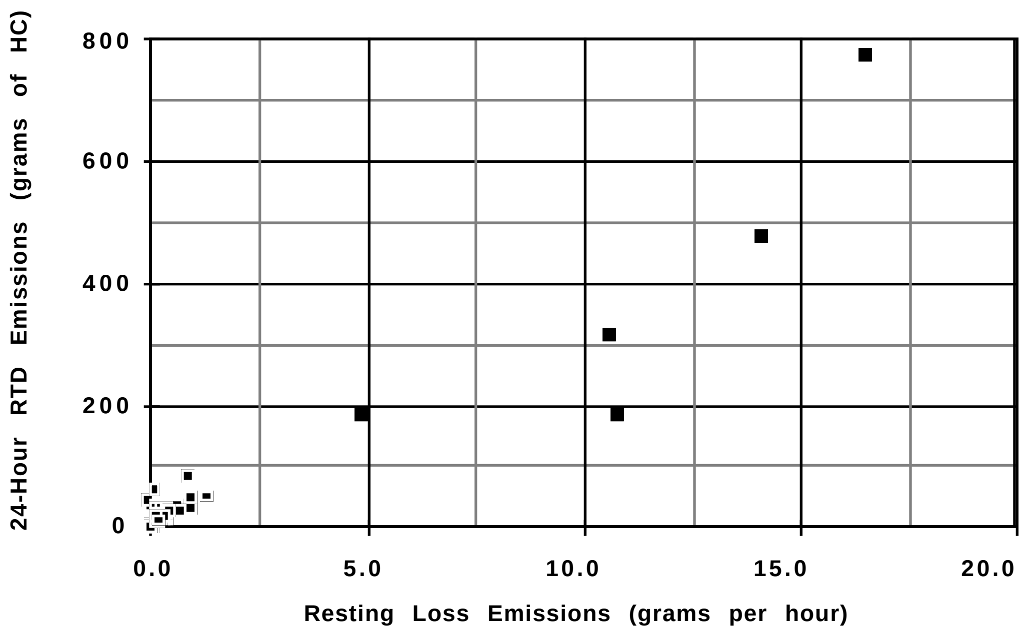
The average (mean) 24-hour diurnal emissions for each of the strata in Section 6.4 are given in Appendix C.

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).

This graph (Figure 7-3) 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 identified, by the mechanics who examined them, as having significant leaks of liquid gasoline (as opposed to simply vapor leaks).

Figure 7-3
Comparison of RTD versus Resting Loss Emissions (72°-96°F Cycle Using 6.7-7.0 RVP Fuel)



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.

8.0 Characterizing Resting Loss Emissions

Resting loss evaporative emissions, like all evaporative emissions, are functions of both fuel volatility and ambient temperature which are themselves interdependent. 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.,
- 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 are more closely related to changes in volatility. Of course, the portion due to the minor liquid leaks (as distinguished from the gross liquid leakers in Section 10) are unaffected by either temperature or volatility 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.

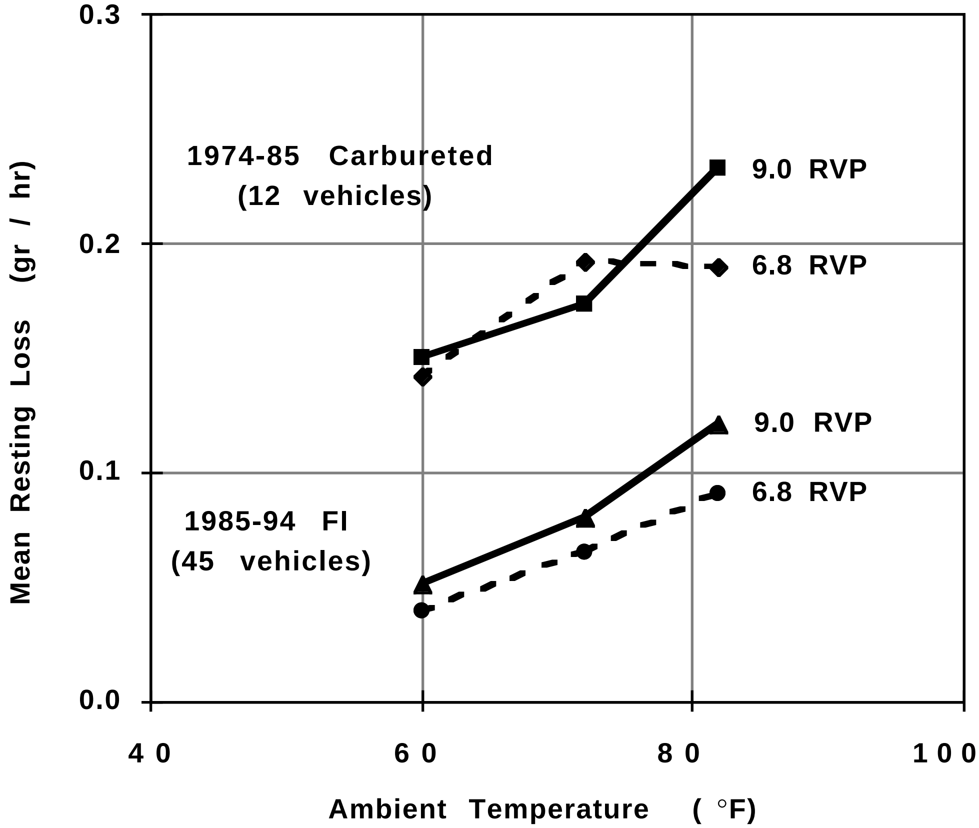
Using this sample permitted us to have exactly the same vehicles being tested at each combination of fuel RVP and temperature; thus, avoiding many of the problems associated with vehicle-to-vehicle test variability. This sample of 57 vehicles consisted of:

- 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.

Figure 8-1

Mean Hourly Resting Loss Versus Temperature
(averaged at each temperature and RVP combination)



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

- Hourly resting loss emissions increase with increasing temperature.
- Hourly resting loss emissions increase with increasing fuel RVP.
- The effects of RVP and temperature changes appear to be interrelated.
- For the fuel injected (i.e., the larger sub-sample, the plots at each fuel RVP appear to be linear in log-space.

For the fuel injected vehicles, the function that most reasonably models the hourly resting loss emissions (within the tested range) is that the logarithm of the emissions is a linear function of both RVP and temperature. That is:

$$\text{Hourly Resting Loss} = \exp\left[A + \left(B * \text{Temperature } (^\circ F) \right) + \left(C * RVP \right) \right]$$

Where:

"A"	"B"	"C"	
-6.38000	0.039163	0.116588	For FI Vehicles

Before attempting to model the resting loss emissions of those 12 carbureted vehicles, we observe (in Figure 8-1) that the average emissions at 72° with the 6.8 RVP fuel are suspiciously high. This suspect value may simply be a result of the small number of carbureted vehicles in this sample. If we first delete that suspicious value, and then use a linear regression (through the remaining five points) to model the logarithm of the emissions as a linear function of both RVP and temperature, we obtain:

$$\text{Hourly Resting Loss} = \exp\left[A + \left(B * \text{Temperature } (^\circ F) \right) + \left(C * RVP \right) \right]$$

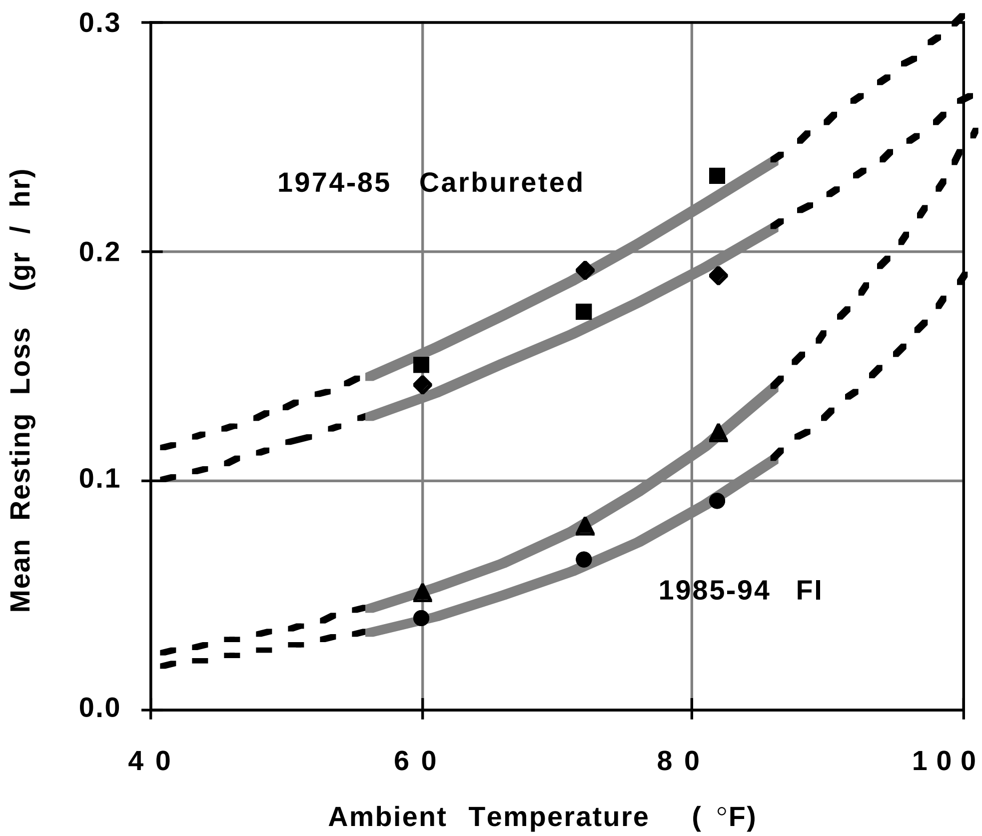
Where:

"A"	"B"	"C"	
-3.39291	0.016599	0.059795	For Carb Vehicles

These equations predict resting loss emissions of the carbureted vehicles to be higher than for the fuel injected vehicles, but the emissions from the fuel injected vehicles would increase at a faster rate with increasing temperature. Adding those regression curves to the values in Figure 8-1 produces Figure 8-2. The "dotted" portion of the regression curves extends the curves beyond the limits of the tested data. 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.

Figure 8-2

Mean Hourly Resting Loss Versus Temperature
(with regression curve)
(averaged at each temperature and RVP combination)



For each of the strata identified in Section 6.4, we calculated the value of "**A**" (in the previous regression equations) that would minimize the difference between the predicted and the actual resting losses. 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**".

Only the test results from the 57 vehicles that were tested over a range of fuel RVPs and temperature cycles were used to determine the coefficients (**B** and **C**) which determine the shapes of the curves. The full data set was used only to solve for the constant term (**A**). In this type of equation (i.e., an exponential function), the constant term (**A**) has a multiplicative effect rather than an additive effect.

This process produced a regression equation for each of the 24 strata. The regression equations are unique for each stratum for which tests were performed. Each untested stratum (see Section 6.5) used the regression equation of a similar tested stratum.

Using these 24 equations, we calculated an estimate of the hourly resting loss emissions associated with each fuel RVP at each hour of the three temperature cycles. Then, adding the hourly estimates for the first 24 hours of each test produced the daily resting loss emissions (for each of the 24 strata). Subtracting those values from the mean RTD emissions (for each of the 24 strata) yielded the estimated diurnal emissions (by strata) that are listed in Appendix C.

9.0 Characterizing 24-Hour Diurnal Emissions

Diurnal evaporative emissions, like other evaporative emissions, are functions of both fuel volatility and ambient 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 EPA program that were tested over a wide range of vapor pressures. These test vehicles were then distributed into 12 tested strata (of the 24 potential strata identified in Section 6.4).

The attempt to use this approach to characterize resting loss emissions (see previous section) had been unsuccessful. 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

---

* Evaporative emissions are functions of both fuel volatility and ambient temperature which are themselves interdependent. The RVP is one measure of vapor pressure (VP) at a single temperature, 100°F. In order to analyze the diurnal emissions as a function of VP, we used the Clausius-Clapeyron relationship to estimate the VP at each combination of temperature and fuel RVPs. See Appendix B.

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*ΔVP) that incorporates the parameters of the RTD test.

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) both the square and the cube of that product term (to allow for expected non-linearity).

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

In all but two (2) of the strata, the data strongly suggest a non-linear relationship (usually cubic) between the diurnal emissions and that product term. Those two strata in which the diurnal emissions are a linear function of that product term are the 1980-85 model year vehicles (both FI and carbureted) that failed the pressure test. In two of the strata in which non-linear curve fits were superior to the linear, the quadratic was a slightly better fit than the cubic, but we elected to use the cubic to be consistent with the form of the majority of the non-linear regression equations. (Those two strata were the 1980-85 and 1986 and newer FI vehicles that failed the purge test but passed the pressure test.)

Additionally, the regressions within several of the strata produced mediocre correlations, resulting in our decision to merge some of the strata.

- The four (4) pre-carbureted vehicles were combined into a single stratum. For those data, both the second and third degree polynomials were each better fits than the linear. Although the quadratic was a slightly better fit than the cubic, we elected to use the cubic to be consistent with the form of the majority of the regression equations.

- The tests on the single 1980-85 FI vehicle the passed both the purge and pressure 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. The cubic equation that modeled this stratum was used only for the stratum of 1980-85 FI vehicles the passed both the purge and pressure tests.

Once the coefficient values of the equation were determined for each stratum, we then transformed 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 D.

10.0 <u>Gross Liquid Leakers</u>

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. However, we anticipate receiving additional data. (CRC recently completed a running loss testing program in which data on gross liquid leakers were gathered.)

10.1 Frequency of Gross Liquid Leakers

To estimate the frequency of these gross liquid leakers, we examined data on the seven (7) vehicles in the two studies that were determined to be gross liquid leakers:

1) In the CRC RTD testing program, four (7.8%) of 51 of the 1971 to 1977 model year vehicles were gross liquid leakers. (All four of these vehicles failed both the purge and the pressure tests. This was the stratum of vehicles not recruited in the EPA program.)

2) In the EPA testing program, one of the five non-randomly selected 1971 to 1977 model year vehicles was a gross liquid leaker. (That single vehicle was one of three that passed the purge test but failed the pressure test. The weighting factors (from Table 4-2) suggest that this single vehicle would represent 8.4% of the 1971 to 1977 model year vehicles.)

3) In the CRC testing program, one (2.0%) of the 50 1980 to 1985 model year vehicles was a gross liquid leaker.

4) In the EPA non-random sample of only 27 1980-85 model year vehicles, no gross liquid leaker was identified; this is consistent with the 2.0 percent rate in the corresponding CRC sample.

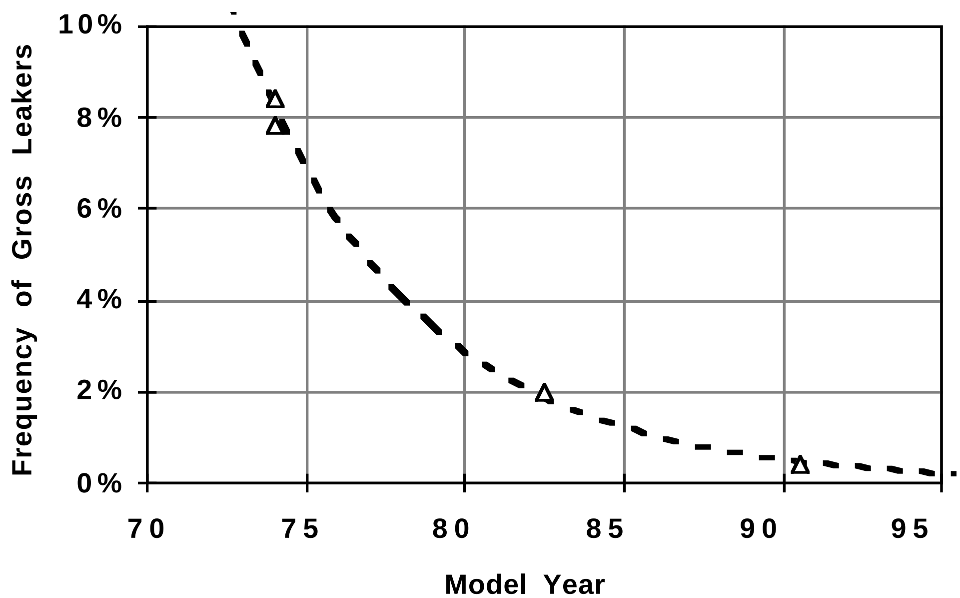
5) In the EPA testing program, one of the 86 (not randomly selected) 1986 to 1995 model year vehicles was a gross liquid leaker. (The weighting factors suggest that this single vehicle would represent 0.45% of the 1986 to 1995 model year vehicles.)

6) In the CRC testing program, none of the 50 1986 and newer model year vehicles was a gross liquid leaker. (This suggests that the true ratio of the gross liquid leakers to the other vehicles in this model year group is most likely less that 1.34 percent which is not inconsistent with the 0.45 percent in the previous point.)

Plotting these four estimates of the frequency of gross liquid leakers versus model year range yields Figure 10-1. The dotted line in that figure is an exponential regression (the corresponding linear regression in log-space has an R-squared of 99.9%). The curve's formula is the frequency equals the exponential of 10.4160 minus the product of -0.174475 with the mid-point model year of the stratum.

Figure 10-1

Frequency of Gross Liquid Leakers



Transforming the frequency relationship from a function of model year into a function of vehicle age yields the following equation (graphed in Figure 10-2)

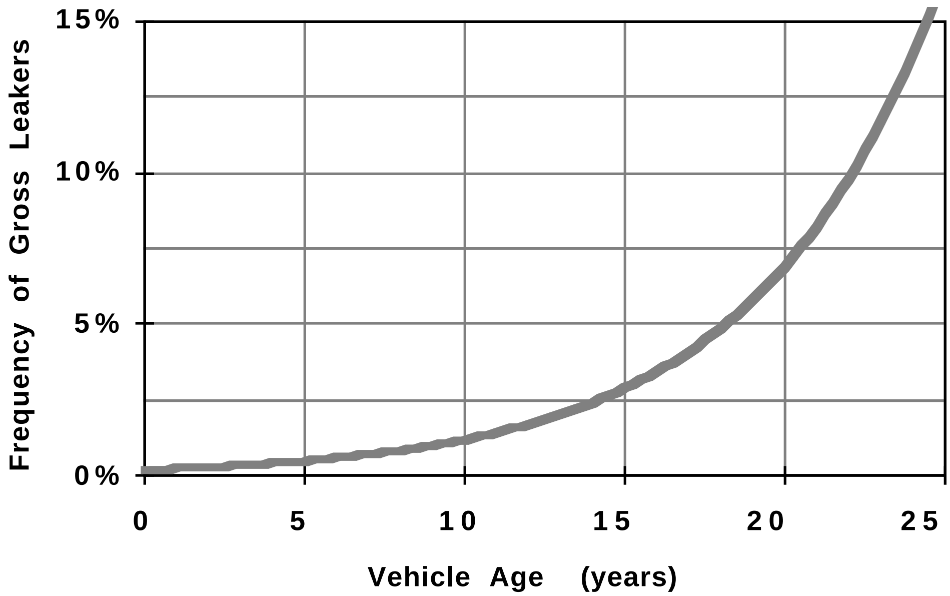
$$\text{Frequency} = \exp\left[-6.159125 + (0.174475 * \text{VEHICLE\_AGE}) \right]$$

This formula predicts that for vehicles that are 30 years of age (i.e., well beyond the actual data) 40 percent will be gross liquid leakers, and that rate would reach 50 percent before the vehicles reach 32 years of age. If these predicted rates for older vehicles turn out to be excessive, the impact of that excess will be minimal due to the relatively small number of vehicles older than 25 years (approximately one percent of the in-use fleet for LDGV).

This equation predicts that one-fourth of one percent of vehicles under the age of one year will be gross liquid leakers; that percentage slowly climbs to one-half of a percent for five year old vehicles, and to one percent for nine year old vehicles. While frequencies of those sizes appear small, the high emission levels associated with these vehicles (see Section 10.2) make them consequential.

Figure 10-2

Predicted Frequency of Gross Liquid Leakers



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 leaks as do the older technology vehicles at the same age. However, if the modern technology vehicles 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 the single curve (in Figures 10-1 and 10-2) with two or three curves. That would lower the predicted rate of such leakers in the current and future in-use fleets.

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 at the sixteenth hour 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. (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. Also, this vehicle exhibited unusually high emissions during the first two hours of the test (relative to its emissions for the next few hours). This might suggest that while the vehicle was in the SHED, prior to the test, some gasoline leaked out and then evaporated after the test had begun. These additional evaporative emissions (if they existed) would have resulted in a higher RTD result than this vehicle would actually have produced.

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 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 RL
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, we obtain:

Veh No	RTD	Hourly RL
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	124.95	2.85
5082	80.47	2.13
Means:	326.44	8.83
Std Dev:	263.97	5.63

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 * 8.83
  = 211.92 **(GRAMS / DAY)**

and

- **DIURNAL** = **RTD** - **DAILY RESTING LOSS**
  = 326.44 - 211.92
  = 114.52 **(GRAMS / DAY)**

These equations suggest that the daily evaporative emissions associated with gross liquid leakers average about 316 grams per vehicle. 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 evaporative emissions.

10.3 Effects of Vapor Pressure Changes on Gross Liquid Leakers

Since only two of the seven vehicles that have been identified as gross liquid leakers were tested over a range of vapor pressures, there are not enough data to relate changes in diurnal and resting loss emissions to changes in temperature and fuel RVP. However, as noted in the preceding section, changes in temperature and fuel RVP have only minimal (proportional) effects on the total diurnal and resting loss emissions. Thus, until additional data are available, we will treat the diurnal and resting loss emissions of the gross liquid leakers as independent of temperature and fuel RVP. This will most likely be the approach used in MOBILE6.

11.0 On-Going Analyses

In Sections 8 and 9, equations were developed that would estimate diurnal and resting loss emissions (within each of the strata identified in Section 6.4) based on temperature (or temperature cycle) and the fuel RVP. Those estimates are reasonable within the range of temperatures and fuel RVPs that were actually tested. Still to be determined is how to extrapolate beyond the limits of those temperature and RVP data.

In the preceding analyses, three temperature cycles were used (Appendix I). While the three starting temperatures were different (i.e., 60°, 72°, and 82° F), the corresponding hourly temperature changes were identical. This yields three parallel temperature profiles. This limitation on the variety of temperature cycles produces the following questions not addressed in this report:

1) Given the RTD evaporative emissions of a vehicle on our standard cycle, how can the vehicle's daily RTD emissions be estimated over different cycles (e.g., cycles whose minimum and maximum temperatures vary by amounts different from 24°F)?

2) How are RTD emissions for periods of less than 24 hours (i.e., partial day diurnals) to be estimated?

3) How are RTD emissions for periods of more than 24 hours (i.e., multiple day diurnals) to be estimated?

We are currently completing analyses that will answer these questions. These analyses make use of the hourly RTD emissions instead of just the total 24-hour results plus the resting loss portion. These results will appear in the next report (M6.RTD.002).

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 **40CFR86**.

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

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

Appendix B

Vapor Pressure

Using the Clausius-Clapeyron Relationship

The Clausius-Clapeyron relationship 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 (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

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

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

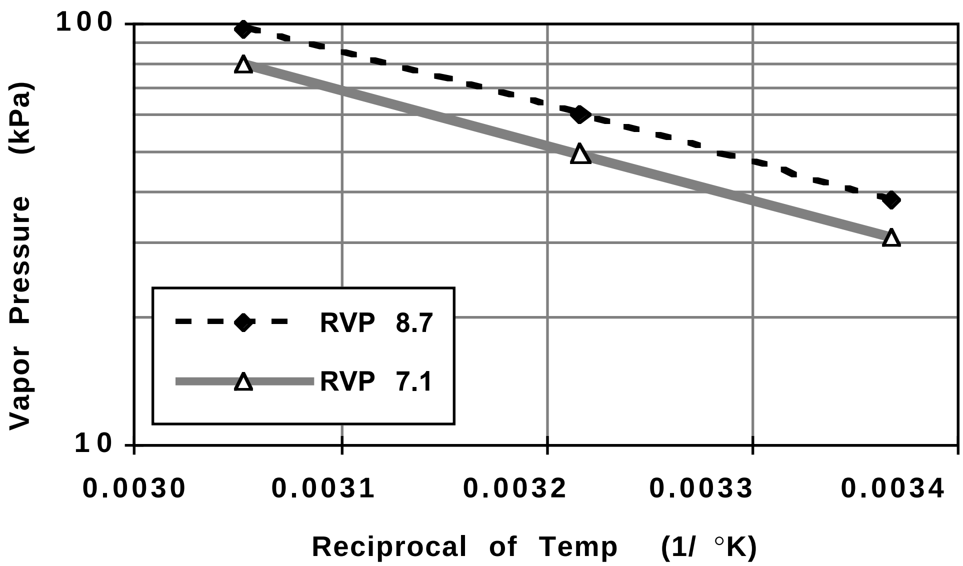
$$\ln(VP) = A + (B / \text{Absolute Temperature}), \text{ where:}$$

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



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.

Appendix C

Mean Evaporative Emissions by Strata
By Vapor Pressure Products

Strata	Fuel RVP	Temp. Cycle	VP times ΔVP	Count	Mean Diurnal	Mean Resting Loss
Pre-1980 Carbureted Fail Purge/ Fail Pressure	6.8	72.TO.96	567.02	13	11.883	0.452
Pre-1980 Carbureted Fail Purge/ Pass Pressure	6.8	60.TO.84	374.77	1	8.910	0.250
	6.8	72.TO.96	567.02	7	12.059	0.218
	9.0	60.TO.84	655.07	1	11.129	0.307
	6.8	82.TO.106	789.30	1	30.349	0.204
	9.0	72.TO.96	968.66	1	36.903	0.250
	9.0	82.TO.106	1323.87	1	69.219	0.259
Pre-1980 Carbureted Pass Purge/ Fail Pressure	6.8	60.TO.84	374.77	2	14.331	0.238
	6.3	72.TO.96	489.32	1	13.327	0.140
	6.8	72.TO.96	567.02	20	17.747	0.103
	9.0	60.TO.84	655.07	3	18.566	0.227
	6.3	82.TO.106	683.98	1	19.205	0.175
	6.8	82.TO.106	789.30	2	37.705	0.174
	9.0	72.TO.96	968.66	3	32.199	0.107
	9.0	82.TO.106	1323.87	2	64.241	0.274
Pre-1980 Carbureted Pass Purge/ Pass Pressure	6.8	60.TO.84	374.77	1	2.972	0.167
	6.8	72.TO.96	567.02	11	5.527	0.239
	9.0	60.TO.84	655.07	1	10.426	0.263
	6.8	82.TO.106	789.30	1	23.714	0.293
	9.0	72.TO.96	968.66	1	32.325	0.204
	9.0	82.TO.106	1323.87	1	98.279	0.062
1980-85 Carbureted Fail Purge/ Fail Pressure	6.8	72.TO.96	567.02	1	19.643	0.265
1980-85 Carbureted Fail Purge/ Pass Pressure	6.8	60.TO.84	374.77	3	5.214	0.124
	6.3	72.TO.96	489.32	1	11.125	0.185
	6.8	72.TO.96	567.02	11	12.981	0.163
	9.0	60.TO.84	655.07	4	11.780	0.172
	6.3	82.TO.106	683.98	1	10.688	0.146
	6.8	82.TO.106	789.30	3	14.731	0.169
	9.0	72.TO.96	968.66	4	20.650	0.163
	9.0	82.TO.106	1323.87	3	50.581	0.162
1980-85 Carbureted Pass Purge/ Fail Pressure	6.8	60.TO.84	374.77	2	9.855	0.121
	6.3	72.TO.96	489.32	1	13.334	0.253
	6.8	72.TO.96	567.02	8	12.453	0.139
	9.0	60.TO.84	655.07	3	24.050	0.127
	6.3	82.TO.106	683.98	1	30.386	0.444
	6.8	82.TO.106	789.30	2	25.641	0.216
	9.0	72.TO.96	968.66	3	37.239	0.276
	9.0	82.TO.106	1323.87	2	44.598	0.308

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

Strata	Fuel RVP	Temp. Cycle	VP times ΔVP	Count	Mean Diurnal	Mean Resting Loss
1980-85 Carbureted Pass Purge/ Pass Pressure	6.8	60.TO.84	374.77	3	3.399	0.065
	6.3	72.TO.96	489.32	3	10.599	0.195
	6.8	72.TO.96	567.02	38	5.940	0.107
	9.0	60.TO.84	655.07	7	7.036	0.147
	6.3	82.TO.106	683.98	3	17.060	0.170
	6.8	82.TO.106	789.30	4	10.066	0.169
	9.0	72.TO.96	968.66	7	15.418	0.194
	9.0	82.TO.106	1323.87	3	35.888	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	7.302	0.100
	9.0	60.TO.84	655.07	1	10.000	0.097
	6.8	82.TO.106	789.30	1	21.182	0.155
	9.0	72.TO.96	968.66	1	13.337	0.148
1986+ Carbureted Pass Purge/ Fail Pressure	6.8	72.TO.96	567.02	2	9.058	0.233
	9.0	60.TO.84	655.07	2	11.767	0.342
	6.8	82.TO.106	789.30	2	17.850	0.124
	9.0	72.TO.96	968.66	2	17.248	0.308
1986+ Carbureted Pass Purge/ Pass Pressure	6.8	72.TO.96	567.02	10	5.447	0.138
	9.0	60.TO.84	655.07	1	3.747	0.092
	6.8	82.TO.106	789.30	1	5.644	0.102
	9.0	72.TO.96	968.66	1	5.944	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	3.946	0.010
	6.8	72.TO.96	567.02	3	7.474	0.011
	9.0	60.TO.84	655.07	4	4.782	0.045
	6.8	82.TO.106	789.30	3	9.119	0.041
	9.0	72.TO.96	968.66	4	8.088	0.086
	9.0	82.TO.106	1323.87	4	21.845	0.123
1980-85 Fuel Injected Pass Purge/ Fail Pressure	6.8	60.TO.84	374.77	2	11.777	0.198
	6.8	72.TO.96	567.02	3	11.331	0.206
	9.0	60.TO.84	655.07	2	18.589	0.184
	6.8	82.TO.106	789.30	2	27.554	0.300
	9.0	72.TO.96	968.66	2	29.930	0.231
	9.0	82.TO.106	1323.87	2	40.287	0.252
1980-85 Fuel Injected Pass Purge/ Pass Pressure	6.8	60.TO.84	374.77	1	1.212	0.296
	6.8	72.TO.96	567.02	4	5.370	0.080
	9.0	60.TO.84	655.07	2	1.622	0.157
	6.8	82.TO.106	789.30	2	3.221	0.218
	9.0	72.TO.96	968.66	2	4.353	0.227
	9.0	82.TO.106	1323.87	1	11.711	0.348

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

Strata	Fuel RVP	Temp. Cycle	VP times ΔVP	Count	Mean Diurnal	Mean 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	3.372	-0.009
	6.8	60.TO.84	374.77	12	4.960	0.011
	6.3	72.TO.96	489.32	5	5.068	0.024
	6.8	72.TO.96	567.02	18	6.698	0.060
	9.0	60.TO.84	655.07	17	6.464	0.034
	6.3	82.TO.106	683.98	5	8.524	0.064
	6.8	82.TO.106	789.30	15	11.624	0.073
	9.0	72.TO.96	968.66	17	9.508	0.056
	9.0	82.TO.106	1323.87	12	20.457	0.087
1986+ Fuel Injected Pass Purge/ Fail Pressure	6.3	60.TO.84	321.73	1	3.740	0.037
	6.8	60.TO.84	374.77	12	4.919	0.042
	6.3	72.TO.96	489.32	4	8.763	0.038
	6.8	72.TO.96	567.02	19	5.470	0.094
	9.0	60.TO.84	655.07	19	6.519	0.053
	6.3	82.TO.106	683.98	4	11.364	0.088
	6.8	82.TO.106	789.30	16	11.457	0.110
	9.0	72.TO.96	968.66	19	11.656	0.114
	9.0	82.TO.106	1323.87	12	27.014	0.129
1986+ Fuel Injected Pass Purge/ Pass Pressure	6.3	60.TO.84	321.73	2	0.622	-0.001
	6.8	60.TO.84	374.77	16	0.524	0.027
	6.3	72.TO.96	489.32	6	1.077	0.032
	6.8	72.TO.96	567.02	69	4.725	0.062
	9.0	60.TO.84	655.07	31	1.042	0.034
	6.3	82.TO.106	683.98	6	1.654	0.049
	6.8	82.TO.106	789.30	24	2.579	0.073
	9.0	72.TO.96	968.66	31	1.889	0.064
	9.0	82.TO.106	1323.87	21	8.782	0.123

Appendix D

Regression Curves of Diurnal Emissions for All Strata

Strata			Constant	Coefficient of VP * ΔVP	Coefficient of (VP * ΔVP)^3
Pre-80	Carb	F/F	6.995852		0.026810
		F/P	8.167144		0.026810
		P/F	12.162899		0.026810
		P/P	4.127629		0.026810
80-85	Carb	F/F	-1.589121	0.037445	
		F/P	6.872729		0.018974
		P/F	-4.323279	0.037445	
		P/P	3.812881		0.014217
86-95	Carb	F/F	-1.589121	0.037445	
		F/P	2.818923		0.018974
		P/F	-16.520726	0.037445	
		P/P	0.224599		0.014217
Pre-80	FI	F/F	6.995852		0.026810
		F/P	8.167144		0.026810
		P/F	12.162899		0.026810
		P/P	4.127629		0.026810
80-85	FI	F/F	-2.524013	0.032554	
		F/P	4.241510		0.006868
		P/F	-2.524013	0.032554	
		P/P	1.843499		0.004744
86-95	FI	F/F	4.396049		0.009876
		F/P	5.676831		0.005993
		P/F	4.396049		0.009876
		P/P	1.773854		0.002850