United States Environmental Protection Agency
Air and Radiation
EPA420-R-01-024
April 2001
M6.EVP.009

Evaporative Emissions of Gross Liquid Leakers in MOBILE6

EPA420-R-01-024
April 2001

Evaporative Emissions of Gross Liquid Leakers in MOBILE6

M6.EVP.009

Larry C. Landman

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

ABSTRACT

In six parallel documents (M6.EVP.001, M6.EVP.002, M6.EVP.004, M6.EVP.005, M6.EVP.006, and M6.EVP.008), EPA noted that a potentially significant portion of evaporative emissions (from the in-use fleet) may be the result of a small number of vehicles leaking liquid gasoline (rather than gasoline vapors). This document describes EPA's approach (in MOBILE6) to estimating both the frequency of occurrence vehicles with these significant leaks of liquid gasoline and the magnitude of the emissions resulting from those leaks.

This report was originally released (as a draft) in June 1999. This current version is the final revision of that draft. This final revision incorporates suggestions and comments received from stakeholders during the 60-day review period and from peer reviewers.

TABLE OF CONTENTS

APPENDICES

Evaporative Emissions of Gross Liquid Leakers in MOBILE6

Report Number M6.EVP.009

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

1.0 INTRODUCTION

In four parallel reports **[1,2,3,4]*** the US Environmental Protection Agency (EPA) noted that for a small number of vehicles, the primary mechanism of evaporative emissions was the substantial** leakage of liquid gasoline (as opposed to simply vapor leaks). In each of those reports, such vehicles were referred to as "Gross Liquid Leakers" (GLLs). One consistent feature of these vehicles is that their evaporative emissions far exceed the evaporative emissions of the vehicles that were not gross liquid leakers (non-GLLs). In this report, EPA:

- develops a set of criteria to define GLLs,
- determines the evaporative emissions produced by these GLLs, and
- determines the occurrence (i.e., frequency) of these GLLs as a function of vehicle age.

2.0 CHARACTERIZING "GROSS LIQUID LEAKERS" (GLLs)

The term "gross liquid leaker" (GLL) identifies vehicles having substantial leaks of liquid gasoline, as opposed to simply vapor leaks. But, this term has been used in different contexts and it is, therefore, likely that some vehicles that behave as GLLs based on one type of evaporative emissions test might not behave as GLLs on another type of test. In this analysis, EPA makes use of four different types of testing programs to identify

* The numbers in brackets refer to the references in Section 4 (page 31).

** Throughout this report, we use adjectives such as "substantial" and "severe" to describe the leaks that produce GLLs. Quantitative estimates of that type of leak can be obtained using the emissions (in grams per hour) from Table 2-1 (page 17).

those vehicles with substantial liquid leaks:

- a real-time diurnal (RTD) test [1,2] in which evaporative emissions are measured for stabilized test vehicles that are enclosed in a sealed housing with the temperatures cycling over a 24-hour period to simulate the pressure-driven evaporative HC emissions that result from the daily increase in ambient temperature,
- a hot soak test [3] in which evaporative emissions are measured for one hour following a driving cycle for test vehicles that are enclosed in a sealed housing,
- a running loss test [4] in which evaporative emissions are measured during a driving cycle for test vehicles that are enclosed in a sealed housing, and
- a visual inspection [5].

In this report, EPA first estimates the mean evaporative emissions of these GLLs for each type of test (Section 2), and then estimates the likelihood of those types of leaks occurring (Section 3).

Generally, when EPA predicts evaporative emissions (either resting loss, diurnal, hot soak, or running loss*) these two variables are critical:

1) the ambient temperature and
2) the fuel volatility as measured by the Reid vapor pressure (RVP) of the test fuel.

However, for vehicles that are classified as GLLs, most (but, not necessarily all) of the evaporative emissions are the result of the leak of liquid gasoline. Since it is unlikely the rate of leakage is a function of either the temperature or the fuel volatility, EPA will treat (in MOBILE6) the evaporative emissions of these vehicles as independent of ambient temperature and RVP.

An additional source of data was a 1998 test program conducted for the Coordinating Research Council (CRC) in which 50 late-model year vehicles (1992 through 1997, with a mean age of 4.5 years) were tested using the hot soak, running loss, and RTD tests.[6] However, none of those 50 vehicles had detected liquid leaks. Thus, the results from these tests were not used in the analyses in Section 2. The observation that no GLLs were identified among this sample of 50 vehicles will be considered in the analysis in Section 3.

---

* MOBILE6 will not consider GLLs in its estimates of evaporative emissions from crankcase losses or refueling. The methodology for estimating these emissions has not changed from that in MOBILE5.

2.1 GLLs on the RTD Test

The category of vehicles identified as GLLs was first discussed in a report dealing with evaporative emissions during resting losses and diurnals. **[1]** In that report, the term "gross liquid leaker" was used to refer to vehicles which had resting loss emissions of at least 2.0 grams per hour. Those analyses were performed on 119 vehicles tested in various EPA programs plus 151 vehicles tested for the Coordinating Research Council (CRC).

The analyses in that report were based on tests in which the ambient temperature cycled over 24 hours to simulate (in real-time) a full day's temperature pattern. The results of those real-time diurnal (RTD) tests were used to estimate both resting loss and diurnal emissions. In that analysis, the diurnal emissions were calculated by subtracting the resting loss emissions from the total RTD test results.

Since the 151 vehicles in the CRC program were randomly recruited (within each of three model year ranges), EPA will use that random sample to estimate the means of the resting loss and diurnal emissions of vehicles that had liquid leaks of gasoline. The mechanics who inspected the test vehicles identified 32 of those vehicles as having evidence of some fuel leakage (from damp hoses and connectors to visible leaks).

Since our intention is to only estimate the mean of the emissions of the vehicles having only substantial leaks (i.e., GLLs), we first limited our sample to vehicles:

1.) whose resting loss emissions (i.e., the mean emissions during the last six hours of the 24-hour RTD test) were at least 0.25 grams per hour and

2.) whose total RTD emissions were at least 30 grams per day.

These limitations produced a set of vehicles whose gasoline leaks had an observable effect on the evaporative emissions (even if that effect was not sufficient to create a GLL). Eleven such vehicles were found among the 32 having identified liquid leaks. The emissions from those 11 vehicles are given in Appendix A. It is important to note that while all of these vehicles leaked liquid gasoline, less than half of them were eventually classified as GLLs (i.e., having resting loss emissions of at least 2.0 grams per hour). All of these 11 vehicles are carbureted. In the absence of evidence to the contrary, EPA will treat fuel injected and carbureted vehicles with liquid leaks the same for the purposes of resting loss and diurnal emissions.

The usual approach that EPA has followed in estimating emission levels is to simply calculate the mean of the sample of applicable test results. However, the number of vehicles identified as GLLs (i.e., having resting loss emissions of at least 2.0 grams per hour) is relatively small, and the range of their emissions is relatively large. From a statistical standpoint, the combination of these two conditions may lead to a high degree of uncertainty in the calculated mean. An alternate approach is to fit an assumed type of distribution curve to those limited number of observations. The type of distribution that has historically been used for emissions is the lognormal distribution [7] (i.e., the logarithms of the emissions, rather than the emissions themselves, are assumed to be normally distributed). EPA will use this approach in MOBILE6.

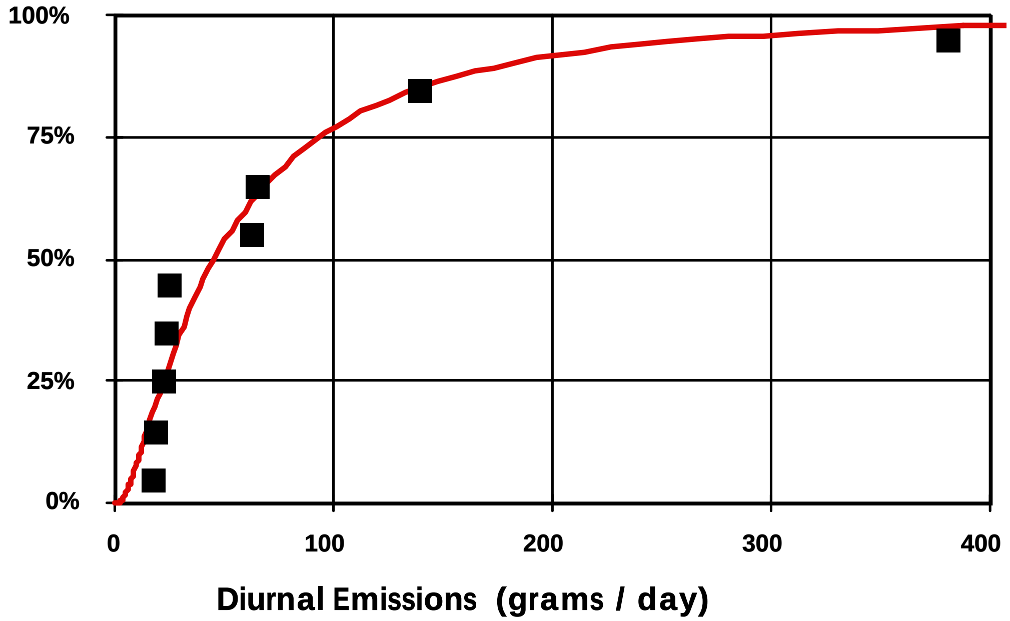
Prior to modeling the estimated diurnal emissions, we reexamined the data in Appendix A. Since our intent was to model the distribution of diurnal emissions from vehicles with the severest leaks, we dropped from the analysis the results of vehicle number 9042 due to its relatively low diurnal emissions (suggesting that it was not a GLL relative to its diurnal emissions). Additionally, we assumed that if a valid estimate of the diurnal emissions from vehicle 9129 had been obtained*, then that estimated diurnal would have been less than the emissions from the two highest emitting vehicles but higher than the emissions from the remaining eight vehicles. Using these two assumptions, we ranked the diurnal emissions and assigned a percentile to each. The plot of those percentiles versus the corresponding diurnal emissions is given in Figure 2-1, on the following page. The solid line in that figure is the graph of the cumulative distribution obtained by assuming that the logarithms of the emissions are normally distributed. (The mean of the logarithms of the emissions is 3.812; the corresponding standard deviation is 1.075.) (Distributions other than the lognormal were examined, but none came as close to approximating the observed distribution.) We then used that lognormal distribution to estimate the frequency associated with each possible diurnal emission level.

---

* In Reference [1], EPA noted that the hourly diurnal emissions from vehicle number 9129 suggest that the leak actually developed around the tenth hour of the test. Hence, that vehicle was a GLL for only the second half of the RTD test. Trying to precisely estimate the emissions during the first half of the RTD test, assuming the vehicle had been a GLL for the entire test, is questionable. However, based on the vehicle's emissions for the last 14 hours of the RTD, it appears that its 24-hour RTD emissions would have fallen between the emissions of vehicles number 9054 and 9087.

Figure 2-1

Cumulative Distribution of Estimated Diurnal Emissions
For Vehicles Exhibiting Liquid Fuel Leaks
With Diurnal Emissions Over 15 grams per day



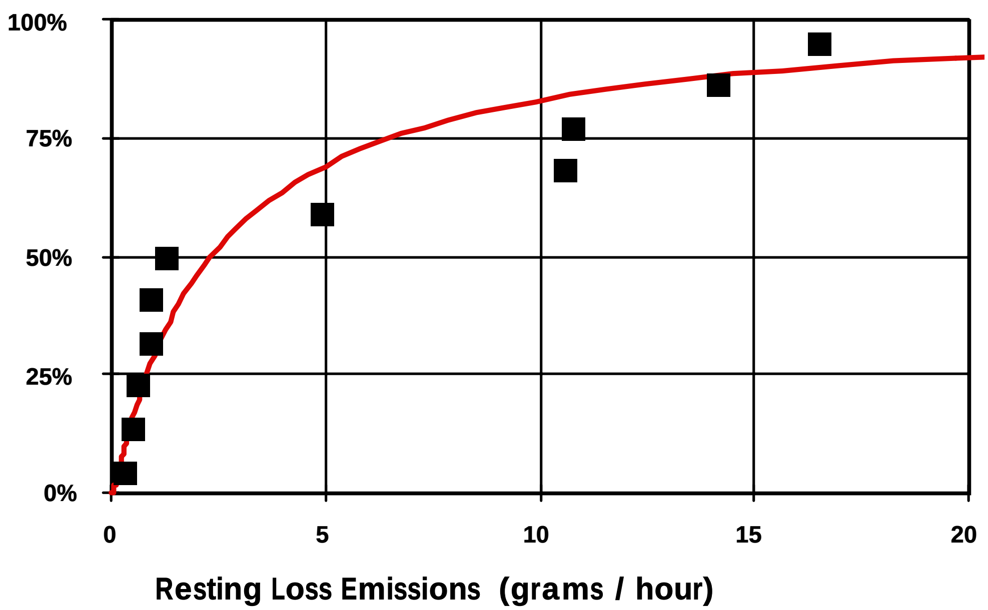
Although the lognormal distribution predicts that a small number of vehicles would have impossibly high diurnal emissions, EPA chose to limit the maximum emissions based on the assumption that a truly severe leak would result in the quick repair of the vehicle. Since one (real world) test vehicle (in our sample) had diurnal emissions of almost 400 grams per day, EPA assumed that the limit of the maximum emissions should be higher than that value. EPA will use 1,000 grams per day as the maximum for the purpose of estimating fleet averages.

The lognormal distribution also predicts that some leaking vehicles will have diurnal emissions of close to zero. To separate the GLLs from vehicles having only minor or moderate leaks, we again examined the estimated diurnal emissions in Appendix A. A visual inspection of those data indicated a relatively large discontinuity (i.e., a break) between 24.86 and 62.64 grams per day. Based on that observation, EPA will use 25 grams per day as the minimum value. For a group of leaking vehicles whose diurnal emissions were between 25 and 1,000 grams per day, the lognormal distribution predicts that the mean diurnal emissions of that group of leakers would be 104.36 grams per day. (Doubling the maximum possible diurnal to 2,000 grams per day would result in increasing the estimated group average only to 107.41 grams daily.)*

EPA will use 104.36 grams per day as the average full-day's diurnal emissions from GLLs over a day for which the maximum daily temperature is exactly 24°F above the daily low temperature. (See report number M6.EVP.002 to use temperature cycles with ranges other than 24°F.) Earlier versions of MOBILE limited diurnal emissions to times when the ambient temperature was at least 40°F. However, we suspect that, at temperatures below 40°F, the diurnal emissions would still continue. However, at those low temperatures, the likelihood of ozone exceedences would be small.

Figure 2-2

Cumulative Distribution of Resting Loss Emissions
For 11 Vehicles Exhibiting Liquid Fuel Leaks
And Having Resting Loss Emissions Over 0.25 grams / hour



The preceding approach was repeated (using the data in Appendix A) for resting loss emissions. The resting loss emissions from the 11 vehicles in Appendix A are plotted in Figure 2-2.

---

* The more traditional approach would have been simply to average the diurnal emissions of the four vehicles in Appendix A having RTD emissions of at least 100 grams with the diurnal emissions of two other leakers from the EPA testing programs. The mean of those six diurnals is 100.29 grams per day, which corresponds to using the lognormal distribution with the maximum diurnal emissions set to 675 grams per day.

As with the previous figure (Figure 2-1), the solid line in Figure 2-2 is the graph of the cumulative distribution obtained by assuming that the logarithms of the resting loss emissions are normally distributed. (The mean of the logarithms of the resting loss emissions is 0.841; the corresponding standard deviation is 1.528.) A visual inspection of that figure suggests that the lognormal model does not fit the resting loss emissions of leaking vehicles as well as it fit the diurnal emissions. In fact, a straight line (i.e., a "uniform" distribution) is the curve that best fits the resting loss emissions for vehicles having at least 1.0 grams per hour (therefore, covering all GLLs). However, it also predicts that forty percent of the vehicles with leaks have zero resting loss emissions.

In previous analyses (see M6.EVP.001), EPA determined that the lower bound of the resting loss emissions of the GLLs would be 2.0 grams per hour. Since one (real world) test vehicle (in our sample) had resting loss emissions of about 16 grams per hour, EPA assumed that the limit of the maximum emissions should be higher than that value. EPA will use 50 grams per hour as the maximum for the purpose of estimating fleet averages. For a group of leaking vehicles whose hourly resting loss emissions were between 2.0 and 50 grams, the lognormal distribution predicts that the mean resting loss emissions of that group of leakers would be 9.163 grams per hour.* (Doubling the maximum possible resting loss to 100 grams per hour would result in increasing the estimated group average only to 10.875 grams hourly.) The linear fit (i.e., uniform distribution) predicts the mean of the resting losses from vehicles emitting at least 2.0 grams per hour would be 10.518 grams per hour. Thus, all of those approaches produce similar estimates of the average hourly resting loss emissions from GLLs.

Although the uniform distribution produces a superior estimate of the observed data compared to the lognormal distribution, both approaches produce similar estimates of the mean resting loss emissions. Therefore, EPA will use the lognormal distribution for consistency among the various evaporative models in this report. EPA will use the estimate based on the lognormal model (i.e., 9.16 grams per hour) as the average hourly resting loss emissions from GLLs. Since the mechanism responsible for the vast majority of the resting loss emissions from these vehicles is the fuel leaking out of the vehicle, and since this process is not dependent upon the ambient temperature or fuel volatility, EPA had proposed (reference [1])

---

* The more traditional approach would have been to simply average the resting loss emissions of the five vehicles in Appendix A having resting loss emissions of at least 2.0 grams per hour with the resting loss emissions of two other leakers from the EPA testing programs. The mean of those seven resting losses is 8.84 grams per hour, which corresponds to using the lognormal distribution with the maximum hourly resting loss emissions set to 45.2 grams per hour.

considering resting loss emissions from GLLs as independent of fuel volatility and temperature.

2.2 GLLs on the Hot Soak Test

The category of vehicles identified as GLLs based on evaporative emissions during a hot soak, are discussed in a report prepared for EPA by one of its contractors **[8]**. In that report, the term GLLs was used to refer to "vehicles which produce abnormally high evaporative emissions as a result of a fuel leak and which have hot soak emissions of over 10 grams per test." Since the hot soak test is one hour in duration, "grams per test" is equivalent to "grams per hour" for the hot soak. (See reference **[8]** to calculate hot soak emissions for time periods less than an hour.) Since the hot soak test measures total evaporative emissions during that hour, the results also include resting loss emissions which must be subtracted to obtain the (net) hot soak emissions.

In the analyses for that report, hot soak test results on 493 vehicles were used. Of those 493 vehicles, the mechanics identified 14 as having evidence of some fuel leakage (from damp hoses and connectors to visible leaks). Those 14 vehicles (along with their hot soak test results) are listed in Appendix B. The hot soak emissions of those 14 leaking vehicles ranged from 2.00 to 88.57 grams per test (averaging 22.47 grams). For the remaining 479 vehicles that did <u>not</u> have liquid leaks detected, their hot soak emissions ranged from 0.04 to 88.35 grams per test (averaging 1.77 grams).

A quick inspection of the emissions listed in Appendix B suggests that the port fuel injected (PFI) vehicles that have leaks exhibit higher hot soak emissions than the carbureted (CARB) vehicles that have leaks. Since the fuel delivery systems in the PFI vehicles operate at a higher pressure than do the systems in the carbureted vehicles, a hole in the fuel system of a PFI vehicle will leak more fuel than a hole of the same size in a carbureted vehicle.* Therefore, the observation that the PFIs with liquid leaks have (on average) higher hot soak emissions than the corresponding carbureted vehicles is reasonable. There was an insufficient sample of leaking vehicles with throttle body injection (TBI) systems to analyze. Therefore, the hot soak emissions from this technology grouping will be estimated using a theoretical rather than statistical approach.

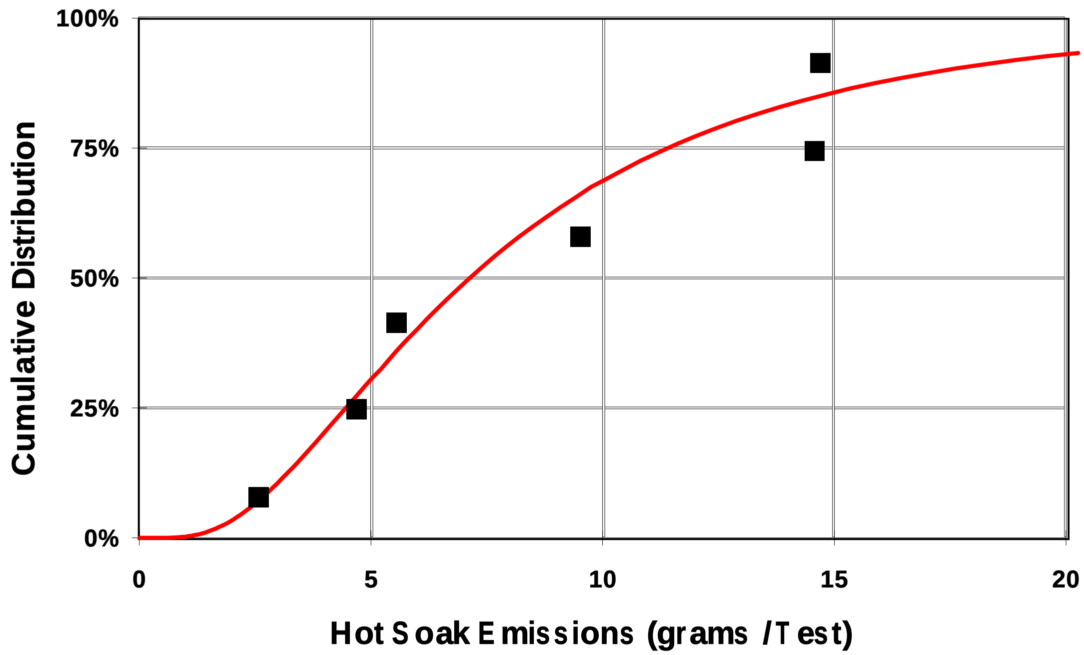
---

* Bernoulli's equation indicates that the leak rate will be proportional to the square root of the ratio of operating pressures.

In Figure 2-3 (below), we plotted the hot soak emissions (in grams per test) of the six carbureted vehicles (from Appendix B) versus the corresponding percentiles. The solid line in that figure is the graph of the cumulative distribution obtained by assuming that the logarithms of the emissions are normally distributed. (The mean of the logarithms of the hot soak emissions is 1.9644; the corresponding standard deviation is 0.6963.)

Figure 2-3

Cumulative Distribution of Hot Soak Emissions
For 6 Carbureted Vehicles Exhibiting Liquid Fuel Leaks



As was done in Section 2.1 with diurnal emissions, that lognormal distribution was used to estimate the frequency associated with each possible hot soak emission level. Although the lognormal distribution predicts that a small number of carbureted vehicles would have impossibly high hot soak emissions, EPA chose to limit the maximum emissions based on the assumption that a truly severe leak would result in the vehicle being quickly repaired. In Appendix B, we can see that one owner tolerated a vehicle having hot soak emissions of almost 90 grams per test. Based on that observation, EPA will assume that, for the purpose of estimating the mean hot soak emissions, the hot soak emissions of the GLLs range between 10 and 300 grams per test.

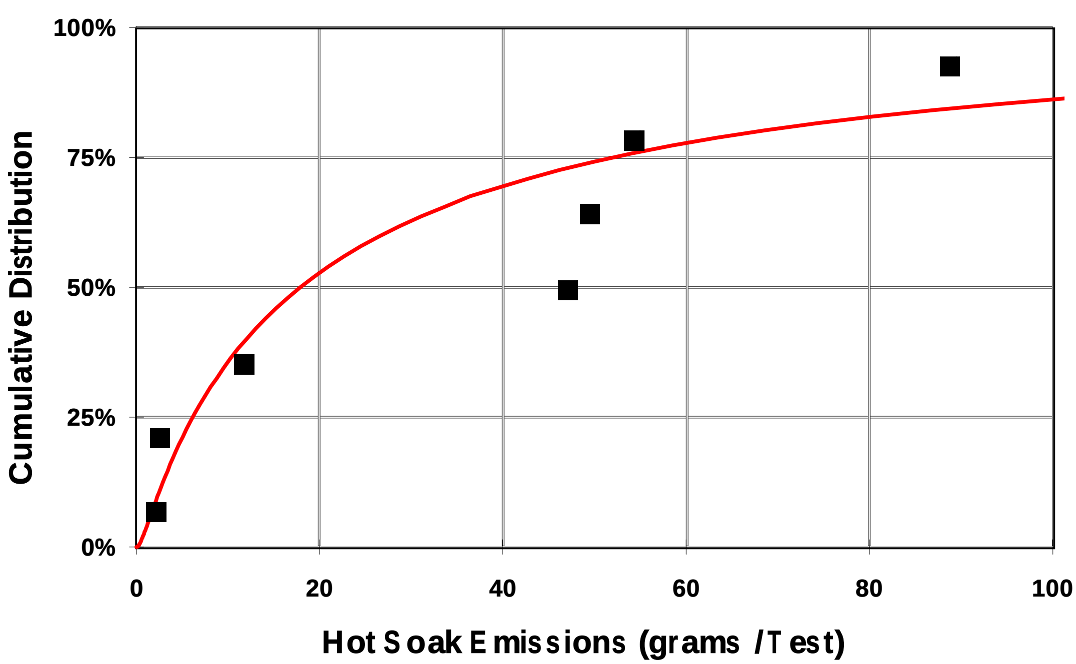
Using the lognormal distribution in Figure 2-3, we can predict the mean hot soak emissions for the GLL carbureted vehicles assuming hot soak emissions ranging between 10 and 300 grams per test. The mean hot soak emissions of that group of leakers would be 16.9549 grams per test (or per hour). (That average emission level was not very sensitive to the assumption of the emissions of the highest possible leaker. Lowering the assumed level of the highest emitting carbureted vehicle to 50 grams reduced the average only to 16.5503. Similarly, raising the assumed level of the highest emitting vehicle to 1,000 grams increased the average only to 16.9550.) EPA, therefore, will use 16.95 grams per test as the estimate of hot soak emissions from GLL carbureted vehicles.

To estimate the mean of the hot soak emissions from the PFI vehicles that had liquid leaks, we proceeded in the same fashion that we employed for the carbureted vehicles. In Figure 2-4 (on the following page), we plotted the hot soak emissions (in grams per test) of the seven PFI vehicles (from Appendix B) versus the corresponding percentiles.

The solid line in Figure 2-4 is the graph of the cumulative distribution obtained by assuming that the logarithms of the emissions are normally distributed. (The mean of the logarithms of the hot soak emissions is 2.8830; the corresponding standard deviation is 1.5822.)

Figure 2-4

Cumulative Distribution of Hot Soak Emissions
For 7 PFI Vehicles Exhibiting Liquid Fuel Leaks



A visual inspection of that figure suggests that the lognormal model does not fit the hot soak emissions of leaking PFI vehicles as well as it fit the carbureted vehicle. In fact, a straight line (i.e., a "uniform" distribution) provides almost as good a fit to the hot soak emissions for the six PFI vehicles having at least 2.25 grams per test. (We are considering the lognormal distribution to be a better fit because the sum of the squares of the residuals is lower than for the linear fit.) EPA will use the lognormal distribution because it is the better fit and for consistency among the various evaporative models in this report.

Using the lognormal distribution in Figure 2-4, we can predict the mean hot soak emissions for the GLL PFI vehicles assuming hot soak emissions ranging between 10 and 300 grams per test. The mean hot soak emissions of that group of leakers would be 57.1425 grams per test (or per hour). (That average emission level is only slightly sensitive to the assumption of the emissions of the highest possible leaker. Lowering the assumed level of the highest emitting carbureted vehicle to 250 grams reduces the average to 53.3468. Similarly, raising the assumed level of the highest emitting vehicle to 400 grams increases the average only to 63.0990.) The linear fit (i.e., uniform distribution) predicts the mean of the hot soak emissions for PFI vehicles emitting at least 10 grams per test would be 52.2481 grams per test. Thus, all of those approaches produce similar estimates of the mean hourly resting loss emissions from GLLs. EPA, therefore, will use 57.14 grams per test as the estimate of hot soak emissions from GLL PFI vehicles.

Due to a lack of data (see Appendix B), we were not able to perform a similar analysis for the TBI vehicles. This situation was addressed in the report on hot soak emissions (M6.EVP.004), in which the author stated:

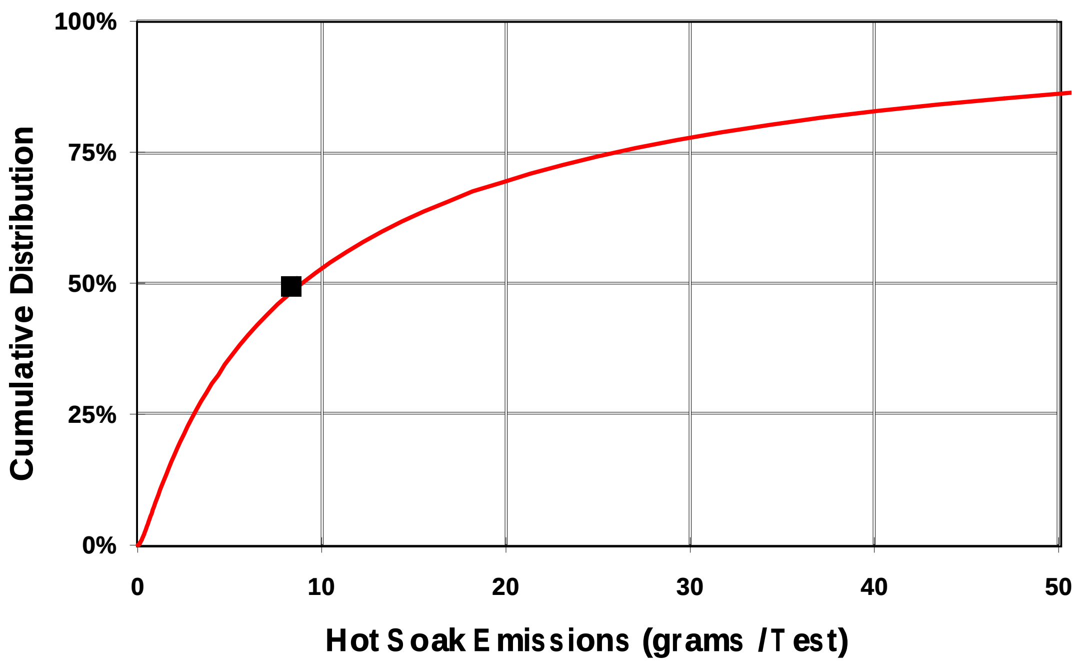
> "While there is no data on TBI liquid leakers in the data sets, Bernoulli's equation indicates that the leak rate for TBI systems would be about one half that for PFI systems (the square root of the ratio of operating pressures). Therefore, without further data, the author suggests assuming that TBI liquid leakers might emit approximately half the emissions of PFI systems."

EPA assumes (in MOBILE6) that the frequency of having a hole of a given size is the same for both the TBI and PFI vehicles. Based on that assumption, Bernoulli's equation predicts that at each frequency in the cumulative distribution curve for PFIs (i.e., Figure 2-4), the corresponding TBI curve would predict only one-half the hot soak emissions. Thus, since the median (i.e., the 50 percentile point) corresponds to a PFI vehicle with a hot soak test of 17.868 grams, the median hot soak test result for a TBI vehicle would be one-half of that (8.9339 grams). Pictorially, the effect would be to maintain the distribution curve (in Figure 2-4) while changing the horizontal scale from zero to 100 to a scale from zero to 50. That transformation is performed in the following graph (Figure 2-5). Also, in that figure, we plotted the single result for TBI vehicles in our data base (from Appendix B).

Using the lognormal distribution in Figure 2-5, we can predict the mean hot soak emissions for the GLL TBI vehicles assuming hot soak emissions ranging between 10 and 300 grams per test. The mean hot soak emissions of that group of leakers would be 44.9990 grams per test. Therefore, EPA will use 45.00 grams per test (or grams per hour) as the estimate of hot soak emissions from GLL TBI vehicles. (It is encouraging, but not statistically significant, that the actual test result of 8.28 from Appendix B is quite similar to the predicted median hot soak test value of 8.9339 grams per test.)

Figure 2-5

Estimated Cumulative Distribution of Hot Soak Emissions
For TBI Vehicles Exhibiting Liquid Fuel Leaks



2.3 GLLs on the Running Loss Test

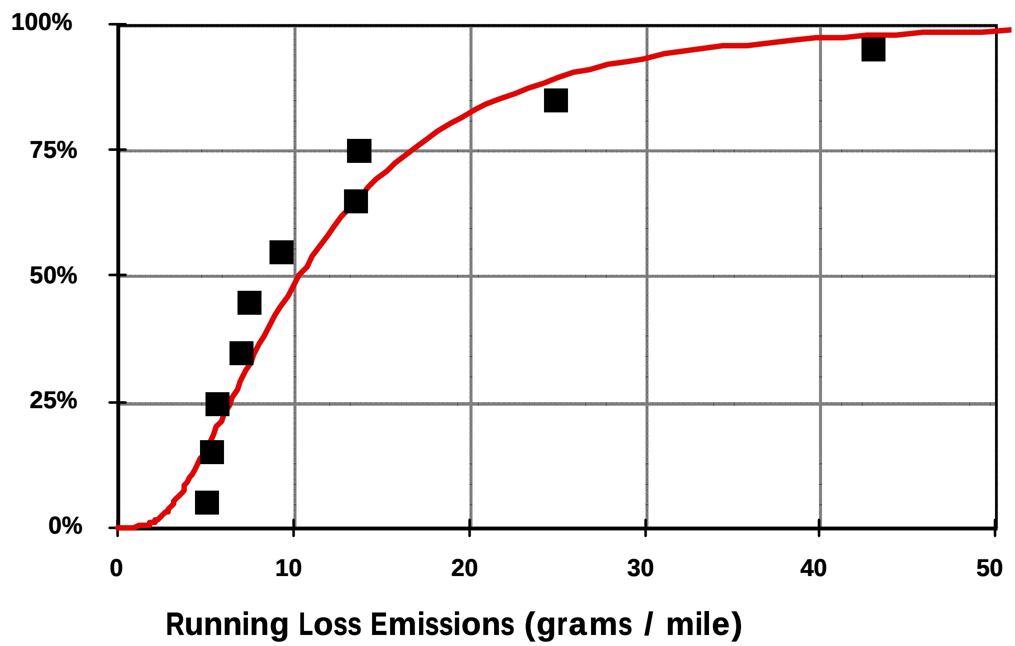
In 1997, running loss tests were performed on 150 vehicles as part of a testing program conducted for the Coordinating Research Council (CRC). The mechanics who inspected those test vehicles identified 40 of those vehicles as having evidence of some fuel leakage (from damp hoses and connectors to visible liquid leaks). The running loss emissions from these vehicles were measured over a single LA-4 driving cycle, using tank fuel (RVP about 6.8 psi), and ambient temperature about 95 degrees Fahrenheit. [9]

Since our intention is to estimate the mean of the emissions of the vehicles having only substantial leaks, we first limited our sample to leaking vehicles whose running loss emissions were at least 5.0 grams per mile over the single LA-4 driving cycle. (Five grams per mile appears to be a reasonable break point since the next highest running loss emissions for a leaking vehicle was only 3.52 grams per mile.) Ten such vehicles were found among those 40 having identified liquid leaks. The emissions from those 10 vehicles (reported as grams per mile, grams per test, and grams per hour) are given in Appendix C. It is important to note that while all of these vehicles leaked liquid gasoline, not all of them are classified as GLLs (using the criteria developed in this section). All of these 10 vehicles are carbureted. (Two of the original 40 leaking vehicles were fuel injected; however, their running loss emissions were each less than 0.4 grams per mile.)

The approach used in the preceding sections (for diurnal, resting loss, and hot soak) was repeated for running loss emissions (using the data in Appendix C). The running loss emissions from the 10 vehicles in Appendix C are plotted in Figure 2-6. As with the previous figures, the solid line is the graph of the cumulative distribution obtained by assuming that the logarithms of the emissions are normally distributed. (The mean of the logarithms of the emissions is 4.2; the corresponding standard deviation is 0.88.)

Figure 2-6

Cumulative Distribution of Running Loss Emissions For Vehicles Exhibiting Liquid Fuel Leaks With Running Loss Emissions Over 5 grams per mile



To determine the appropriate range of running loss emissions for these GLLs, we reexamined the running loss test results on all 150 vehicles. All of the vehicles that did not have an identified liquid leak had running loss emissions (for the single LA-4 cycle) of less than 4.2 grams per mile. EPA selected 7.0 grams per mile as the value that distinguished between vehicles that have liquid leaks and those defined as GLLs.* Since one (real world) test vehicle (in the CRC sample) had emissions on the running loss test of about almost 43 grams per mile, EPA assumed that the limit of the maximum emissions should be higher than that value. EPA will use 200 grams per hour as the maximum for the purpose of estimating fleet averages. For a group of leaking vehicles whose running loss emissions were between 7.0 and 200 grams per mile, the lognormal distribution predicts that the mean running loss emissions of that group of leakers would be 17.649 grams per mile. (As with the emissions on the hot soak and diurnal tests, that average emission level was not very sensitive to the assumption of the emissions of the highest possible leaker. Lowering the assumed level of the highest emitting carbureted vehicle to 90 grams/mile reduced the average

---

* This 7.0 grams per mile test result over a 19.6 mile per hour driving cycle is equivalent to 137.2 grams per hour (which includes resting loss emissions).

only to 17.181. Similarly, raising the assumed level of the highest emitting vehicle to 500 grams/ mile increased the average only to 17.696.) As previously stated, this analysis of running loss emissions of GLLs is based solely on carbureted vehicles. Using the logic (and Bernoulli's equation) from Section 2.2, it could be argued that the running loss emissions from PFI GLLs would be four times that amount. However, it does not seem reasonable to assume such a high emissions rate based on no data. Therefore, in the absence of evidence to the contrary, (for the purposes of running loss emissions of GLLs) EPA will treat fuel injected and carbureted vehicles the same.

Thus, EPA will use 17.65 grams per mile as the estimate of the emissions from a running loss test from ALL GLLs over a single LA-4 driving cycle. Since all of those GLLs were tested over only that single cycle, an approach needed to be found to estimate running loss emissions over different cycles (i.e., speed correction factors were needed). EPA assumed (for MOBILE6) that the magnitude of the leaks were essentially independent of speed. Thus, the 17.65 grams per mile (at 19.6 miles per hour) results in a running loss (test) rate of 345.94 grams per hour which includes resting loss emissions of 9.16 grams per hour (from Section 2.1, page 8).

Therefore, the running loss emissions (in MOBILE6) were obtained by subtracting the mean resting loss (hourly) emissions from the total mean running loss (hourly) test emissions to obtain the rate of 336.78 grams per hour.

2.4 Summary of Magnitudes of Evaporative Emissions

For the full-day diurnal emissions (based on the temperatures cycling over a 24 degree Fahrenheit range) of GLLs, EPA will use 104.36 grams per day. (See report number M6.EVP.002 to use other temperature cycles or to estimate hourly diurnal emissions.)

For the resting loss emissions of all GLLs, EPA will use 9.16 grams per hour.

To estimate the result of a hot soak test on GLLs:

- EPA will use 16.95 grams per test for carbureted vehicles,
- EPA will use 45.00 grams per test for TBI vehicles, and
- determine the occurrence (i.e., frequency) of these GLLs as a function of vehicle age.

To calculate the actual hot soak emissions per hour, the resting loss emissions must be subtracted from the hot soak test emissions.

To estimate the result of a running loss emissions on all GLLs, EPA will use 336.78 grams per hour. The resting loss emissions have already been subtracted to obtain this value.

These average (mean) emissions as well as the minimum (threshold) values are summarized in the Table 2-1 (on the following page).

Table 2-1

Summary of Emissions from Vehicles with Gross Liquid Leaks

	Emissions by Test Type	
Type of Emissions	**Minimum**	**Average**
Hot Soak (grams per test)		
• **Carbureted Vehicles**	10.0*	16.95*
• **TBI Vehicles**	10.0*	45.00*
• **PFI Vehicles**	10.0*	57.14*
Resting Loss (grams per hour)	2.0	9.16
Diurnal (grams per day)	25.0	104.36
Running Loss (grams per hour)	137.2**	336.78

* **The Hot Soak test emissions (both Minimum and Average) include resting loss emissions which must be subtracted.**

** **The Minimum Running Loss test emissions include resting loss emissions which must be subtracted.**

3.0 FREQUENCY OF OCCURRENCE OF "GROSS LIQUID LEAKERS"

In Section 2, the magnitude of each type of evaporative emissions from liquid leakers was estimated independently using lognormal distributions. Also, EPA believes the data can be linked when estimating the frequency of the GLLs. However, due to the lack of data on the occurrence of GLLS on the hot soak test for vehicles over the age of 10, EPA made the following two basic assumptions in predicting the frequency of GLLs:

1.) For each test of evaporative emissions (i.e., RTD, hot soak, and running loss tests), the frequency of GLLs increases as a function of only age. This model of the frequency is based on the assumption that modern technology vehicles will show the same tendency toward developing these severe liquid leaks as do the older technology vehicles at the same age.* EPA modified this assumption (in reference number [10]) for the 1996 and newer vehicles certified to the new enhanced evaporative standard.

2.) The vehicles classified as GLLs on the hot soak test are the same vehicles identified as GLLs on either the running loss or RTD tests. (That is, the set of vehicles classified as GLLs on the hot soak test is the union of the set of vehicles classified as GLLs on the RTD test with the set of vehicles classified as GLLs on the running loss test.) Therefore, the rate of GLLs as identified on the hot soak test would be the sum of the two rates for the RTD testing and the running loss of the two rates for the RTD testing and the running loss testing minus the number of double counted vehicles (i.e., the product of those two rates assuming these two categories are independent of each other).

Implicit in this assumption is EPA's belief that these three tests of evaporative emissions do not identify the same vehicles as being GLLs. For example, if there were a leak in the fuel line of a vehicle, that leak may be severe when the fuel system is under pressure (i.e., when the engine is on). Thus, a running loss or a hot soak test would identify the vehicle as a GLL, but the RTD test might not (since the engine would be off).

EPA considered the following two different approaches to predicting the occurrence of GLLs. (See footnote on page 22.)

3.1 First Approach to Estimate Frequency

The first approach involved two basic steps:

1.) Find two logistic growth functions that separately predict the rate of GLLs on the RTD test and on the running loss test, respectively.

2.) Verify that the union of those two functions approximate the results observed on the hot soak test.

3.1.1 First Approach Estimating Frequency of GLLs on the RTD Test

In the report dealing with evaporative emissions measured during the RTD tests (M6.EVP.001), EPA used the results from a

* An alternative approach that EPA is not proposing (due to lack of data) assumes that 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, such as, fuel tank protection and elimination of fuel line leaks). This approach would result in replacing each single logistic growth function with a family of two or more curves.

test fleet of 270 vehicles (i.e., the combined EPA and CRC samples) to estimate the occurrence of GLLs within each of the three model year ranges used in the recruitment process (the pre-1980, 1980-85, and 1986-95 vehicles). The estimated rate of occurrence of the GLLs is reproduced in the following table (Table 3-1). The large confidence intervals are the result of the relatively small sample sizes.

Table 3-1

Frequency of Gross Liquid Leakers Based on RTD Testing

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

* "**Vehicle Age**" was calculated by subtracting the model year from the test year and then adding one-half to simulate the rate as of January first.

In one of the parallel reports (M6.EVP.001), EPA derived a logistic growth curve that exactly fit those three data points (from Table 3-1). The equation of that function is given below:

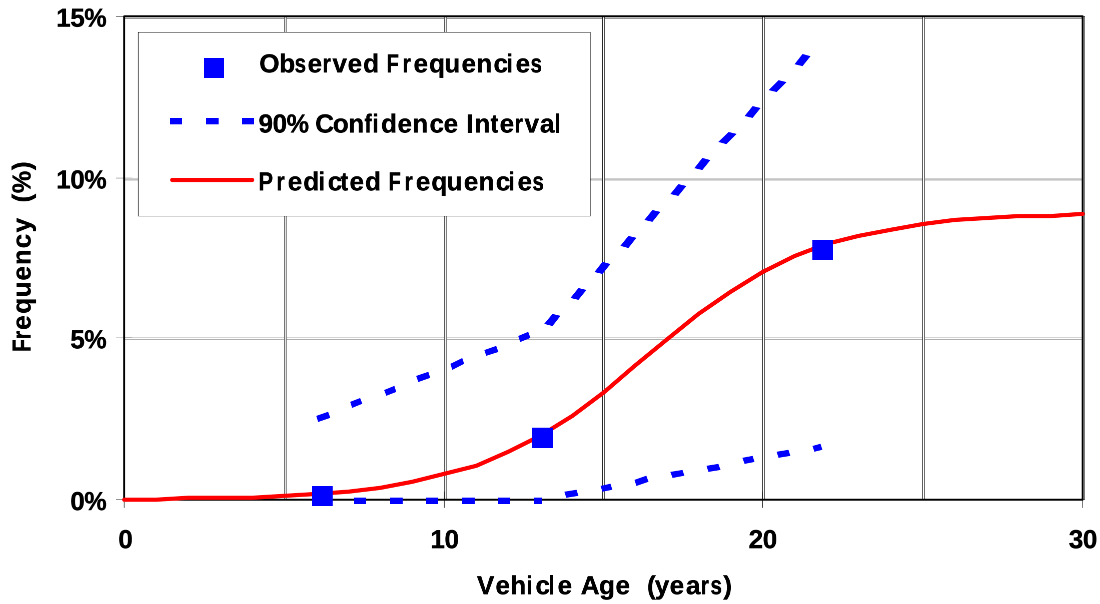
$$\text{Rate of Gross Liquid Leakers Based on RTD/Resting Loss Testing} = \frac{0.08902}{1 + 414.613 \cdot \exp[-0.3684 \cdot \text{AGE}]}$$

The predicted occurrences of GLLs based on this equation are given in Appendix D. The frequencies from Table 3-1 are plotted in the following figure (Figure 3-1). Also graphed in that figure are the 90 percent confidence intervals (as dotted lines) from Table 3-1 and the predicted frequencies (as the solid line) from Appendix D (or from the preceding equation).

After EPA had created the preceding equation, additional test data were provided by CRC (project number E-41). Specifically, a test program run during 1998 found no GLLs on the RTD test in a sample of 50 late-model year vehicles (1992 through 1997, with a mean age of 4.5 years). (See reference **[6]**.) Those results are consistent with that preceding equation.

Figure 3-1

Predicted Frequency of Gross Liquid Leakers
With Observed Frequencies and 90 Percent Confidence Intervals
Based on RTD Testing



3.1.2 First Approach Estimating Frequency of GLLs on the Running Loss Test

For the 150 vehicles in the CRC running loss testing program, the occurrence of GLLs (i.e., the six vehicles in Appendix B whose running loss emissions exceeded 7.0 grams/mile), the occurrence of GLLs was calculated within each of the three model year ranges used in the recruitment process (the same model year ranges used in the RTD testing). Those estimated rates of occurrence of the GLLs appear in the following table (Table 3-2). The large confidence intervals are again the result of the relatively small sample sizes.

Table 3-2

Frequency of Gross Liquid Leakers
Based on Running Loss Testing

Vehicle Age (years)	Sample Size	Frequency	Standard Deviation	90% Confidence Interval Lower	90% Confidence Interval Upper
8.84	50	2.00%	1.98%	0.00%	5.26%
14.24	39	5.13%	3.53%	0.00%	10.94%
22.48	61	4.92%	2.77%	0.36%	9.47%

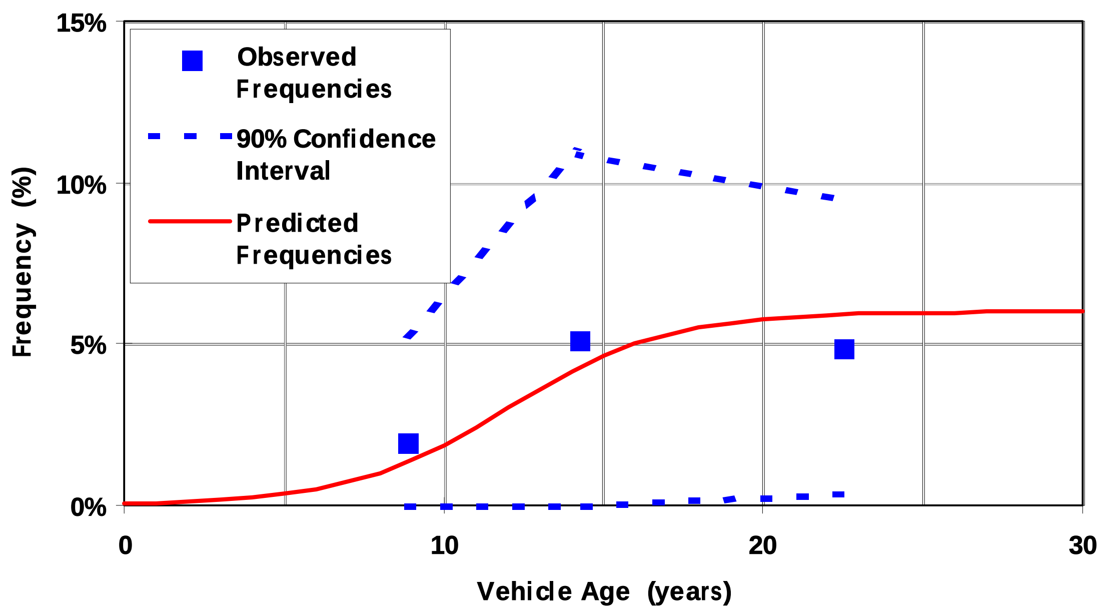
It was not possible to exactly fit the frequencies in Table 3-2 with an increasing function (since the observed frequencies seem to drop after age 14.24 years). EPA derived a logistic growth curve that best fit those three data points. The equation of that function is:

$$\text{Rate of Gross Liquid Leakers Based on Running Loss Testing} = \frac{0.06}{1 + 120 * \exp[-0.4 * AGE]}$$

The predicted occurrences of GLLs based on that equation are also given in Appendix D. The frequencies from Table 3-2 are plotted below in Figure 3-2. Also graphed in that figure are the 90 percent confidence intervals (as dotted lines) from Table 3-2 and the predicted frequencies (as the solid line) from Appendix D (or from the preceding equation).

Figure 3-2

Predicted Frequency of Gross Liquid Leakers
With Observed Frequencies and 90 Percent Confidence Intervals
Based on Running Loss Testing



Again, the newly acquired data (noted at the end of Section 3.1.1) in which no GLLs were found during running loss testing in a sample of 50 late-model year vehicles (mean age of 4.5 years) are consistent with that preceding equation.

3.1.3 First Approach Estimating Frequency of GLLs on the Hot Soak Test

To estimate the rate of occurrence of GLLs on the hot soak test, we first referred to the second assumption on page 18, which states that the collection of vehicles that are GLLs on the hot soak test is the union of the collection of vehicles identified as GLLs on the running loss test with the collection of vehicles identified as GLLs on the RTD test. Thus, we were able to estimate the rate of GLLs on the hot soak test based solely on the rates of GLLs on the running loss and RTD tests. In the last column of Appendix D, the rate of GLLs on the hot soak was calculated by adding the two preceding columns and then subtracting the product of those two columns. (As stated at the beginning of Section 3.0, due to the lack of data at ages over 10 years, we were not able to use the same approach to predict GLLs on the hot soak as we did on the other two tests.)

To test the reasonableness of the results of the above assumption, we identified the six vehicles (in the hot soak testing program of 300 vehicles conducted for Auto Oil) that had hot soak test emissions in excess of 10 grams per test. In this testing program, the test fleet was again stratified into three model year ranges, but they were different groupings (1983-85, 1986-90, and 1991-93). This resulted in a sample of newer vehicles than were used in the RTD or running loss testing programs.* Those estimated rates of occurrence of the GLLs within each of the three new model year ranges appear below in Table 3-3. The large confidence intervals are again the result of the relatively small sample sizes. We then compared those observed rates (in Table 3-3) with the predicted rates in Appendix D.

Table 3-3

Frequency of Gross Liquid Leakers Based on Hot Soak Testing

Vehicle Age (years)	Sample Size	Frequency	Standard Deviation	90% Confidence Interval Lower	90% Confidence Interval Upper
1.98	66	1.04%	1.25%	0.00%	3.10%
5.55	166	1.20%	0.85%	0.00%	2.60%
9.38	64	6.25%	3.03%	1.27%	11.23%

The observed frequencies from Table 3-3 are plotted in Figure 3-3 (below). Also graphed in that figure are the 90 percent

---

* Since none of the mean ages in Table 3-3 exceeded 10 years, EPA chose approaches different from those used with the diurnal or running loss emissions. Rather than predicting the occurrence on the hot soak test of GLLs among older vehicles based only on data from newer vehicles, EPA estimated those rates based on the rates of GLLs on both the RTD an running loss tests.

confidence intervals (as dotted lines) from Table 3-3 and the predicted frequencies (as the solid line) from Appendix D. Those predicted occurrences from Appendix D are based not on hot soak test results, but on results of running loss tests and RTD tests.

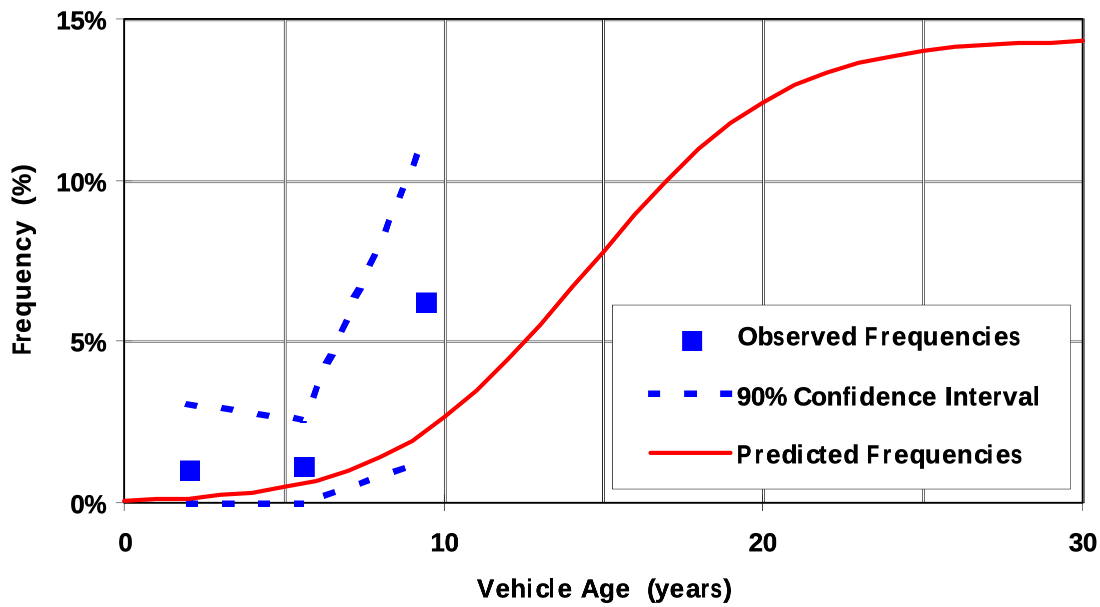
Comparing, in Figure 3-3, the predicted rates of GLLs occurring with the observed rates of GLLs on the hot soak test, we observe:

- the predicted rates are all lower than the observed rates which were based on relatively small samples, but
- the predicted rates are all within the 90 percent confidence intervals of the observed rates (at each of the three points).

These differences between the predicted and observed rates may simply be the result of the small sample sizes.

Figure 3-3

**Predicted Frequency of Gross Liquid Leakers
With Observed Frequencies and 90 Percent Confidence Intervals
On the Hot Soak Test
(Based on RTD and Running Loss Testing)**



Again, the newly acquired data (noted at the end of Sections 3.1.1 and 3.1.2) in which no GLLs were found during hot soak testing in a sample of 50 late-model year vehicles (mean age of 4.5 years) are consistent with the preceding hot soak predictions.

3.2 Second Approach to Estimate Frequency

The second approach employed by EPA was to use all of the observations (in Tables 3-1 through 3-3) to find logistic functions that optimize (simultaneously) all of the predictions. This approach produced the following two equations:

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

$$\text{Rate of Gross Liquid Leakers Based on Running Loss Testing} = \frac{0.058}{1 + 70 * \exp[-0.48 * AGE]}$$

These two equations (and their union which estimates GLLs on hot soak tests) predict rates of occurrence that are all within one-half of the corresponding standard deviations at each of the nine observations (in Tables 3-1 through 3-3). We can again graph those data (i.e., observed rates and confidence intervals) from Tables 3-1 through 3-3, but now in figures with curves from these new predictions (Figures 3-4 through 3-6). The only differences between the three figures in Section 3.1 and these new corresponding figures are the solid lines designating the predicted frequencies.

Figure 3-4

Predicted Frequency of Gross Liquid Leakers Using Second Approach With Observed Frequencies and 90 Percent Confidence Intervals Based on RTD Testing

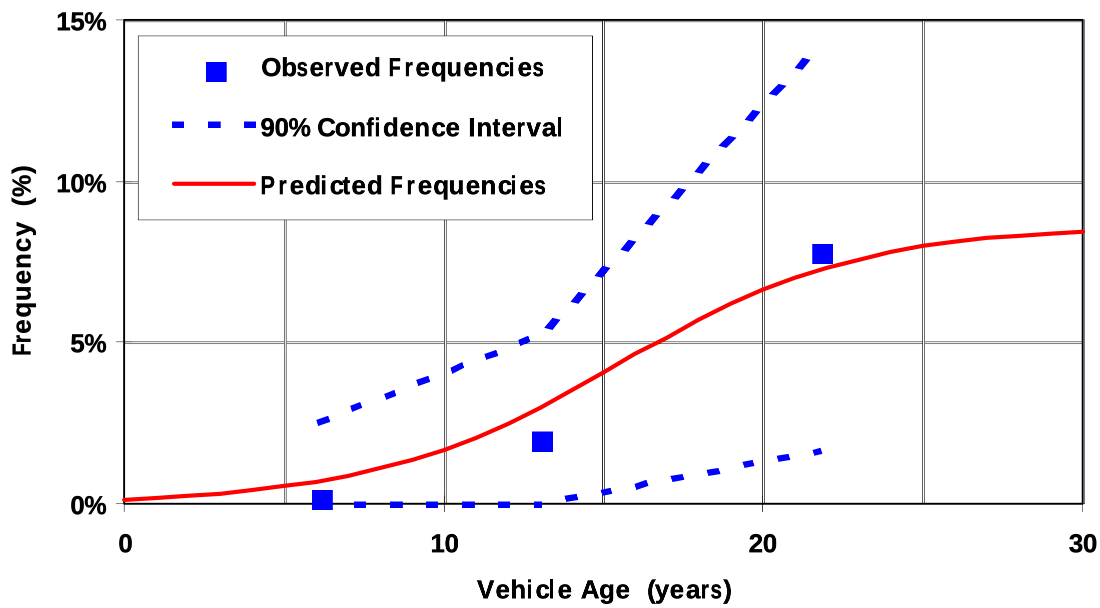


Figure 3-5

Predicted Frequency of Gross Liquid Leakers Using Second Approach With Observed Frequencies and 90 Percent Confidence Intervals Based on Running Loss Testing

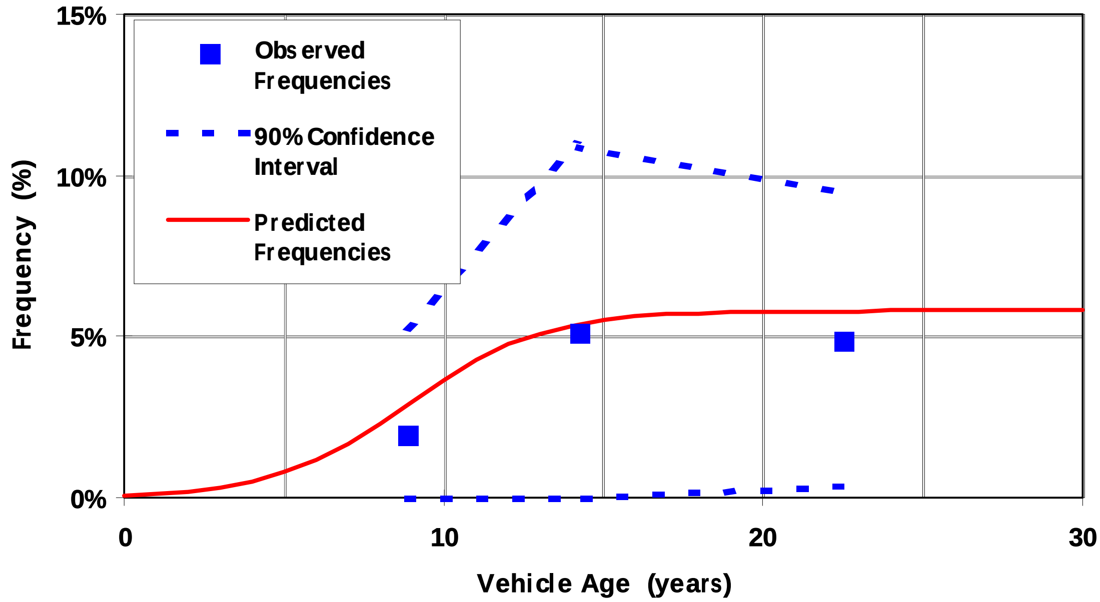
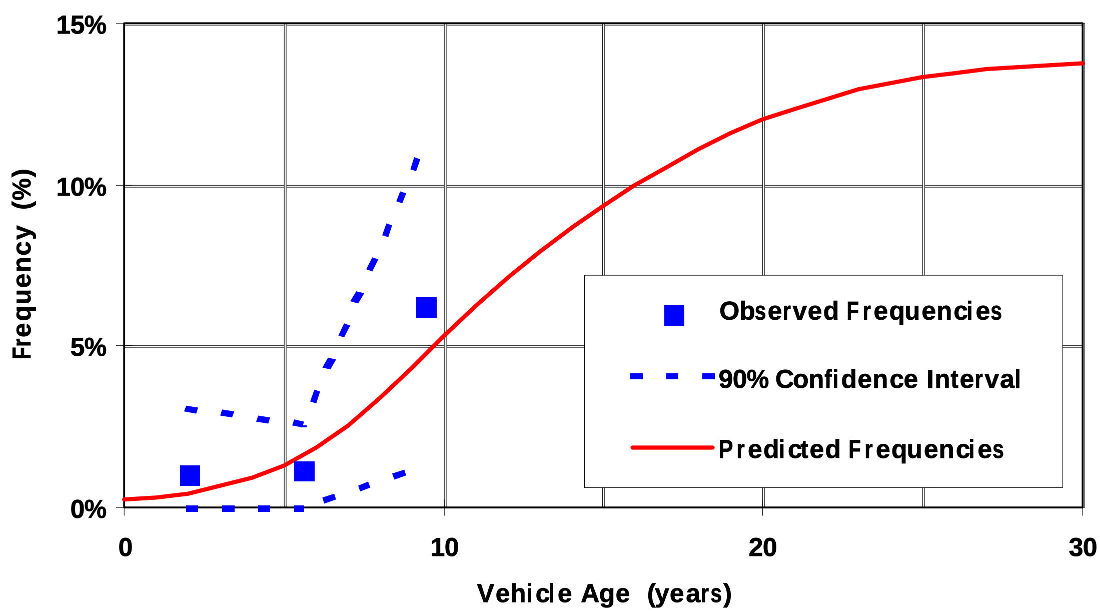


Figure 3-6

Predicted Frequency of Gross Liquid Leakers Using Second Approach On the Hot Soak Test with Observed Frequencies and 90 Percent Confidence Intervals (Based on RTD and Running Loss Testing)



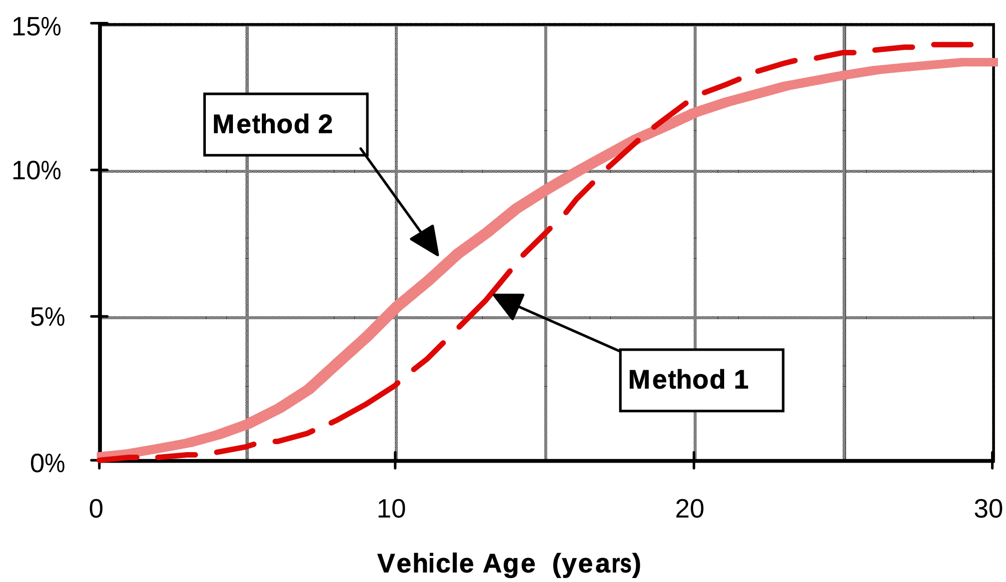
A visual inspection of these three figures (3-4 through 3-6) indicates that this approach produces predicted rates (of the occurrence of GLLs) that are all well within the 90 percent confidence intervals of the observed rates (at each of the nine points). In fact (as noted earlier in this section), all nine predicted rates are within one-half of the corresponding standard deviations at each of the observations.

3.3 Selection of Approach to Estimate Frequency

In choosing between these two methods (which in EPA's opinion are the two best candidates) of predicting the frequency of GLLs, we first observed that the greatest difference between these two methods was in estimating the rate of GLLs on the hot soak test. In Figure 3-7 (on the following page), we reproduced the estimated frequency curves from Figures 3-3 and 3-6. In this figure, the "dashed" line is the estimate produced using the first method (i.e., from Figure 3-3 in Section 3.1.3), and the solid line is the estimate produced using the second method (i.e., from Figure 3-6 in Section 3.2).

Figure 3-7

Comparing Predicted Frequency of Gross Liquid Leakers On the Hot Soak Test



A visual inspection of this figure indicates that:

- The two predicted rates are similar for vehicles at least 17 years of age or older.
- For vehicles newer than 17 years of age, the second method predicts a substantially higher occurrence of GLLs. (For vehicles up through the age of 10, the second method predicts more than twice as many GLLs as does the first method.)

To decide between these two models, EPA made use of a recent testing program run jointly by the CRC and the American Petroleum Institute (API). **[5]** This program was specifically designed to determine the frequency of vehicles with liquid leaks. Since actual measurements of evaporative emissions were not performed in this program, we cannot determine which of those vehicles identified as having liquid leaks would have met our criteria for GLLs.

In that API/CRC program, 1,000 vehicles were inspected for any signs of leaks with the engine operating (during at least a portion of the visual inspection). (This protocol was expected to permit identification of vehicles exhibiting fuel leaks on the RTD, hot soak, or running loss tests.) The vehicles were then classified by the mechanic according to the severity of the observed leaks. The visible liquid leaks were classified as either:

- small liquid leaks (e.g., single drops) or
- larger leaks (e.g., steady flow of drops).

This classification was based on a visual inspection rather than on the results of a test of the actual evaporative emissions. The results of that study are summarized in the following table:

Table 3-4

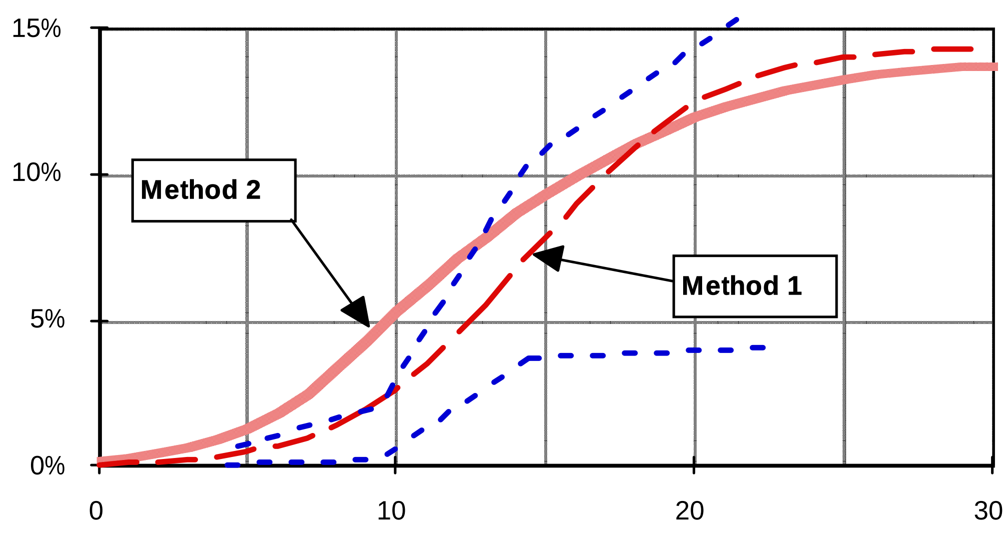
Frequency of Leaking Vehicles
In API/CRC Testing Program

Model Year Range	Mean Age (years)	Sample Sizes	Vehicles with Small Leaks	Vehicles with Larger Leaks	Total with Any Leaks	90% Conf Interval Lower	90% Conf Interval Upper
Pre-80s	22.329	70	5	2	7	4.10%	15.90%
80-85	14.394	155	10	1	11	3.70%	10.49%
86-91	9.429	352	2	2	4	0.21%	2.07%
92-98	3.979	423	0	0	0	0.00%	0.49%

The 90 percent confidence intervals in Table 3-4 are based on the (total) number of vehicles with either small or large visible leaks. Those vehicles which were identified as having large visible liquid fuel leaks were almost certainly GLLs, and many of the vehicles which were identified as having small visible liquid fuel leaks were possibly GLLs as well. Thus, EPA considers the upper bound of the confidence intervals as a conservative estimate of the occurrence of the GLLs. If we reproduce Figure 3-7, and include the 90 percent confidence intervals from Table 3-4 (as dotted lines), we produce Figure 3-8.

Figure 3-8

Comparing Predicted Frequency of Gross Liquid Leakers On the Hot Soak Test (New Confidence Intervals from Table 3-4)



A visual inspection of Figure 3-8 strongly suggests the second method for predicting the frequency of GLLs over predicts the actual occurrence of GLLs for vehicles under the age of 13 years. (The conclusion that the second method "**OVER PREDICTS**" the frequency is based on EPA's choice of basing the confidence intervals on Table 3-4 instead of Table 3-3. That choice reflects primarily the relatively large sample sizes in Table 3-4 compared with those in Table 3-3.)

Therefore, EPA will use the first method (Section 3.1) to estimate the frequencies of the occurrence of GLLs on the three types of tests for evaporative emissions. The results of that method are given in Appendix D.

3.4 Overall Occurrence of GLLs in the In-Use Fleet

The equations in Section 3.1 (or the results in Appendix D) predict the occurrence of GLLs identified on the RTD test to range between 0.02 to 8.55 percent by vehicle age, and for those identified on the running loss test to range between 0.05 and 5.97 percent by vehicle age. It is reasonable to ask what is the overall percentage of these vehicles in the entire in-use fleet. To answer that question, we referred to another report which provides an estimate of the national distribution by age of light-duty vehicles (LDVs) and light-duty trucks (LDTs). (See reference [11].) Applying the percentages from Appendix D to those estimated vehicle counts produces Table 3-5 (on the following page). The predicted total counts in Table 3-5 suggest that GLLs represent approximately 1.2 to 1.6 percent of the entire in-use fleet.

Table 3-5

Predicted Occurrence of Gross Liquid Leakers In the National In-Use Fleet of LDVs and LDTs

(as of January 1995)

Calendar Year Minus Model Year	Vehicle Counts	GLLs Identified on: RTD	GLLs Identified on: Running Loss
0	9,581,160	2,052.19	4,750.99
1	12,690,223	3,924.61	9,349.56
2	12,595,718	5,621.77	13,760.93
3	12,479,871	8,033.14	20,159.55
4	12,328,489	11,433.59	29,321.45
5	12,124,815	16,178.24	42,197.16
6	11,850,006	22,702.78	59,817.53
7	11,484,110	31,499.85	83,045.60
8	11,007,677	43,050.78	112,104.66
9	10,404,139	57,685.81	145,891.73
10	9,663,040	75,350.55	181,302.31
11	8,783,860	95,286.08	213,090.08
12	7,508,980	111,677.02	226,678.25
13	6,076,245	121,573.75	219,360.63
14	4,896,767	128,727.45	203,502.92
15	3,929,300	131,947.97	181,708.71
16	3,140,650	130,511.75	157,112.78
17	2,503,094	124,468.78	132,479.39
18	2,030,454	116,862.35	111,810.15
19	1,710,242	110,464.75	96,801.22
20	1,451,096	102,385.03	83,696.51
21	1,240,664	93,514.33	72,483.90
22	1,069,132	84,580.52	63,008.21
23	928,705	76,080.74	55,054.76
24 and older	3,724,043	312,764.31	221,641.23
TOTALS:	175,202,480	2,018,378	2,740,130

4.0 REFERENCES

1) Larry Landman, "Evaluating Resting Loss and Diurnal Evaporative Emissions Using RTD Tests," Report numbered M6.EVP.001, April 2001.

2) Larry Landman, "Modeling Hourly Diurnal Emissions and Interrupted Diurnal Emissions Based on Real-Time Diurnal Data," Report numbered M6.EVP.002, April 2001.

3) Louis Browning, "Update of Hot Soak Emissions Analysis" prepared by Louis Browning of ARCADIS Geraghty & Miller, Inc. for EPA, Report numbered M6.EVP.004, September 1998

4) Larry Landman, "Estimating Running Loss Evaporative Emissions in MOBILE6," Report numbered M6.EVP.008, April 2001.

5) D. McClement, "Raw Fuel Survey in I/M Lanes", Prepared for the American Petroleum Institute and the Coordinating Research Council, Inc. by Automotive Testing Laboratories, Inc., June 10, 1998.

6) D. McClement, "Real World Evaporative Testing of Late Model In-Use Vehicles, CRC Project E-41", Prepared for the Coordinating Research Council, Inc. by Automotive Testing Laboratories, Inc., December 17, 1998.

7) Melvin Ingalls, "Mobile Source Exposure Estimation," prepared by Southwest Research Institute for EPA, EPA Report Number EPA460/3-84-008, March 1984, Appendix A.

8) Edward L. Glover, "Hot Soak Emissions as a Function of Soak Time," Report numbered M6.EVP.007.

9) D. McClement, "Measurement of Running Loss Emissions from In-Use Vehicles (CRC Project E-35)", CRC Report No. 611, Prepared for the Coordinating Research Council, Inc. by Automotive Testing Laboratories, Inc., February 1998.

10) Larry Landman, "Modeling Diurnal and Resting Loss Emissions from Vehicles Certified to the Enhanced Evaporative Standards," Report numbered M6.EVP.005, April 2001.

11) Tracie R. Jackson, "Fleet Characterization Data for MOBILE6: Development and Use of Age Distributions, Average Annual Mileage Accumulation Rates, and Projected Vehicle Counts for Use in MOBILE6," Report numbered M6.FLT.007.

Appendix A

RTD Emissions of 11 Vehicles with Liquid Leaks With RTD > 30 and Resting Loss > 0.25

(Arranged in Increasing Order of Estimated Resting Losses)

(ALL of the Leaking Vehicles Were Carbureted)

Vehicle Number	Real-Time Diurnal (RTD) Test (grams / day)	Estimated Rst Loss (at 72°F) (grams / hr)	Estimated Diurnal (grams / day)
9095	32.26	0.28	24.85
9037	33.44	0.47	21.47
9046	33.76	0.62	18.21
9042	30.88	0.89	8.83
9098	45.21	0.90	22.91
9148	47.97	1.27	16.63
9049	181.35	4.87	64.55
9054	316.59	10.58	62.64
9129	181.79	10.77	IGNORE*
9087	478.16	14.12	139.22
9111	777.14	16.51	380.79

* An examination of the hourly RTD data from this vehicle (in reference **[1]**) suggests that the leak actually developed around the tenth hour of the 24-hour test. While the resting loss estimate (based on hours 19 through 24) is most likely valid, the estimate of diurnal emissions is unreliable (in fact, it is negative).

Note that while <u>all</u> 11 of these vehicles have liquid leaks most of them do **<u>NOT</u>** qualify as **<u>Gross</u>** Liquid Leakers (only the five highest emitting vehicles meet the necessary criteria).

Appendix B

Hot Soak Emissions of 14 Vehicles with Liquid Leaks (With Hot Soak Emissions At Least 2.0 grams / test)

Sorted by Fuel Delivery System In Increasing Order of Emissions

Program	Vehicle Number	Fuel System	Temp (°F)	RVP (psi)	Hot Soak (grams HC)
Auto Oil	134	CARB	94	6.0	2.54
EPA	177	CARB	95	6.1	4.63
EPA	122	CARB	105	6.1	5.53
Auto Oil	79	CARB	92	7.0	9.49
EPA	173	CARB	92	6.7	14.53
EPA	97	CARB	110	6.7	14.66

Program	Vehicle Number	Fuel System	Temp (°F)	RVP (psi)	Hot Soak (grams HC)
EPA	143	TBI	94	6.4	8.28

Program	Vehicle Number	Fuel System	Temp (°F)	RVP (psi)	Hot Soak (grams HC)
Auto Oil	35	PFI	104	6.7	2.00
Auto Oil	199	PFI	96	6.5	2.26
Auto Oil	47	PFI	93	6.1	11.56
EPA	33	PFI	113	6.0	46.95
Auto Oil	276	PFI	87	6.3	49.39
EPA*	372	PFI	106	9.0	54.18
EPA*	266	PFI	105	9.0	88.57

* These two vehicles were tested using a substantially more volatile fuel.

Appendix C

Running Loss Emissions of 10 Vehicles with Liquid Leaks (With Running Loss Emissions At Least 5.0 grams / mile)

(Arranged in Increasing Order of Estimated Resting Losses)

(ALL of the Leaking Vehicles Were Carbureted)

Vehicle Number	Running Loss HC (grams / mile)	Running Loss HC (grams / LA-4)	Running Loss HC (grams / hour)
35044	5.009	37.47	98.32
35125	5.297	39.44	103.49
35099	5.649	42.17	110.65
35085	6.880	51.18	134.29
35045	7.469	55.79	146.39
35071	9.175	68.84	180.63
35047	13.480	100.19	262.89
35129	13.566	100.72	264.28
35054	24.841	184.96	485.32
35091	42.973	318.90	836.76

Appendix D

Predicted Frequency of Occurrence of GLLs

Vehicle Age (years)	Resting Loss / Diurnal	Running Loss	Hot Soak
0	0.02%	0.05%	0.07%
1	0.03%	0.07%	0.10%
2	0.04%	0.11%	0.15%
3	0.06%	0.16%	0.23%
4	0.09%	0.24%	0.33%
5	0.13%	0.35%	0.48%
6	0.19%	0.50%	0.70%
7	0.27%	0.72%	1.00%
8	0.39%	1.02%	1.41%
9	0.55%	1.40%	1.95%
10	0.78%	1.88%	2.64%
11	1.08%	2.43%	3.48%
12	1.49%	3.02%	4.46%
13	2.00%	3.61%	5.54%
14	2.63%	4.16%	6.67%
15	3.36%	4.62%	7.83%
16	4.15%	5.00%	8.95%
17	4.97%	5.29%	10.00%
18	5.75%	5.51%	10.94%
19	6.46%	5.66%	11.75%
20	7.05%	5.77%	12.42%
21	7.54%	5.84%	12.94%
22	7.91%	5.89%	13.34%
23	8.19%	5.93%	13.63%
24	8.40%	5.95%	13.85%
25	8.55%	5.97%	14.00%

Appendix E

Response to Peer Review Comments from Sandeep Kishan

This report was formally peer reviewed by one peer reviewer (Sandeep Kishan). In this appendix, comments from Sandeep Kishan are reproduced in plain text, and EPA's responses to those comments are interspersed in indented italics. Each of these comments refer to page numbers in the earlier draft version (dated June 30, 1999) that do not necessarily match the page numbers in this final version.

****

This memorandum provides peer review comments on two EPA documents: "Estimating Running Loss Evaporative Emissions in MOBILE6," Document No. M6.EVP.008, June 28, 1999, and "Evaporative Emissions of Gross Liquid Leakers in MOBILE6," Report Number M6.EVP.009, June 30, 1999. Both of these are draft reports.

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

<u>Document No. M6.EVP.009 (June 30, 1999)</u>

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

We found that the first half of the report, which estimates the average emissions rate of gross liquid leakers, was well written and, in addition, we thought that the technique of fitting the sparse data to log-normal distributions was excellent. However, in the second half of the report which estimates the frequency of gross liquid leakers of different types in the vehicle population, we had difficulty understanding the distinction between the first approach and the second approach. We did understand the development of the logistic growth curves for each emission type. However, we think that there is no reason to average this data, which causes loss of important information, before building the logistic models. More defensible relationships could easily be built using the individual car data rather than averages of data.

1. In general, the report presents the final story of the analysis and shows how the data fits that story. In many cases, we are more accustomed to a method of analysis reporting that demonstrates how the data reveals what the most likely story is. Consequently, we have looked to see if the data have been presented in a way so that the story holds together.

2. Page 2, Second paragraph from bottom – We agree with the EPA proposed treatment of considering evaporative emissions for gross liquid leakers as independent of ambient temperature and RVP.

   EPA, of course, agrees with its own methodology.

3. Page 3, Paragraph 3 – The report seems to begin the discussion of substantial leakers and gross leakers in a manner that is confusing to the reader. We suggest, and perhaps this is the intended meaning of the author, that substantial leakers are those leakers which have a lower limit of liquid leak rates than do gross liquid leakers. For each type of emission a set of substantial liquid leakers are analyzed. Then, at some point in the development, only the gross liquid leakers are analyzed. For example, later in the report for the hot soaks tests, the substantial liquid leakers have rates of greater than 2 grams per hour and the gross liquid leakers have rates of greater than 10 grams per hour. Consequently, we suggest that beginning in Section 2.1, a distinction between substantial and gross liquid leakers be made. The parenthetical comments in Section 2.1 seem to say that substantial liquid leakers and gross liquid leakers are synonymous. We think that these parenthetical comments only serve to cloud the distinction between substantial and gross liquid leakers and, therefore, they should be removed. These comments appear in the third, fourth and fifth paragraphs on Page 3.

   No, there was no attempt to define a "substantial" leaker category. The word "substantial" only refers to the magnitude of the leak. Our intent was to define a "Gross Liquid Leaker" (GLL) as a vehicle having a substantial leak of liquid gasoline. The exact magnitude of a "substantial leak" (in terms of drops of gasoline per hour) was left vague. However, the reader could use the lower bounds specified for GLLs (see Table 2-1) to calculate such hourly rates. The text has been revised to avoid this confusion.

4. Page 3, Paragraph 5 – We agree with the approach of using a log-normal fit of the sparse data to estimate the gross liquid leaker average emission rates to avoid simply

calculating the mean of the sparse values which are available.

5. Page 4, Second Paragraph – It took me a while to recognize that the estimated diurnal emissions, which are referred to in the second paragraph, is equal to the RTD emissions minus 24 times the resting loss emissions. We think it would be helpful to the reader to insert a short paragraph before this paragraph to remind the reader of this relationship.

   We added that explanation to the beginning of Section 2.1.

6. Page 5, Paragraph 1 – We agree with the technique of trimming the upper tail off the log-normal distribution for the purposes of calculating the mean gross liquid leaker emission rate; it reflects an engineering reality. We also like the technique of determining the sensitivity of the mean to doubling the value of the upper cutpoint. However, we were curious about how much the mean would change if no upper cutpoint were used, and we suspect that other readers would have the same curiosity. Our gut feel is that, if the upper cutpoints were at +infinity, the average emission rate would be only slightly increased.

   The RTD test of the vehicle with the highest diurnal (380.79 grams per day) was aborted after 16 hours because the technicians were concerned that the SHED was approaching an explosive concentration level. In this report we calculated an average diurnal using a maximum of 5 times that potentially explosive rate. Even that maximum seems too high. By using still higher values, we risk reducing the credibility of the analysis. The reader is of course free to perform that calculation.

7. Page 5, Paragraph 2 – Choosing the value of the lower cutpoint of the lognormal distribution is more problematic then choosing the upper cutpoint. We felt that the discontinuity argument of values between 25 and 62 grams per day in the second paragraph was pretty weak since there are larger discontinuities at larger emission values. We think we agree that a lower limit is needed (on the other hand, it may be possible that calculating the average value using the lower tail of the log-normal distribution may not change the average value much) to avoid double counting of emissions from gross liquid leakers and the diurnal emissions of non-gross liquid leakers which will be estimated from a different routine in a MOBILE code. We think that a more defensible approach to selecting the lower cutpoint would be to consider the range of normal (not leakers) diurnal emission values for the fleet using the existing routines in MOBILE. In other words, could an analysis of the diurnal emissions emitter model in MOBILE be done to verify that the

lower cutpoint chosen for the diurnal emission gross liquid leaker distribution does not produce a gap or a bump in the distribution between the normal and the gross liquid leaker models?

We agree that the selection of the lower bound (threshold) for the gross liquid leakers is a weak point. It is highly sample dependent. If a higher threshold value were selected, the effect would be to increase the estimated average diurnal emissions (from these GLLs). For example, doubling the threshold from 25 to 50 grams per day would increase the estimated average by almost 35 percent. While this seems to be a large change, the actual effect on total evaporative hydrocarbon is in consequential. As more data become available, we may revise these threshold values.

8. Page 5, Paragraph 2 – It would be beneficial to the reader to have an appendix to show how the average emissions for the log-normal distribution with the cutpoints on the upper and lower end are calculated. Most readers won't want to or won't be able to go through this tricky calculation.

   These averages were calculated by computing the area under curves using Riemann sums (from first semester Calculus). We see no need to include these calculations in this report.

9. Page 6, Second full paragraph – Comments 4, 6, 7, and 8 above apply generally to all of the different types of gross liquid leaker calculations in Section 2. From this point forward, the comments will apply only to specific issues on individual gross liquid leaker types.

10. Page 7, Paragraph 1 – The last sentence talks about a uniform distribution. We think that this is a relatively minor comment but it did take me a while to understand what the author was referring to. In the last paragraph on the page, the report mentions that the uniform distribution would have a better fit but the only reason that the report gives to not chose the uniform distribution was for consistency with other models in the report. However, there is another reason that could be considered, and perhaps mentioned, is that the uniform distribution would imply that 40% of the vehicles would have zero resting loss emissions. We think that you will agree this is probably not the case. The third paragraph on Page 7 also has a typo in the third line: the word approached should be approaches.

    Good point, the material has been revised to include this.

11. Page 11, Second full paragraph – The reference to the other report suggests that the relative fuel pressures between TBI and PFI systems are a factor of 4 different. This is not

explicitly stated in this report. Perhaps it should be if the author believes it still to be correct.

We believe that the critical assumptions were stated. Going off into a detailed discussion of relative pressures might only cloud the issue.

12. Page 15, Table 2-1 – The footnote at the bottom of Table 2-1 brings up an issue. For the RTD data analysis, the resting losses were removed from RTD to get diurnal emissions. But the same approach was not used to separate resting losses from hot soak emissions and running loss emissions. Why is there a difference in analysis methods? Perhaps, it would have been just as easy to determine the average RTD emissions per day and then Table 2-1 would have had an entry for RTD in place of diurnal.

    Since we estimated resting loss emissions by averaging the emissions during last six hours of the RTD test (i.e., the hours corresponding to the period from midnight to 6 AM), the resting loss values were available for each RTD test. This permitted us to easily calculate for each RTD test a resting loss / diurnal pair. This was not true of the hot soak or running loss tests. Therefore, different approaches were used.

    The footnote at the bottom of Table 2-1 also is a surprise to the reader. At a minimum, we suggest that the reader be warned that this subtraction will occur by placing an appropriate statement at the beginning of the analysis sections for hot soak and running loss average emission rate determinations.

    As the reviewer suggested, an explanation has been added to both the hot soak section and to the running loss section.

13. Page 15, Table 2-1 – One of the problems that we had in following the discussion in the previous sections about the determination of average gross liquid leaker emission rates was the values used to determine substantial leakers, gross leakers, lower cutpoints, and upper cutpoints of the log-normal distributions. A table placed somewhere in the report such as the following would help guide the reader through these different values.

	Liquid Leakers		Averaging Range	**GLL Average**
	Substantial	**Gross**		
Hot Soak Test (g/hr)*	>2	>10		
Carbureted			10-300	16.95
TBI			10-300	45.00
PFI			10-300	57.14

Resting Loss (g/hr)	>0.25	>2	2-50	9.16
Diurnal (g/day)	RTD>30	>25	25-1000	104.36
Running Loss (g/mile)*	>5	>7	7-200	17.65

We agree that such a revised table would be useful. We replaced Table 2-1 with a revised table, similar to this one. (We noted, in response to the third comment, that there is no category of "substantial leakers." Therefore, the revised table is different from this one.)

14. Page 15, Second paragraph – The first assumption states that for each test of evaporative emissions (RTD, hot soak, and running loss tests)… Immediately we thought, where are the resting losses? Aren't the frequencies of occurrence for gross liquid leaker resting losses going to be estimated? This seems to be a glaring omission.

    The second paragraph of Section 2.1 explains that the RTD test is used to obtain both the diurnal emissions and the resting loss emissions.

15. Page 15, Paragraph 3 – In the second assumption, we think that it is important to bring in engineering concepts about how gross liquid leaks are related to the different types of evaporative emissions. For example, if gross liquid leaks are related to fuel pressure, they could occur for running losses and hot soaks but not occur for resting losses and diurnals. We think that this type of discussion would lend engineering support to Assumption 2.

    We have added that assumption (and example) to Section 3.0.

16. Page 15, Paragraph 3 – We think that we can understand what Assumption 2 says. However, we do not follow the reasoning behind the assumption. It seems to us that there should be gross liquid leakers for each of the four types of emissions. We do not understand why the report suggests using two types to estimate the third type (that is, the running loss and the RTD results to determine the hot soak results). Because we could not understand the reasoning behind this assumption, we did not understand why, on Page 16, the second step in Section 3.1 was necessary and, of course, when it came to understanding the distinction between Approach 2 and Approach 1, we were lost.

    The approach was necessary because EPA lacked data on GLLs on the hot soak test at ages over 10 years. This statement has been added to the beginning of Section 3.0.

17. Page 16, Section 3.1.1 – We think that using averages of frequencies of occurrence of gross liquid leakers for the three model year groups used in recruitment causes a large amount of information to be lost from the data. Additionally, since Assumption 1 states that gross liquid leaker frequencies will be assumed to be the same for older and newer technologies, there is no need to divide vehicles into model year groups. A better and more defensible approach for determining the logistic growth functions would be simply to use logistic regression on the gross liquid leak leaker indicators for each vehicle that was tested. A logistic regression procedure, which is simple to use, is available in SAS. For each logistic regression, the input variable would be vehicle age and the response variable would be an indicator variable that would have a value of zero for a non-gross liquid leaker and one for a gross liquid leaker. The procedure would fit the data to a model with the same shape as shown in Figure 3-1. The procedure also has options for outputting the confidence limits of the predicted values.

    True. However, we believe that Figure 3-1 (and the similar figures that follow) illustrating the resulting equation (curve) closely approximating the three averaged rates (frequencies) is far more informative than having the same cumulative distribution curve drawn through a cloud of data. Additionally, the stratification into model year groups was based upon the stratified (targeted) recruitment that was used, not on potential differences in the rates of GLLs.

18. Page 17, Figure 3-1 – The figures such as Figure 3-1 could still be used to show trends in the data and the model results when logistic regression is used to build the models. For example, the plot could be made to have the average frequency for every five years of age and the model resulting from logistic regression and the confidence limits could be drawn as curves on the plot. The confidence limits provided by the model would span the entire range of the data.

    That approach would produce a graph similar to the existing Figure 3-1, with the exception that the individual points would be equally spaced, but with more variance at each point. We see no advantage to this, but the reader is free to reanalyze the data.

    Use of logistic regression would also appropriately solve the logistic growth expression for gross liquid leakers based on running loss testing, which is shown on Page 19 in Figure 3-2. In this instance, using the average values for the three model year groups caused a problem which has probably occurred by chance alone, in that the oldest model year average had a lower value than the middle model year value.

This approach only solves the "problem" by obscuring the fact that the calculated rate of occurrence of GLLs in this sample is slightly lower for the older vehicles. We still believe (as noted in our response to comment 17) that this graphical approach is more useful to the readers.

19. Page 19, Section 3.1.3 – This section starts with the phrase "to estimate the rate of occurrence of gross liquid leakers on the hot soak test…" since we did not understand Assumption 2 fully, we do not understand why the gross liquid leaker rate of hot soak needs to be estimated when it could have been modeled just like it was for RTD and running loss. We think that perhaps a Venn diagram would help in clarifying the gross liquid leakers. We think the report is using the following Venn diagram with two overlapping circles for diurnal and running loss with the union of the circles being hot soak gross liquid leakers.

    The explanation that was added to the beginning of Section 3.0 (in response comment 16) was repeated (in the beginning of Section 3.1.3) for emphasis.

    We think that the Venn diagram for the gross liquid leakers should start with the following Venn diagram which has four overlapping circles for resting loss, diurnal, running loss, and hot soak emissions. Then the report should consider engineering relationships to see if it is possible to simplify the diagram.

    We do not believe that Venn diagrams are necessary.

20. Page 21, Section 3.2 – The only clue that we have as to how the second approach differs from the first approach are the two words "optimize simultaneously." If the frequency of gross liquid leakers in the fleet is calculated simultaneously (we assume this means a vehicle would be a gross liquid leaker for all types of emissions) then wouldn't there be just one equation to predict the gross liquid leaker rate of occurrence? Because we could not understand Assumption 2 and the distinction between Approach 1 and Approach 2, we could not comment intelligently on Section 3.3.

    As the reviewer pointed out (in comment 15), a vehicle might qualify as a GLL on only one or two the three evaporative tests that we used. (An explanation of that was added to the end of Section 3.0.) Thus, it is not only possible, it is likely that there would be three distinct equations (curves) for the frequency of the different types of GLLs.

Appendix F

Response to Comments from Stakeholders

No comments were submitted in response to EPA’s posting a draft of this report on the MOBILE6 website.