United States
Environmental Protection
Agency

Air and Radiation

EPA420-R-01-023
April 2001
M6.EVP.008

Estimating Running Loss Evaporative Emissions in MOBILE6

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NOTICE

This technical report does not necessarily represent final EPA decisions or positions. It is intended to present technical analysis of issues using data which are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments which may form the basis for a final EPA decision, position, or regulatory action.

ABSTRACT

This report documents the method used in MOBILE6 for estimating the running loss emissions from vehicles.

In earlier versions of EPA's MOBILE model, running loss emissions (defined as evaporative hydrocarbons that are emitted when the vehicle is in operation) were calculated as functions of ambient temperature, fuel volatility, driving cycle, and vehicle parameters (i.e., fuel delivery system, model year ranges, and functionality of the evaporative control system). This report is not a complete re-analysis of the older data used in those previous versions of MOBILE. Rather, this report incorporates the effects of "gross liquid leakers" (see report M6.EVP.009) with the MOBILE5 running loss estimates, and then verifies that this approach is consistent with the results of recent running loss testing (while the MOBILE5 estimates alone are not).

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.

Estimating Running Loss Evaporative Emissions in MOBILE6

Report Number M6.EVP.008

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

1.0 INTRODUCTION

Running loss emissions are defined as evaporative hydrocarbons that are emitted when the vehicle is in operation. Since the MOBILE4 computer model, the US Environmental Protection Agency (EPA) has estimated running loss emissions based on analyses of testing performed by one of its contractors (Automotive Testing Laboratories, Inc.). In MOBILE6, the running loss emissions are calculated separately for each hour of the day, based on the vehicle activity for that hour. The hourly emissions are then weighted together (to form a daily composite value) proportional to the number of miles driven each hour.

The test programs were designed to test in-use vehicles with three different driving cycles:

- The New York City Cycle (NYCC) features low speed stop-and-go traffic conditions with an average speed of 7.1 mph. Details on this cycle can be found on EPA's website (at http://www.epa.gov/oms/emisslab/methods/nycccol.txt).
- The EPA Urban Dynamometer Driving Schedule (UDDS) is commonly called the "LA-4" or "the city test" and represents city driving conditions. It is used for light-duty vehicle testing and has an average speed of 19.6 mph. Details on this cycle can be found on EPA's website (at http://www.epa.gov/oms/emisslab/methods/uddscol.txt).
- The Highway Fuel Economy Driving Schedule (HWFET or HFET) represents highway driving conditions under 60 mph with an average speed of 47.9 mph. Details on this cycle can be found on EPA's website (at http://www.epa.gov/oms/emisslab/methods/hwycol.txt).

The duration of the running loss test is approximately one hour for each of those three driving cycles. Therefore, the NYC driving cycle is repeated six times (6 bags), the two portions of the LA-4 cycle are repeated three times (6 bags), and the HFET driving cycle is repeated five times (5 bags).

The running loss emissions test programs were designed to collect data at four levels of fuel volatility (7.0, 9.0, 10.4, 11.7 psi in Reid Vapor Pressure [RVP]) and at three levels of ambient temperature (80, 95, and 105° F). Not all vehicles were tested for all combinations of fuel RVPs and ambient temperatures, however. There was usually no testing at extreme conditions, such as the combinations of high RVP fuel and high ambient temperature (e.g., 11.7 psi/105° F), and low RVP fuel and low ambient temperature (e.g., 7.0 psi/80° F), because of their less likely occurrences in the real world. Also, if the running loss emission results from a test vehicle were low (less than 0.5 grams) at certain fuel and temperature combination (for example, 9.0 psi/95° F), it was assumed that at the combinations of lower fuel volatility and/or lower ambient temperatures (i.e., 7.0 psi/95° F, 9.0 psi/80° F, and, 7.0 psi/80° F), this vehicle would have emissions at a similarly low level. Therefore, to save resources, the vehicle was not tested for the combinations of lower fuel volatility and lower ambient temperatures. Further, there have been no tests on 11.7 psi RVP fuel shortly after the issuance of MOBILE4 in 1989.

In MOBILE4 model, when the test data were not available at certain combinations of fuel volatility and ambient temperature, the gram per mile (g/mi) running loss emissions were estimated from a variable called "True Vapor Pressure (TVP)." In the MOBILE4.l model, this TVP was used to correlate with the running loss emissions from failed vehicles. These TVPs by bag are expressed as functions of fuel volatility and fuel tank temperature. The TVP values were calculated for all combinations of fuel volatility (7.0, 9.0, 10.4, and 11.7 psi RVP) and tank temperature profiles (with the initial tank temperatures at 80, 87, 95, and 105° F).

In recent years, industry sources have performed running loss testing programs in which random samples of in-use vehicles were tested (see Section 2). In this analysis, we compared these new data to the MOBILE5 predictions to determine whether changes need to be made for MOBILE6.

2.0 NEW RUNNING LOSS TEST DATA

During the summer of 1997, running loss tests were performed on 150 vehicles as part of a testing program (project number E-35) conducted for the Coordinating Research Council (CRC). **[1]*** The running loss emissions for 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. The following summer (1998), CRC conducted a testing program in which

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***** The numbers in brackets refer to the references in Section 6 (page 8).

running loss tests were performed on 50 late-model year vehicles (1992 through 1997, with a mean age of 4.5 years) (project number E-41). **[2]** These 50 newer vehicles were again tested using tank fuel (RVP about 6.8 psi) and with an ambient temperature of about 95 degrees Fahrenheit; however, a longer driving cycle was used consisting of an LA-4 followed by two NYCC cycles followed by a second LA-4. A summary of the results from those two programs are given below in Table 1. Within each age range, the mean running loss test emissions were calculated as well as the 90 percent confidence intervals. The value "**Mean Age**" was calculated by subtracting the model year from the test year (either 1997 or 1998).

Table 1

Summary of CRC Running Loss Testing

CRC Project	Md Yr Range	Mean Age (years)	Sample Size	Runing Loss (gram/mile)	90 Percent Confidence Interval	
E-35	Pre-80	21.984	61	2.3044	0.9730	3.6358
	80-85	13.744	39	1.3800	0.5745	2.1855
	86-91	8.340	50	0.4678	0.1497	0.7859
E-41**	92-97	4.320	50	0.3351	0.0901	0.5801

****** The running loss results of the vehicles tested in Project E-41 are based on a longer driving cycle but at a slower average speed than the cycle used in E-35.

3.0 MOBILE5 PREDICTIONS OF RUNNING LOSS EMISSIONS

The MOBILE5 model was run to generate predictions of the running loss emissions in the CRC project E-35, that is:

- the ambient temperature was set equal to 95° F,
- the driving cycle was set to a single LA-4, and
- the fuel RVP was set to 6.8 psi.

MOBILE5 estimates were calculated for each model year within each of the three purge/pressure strata from reference **[4]**. Then, using the weighting factors from Appendix A of that reference, revised (i.e., re-weighted) MOBILE5 predictions were produced for the running loss emissions. Since the CRC testing measured all evaporative emissions that occurred during the test, those results (in Table 1) include both running loss and resting loss emissions. Therefore, resting loss emissions (from reference **[3]**) were calculated and added to the re-weighted MOBILE5 estimates.

Since most of the CRC testing was performed during the summer of 1997, two separate MOBILE5 runs were necessary (one on January 1, 1997 and the second on January 1, 1998). The two

MOBILE5 runs were averaged together to estimate the running loss emissions of the in-use fleet (by vehicle age) measured during summer 1997. Those predictions are given below in Table 2.

Table 2

Re-Weighted MOBILE5 Predictions of Fleet Running Loss (At CRC Test Conditions)

Age (years)	Predicted Run Loss (g/mi)	Age (years)	Predicted Run Loss (g/mi)	Age (years)	Predicted Run Loss (g/mi)
0	0.1028	8	0.1975	16	0.5434
1	0.1220	9	0.2199	17	0.5836
2	0.1421	10	0.2498	18	0.6193
3	0.1456	11	0.2863	19	0.6409
4	0.1507	12	0.3334	20	0.6554
5	0.1576	13	0.3850	21	0.6648
6	0.1672	14	0.4403	22	0.6706
7	0.1800	15	0.4945	23	0.6742
				24	0.6759

The comparison (between the data in Tables 1 and 2) is illustrated by the following graph (Figure 1).

Even the most cursory comparison between the average running loss emissions in Table 1 and the re-weighted MOBILE5 predicted running loss emissions in Table 2 (or simply between the data in Figure 1) suggests that not only do the predicted values underestimate the observed mean values, but they also do not even fall within those rather large 90 percent confidence intervals. This underestimation is most significant for vehicles over the age of 10 years. There are a number of possible explanations for those differences; however, EPA believes that the most likely explanation is the presence of vehicles identified as "gross liquid leakers" (GLLs) (see reference **[5]**) in the CRC sample.

In reference **[5]**, EPA used the term "gross liquid leaker" to identify vehicles having substantial leaks of liquid gasoline, as opposed to simply vapor leaks. In that report, EPA stated that the running loss emissions from such a vehicle tested over a single LA-4 driving cycle would be at least 7.0 grams per mile. When we examine the running loss test data used in the analysis for MOBILE5, it is questionable whether any of the test vehicles would meet EPA's definition of a GLL.* In the upcoming section (Section 4.0), we will consider the effect of adding the emissions from the GLLs to the (preceding) MOBILE5 estimate.

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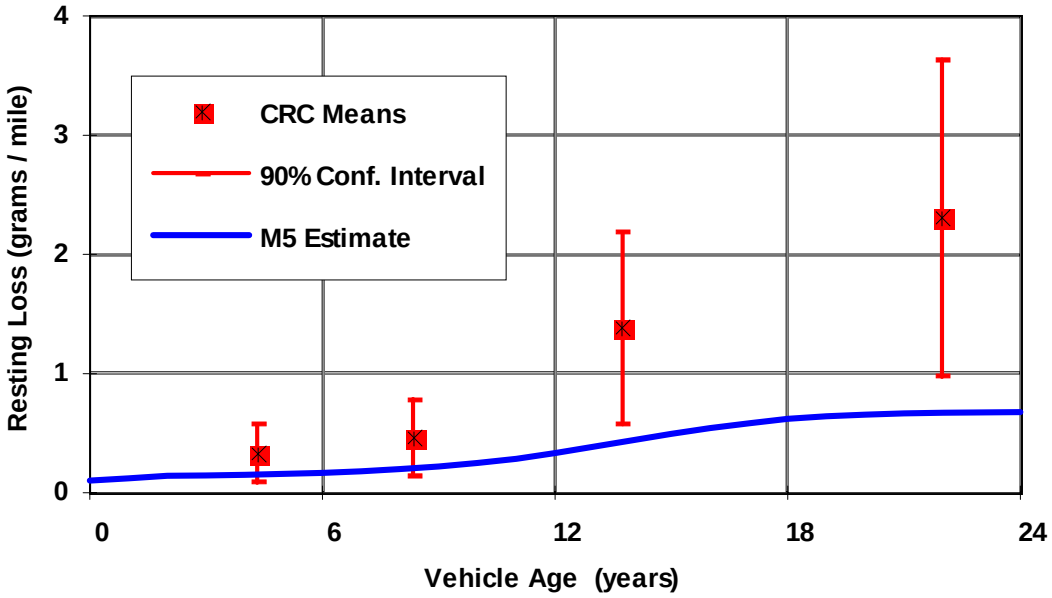
* The possible absence of "gross liquid leakers" in the data set used for MOBILE5 is not unreasonable considering the relatively small number of such vehicles in the in-use fleet.

Figure 1

Comparing Re-Weighted MOBILE5 Predictions with CRC Running Loss Emissions



4.0 EFFECT OF "GROSS LIQUID LEAKERS" ON RUNNING LOSS EMISSIONS

In reference [5], EPA defined for running loss testing, "gross liquid leakers" to be vehicles with both liquid leaks of gasoline and running loss test emissions of at least 7.0 grams per mile. Using that definition, we note that six (6) of the vehicles in the CRC testing programs met those criteria. We can then revise Table 2 by including the estimated running loss emissions of the "gross liquid leakers" (from reference [5]). The revised values are in Table 3 (on the following page).

When we compared the CRC running loss test results (from Table 1) with these MOBILE5 predictions that were modified to include the effects of GLLs (from Table 3), we obtained the graph in Figure 2 (on the following page).

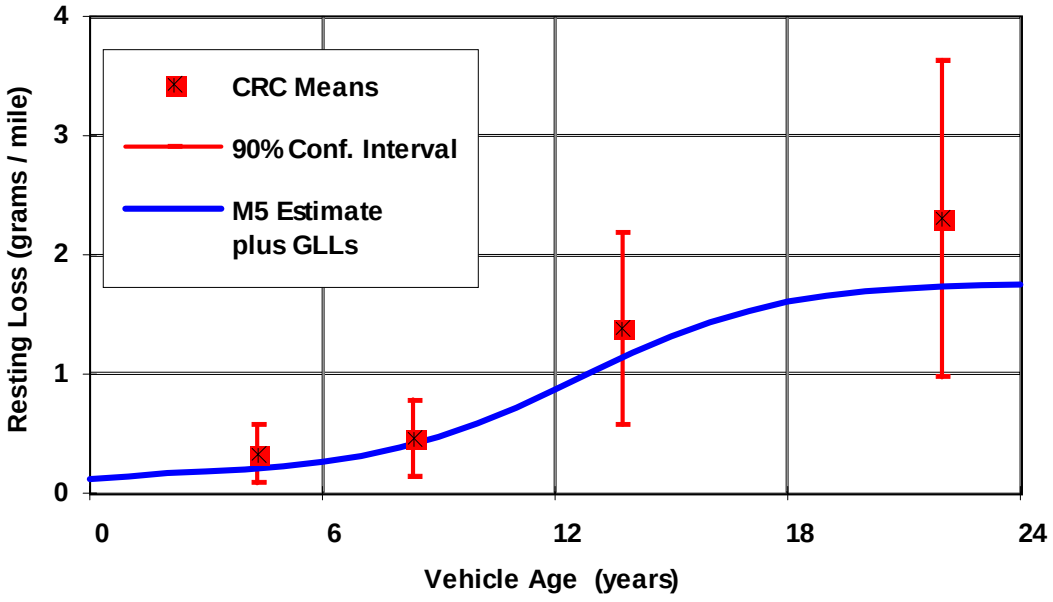
Table 3

Re-Weighted MOBILE5 Predictions of Fleet Running Loss Including GLLs (At CRC Test Conditions)

Age (years)	Predicted Run Loss (g/mi)	Age (years)	Predicted Run Loss (g/mi)	Age (years)	Predicted Run Loss (g/mi)
0	0.1170	8	0.3877	16	1.4559
1	0.1411	9	0.4778	17	1.5509
2	0.1697	10	0.5940	18	1.6335
3	0.1821	11	0.7292	19	1.6846
4	0.2014	12	0.8843	20	1.7210
5	0.2279	13	1.0426	21	1.7447
6	0.2642	14	1.1978	22	1.7609
7	0.3163	15	1.3365	23	1.7727
				24	1.7788

Figure 2

Comparing CRC Running Loss Emissions with Re-Weighted MOBILE5 Predictions Including GLLs



A visual examination of Figure 2 (or of Tables 2 and 3) indicates that for vehicles up through the age of 11 years, the re-weighted MOBILE5 predictions are excellent estimates of the mean CRC results (i.e., within 0.15 grams per mile). And, even

though the difference grows to almost 0.58 grams per mile for the oldest vehicles:

- From a statistical standpoint, those larger differences are actually relatively small, less than 10 percent of a standard deviation.

And,

- The differences between the CRC averages and the predicted results are the largest in the portion of the in-use fleet that contributes the least to the total emissions due to the small number of in-use vehicles involved. For example, fewer that one-tenth of the fleet is composed of vehicles older than 15 years of age, thereby reducing the effect of any potential offset.

5.0 CONCLUSIONS

EPA proposes, for MOBILE6, to use the MOBILE5 model to estimate the running loss emissions from that portion of the fleet that does not contain vehicles that are "gross liquid leakers." For the portion of the fleet composed (entirely) of vehicles that are "gross liquid leakers," EPA proposes to use report M6.EVP.009 (i.e., reference **[5]**) to both estimate and weight the emissions. The mean running loss emissions of "gross liquid leakers" was estimated to be 336.78 grams per hour (divided by the average speed to obtain units of "grams per mile").

In that same report, the estimated frequency of "gross liquid leakers" in the in-use fleet (as a function of the vehicle's age) is given by the equation:

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

Although this analysis concentrates on light-duty vehicles, this approach shall be used in MOBILE6 for all vehicle types.

6.0 REFERENCES

1) 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.

2) 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.

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

4) Larry Landman, "Estimating Weighting Factors for Evaporative Emissions in MOBILE6," Report numbered M6.EVP.006, April 2001.

5) Larry Landman, "Evaporative Emissions of Gross Liquid Leakers in MOBILE6," Report numbered M6.EVP.009, April 2001.

Appendix A

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 July 1, 1999) that do not necessarily match the page numbers in this final version.

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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.

Document No. M6.EVP.008 (June 28, 1999)

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

Overall this report was clearly written and the general methodology seems alright. We do not have any recommendations of any alternate datasets. It seems to us that the more serious problem with the report is that we are not convinced that the MOBILE5 predictions adequately describe the new CRC E-35 and E-41 data. In the comments below, we make suggestions which would help clarify this comparison to the reader.

1. Page 1, Section 1.0 – We agree with the general methodology used for data collection in past studies. That is, we agree that the running loss emissions do not need to be tested at combinations of temperatures and volatilities that are either both low or both high.

   EPA, of course, agrees with its own methodology.

2. Page 4, Paragraph 1 – The report suggests a number of possible explanations for the differences between corresponding values in Table 1 and Table 2. A short paragraph listing and very briefly discussing alternative explanations would give credence to the conclusion that gross liquid leakers is the most likely explanation.

   It was not EPA's intention to develop several possible explanations as to why the CRC running loss results were substantially higher than the predictions from MOBILE5. Rather, EPA's goal was to find (and test) a reasonable hypothesis. This report concludes that the sum of the running loss emissions attributable to "gross liquid leakers" (GLLs) and the MOBILE5 estimates of running loss emissions from the non-GLLs is a close approximation of the actual results found in the CRC sample.

3. Page 4, Paragraph 1 – A comparison of the Table 2 averaged results from the CRC projects with the Table 2 MOBILE5 predictions by age is a weak comparison. In general, whenever averages are used in data analysis, information is lost. We suggest that instead, a tougher, and therefore more revealing, comparison should be made by comparing the individual running loss minus resting loss values from the CRC studies with the MOBILE5 predictions by vehicle age. This could be conveniently done in a plot of running loss versus vehicle age with the CRC data points on the plot and the MOBILE5 curve on the plot. If it is possible to make such a plot with the CRC data, the result avoids the loss of information produced by taking averages. Also, if the plot were made in this way, it would not be necessary to delete suspected gross liquid leaker running loss values from the plot. These points would merely be points with high running loss values and could be highlighted as those which are suspected of being gross liquid leakers.

   The CRC data will be provided (in a spreadsheet) with this report. So, the users may create their own scatter plots if they desire. The plots in this report have been revised to include the (90 percent) confidence intervals at each point rather than the full scatter plot of all the data.

4. Page 5, Table 3 – The values for mean age in Table 3 are exactly the same as the values in Table 1. Presumably, if six vehicles have been removed to produce Table 3 the mean ages will be different.

   The reviewer is correct about that error. However, based on some of the comments from this reviewer, EPA decided to change the approach / emphasis (not the actual analysis or

conclusions) to improve clarity. One of the results of that change was the dropping of that table from this revision.

5. Page 5, bottom half –

[This material is now on the bottom half of page 6.]

At this point in the report, the discussion centers around the significance of the differences between the MOBILE5 prediction curve and the CRC data values. There are two problems with this analysis.

First, statistical tests of significance are usually made in a space where the variance is relatively homogeneous and normally distributed. The fact that the standard deviations of the measured values in Tables 1 and 3 are one and a half to three times the means indicates to us that the running loss values have skewed distributions. Since automotive emissions values typically are skewed approximately in a log-normal fashion, we suggest that instead the test of significance be based in log space. For us, this would most convincingly be put forward by plotting the running loss emissions on a log scale in the plot suggested by Comment 3. The MOBILE5 curve should pass somewhere through the center of the 200 CRC measurements.

As noted in our response to the third comment, the users may create their own scatter plots (using a logarithm scale in this case) to compare the results from the CRC sample with the estimates from MOBILE5 and MOBILE6.

Second, to verify that no significant difference exists between the measured CRC values and the MOBILE5 predicted value, some sort of formal statistical test should be performed. We suggest that a paired t-test be used to compare the average of the residuals (measured CRC value – predicted MOBILE5 value) for each car with the standard deviation <u>of the mean</u> of the residuals. These calculations should be done in log space, where we presume the variance is homogeneous and normal. If the mean residual is found to be not significantly different from zero, then it can be concluded that the measurements and the predictions are the same. If the mean residual is significantly different from zero, then either the MOBILE5 model needs to be changed or an explanation needs to be provided that the significant difference is small and is of small practical importance.

The approach suggested by the reviewer is valid; however, it is more extensive than what EPA is attempting. In fact, a statistical analysis of the results at the age of 20 years <u>may</u> find the difference to be statistically significant, but the relatively small number of in-use vehicles at that age reduces the effect of that difference on the overall in-use

fleet (composite) running loss value to be insignificant for practical purposes.

6. Page 6, Figure 1 – It appears to us that this figure indicates that MOBILE5 under predicts the CRC values by about 40%. Since the standard deviations in linear space of the running loss values from the CRC studies are greater than the means of those running loss emissions, any model which has a curve between 0 and the means will be within one standard deviation of the means.

   The reviewer is correct. We have, therefore, dropped this figure (graph) from this revision (as noted in the response to the fourth comment) to improve clarity. The new Figure 2 (in this revision) avoids these problems and still conveys the desired information.

7. Page 5, Paragraph 2 –

   [This material is now on page 6.]

   The word "excellent" is glaring in light of the relationships shown in Figure 1. Regardless of the outcome of any further analysis on this data in this report, we suggest selecting a less enthusiastic word.

   As noted in the response to the preceding comment, that figure has been dropped (replaced) to improve clarity. However, the word "excellent" has been retained, but it now applies to the fit in the (new) Figure 2 (for vehicles under the age of 11). We believe that its use is appropriate.

8. Page 6, Section 5.0 –

   [This section ("Conclusions") is now on page 7.]

   Based on our comments above, the report does not convince us that there is no significant or important difference between the CRC running loss values and the MOBILE5 running loss predictions. Nevertheless, it could very well be that the conclusions stated in Section 5.0 are correct.

   *The differences between the MOBILE5 estimates of running loss (plus resting loss) emissions and the results obtained by CRC in its recent testing programs **are** significant. We believe that (for practical purposes) those differences are explained (and eliminated) by including the emissions from the "gross liquid leakers" as illustrated in Figure 2 on page 6 (of this revision) which was added to improve clarity.*

Appendix B

Response to Comments from Stakeholders

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