Development of Evaporative Emissions Calculations for the Motor Vehicle Emissions Simulator MOVES2010

Final Report

United States
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Assessment and Standards Division
Office of Transportation and Air Quality
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EPA United States Environmental Protection Agency

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1 Background

Vehicles emit hydrocarbon (HC) emissions in addition to exhaust emissions due to driving. HC emissions "evaporate" from the fuel system while a vehicle is sitting or driving, and are largely driven by changes in the ambient temperature. For gasoline fueled vehicles, evaporative emissions can account for a significant portion of the total gaseous hydrocarbon inventory. The processes are unique from exhaust and require their own modeling approach. In the MOBILE series of models, and in certification test procedures, evaporative emissions were quantified in distinct modes based on the test procedures used to measure them:

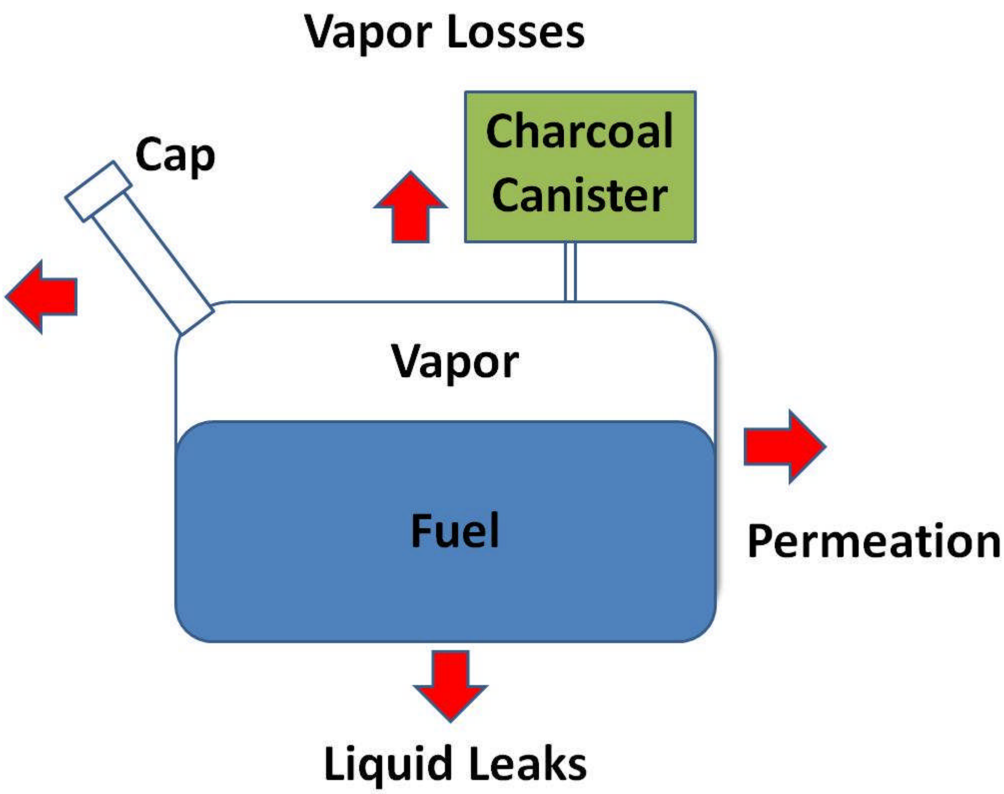
- **Running Loss –** vapor lost during vehicle operation.
- **Hot Soak –** vapor lost while parked, immediately after turning off a vehicle.
- **Diurnal / Cold Soak** - vapor lost while parked and with a stabilized temperature.
- **Refueling Loss -** vapor lost and spillage occurring during refueling.

However, for MOVES, a change from this approach was proposed to better account for the underlying physical processes involved in evaporation of fuels, and thus to better model evaporative emissions under different ambient temperatures and fuel types. For example, Ethanol (EtOH) has a unique effect on permeation, which is distributed among the modes listed above. Instead MOVES groups evaporative emissions based on the evaporative mechanism, using the following "processes":

- **Permeation –** the migration of hydrocarbons through elastomers in the vehicle's fuel system.
- **Tank Vapor Venting (TVV) –** vapor generated in fuel system that is expelled into the atmosphere.
- **Liquid Leaks –** liquid fuel leaking from the fuel system, eventually evaporating into the atmosphere.
- **Refueling Emissions –** vapor in the fuel system that is displaced into the atmosphere as a vehicle refuels and spillage.

These processes can occur for each of the modes (Running Loss, Hot Soak, Cold Soak) used in the MOBILE models. MOVES calculates permeation, tank vapor venting, and liquid leaks in each of the operating modes. The benefit is that each emission process can be modeled using the different factors that affect it, independently of how the vehicle is operating. This makes for easier, more accurate modeling of scenarios that do not perfectly replicate the test procedures. The emission processes used by MOVES and the operating modes used for evaporative processes are shown in Appendix C.

The graphic below shows the evaporative emission processes. Permeation of the fuel through the tank walls, hoses and seals occurs continuously, but is affected by the tank temperature. Vapor is generated by a change in tank temperature and is intended to be captured by the charcoal canister. If the canister is not purged enough or if there are leaks in the system, vapors can be expelled when temperatures rise. Liquid leaks can occur in connections, hoses and the tank itself. Refueling displaces the vapor in the tank and can result in spillage.



Evaporative emissions depend on a number of variables. In MOVES, we model the impact of the following factors:

- Ambient Temperature
- Fuel Tank Temperature
- Model year group (standard)
- Vehicle age
- Vehicle class
- Fuel Properties
    - Ethanol content
    - Reid Vapor Pressure (RVP)
- Failure Modes
- Presence of inspection and maintenance programs

Both ambient temperature and engine operation can increase fuel tank temperature. Any increase in fuel tank temperature will generate vapor in the tank and pressure in the tank. Charcoal canisters connected to the gas tank are intended to vent these vapors through activated charcoal and remove the hydrocarbons. When the engine is operated the canister is "purged" periodically and the captured hydrocarbons are diverted to the intake manifold of the engine and burned. The emission standards (model year and vehicle class) determine the amount of capacity the canister system is designed to hold. If the amount of vapors generated exceeds the capacity of the canister, the vapors are vented to the atmosphere. This can occur if a vehicle is not driven and undergoes several days of ambient temperature rises.

Fuel properties are important for evaporative emissions. Since evaporative emissions are just fuel, the fuel properties will have a significant effect on the amount and types of hydrocarbons emitted.

Fuel systems will sometimes generate leaks that allow liquid fuel or vapors to circumvent and escape the control systems on the vehicle. Inspection and maintenance (I/M) programs sometimes explicitly include inspections intended to identify vehicle in need of evaporative system repairs. Stage 2 programs are designed to capture the vapors released during refueling.

The model year groups for evaporative emissions are shown in Table 1. They depend on evaporative emission standards and related technological improvement designed to control evaporative emissions.

Table 1 - Model Year Groups used for MOVES

Model year group	Emissions standard or technology level
1971-1977	Pre-control
1978-1995	Early control
1996	80% early control, 20% enhanced evap.
1997	60% early control, 40% enhanced evap.
1998	10% early control, 90% enhanced evap.
1999-2003	100% Enhanced evap.
2004 and later	Tier 2, LEV II

All evaporative emissions from vehicles derive directly from the fuels used and are not affected by the combustion process. This means that hydrocarbons not present in the fuels that are a product of combustion (such as methane) will not appear in evaporative emissions. Appendix D contains a list of the non-combustion pollutants calculated by MOVES from evaporative emissions.

The data used for this evaporative analysis was collected on Light-Duty gasoline vehicles but will also be used in application for Heavy-Duty gasoline vehicles. For diesel vehicles, there are no evaporative emission losses except for refueling spillage. All other diesel evaporative losses are considered negligible.

2 List of Data Sources

The evaporative emissions in MOVES are based on data from a large number of studies.

- CRC E-9 – Measurement of Diurnal Emissions from In-Use Vehicles[1]
- CRC E-35 – Measurement of Running Loss Emissions in In-Use Vehicles[2,3]
- CRC E-41 – Evaporative Emissions from Late-Model In-Use Vehicles[4,5]
- CRC E-65 – Fuel Permeation from Automotive Systems[6]
- CRC E-65-3 – Fuel Permeation from Automotive Systems: E0, E6, E10, and E85[7]
- CRC E-77 – Vehicle Evaporative Emission Mechanisms: A Pilot Study
- CRC E-77-2 – Enhanced Evaporative Emission Vehicles
- CRC E-77-2b – Aging Enhanced Evaporative Emission Vehicles (DRAFT)
- CRC E-77-2c – Aging Enhanced Evaporative Emission Vehicles with E20 Fuel
- BAR Gas Cap Study
- API Gas Cap Study
- EPA Compliance Testing

Appendix A has a summary of the test programs mentioned above.

3 Design and Analysis

Fuel tank temperature was empirically found to be the driver of the transient emissions processes, permeation and vapor venting in the CRC E-77 pilot testing program which included ten vehicles.[8] Therefore, determining fuel temperature is critical in predicting emissions in each operating mode. Fuel tank temperature is dependent on the daily ambient temperature profile, vehicle operation patterns, and vehicle model year. As standards have tightened, fuel system materials and connections have become more efficient at containing gaseous HC's from escaping to the atmosphere. Purge systems and canister technologies have also advanced resulting in lower emissions.The calculated fuel tank temperature can be used in modeling permeation and vapor venting. Because liquid leaks are liquid rather than vapor, they are not dependent on temperature..

3.1 Fuel Tank Temperature Generator

This section explains how MOVES generates fuel tank temperature over a diurnal ambient temperature profile and the vehicle trip schedule. Tank temperature is used in later calculation of permeation and vapor venting, which makes this an instrumental algorithm in modeling evaporative emissions for MOVES.

3.1.1 Fuel Tank Temperature Calculator General Steps

Define Input Parameters:

- Hourly ambient temperature profile (zoneMonthHour table)
- Key on and key off times (sampleVehicleTrip table)[9]
- Day and hour of first KeyON (hourDay table)
- Vehicle Type (Light-duty vehicle, Light-duty truck, Heavy-duty gas truck)
- Pre-enhanced or enhanced evaporative emissions control system

Tank temperature is modeled for the three primary operating modes of a vehicle. Operating, hot soak, and cold soak. Operating vehicles tanks are warmer than ambient due to recirculation from the engine. Hot soak is the period after a vehicle's engine ceases to run, and the vehicle begins to cool to ambient temperature. Cold soak is the period in which a vehicle is not running and is not hot soaking, therefore the primary driver of tank temperature of a cold-soaking vehicle is the ambient temperature.

3.1.2 Calculate fuel tank temperature for hot and cold soaks

The following equation is used to model tank temperature as a function of ambient temperature.

$$\frac{dT_{Tank}}{dt} = k(T_{air} - T_{Tank}) \quad \textbf{Equation 1}$$

T_{Tank} is the fuel tank temperature, T_{air} is the ambient temperature, and k is a constant proportionality factor ($k = 1.4\ hr^{-1}$, reciprocal of time constant). The value of k was established by trial and error using EPA compliance data. Compliance data was available on 77 vehicles that underwent a 2-day diurnal test and had a 1-hour hot soak. There was no distinction made between hot and cold soak calculations. We assume that during any soak, the only factor driving change in the fuel tank temperature is the difference between the tank temperature and the ambient temperature.

As stated before this equation only applies during all parked conditions, which include the following time intervals:

- From the start of the day (midnight) until the first trip (keyON)
- From a keyOFF time until the next keyON time
- From the final keyOFF time until the end of the day

For more information on the activity data used to determine the time of keyOn and keyOff events, see the MOVE technical report[10] and supporting contractor reports[11,12].

Mathematical steps

a) At time $t_0 = 0$ or KeyOFF (start of soak), $T_{Tank} = T_i$. This value will either be the ambient temperature at the start of the day, or the fuel tank temperature at the end of a trip.
b) Then, for all $t > 0$ and KeyOFF, the next tank temperature is calculated in this manner:

$$(T_{Tank})_{n+1} = \left[\sum_{j=0}^{n} k(T_{air} - T_{Tank})_j \Delta t \right] + T_i \qquad \textbf{Equation 2a}$$

$$(T_{Tank})_{n+1} = T_{Tank\ n} + k(T_{air} - T_{Tank})_n \Delta t \qquad \textbf{Equation 2b}$$

$(T_{air} - T_{tank})$ is a function of time. Since analytical integration is too complicated (the input ambient temperature data is in a table), numerical integration is used to perform this step. The method of numerical integration varies based on the accuracy desired. The above method represents the Euler method, one of the simplest methods of integration. The smaller the time step Δt, the more accurate the solution. MOVES uses a Δt of 15 minutes, which is accurate enough for our modeling purposes without causing tremendous strain on computing resources.

3.1.3 Calculate fuel tank temperature during operation

Vehicle trips are relatively short compared to the length of the day or modeling period. Therefore, even though the fuel tank temperature profile is not perfectly linear with time, assuming a linear increase in temperature makes calculations easier without compromising accuracy.

The convention used in this algorithm is that ΔT_{tank} applies over a 4300 second period. This is the length of the running loss test performed by manufacturers at certification. To find ΔT_{tank}, we must first find ΔT_{tank95}, the average increase in tank temperature during a standard 4300 second 95°F running loss test. The increase in fuel tank temperature depends on the temperature of the tank at the KeyON time. It also depends on vehicle type and technology, due to different configuration and design that affect heat loss. The different ΔT_{tank95} temperatures are as follows:

- If the vehicle is evap-enhanced, then ΔT_{tank95} = 24°F [13]
- If the vehicle is pre-enhanced, the vehicle type affects ΔT_{tank95}. [2]

- If LDV, then ΔT_{tank95} = 35°F.
- If LDT, then ΔT_{tank95} = 29°F.

We use these values to calculate to calculate the ΔT_{tank} for other starting fuel tank temperatures using equation 3.

$$\Delta T_{Tank} = 0.352(95 - T_{Tank,KeyON}) + \Delta T_{Tank95}$$ **Equation 3**

This equation comes from GM regression analyses of light-duty vehicles driving the running loss drive cycle with several different starting temperatures.[14] The average slope of fuel temperature increase to starting fuel temperature is -0.352 with a standard error of the mean of 9.5%. This is to say that the lower the starting fuel tank temperature, the bigger the increase over a drive cycle. This gives us the increase in tank temperature so we can create a linear function that models fuel tank temperature for each trip.

$$T_{Tank} = \frac{\Delta T_{Tank}}{4300/3600}(t - t_{keyON}) + T_{Tank,KeyON}$$ **Equation 4**

The 4300/3600 is in the denominator as a conversion from seconds to hours, maintaining consistency in the algorithm.

Assumptions:

- The first trip is assumed to start halfway into the hour stated in the first trip's HourDayID.
- The effect of a change in ambient temperature during a trip is a negligible compared to the temperature change caused by operation.
- The KeyON tank temperature is known from calculation of tank temperature from the previous soak.

3.2 Permeation

Permeation emissions are fuel vapor emissions that escape through micro-pores in pipes, fittings, fuel tanks, and other vehicle components. They differ from leaks in that they occur on the molecular level and do not represent a mechanical/material failure in a specific location.

3.2.1 Base Rates

We first determined base rates for permeation. These were determined using the per-hour emission rate during the last six hours of a 72-96-72°F diurnal test (also known as cold soak/resting loss) The diurnal tests analyzed are federal cycle (72F-96F) tests from the CRC E-9 and E-41 programs. These two programs together represent a total of 151 vehicles with model years ranging from 1971 to 1997.[1,4,5] In the final six hours of the diurnal; the emissions rate, ambient temperature, and fuel temperature are relatively stable or constant. This leads us to believe that permeation is the only process occurring. The rates are broken out by model year group and age group. The base permeation rates are in Table 2. Model years 1996-1998 are represented individually to reflect the 20/40/90% phase-in of enhanced evaporative emissions standards.

Table 2 - Base permeation rates at 72°F

Model year group	Age group	Base permeation rate [g/hr]
1971-1977	10-14	0.192
	15-19	0.229
	20+	0.311
1978-1995	0-3	0.0554
	4-5	0.0554
	6-7	0.0913
	8-9	0.0913
	10-14	0.124
	15-19	0.148
	20+	0.201
1996	0-3	0.046
	4-5	0.046
	6-7	0.075
	8-9	0.075
	10-14	0.101
	15-19	0.120
	20+	0.163
1997	0-3	0.037
	4-5	0.037
	6-7	0.059
	8-9	0.059
	10-14	0.079
	15-19	0.093
	20+	0.125
1998	0-3	0.015
	4-5	0.015
	6-7	0.018
	8-9	0.018
	10-14	0.022
	15-19	0.024
	20+	0.029
1999 and Newer	0-3	0.0102
	4-5	0.0102
	6-7	0.0102
	8-9	0.0102
	10-14	0.0102
	15-19	0.0102
	20+	0.0102

3.2.2 Temperature adjustment

In the E-65 permeation study, it was found that permeation rates, on average, double for every 18°F (10°C).[6] This study included permeation testing performed on 10 vehicle fuel rigs at 85°F and 105°F. The vehicles ranged in model year from 1978-2001. In MOVES the base permeation rates are calculated at 72°F.

The following equation is derived from that study and used to adjust the base permeation rate:

$$P_{adj} = P_{base}\, e^{0.0385\,(T_{Tank} - T_{base})} \quad \textbf{Equation 5}$$

P_{base} is the base permeation rate, T_{tank} is the tank temperature, and T_{base} is the base temperature for a given temperature cycle (e.g. 72°F for a 72-86-72°F diurnal test).

3.2.3 Fuel Adjustment

E10 affects evaporative emissions from gasoline vehicles due to the increased permeation of fuel vapors through tanks and hoses. The model separates permeation emissions from vapor venting emissions to allow better accounting of vapor losses for these different processes.

Fuel effects on permeation were developed from CRC's E-65 and E-65-3 programs, which measured evaporative emissions from ten fuel systems that were removed from the vehicles on E0, E5.7, and E10 fuels; and CRC's E-77-2 and E-77-2b programs, which measured evaporative emissions from sixteen vehicles. For this analysis, we separated the evaporative enhanced and Tier 2 vehicles from the pre-enhanced vehicles. Enhanced evaporative vehicles began being phased in from 1996 through 1999 and needed to meet a 2.0 g standard over a 24-hour diurnal test. Pre-enhanced vehicles needed to meet 2.0 g over a 1-hour simulated diurnal. We estimated the ethanol effect by using a mixed model. The vehicle's evaporative certification, fuel ethanol content, and fuel RVP were modeled as fixed effects and the particular vehicle modeled as a random effect. The natural log of the emission rates over the 65-105-65°F diurnal cycle provided a normally distributed dataset to the model. Due to a relatively small amount of data, in order to find a significant effect of ethanol within different evaporative certifications (enhanced AND Tier 2 vs. pre-enhanced), we had to combine E5.7 and E10 results into one category of "Ethanol" fuel. Ethanol fuel could then be seen to have a significant influence on permeation from a baseline E0 fuel. The percent difference between the Ethanol rate and the E0 rate was input into MOVES as the fuel adjustment. Due to the phase in from 1996 to 1999 (20/40/90/100%), the two fuel adjustments must be properly weighted for those model years. The fuel adjustment in MOVES is based on a variable called fuelModelYearID. Table 3 shows the fuel adjustments used for E5 through E85 for the fuelModelYearID's used in MOVES.

Table 3 – Increase in Emissions
Due to ethanol levels of 5% to 85% compared to E0 (gasoline)

Model years (via fuelModelYearID in MOVES)	Percent increase due to ethanol (E5 through E85)
1995 and earlier	65.9
1996	75.5
1997-2000	107.3
2001 and later	113.8

There is more information regarding permeation emissions in the final releases of the CRC E-77-2b and E-77-2c studies which can be used to update the permeation estimates in future versions of MOVES.

3.3 Tank Vapor Venting

It is important to understand TVV emissions and their various sources. As tank temperature rises and vapor is generated within the tank, it is consequently driven from the fuel system due to increased pressure. Most modern vehicles are equipped with some kind of control strategy, such as a carbon canister, to try and capture these vapors as they are generated. Later, the vapors are consumed as they purge to the engine when the vehicle is operated next. However, the canister is vented to the atmosphere to prevent unwanted pressure build-up within the fuel system allowing emissions to "bleed" through the carbon, or even freely pass through a completely saturated carbon bed. Problems with the evaporative control systems such as tampering, mal-maintenance, and inadequate durability result in evaporative system failures and can also cause the unintended release of vapors. The inclusion of these problems in the emission estimate and the use of inspection and maintenance (I/M) programs to make repairs are handled through the cold soak calculation.

Integral to the understanding of Tank Vapor Venting (TVV) is how to calculate Tank Vapor Generated (TVG). This is a function of increase in fuel tank temperature, ethanol content, altitude and RVP. MOVES uses the Wade-Reddy equation for vapor generation.

$$TVG = Ae^{B*RVP}(e^{CT_x} - e^{CT_1})$$ **Equation 6**[15]

In Equation 6, T_1 is the starting temperature and T_x is the temperature at hour x. Coefficients A,B,C are required and represent the different altitude and ethanol effects. These coefficients are shown below in Table 4.

Table 4 – TVG constants for Equation 6

	Gasoline		E10	
Constant	**Sea Level**	**Denver alt.**	**Sea Level**	**Denver alt.**
A	0.00817	0.00518	0.00875	0.00665
B	0.2357	0.2649	0.2056	0.2228
C	0.0409	0.0461	0.0430	0.0474

The following explains how vapor venting rates are calculated for each operating mode. For cold soak, MOVES first finds the amount of vapor generated in the tank as a function of fuel tank temperature and RVP. Then, it determines how much of this vapor is released into the atmosphere based on several criteria, such as model year and fill pipe pressure test result. The temperatures will have been generated by the fuel tank temperature generator, and the RVP will have been generated by the MOVES tank fuel generator[16]. This cannot apply for when vapor is not generated (when fuel tank temperature is not increasing), such as during a hot soak, but is released. For these situations, we have aggregated TVV rates after subtracting out permeation and leaks from the test results. Also, due to the availability of test data for running loss and the short length of trips, we determined TVV rates during operation the same way we did for hot soak.

3.2.4 Cold Soak

Cold soak vapor emissions are occurring while a vehicle is not operating and therefore only responding to changes in ambient temperature. These are also commonly referred to as "diurnal" emissions. To calculate emissions during cold soak, we again use diurnal data from CRC programs E-9 and E-41. First we need to filter the dataset so that each test meets the following requirements:

- Vehicle has no vapor leaks
- Vehicle is "As received" (not a retest)
- We only include hours of increasing temperature (no TVG while temperature decreases)
- Pressure test result is pass, fail, or blank (no dashes, slashes, "I", etc.)

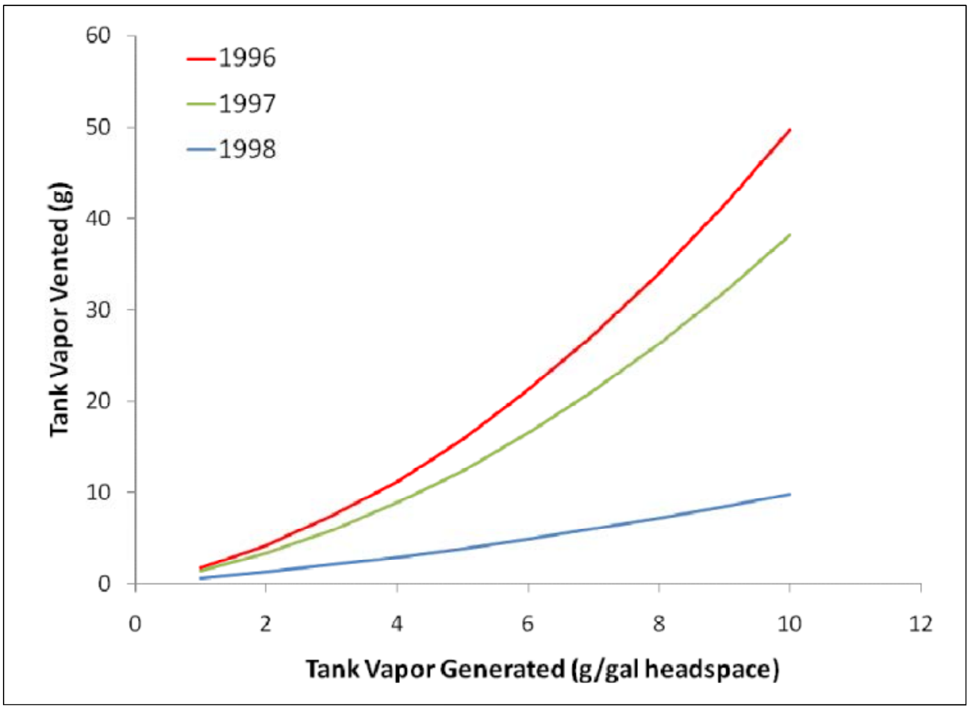
1) For each diurnal test, fuel tank temperature is calculated at each hour using the fuel tank temperature algorithm described in section 3.1.
2) We calculate the base permeation rate using the method described in 3.2.1. (Average of last six hours of HC evaporative emissions). Then, using the temperature adjustment described in section 3.2.2 we calculate the temperature adjusted permeation rate for each hour of diurnal.
3) Subtract the temperature adjusted permeation rate from the total HC for every hour. Because the SHED can only measure total HC, it cannot distinguish permeation from TVV, so we must make this correction.
4) Sum TVV from beginning of diurnal to each hour to get Cumulative TVV.
5) Using Equation 6, calculate TVG in grams per gallon of vapor space, from hour 1 to hour x. where hour x is the last hour where temperature is increasing.

TVG is the amount of vapor generated in the tank. We establish a relationship between Cumulative TVV and TVG for inputs into MOVES. This is done by constructing a quadratic curve of CumTVV vs. TVG for each model year group, age group, and pressure test result.

$$CumTVV = a_1 TVG + a_2 TVG^2 \qquad \textbf{Equation 7}$$

The curve is set to have a zero-intercept (0,0) to ensure that at 0 TVG, there is no tank vapor venting, an accurate physical assumption. Figure 1 below illustrates the phase-in of evaporative enhanced vehicles over the model years 1996-1998. For instance, a given amount of vapor generated (x-axis) a smaller amount of vapor is vented as the technology phases in. The curves used in Figure 1 use the combined passing and failing coefficients for the case of vehicles in the 6-7 age group. A complete set of coefficients for Equation 7 can be found in Appendix B. The aggregate columns are the inputs used in the MOVES model for the I/M and non-I/M coefficient cases in the cumTVVCoeffs table.

Figure 1 – MOVES Composite Vapor Generation Curves
Model Years 1996-1998



Curves were generated for model year groups 1971-1977 (ages 20+), 1978-1995 (ages 0-19) and 1996-2003 (ages 0-9). The curves are also broken out by pressure test result. In failing vehicles, there is more vapor vented than in an otherwise equivalent passing vehicle with properly functioning evaporative controls. Coefficients for remaining age and model year groups are determined by extrapolation. The coefficients of variation (CVs) are calculated by dividing the standard error of the sample (calculated by SPSS) by the mean, for each coefficient in the quadratic equation.

6) Failure frequencies (*F*) are determined from pressure, gas cap, and OBD test results from the Phoenix I/M program (See section 3.4 *Inspection/Maintenance (I/M) Program effects*) This allows calculation of aggregate coefficients that properly weight the pass and failing vehicles in the fleet. They are calculated in equation 8.

$$a_{x,agg} = a_{x,fail} F + a_{x,pass} (1 - F) \qquad \textbf{Equation 8}$$

Equation 8 is repeated with the coefficients for each model year and age group stratification, to create the curve that accurately represents a given fleet's pass/fail ratio.

7) Since the aggregate coefficients are determined using the failure rates, which are essentially weighting factors, the standard errors of the aggregate coefficients are calculated:

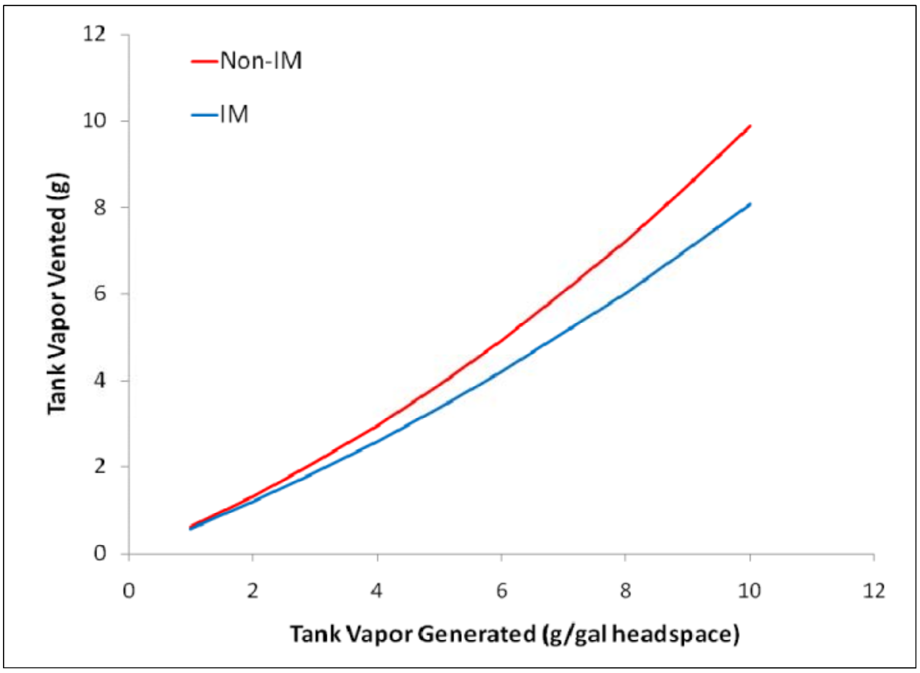
$$s_{\bar{y},a_{x,agg}} = \sqrt{F^2 s^2_{\bar{y},a_{x,fail}} + (1-F)^2 s^2_{\bar{y},a_{x,pass}}} \qquad \textbf{Equation 9}$$

As a result, the CV's for the aggregate coefficients are calculated:

$$CV_{a_{x,agg}} = \frac{1}{a_{x,agg}} \sqrt{F^2 a^2_{x,fail} CV^2_{a_{x,fail}} + (1-F)^2 a^2_{x,pass} CV^2_{a_{x,pass}}} \qquad \textbf{Equation 10}$$

Error! Reference source not found. Appendix B shows a selection of the coefficients resulting from the analysis. Ratios between age groups are used to extrapolate for the 10-14 age group in the 1971-1977 model year groups, and older age groups where data did not exist are assumed to have the same coefficients as their preceding age groups. The passing coefficients for the 2004 and later model year group were reduced by 32% from the 1999-2003 model year group, which reflects a reduction in the evaporative emissions standard from enhanced-evap to Tier 2/LEV II. Separate model year groups are created for 1996 through 1998 due to the phasing of enhanced evaporative standards. These three groups are only different weightings of the 1978-1995 and 1999-2003 model year groups based on the 20/40/90% phase-in for 1996/1997/1998. Similarly, though not shown, is a table developed for non-I/M vehicles using non-I/M failure frequencies calculated from the Phoenix I/M data set. Figure 2 shows an example of the difference between I/M areas and non-I/M areas for model year 1998 (6-7) using Equation 7 and the coefficients shown in Appendix B.

Figure 2 - MOVES Vapor Generation Curves
Model Year 1998



3.2.5 Hot Soak

Hot soak vapor emissions refer to the vapor vented immediately after a car ceases operation and begins to cool; until it reaches the ambient temperature. In MOVES, the TVV apportioned to Hot Soak is a simpler process than the Cold Soak calculations. Base rates in grams per hour are used for each model year and age group. Pass and fail results are weighted together to form the aggregate rate, similarly to Cold Soak. The process for developing the rates is described below:

Data is used from CRC E-41 Late Model In-Use Evap. Emission Hot Soak Study. This study included 50 vehicles (30 passenger cars and 20 light duty trucks) ranging from model year 1992 to 1997. The driving schedule is a full LA-4, NYCC, NYCC, and LA-4 with a two minute idle period following the first LA-4, the second NYCC and the final LA-4.

The data must first be filtered by the following criteria:

a. Vehicles are Non-leakers (emissions less than 10.0 grams[17]; taken from M6.EVP.009_2.4; Since hot soak emissions are measured after one hour, the total emissions is "equal" to its g/hr rate)
b. Vehicles are "As received" (no retests)
c. Vehicle pressure test result must be pass, fail, or blank only (no dashes, slashes, "I", etc.)

1) First, we find the temperature at the start of the soak for each hot soak test. This is done by adding the calculated temperature increase experienced during an LA-4 running loss test cycle (1372 seconds), since the vehicle is put through this test before entering the soak chamber. The temperature rise depends on the fuel tank temperature at the start of the LA-4 test. To calculate the temperature T_{start}, see section 3.1.3 *Calculating fuel tank temperatures during operation.* Then we find the average tank temperature in that hour:

$$T_{avg} = \frac{1}{k}(T_{start} - T_{air})(1 - e^{-k}) + T_{air}$$ **Equation 11**

This is derived from the average value of a function over an interval (in this case, between 0 and 1 hour after the start of the hot soak). As stated in section 3.1.2, k = 1.4 hrs^{-1}.

2) Similarly to the Cold Soak calculations, permeation HC must be subtracted from the SHED measurement during the Hot Soak period so that we do not wrongly allocate the measured HC. The average temperature calculated in Step 2 is used to correct the 72°F base permeation rate, which is then subtracted from HC for each hour to get the TVV rate.

   TVV rates are averaged by model year group, age group, and pressure test results, shown in the table below.

Table 5 - Average hot soak tank vapor venting rates

Model year group	Age group	Pressure test result	TVV rate (g/hr)	Number of Cases
1971-1977	20+	F	6.17	5
	20+	P	2	4
1978-1995	0-5	Unknown	1.25	5589
	0-5	P	0.56	901
	0-9	F	2.37	170
	6-9	Unknown	1.75	202
	6-9	P	1.38	255
	10-14	Unknown	5.13	2
	10-14	F	3.41	31
	10-14	P	1.76	64
	15-19	F	4.51	5
	15-19	P	2.99	14
1996-2003	all	Unknown	0.1073	83

3) As with cold soak, aggregate rates are found using failure rates involving pressure, gas cap, and OBD tests for non-I/M and I/M. Table 6 reflects the most updated I/M analysis explained in section 3.4 *Inspection/Maintenance (I/M) Program effects* (unlike the cold soak coefficients in Table 5) or the enhanced evaporative phase-in.

Table 6 - Hot soak tank vapor venting rates

Model year group	Age group	Non-I/M TVV rate [g/hr]	I/M TVV rate [g/hr]
Pre-1971	20+	5.455	5.116
1971-1977	10-14	3.099	2.957
	15-19	5.149	4.881
	20+	5.455	5.116
1978-1995	0-3	0.627	0.612
	4-5	0.627	0.612
	6-7	1.451	1.43
	8-9	1.471	1.455
	10-14	2.082	1.963
	15-19	3.492	3.225
	20+	3.817	3.49
1996-2003	0-3	0.124	0.099
	4-5	0.124	0.1
	6-7	0.15	0.1
	8-9	0.168	0.103
	10-14	0.25	0.113
	15-19	0.383	0.137
	20+	0.611	0.198
2004 and later	0-3	0.06	0.035
	4-5	0.06	0.036
	6-7	0.086	0.036
	8-9	0.105	0.039
	10-14	0.187	0.05
	15-19	0.323	0.074
	20+	0.553	0.137

3.3.3 Running Loss

Running Loss is the process of vapor venting that occurs during vehicle operation. Data for developing running loss emission rates came from CRC E-35[2,3] and CRC E-41[4,5]. Between these two programs 200 vehicles were testing with model years ranging from 1971-1997.

1) For each vehicle, we calculated fuel tank temperature at the end of the running loss test using the fuel tank temperature algorithm (see section 3.1.2). The running loss test performed in E-41 was the typical 4375-second LA-4 – NYCC – NYCC – LA-4 sequence, with two minute idle periods following the first LA-4, the second NYCC, and the final LA-4.
2) We found the average temperature during the test by assuming a linear increase in temperature during the test. Thus, the average was calculated by averaging the start temperature of the test and the final temperature of the test found in step 1.
3) We used this average temperature to determine the average permeation rate during the hot soak via the permeation temperature adjustment using the 72°F base permeation rates determine by model year, age.

4) We calculated gram/hour rates by dividing total emissions by the duration of the running loss test (4300 seconds)
5) We filtered/reduced the data set such that each test met the following requirements:
    a. Non-liquid-leakers (emissions less than 137.2 g/hour[17]; taken from M6.EVP.009, Section 2.4, Table 2-1)
    b. "As received" vehicles (no retests)
    c. Pressure test result must be pass, fail, or blank only (no dashes, slashes, "I", etc.)
6) Subtract permeation from HC for each hour to get tank vapor venting (*TVV*) rate
7) After analysis of TVV data, we found that the best way to stratify running loss TVV was by model year only. The table below shows the results of the analysis.

Table 7 - Final average running loss tank vapor venting emission rates

Model year group	TVV mean [g/hr]
Pre-1971	12.59
1971-1977	12.59
1978-1995	11.6
1996-2003	0.72
2004 and later	0.234

8) Since model year group is the only stratification available in the data, the running loss TVV rates for I/M and non-I/M rates are the same.

3.4 Inspection/Maintenance (I/M) Program effects

Our assumption in MOVES is that tank vapor venting is the only evaporative process where the benefits of I/M are realized. The types of evaporative tests performed in I/M programs (gas cap test, fill pipe pressure test, OBD scans) do not affect permeation or liquid leaks.

In order to develop I/M and non-I/M tank vapor venting rates, we used available data from I/M programs to determine the failure frequencies of evaporative control systems. These frequencies were then used to combine the rates for failing vehicles and those for passing vehicles. Details of each of the four programs in our dataset are in the table below.

Table 8- Description of evaporative characteristics of available I/M programs [18]

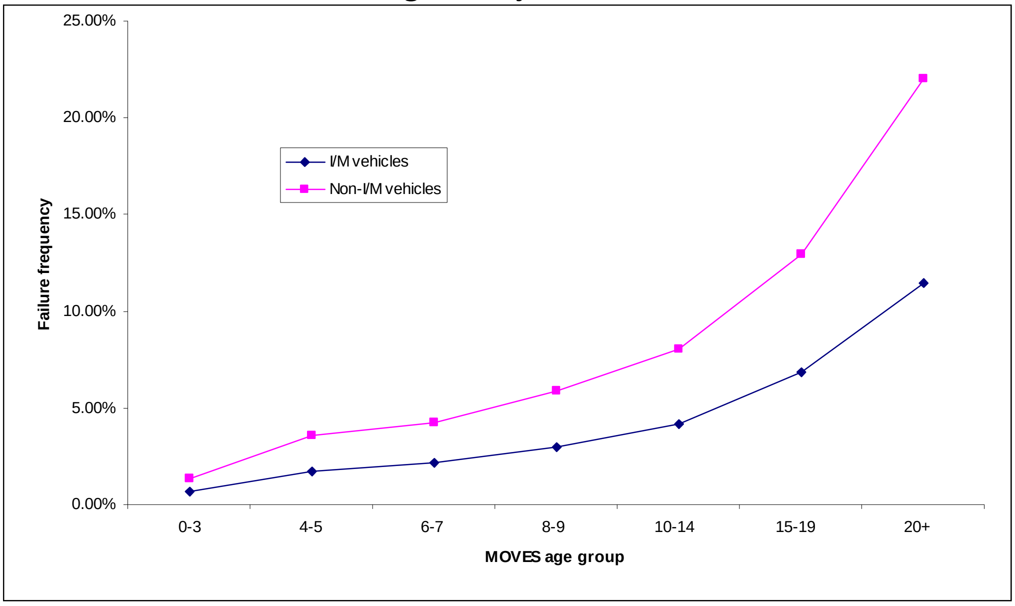
	Gas cap test	OBD	Pressure test	Frequency	Network	Calendar years
Colorado	*Y*	*Advisory only*	*N*	*Biennial*	*Hybrid*	*2003-2006*
N. Carolina	*N*	*Y*	*N*	*Annual*	*Decentralized*	*2002-2006*
Phoenix	*Y*	*Y*	*Y*	*Biennial*	*Centralized*	*2002-2006*
Tucson	*Y*	*Y*	*N*	*Annual*	*Centralized*	*2002-2006*

Since the Phoenix program contained the most extensive amount of data, we used it to develop the reference I/M evaporative failure frequency. The Tucson, Colorado, and North Carolina data were used to adjust the Phoenix numbers for differences in I/M programs.

The Phoenix evaporative I/M program used gas cap tests on all vehicles, OBD scans on OBD-equipped vehicles, and fill pipe pressure tests on pre-OBD vehicles. The OBD codes used to determine evaporative failures were P0440, P0442, P0445, P0446, and P0447 for all vehicle makes and additionally P1456 and P1457 for Honda and Acura vehicles. Vehicles that had one or more of these faults were flagged as failing vehicles, analogous to pre-OBD vehicles that failed the pressure test. Very few vehicles failed both the gas cap test and the pressure/OBD test. Therefore, our total number of failures was the sum of gas cap and pressure/OBD failures.

To determine failure frequencies for I/M areas, from the Phoenix data, we looked at the initial and final results for each vehicle in a given I/M cycle. For passing vehicles, the initial test and the final tests are one and the same. We averaged the initial and final failure frequencies (weighted equally) to calculate an overall I/M failure frequency by model year group and age group. Using the initial failure frequencies alone would neglect the effect of repair that most failing vehicles would be required to undergo, and using the final failure frequencies alone would neglect the existence of the failing vehicles driving around in the fleet in the first place. To determine non-I/M failure frequencies, we restricted our sample in the Phoenix data to those vehicles with license plates from states that do not have an I/M program anywhere. Figure 3 gives an example of how failure frequencies increase with age. Shown are frequencies for model years 1978-1995, where data was extrapolated for the youngest age groups.

Figure 3 – Evaporative failure frequencies for I/M and non-I/M vehicles in the Phoenix area showing model years 1978 to 1995.



The Tucson data was used to determine the effect of program frequency (annual vs. biennial). For OBD vehicles, Tucson performs gas cap and OBD tests annually, while Phoenix performs them biennially. Therefore, we were able to develop failure frequencies for annual programs by analyzing the Tucson data. We applied the ratio between Tucson and Phoenix to determine the failure frequencies for where we did not have data (e.g. pre-OBD vehicles).

The North Carolina data was used to determine non-I/M failure frequencies for OBD tests. In North Carolina, expansion of I/M program has led to counties where many vehicles were tested under the I/M program for the first time. Vehicles were flagged as non-I/M tests if they were tested:

- before the official start of the I/M program,
- in a new I/M county and were registered in that same county, or
- in a new I/M county and were registered in a non-I/M county or a county that did not start I/M within the last year.

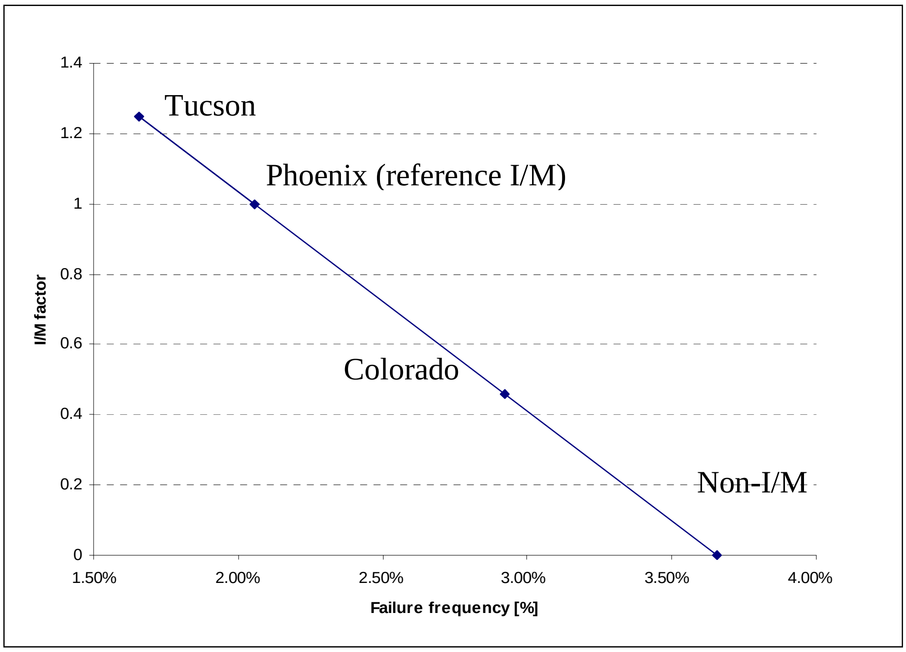
We compared those failure frequencies to those for vehicles tested in older I/M areas, where vehicles were previously tested. From the North Carolina data, the average ratio of non-I/M to I/M OBD failure frequencies is 1.6. This ratio was then applied to the Phoenix OBD and pressure test failure frequencies to determine non-I/M failure frequencies.

The Colorado data was used to determine non-I/M failure frequencies for gas cap tests. In Colorado, the I/M data comes mostly from the Denver and Boulder metropolitan areas. Many residents are new to this area, with many having moved in from non-I/M areas in Colorado or non-I/M states. Vehicles were flagged as non-I/M tests if their registration state was a 100% non-I/M state, or if the registration county was a non-I/M county in Colorado. We compared the failure rates of the flagged vehicles to those of the full tested fleet. The ratio of these two frequencies was then applied to the Phoenix gas cap failure frequencies to determine non-I/M failure frequencies. Colorado OBD data was not used, since OBD in Colorado is only advisory, and does not pass or fail a vehicle.

From the Colorado data, the average ratio of non-I/M to I/M gas cap failure frequencies is 2.2. This ratio was then applied to the gas cap failure frequencies to determine non-I/M failure frequencies.

The IM factor lets MOVES interpolate and extrapolate the non-I/M emission rates and the I/M emission rates depending on the characteristics of the I/M program in each county. Our reference program, Phoenix, was given an IM factor of 1. The non-I/M rates were given an IM factor of 0. For each model year group and age group stratification, we used the failure frequencies determined from the analysis described above to calculate IM factors for the diverse types of evaporative I/M programs. Figure 4 illustrates how the I/M factor is influenced by the types of evaporative tests conducted in I/M programs. We modeled the estimated failure frequency linearly with the I/M factor, with Phoenix, our reference program, always receiving a value of 1, and our non-I/M failure frequency always receiving a value of 0. Different programs move along the line, as determined by the analysis from above, based on which evaporative tests they choose to use. The figure is an example using model year group 1999-2003 and age group 4-5. For these vehicles, Tucson's OBD and gas cap tests are annual, compared to Phoenix's biennial requirement, which gives Tucson a lower failure frequency and a higher I/M factor. Colorado's frequency is biennial, like Phoenix's, but its OBD test is non-enforcing. As a result, their data shows a higher failure frequency, which results in a lower I/M factor.

Figure 4 – Example of how we calculated the I/M adjustment factor. This figure applies for model years 1999-2003 ages 4-5. The Phoenix and non-I/M results were used to construct the line.



A table showing the resulting evaporative failure frequency values by age group for all model years can be found in Appendix E.

3.5 Liquid Leaks

Liquid leaks are the final evaporative emissions process discussed in this document. Liquid leaks include any non-vapor form of fuel escaping the fuel system. To calculate the average leaking rate, we used the leaking vehicles excluded from the previous analysis for tank vapor venting. We estimated permeation and tank vapor venting on these vehicles using the calculation methods described in Section 3.2 *Permeation* and Section 3.3 *Tank Vapor Venting*. We assumed the remainder of emissions to be caused by liquid leaks. We averaged these emissions by the three different modes, shown in Table 9.

Table 9 – Emission rates [g/hr] for liquid leakers by mode.

Model year group	Liquid leak rate
Cold Soak	9.85
Hot Soak	19.0
Operating	178

The rates in Table 9 must be multiplied by the percentage of leakers in the fleet to get an average liquid leaking emission rate. For this we relied on the studies by BAR and API. Our estimates of the percentage of liquid leakers are shown in the table below. On average, we assume that most leaks do not occur until vehicles are 15 years or older.

Table 10 – Percentage of liquid leakers by age.

Age group	Percentage of leakers in fleet
0-9	0.09 %
10-14	0.25 %
15-19	0.77 %
20+	2.38 %

Combining Table 9 and Table 10, we get Table 11, which shows the liquid leaking rate of the entire fleet. We assume that this rate does not change with model year nor is it affected by I/M.

Table 11 – Final liquid leak rates in g/hr by age group and mode

Age group	Cold soak	Hot soak	Operating
0-9	0.009	0.017	0.158
10-14	0.025	0.048	0.450
15-19	0.075	0.145	1.36
20+	0.235	0.452	4.23

3.6 Refueling

Refueling emissions are the fuel vapors pushed out of the fuel tank when liquid fuel is added to the tank. The calculation of vapor losses includes any liquid fuel that is spilled during refueling and evaporates. Refueling emissions are determined on the basis of the total gallons of fuel dispensed based on average daily vehicle miles traveled and the estimated fuel consumption rates. Both the spillage and the vapor displacement associated with refueling events are in terms of grams spilled per gallon of fuel dispensed. Diesel fueled vehicles are assumed to have negligible vapor displacement, but fuel spillage is used to calculate grams of refueling loss for diesel vehicles.

Uncontrolled and unadjusted refueling emissions are the displaced grams per gallon of dispensed fuel, plus a small amount of grams (0.31) per gallon for spillage. AP-42 Volume I Section 5.2.2.3[19] lists the spillage as 0.7 lb/1000 gallons, which is 0.31g/gallon of fuel dispensed. The vapor displaced by refueling of gasoline fueled vehicles is calculated accounting for temperature and gasoline volatility using the Reid Vapor Pressure (RVP):

$$DISPL = -5.909 - 0.0949 * TDFDIF + 0.0884 * DFTEMP + 0.485 * RVP \qquad \textbf{Equation 12}$$

Where:
DISPL = grams of displaced vapor (all non-methane).
DFTEMP = dispensed gasoline temperature in degrees Fahrenheit.
RVP = gasoline Reid Vapor Pressure in pounds per square inch (psi).
TDFDIF = tank gasoline temperature (0.418*DFTEMP-16.6).

Temperatures are limited to those between 20 degrees and 95 degrees Fahrenheit. The TDFDIF value is not allowed to be greater than 20 degrees. For dispensed fuel temperature (DFTEMP) and the difference in temperature of the fuel in the vehicle and that of the dispensed fuel (TDFDIF), values that are outside the limits are set equal to the limits. The temperature limits reflect the range of the underlying data. The equation that determines the difference in temperature of the fuel in the vehicle and that of the dispensed fuel comes from a study done by Amoco[20]. In that study, the difference in temperature of the fuel in the vehicle and that of the dispensed fuel was never greater than 20 degrees.

Two additional factors affect the fuel lost during refueling. First, there exist programs designed to capture refueling vapors at the pump, often referred to as "Stage 2" or "Stage II" vapor control programs. Second, most modern vehicles have onboard refueling vapor recovery (ORVR) systems on gasoline fueled vehicles that capture vapors released during refueling in the vehicle's evaporative emissions canister.

The effectiveness of Stage 2 programs vary depending on the scope of the program, which affects how much of the gasoline fuel dispensed is affected by the control technologies, the technology employed to capture refueling emissions, the effectiveness of the technology in capturing all of the refueling emissions and reducing spillage and the state of repair (functionality) of the equipment. These factors will vary from area to area. MOVES uses two factors, to make adjustments to the refueling losses to account for Stage 2 programs.

Definition: refuelingVaporProgramAdjustment

The refuelingVaporProgramAdjustment is a number between zero and one which indicates the reduction in full refueling displacement vapor losses that result from state or local programs (such as Stage 2 recovery programs).

Definition: refuelingSpillProgramAdjustment

The refuelingSpillProgramAdjustment is a number between zero and one which indicates the reduction in full refueling spillage losses that result from state or local programs (such as Stage 2 recovery programs).

The program adjustments in MOVES are stored and applied on a county basis. Each county has a separate value for vapor and spillage program adjustments. The program adjustment values for each county in each calendar year are stored in the default MOVES database CountyYear table.

MOVES uses another factor to address the phase in for on-board refueling vapor recovery (ORVR) systems on vehicles. MOVES applies a 98 percent reduction in refueling vapor losses and 50 percent reduction in refueling spillage losses from uncontrolled levels for ORVR equipped vehicles. The effects of ORVR technology is phased in over several model years beginning in model year 1998.

Table 12 - Phase In of Onboard Refueling Vapor Recovery (ORVR) Systems

Model Year	Passemger Cars	Light Trucks <6,000 lbs GVWR	Light Trucks 6,000-8,500 lbs GVWR	Heavy Duty Trucks
1998	40%	0%	0%	0%
1999	80%	0%	0%	0%
2000	100%	0%	0%	0%
2001	100%	40%	0%	0%
2002	100%	80%	0%	0%
2003	100%	100%	0%	0%
2004	100%	100%	40%	40%
2005	100%	100%	80%	80%
2006 and Newer	100%	100%	100%	100%

Definition: refuelingTechAdjustment

The refuelingTechAdjustment is a number between zero and one which indicates the reduction in full refueling spillage losses that result from improvements in vehicle technology (such as the Onboard Refueling Vapor Recovery rule). The technology adjustment is applied the same in all locations.

The technology adjustment values are stored in the default MOVES database SourceTypeTechAdjustment table.

MOVES applies both the program adjustment and the technology adjustment to all model years. This means that Stage 2 programs are assumed to affect vehicles not affected by the technology adjustment (ORVR) and any refueling emissions that are not captured by the ORVR systems. MOVES does not account for the interaction between ORVR systems and the vapors stored at gasoline dispensing stations equipped with Stage 2 equipment.

The vapor losses (processid=18) and spillage losses (process=19) from refueling are reported by MOVES as separate emission processes.

Appendix A - Notes on Evaporative Emission Data

Parameters: Vehicle Numbers, Test #, Ambient Temperature, RVP, Model Year, Fuel System, Purge, Pressure, Canister, Gram HC, Retest

E-41 CRC Late Model In-Use Evap. Emission Hot Soak Study (1998)

- 50 vehicles (30 passenger cars and 20 light duty trucks)
- Model years 1992 to 1997
- Average RVP: 6.5 psi
- Diurnal Temperature: 72 to 96°F
- Fuel System: Port Fuel Injection, Throttle Body Injection
- Vehicle fuel tank drained and refilled to 40% of capacity with Federal Evaporative Emission Test Fuel
- Driving schedule will be a full LA-4-NYCC-NYCC-LA4 sequence, with two minute idle periods following the first LA-4, the second NYCC, and the final LA-4.
- Hydrocarbon readings will be taken continuously throughout the running loss test.
- Cumulative mass emissions will be reported at one minute intervals.
- Ambient Temperature in running loss enclosure: 95°F

E-9 CRC Real Time Diurnal Study (1996)

- 151 vehicles (51 vehicles MY 1971-1977, 50 vehicles MY 1980-1985, 50 vehicles MY 1986-1991)
- Odometers range from 39,000 to 439,000 miles
- Fuel tank volume was 15% of the rated capacity
- RVP: 6.62 psi (average sum of 47 vehicles)
- Diurnal temperature: 72 to 96°F
- Fuel System: Port Fuel Injection, Carburetor, Throttle Body Injection

CRC E-35 Running Loss Study (1997)

- 150 vehicles (50 vehicles MY 1971-1977, 50 vehicles MY 1980-1985, 50 vehicles MY 1986-1991)
- Ambient Temperature in running loss enclosure: 95°F
- RVP: 6.8 psi
- Fuel System: Port Fuel Injection, Carburetor, Throttle Body Injection

EPA Compliance Data

- 2-Day Test
- Length of the hot soak: 1 hour
- 77 vehicles
- RVP: average 8.81 psi
- Ambient Temperature:
- Federal Standard (72 to 96°F) Diurnal
- Cal. (65 to 105°F) Diurnal
- Hot Soak: 81.67°F

- Fuel System: Port Fuel Injection

Unleaded Cert Fuel

Sulfur	RVP	Date
wt %		
0.0048	9.04	Jul-98
0.0045	9.2	Dec-98
0.0063	9.04	Aug-99
0.0048	8.99	May-00
0.0042	9.05	Sep-01
0.003	9.12	Dec-01
0.003	9.12	Dec-02
0.0031	8.8	May-03
0.0035	8.91	Apr-04
0.0027	8.95	Jun-04

CARB Phase II Fuel

Sulfur	RVP	Date
wt %		
0.0023	6.92	Aug-99
0.0023	6.92	May-00
0.0038	6.92	Jan-01
0.0033	6.92	Oct-02
0.0036	6.77	Mar-04

MSOD (Mobile Source Observation Database):

Hot Soak: 1 hour hot soak evaporative test
FTP: Federal test procedure (19.53 mph), also referred to as the UDDP schedule
NYCC: New York City Cycle Test (7.04 mph)
BL_1A: 1 hour Breathing Loss Evap. Test – Gas Cap left “On”
BL_1B: 1 hour Breathing Loss Evap. Test – Canister as recd.
ST01: Engine Start cycle test
4HD: 4 hour Diurnal test
24RTD: 24 Hour Real Time Diurnal
33RTD: 33 Hour Real Time Diurnal
72RTD: 72 Hour Real Time Diurnal
3Rest: 3 Hour Resting Loss Evap. Emission Test (follows 1 HR Hot Soak)
CY6084: Real time diurnal temperature pattern: range 60 to 84 F
CY7296: Real time diurnal temperature pattern: range 72 to 96 F
CY8210: Real time diurnal temperature pattern: range 82 to 102 F
DIURBL: Standard temperature rise for 1 hour diurnal or breathing loss evaporative emission test
F505: Bag 1 of federal test procedure (25.55 mph)
ASM: Acceleration Simulation Mode Test Procedure
ATD: Ambient Temperature diurnal evaporative Test, shed temp constant, vehicle begins 24 degree cooler

Appendix B - CumTVVCoeffs Table

Cumulative Tank Vapor Vented Coefficients (Equation 7)									
		a1 (TermB)	a1 (TermB)	a2 (TermC)	a2 (TermC)	Non-I/M Case		I/M Case	
model year group	age group	pass	fail	pass	fail	tvvtermb	tvvtermc	tvvtermbim	tvvtermcim
1960-1970	20+	5.406	9.254	2.331	3.117	6.59	2.573	6.127	2.479
1971-1977	10-14	1.227	11.314	2.175	0.402	2.457	1.959	1.941	2.049
1971-1977	15-19	5.406	9.254	2.331	3.117	6.093	2.472	5.835	2.419
1971-1977	20+	5.406	9.254	2.331	3.117	6.59	2.573	6.127	2.479
1978-1995	0-3	1.578	3.073	0.44	1.338	1.599	0.452	1.589	0.446
1978-1995	4-5	1.578	3.073	0.44	1.338	1.631	0.471	1.604	0.455
1978-1995	6-7	1.578	3.073	0.44	1.338	1.642	0.478	1.61	0.459
1978-1995	8-9	1.578	3.073	0.44	1.338	1.666	0.492	1.623	0.466
1978-1995	10-14	0.849	11.314	2.095	0.402	1.692	1.959	1.283	2.025
1978-1995	15-19	3.743	9.254	2.246	3.117	4.458	2.359	4.12	2.305
1978-1995	20+	3.743	9.254	2.246	3.117	4.955	2.438	4.376	2.346
1996	0-3	1.339	3.073	0.344	1.338	1.369	0.36	1.354	0.352
1996	4-5	1.339	3.073	0.344	1.338	1.401	0.368	1.362	0.357
1996	6-7	1.339	3.073	0.344	1.338	1.419	0.385	1.376	0.365
1996	8-9	1.339	3.073	0.344	1.338	1.447	0.403	1.392	0.374
1996	10-14	0.756	9.666	1.668	0.589	1.477	1.582	1.124	1.624
1996	15-19	3.071	8.017	1.789	2.762	3.707	1.911	3.399	1.853
1996	20+	3.071	8.017	1.789	2.762	4.122	1.958	3.53	1.879
1997	0-3	1.1	3.073	0.248	1.338	1.14	0.268	1.12	0.259
1997	4-5	1.1	3.073	0.248	1.338	1.171	0.278	1.129	0.264
1997	6-7	1.1	3.073	0.248	1.338	1.196	0.297	1.146	0.273
1997	8-9	1.1	3.073	0.248	1.338	1.228	0.316	1.163	0.283
1997	10-14	0.663	8.018	1.241	0.776	1.263	1.203	0.976	1.222
1997	15-19	2.399	6.781	1.332	2.406	2.957	1.465	2.686	1.402
1997	20+	2.399	6.781	1.332	2.406	3.29	1.512	2.791	1.428
1998	0-3	0.502	3.073	0.009	1.338	0.567	0.042	0.538	0.027
1998	4-5	0.502	3.073	0.009	1.338	0.596	0.055	0.553	0.035
1998	6-7	0.502	3.073	0.009	1.338	0.639	0.078	0.575	0.046
1998	8-9	0.502	3.073	0.009	1.338	0.681	0.1	0.596	0.057
1998	10-14	0.429	3.897	0.174	1.244	0.727	0.267	0.589	0.223
1998	15-19	0.719	3.691	0.189	1.516	1.081	0.35	0.907	0.273
1998	20+	0.719	3.691	0.189	1.516	1.207	0.394	0.959	0.296
1999-2003	0-3	0.383	3.073	-0.039	1.338	0.453	-0.003	0.422	-0.019
1999-2003	4-5	0.383	3.073	-0.039	1.338	0.481	0.011	0.438	-0.011
1999-2003	6-7	0.383	3.073	-0.039	1.338	0.528	0.035	0.461	0.001
1999-2003	8-9	0.383	3.073	-0.039	1.338	0.572	0.057	0.483	0.012
1999-2003	10-14	0.383	3.073	-0.039	1.338	0.619	0.082	0.508	0.025
1999-2003	15-19	0.383	3.073	-0.039	1.338	0.706	0.126	0.552	0.048
1999-2003	20+	0.383	3.073	-0.039	1.338	0.791	0.17	0.595	0.07
2004 & later	0-3	0.124	3.073	-0.013	1.338	0.17	0.008	0.151	-0.001

Cumulative Tank Vapor Vented Coefficients (Equation 7)									
		a1 (TermB)	a1 (TermB)	a2 (TermC)	a2 (TermC)	Non-I/M Case		I/M Case	
model year group	age group	pass	fail	pass	fail	tvvtermb	tvvtermc	tvvtermbim	tvvtermcim
2004 & later	4-5	0.124	3.073	-0.013	1.338	0.189	0.017	0.161	0.004
2004 & later	6-7	0.124	3.073	-0.013	1.338	0.215	0.029	0.175	0.01
2004 & later	8-9	0.124	3.073	-0.013	1.338	0.24	0.04	0.187	0.016
2004 & later	10-14	0.124	3.073	-0.013	1.338	0.269	0.053	0.203	0.023
2004 & later	15-19	0.124	3.073	-0.013	1.338	0.319	0.077	0.229	0.035
2004 & later	20+	0.124	3.073	-0.013	1.338	0.368	0.099	0.255	0.047

Appendix C - MOVES Operating Modes and Emission Processes

opModeID	Operating mode description
150	Hot Soaking
151	Cold Soaking
300	Engine Operation

processID	Emission process description
11	Evap permeation
12	Evap vapor venting losses
13	Evap liquid leaks
18	Refueling displacement vapor losses
19	Refueling fuel spillage

Appendix D - Evaporative Pollutants

pollutantID	pollutantName	NEIPollutantCode	shortName
1	Total FID Hydrocarbons	HC	THC
20	Benzene	71432	Benzene
21	Ethanol		ETOH
22	Methyl tert-butyl ether	1634044	MTBE
40	2,2,4-Trimethylpentane	540841	2,2,4-Trimethylpentane
41	Ethyl Benzene	218019	Ethyl Benzene
42	Hexane	206440	Hexane
45	Toluene	85018	Toluene
46	Xylene	123386	Xylene
79	Non-Methane Hydrocarbons	NMHC	NMHC
80	Non-Methane Organic Gases	NMOG	NMOG
86	Total Organic Gases	TOG	TOG
87	Volatile Organic Compounds	VOC	VOC
185	Naphthalene gas	91203	Naphthalene Gas

Appendix E – Evaporative Failure Frequency

Non-I/M Evaporative Failure Frequency				
Age Group	**1960-1977**	**1978-1997**	**1998-2003**	**2004 and Later**
0-3		0.026	0.026	0.016
4-5		0.035	0.035	0.022
6-7		0.043	0.043	0.031
8-9		0.059	0.059	0.039
10-14	0.122	0.081	0.081	0.049
15-19	0.179	0.130	0.120	0.066
20+	0.308	0.220	0.152	0.083
Base I/M Evaporative Failure Frequency				
Age Group	**1960-1977**	**1978-1997**	**1998-2003**	**2004 and Later**
0-3		0.014	0.014	0.009
4-5		0.017	0.017	0.013
6-7		0.021	0.021	0.017
8-9		0.030	0.030	0.021
10-14	0.071	0.041	0.041	0.027
15-19	0.111	0.068	0.063	0.036
20+	0.187	0.115	0.079	0.044

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