Development of Evaporative Emissions Calculations for MOVES2014

USEPA Office of Transportation and Air Quality

Assessment and Standards Division

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This technical report does not necessarily represent final EPA decisions or positions. It is intended to present technical analysis of issues using data that are currently available. The purpose of 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.

Contents

1 Background

EPA's Office of Transportation and Air Quality (OTAQ) has developed the MOtor Vehicle Emission Simulator (MOVES). This emission modeling system estimates emissions for mobile sources covering a broad range of pollutants and allows multiple scale analysis. MOVES currently estimates emissions from cars, trucks & motorcycles.

Evaporative processes can account for a significant portion of gaseous hydrocarbon emissions from gasoline vehicles. Volatile hydrocarbons evaporate from the fuel system while a vehicle is refueling, parked or driving. Evaporative processes differ from exhaust emissions because none involve combustion; the sole process driving exhaust emissions. For this reason evaporative emissions require a different modeling approach. In the MOBILE models and certification test procedures, evaporative emissions were quantified by the test procedures used to measure them:

Running Loss - Vapor lost during vehicle operation.
Hot Soak - Vapor lost after turning off a vehicle.
DiurnalCold Soak - Vapor lost while parked at ambient temperature.
Refueling Loss - Vapor lost and spillage occurring during refueling.

For MOVES, a new approach has been adopted to model the underlying physical processes involved in evaporation of fuels. This modal approach characterizes the emissions by physical modes of generation. This improvement in MOVES is consistent with significant changes made in MOVES2010 when, for example, the model diverged from MOBILE6 speed bins to vehicle specific power (VSP) bins. Likewise, evaporative emissions can be separated by different emissions generation processes, each having its own engineering design characteristics and failure rates. This way, certain physical processes can be isolated, for example, Ethanol (EtOH) has a unique effect on permeation, which occurs in all the above modes. The approach used in MOVES categorizes evaporative emissions based on the evaporative mechanism, using the following processes:

Permeation - The migration of hydrocarbons through materials in the fuel system.
Tank Vapor Venting (TVV) - Uncontained vapor generated in fuel system.
Liquid Leaks - Liquid fuel leaking from the fuel system, ultimately evaporating.
Refueling Emissions - Spillage and vapor displacement as a result of refueling.

These processes occur in each operating mode (Running Loss, Hot Soak, Cold Soak) used in the MOVES model. Each emission process can be modeled over a user-defined mix of operating modes. This makes for more accurate modeling of scenarios that do not replicate test procedures. The emission processes used by MOVES and the operating modes used for evaporative processes are shown below.

Figure 1 illustrates the evaporative emission processes. Permeation occurs continuously through the tank walls, hoses, and seals. It is affected by fuel tank temperature and fuel properties. Vapor is generated by increasing tank temperature. These vapors are typically mitigated by a charcoal canister. If the canister is saturated or there are leaks in the system, vapors can bypass the emissions control system directly to the atmosphere. Liquid leaks can occur anywhere in the fuel system. Moreover, refueling displaces the vapor in the tank and can also result in spillage.

Table 1: MOVES opModes

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

Table 2: MOVES Emission Processes

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

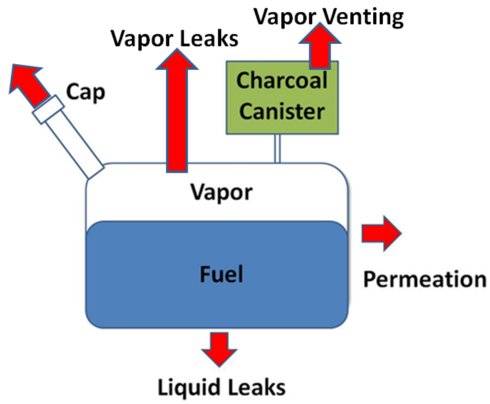
Evaporative emissions are a function of many variables. In MOVES, these variables include:

- Ambient Temperature
- Fuel Tank Temperature
- Model year group
  - Evaporative Emissions Standard
- Vehicle age
- Vehicle class
  - Passenger Vehicle
  - Motorcycle
  - Short/Long-haul Trucks
- Fuel Properties
  - Ethanol content
  - Reid Vapor Pressure (RVP)[1]
- Failure Modes
- Presence of inspection and maintenance (I/M) programs

Both ambient temperature and engine operation cause increases in fuel tank temperature. An increase in fuel tank temperature will generate more vapor in the tank. Activated charcoal canisters are a control strategy commonly used to adsorb the generated vapor. During engine operation, the canister is purged periodically and the captured vapor is diverted to the engine and burned as fuel. The emission certification standards for a vehicle (associated with model year and vehicle class)

[1] The MOVES fuel supply table provides the characteristics of gasoline sold in each county and month

Figure 1: Illustration of Evaporative Processes



influence the capacity of the canister system. When the generated vapor exceeds the capacity of the canister, the vapor is vented to the atmosphere. This can occur when a fuel undergoes a large ambient temperature increase, or if a higher volatile fuel is used, or when a vehicle canister collects vapor for many days without purging. MOVES accounts for co-mingling ethanol and non-ethanol gasoline and for RVP weathering of in-use fuel. Details on the Tank Fuel Generator are provided in the MOVES Software Design and Reference Manual

Fuel systems can develop liquid and vapor leaks that circumvent the vehicle emissions control system. Some inspection and maintenance (I/M) programs explicitly intend to identify vehicles in need of evaporative system repairs. Specific states also implement Stage 2 programs at gas stations to capture the vapors released during refueling. These programs capture refueling vapor with technology installed at the pump rather than internal to the vehicle.

The model year groups for evaporative emissions are shown in Table 3. They reflect evaporative emission standards and related technological improvements. Early control saw the introduction of activated charcoal canisters for controlling fuel vapor emissions. Later controls included fuel tanks and hoses built with more advanced materials less prone to allowing permeation emissions. Also, reduction of fittings and connections became an important consideration for vapor mitigation.

Evaporative emissions derive from fuels and are not directly affected by the combustion process, thus hydrocarbons such as methane that are not present in uncombusted fuels will not appear in evaporative emissions. Table 21 in Appendix A contains a list of the evaporative pollutants calculated by MOVES.

As shown, MOVES produces aggregate species (e.g Total hydrocarbons, Volatile Organic Compounds) and specific hydrocarbon species (e.g. benzene, ethanol) which are important mobile-source air toxics (MSATs). The MSAT emission rates are produced as ratios from the aggregate species as documented in a separate MOVES2014 report [16].

The data used for this evaporative analysis was collected on light-duty gasoline vehicles but will also be applied to heavy-duty gasoline vehicles since heavy-duty gasoline data is not available.

For diesel vehicles, it is assumed that there are no evaporative emission losses except for refueling spillage. All other diesel evaporative losses are considered negligible.

For compressed natural gas (CNG) vehicles, we are not aware of any relevant evaporative emissions

Table 3: Model Year Groups in MOVES

Model year group	**Evaporative 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
2004-2015	Tier 2, LEV II
2016-2017	40% Tier 3
2018-2019	60% Tier 3
2020-2021	80% Tier 3
2022+	Tier 3

data. CNG fuel systems and refueling procedures are significantly different from those of liquid petroleum-based fuels. For the current release of MOVES, all evaporative emission rates for CNG vehicles are set at zero.

2 Test Programs and Data Collection

The modeling of evaporative emissions in MOVES is based on data from a large number of studies. Over a decade of research has greatly modernized evaporative emissions modeling. New test procedures provide modal emissions data that greatly advance the state of the science. For example, the CRC E-77 test programs [19] [22] [20] [21] measured permeation emissions separately from vapor emissions. Implanted leak testing from these studies along with further field research has provided the first large database regarding the prevalence and severity of evaporative leaks and other malfunctions. Discoveries from these studies are introduced in MOVES2014 with the explicit modeling of vapor leaks. High evaporative emissions field studies used a portable test cell (PSHED) to measure in-use hot soak emissions on a large number of vehicles. The studies utilized an innovative sampling design which recruited the higher end of emissions more heavily with the aid of infrared ultraviolet remote sensing devices [12] [11].

Appendix A has a more detailed summary of these test programs.

Table 4: List of Research Programs

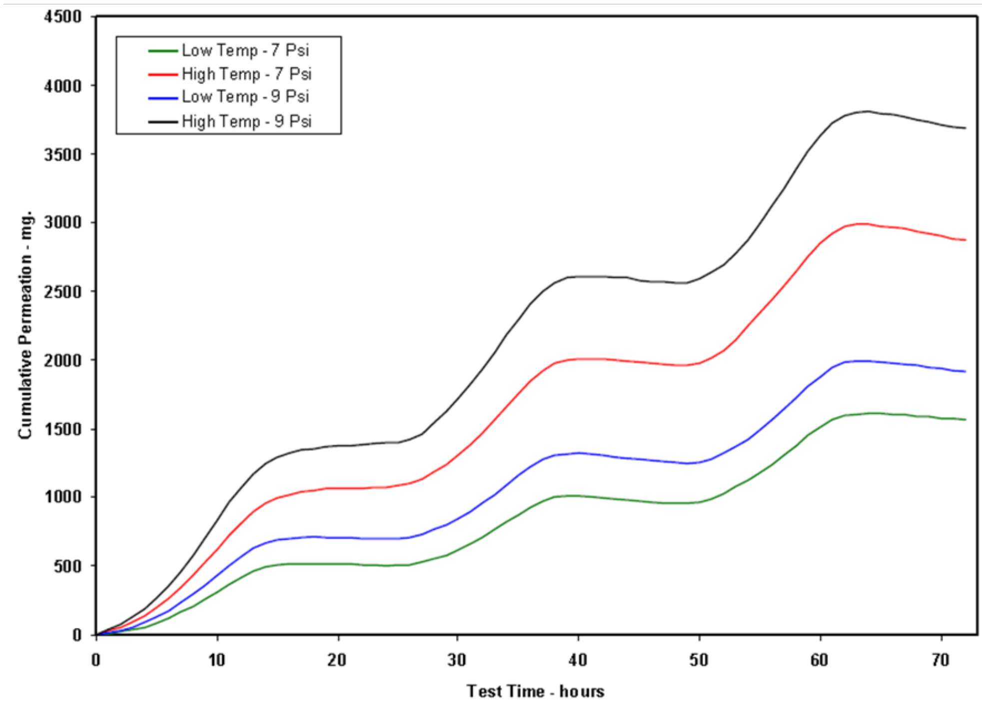
Program	# of Vehicles
CRC E-9 Measurement of Diurnal Emissions from In-Use Vehicles [2]	151
CRC E-35 Measurement of Running Loss Emissions in In-Use Vehicles [18]	150
CRC E-41 Evaporative Emissions from Late-Model In-Use Vehicles [3] [4]	50
CRC E-65 Fuel Permeation from Automotive Systems [23]	10
CRC E-65-3 Fuel Permeation from Automotive Systems: E0, E6, E10, and E85 [24]	10
CRC E-77 Vehicle Evaporative Emission Mechanisms: A Pilot Study [19]	8
CRC E-77-2 Enhanced Evaporative Emission Vehicles [22]	8
CRC E-77-2b Aging Enhanced Evaporative Emission Vehicles [20]	16
CRC E-77-2c Aging Enhanced Evaporative Emission Vehicles with E20 Fuel [21]	16
High Evap field studies [12] [11]	Thousands
Fourteen Day Diurnal study [27]	5
PI Leakage Study [5]	-
API Gas Cap Study [28]	-
EPA Compliance Testing [1]	Thousands

3 Design and Analysis

Fuel tank temperature is closely correlated with permeation and vapor venting as observed in the CRC E-77 pilot testing program [19]. This program tested ten vehicles in model years 1992 through 2007. The results showed that fuel temperature strongly influences evaporative emissions in all testing regimes. Fuel tank temperature is dependent on the daily ambient temperature profile and vehicle operation patterns. Modern vehicles (enhanced-evap, 1996 & later) do not recirculate fuel from the engine to the fuel tank and therefore have a lower temperature rise than older vehicles during operation. In Figure 2, the permeation emissions are plotted over a 3-day California diurnal test (65-105°F) as the low temp, and 85-120°F as the high temp. Both the effects of temperature and fuel volatility can be observed.

As emission standards have tightened, fuel system materials and connections have become more efficient at containing fuel vapors. Purge systems and canister technologies have also advanced, resulting in less vented emissions. Fuel tank temperature can be used in modeling permeation and vapor emissions. However, liquid leaks occur regardless and therefore are not dependent on temperature.

Figure 2: Permeation Temperature and RVP effects



3.1 Fuel Tank Temperature Generator

MOVES calculates fuel tank temperature for a given ambient temperature profile and vehicle trip schedule based on the vehicle type and model year. Different equations are used depending on the operating mode of the vehicle; running, hot soak, or cold soak. Fuel tanks are warmer during running operation than the ambient temperature. The routing of hot exhaust, vehicle speed, and airflow can all affect tank temperature. Immediately after the engine is turned off, the vehicle is in a hot-soak condition, and the fuel tank begins to cool to ambient temperature. In cold soak mode, the vehicle has reached ambient temperature.

Input parameters for the fuel tank temperature generator are:

- Hourly ambient temperature profile (zoneMonthHour table)
- Key on and key off times (sampleVehicleTrip table) [15]
- 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

3.1.1 Fuel Temperature for Hot and Cold Soaks

Equation 1 is used to model tank temperature as a function of ambient temperature.

$$\frac{dT_{tank}}{dt} = k(T_{air} - T_{tank}) \tag{1}$$

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 from EPA compliance data. Compliance data was available on 77 vehicles that underwent a 2-day diurnal test and had a 1-hour hot soak (See A). No distinction was made between hot and cold soak for this derivation. 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.

This equation only applies during 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 [15] and supporting contractor reports [30] [31]. The activity information is in the process of being updated for the next version of MOVES.

Mathematical steps:

1. 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.

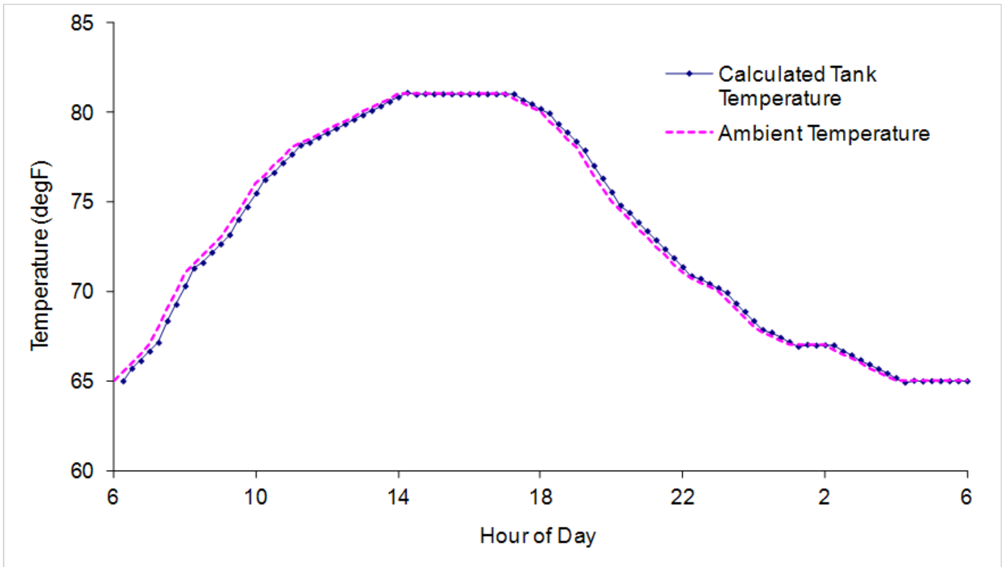
2. Then, for all t >0 and KeyOFF, the next tank temperature is calculated by integrating numerically[2] over the function for temperature change, using Equation 2

$$(T_{Tank})_{n+1} = T_{Tank} + k(T_{air} - T_{Tank})\Delta t \tag{2}$$

Figure 3 demonstrates the Euler approximation for calculating the tank temperature based on ambient temperature.

[2]Numerical integration is used to perform this step using 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.

Figure 3: Example Day Modeled with Euler Method



3.1.2 Fuel Temperature while Running

Vehicle trips are short compared to the length of the day. Therefore, we assume a linear temperature increase during a trip to improve model performance with minimal compromise to accuracy.

In this algorithm, we initially calculate the tank temperature increases over a period of 4,300 seconds (1.19 hr), which is the duration of the certification running loss test. To determine ΔT_{tank}, tank temperature, we must first find ΔT_{tank95}, the average increase in tank temperature during a standard 4300 second, 95°F running loss test. The algorithm models the increase in fuel tank temperature using the tank temperature at KeyON time, the amount of running time, and the vehicle type and technology. Newer technologies are able to reduce the heat transferred to the fuel tank. The MOVES ΔT_{tank95} temperatures are as follows:

- If the vehicle is pre-enhanced (pre-1996), vehicle type affects ΔT_{tank95}: [18]

  LDV $\Delta T_{tank95} = 35°F$
  LDT $\Delta T_{tank95} = 29°F$

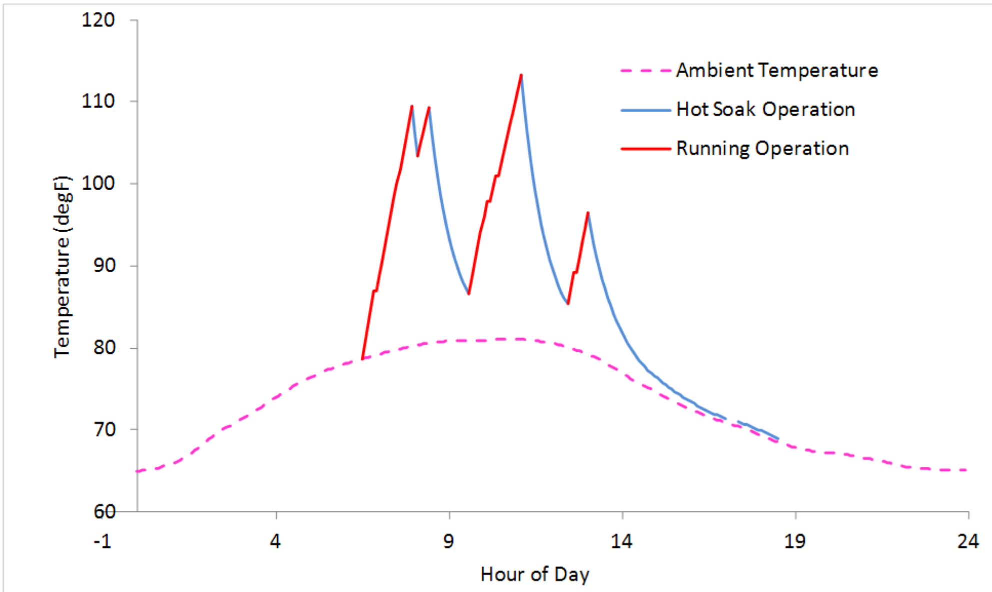
- If the vehicle is evap-enhanced (1996+):
- $\Delta T_{tank95} = 24°F$

These values are used to calculate the ΔT_{tank} for starting fuel tank temperatures using Equation 3.

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

The parameters in Equation 3 are derived from regression analyses of light-duty vehicles driving the running loss drive cycle with varied starting temperatures [9]. The lower the initial tank temperature, the larger the increase over a given drive cycle. The average ratio of fuel temperature

Figure 4: Modeled Vehicle Tank Temperature During a Day of Operation



increase to initial fuel temperature is -0.352. This gives us the increase in tank temperature so we can create a linear function that models fuel tank temperature for each trip.

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

where:

T_{Tank} = Tank temperature
t = Time
t_{keyON} = Time of engine start

The 4300/3600 in the Equation 4 denominator converts seconds to hours (4300 seconds in the running loss certification test), maintaining temporal consistency in the algorithm. The resultant tank temperatures for an example temperature cycle are illustrated in Figure 4. Running operation is shown as a red line, and hot soak operation is shown as a blue line.

Assumptions:

- The first trip is assumed to start halfway into the hour stated in the first trips HourDayID.
- The effect of a change in ambient temperature during a trip is 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 species that escape through micro-pores in pipes, fittings, fuel tanks, and other vehicle components (typically made of plastic or rubber). They differ from leaks in that they occur on the molecular level and do not represent a mechanical/material failure in a specific location. In MOVES, base permeation rates are estimated, and then adjusted for non-standard for tank temperature and fuel property conditions.

3.2.1 Base Rates

Permeation base rates are developed using the mg/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 were measured on the federal cycle (72F-96°F) for the CRC E-9 and E-41 programs [2] [3] [4]. Together, these two programs represent a total of 151 vehicles with model years ranging from 1971 to 1997. The final six hours of the diurnal are the most appropriate times to isolate the effect of permeation since the emission rate, ambient temperature, and fuel temperature are relatively stable or constant. Permeation should be the only evaporative process occurring. The rates are developed for distinct model year and age groups. Model years 1996-1998 are represented individually to reflect the 20/40/90% phase-in of enhanced evaporative emissions standards. Recent data from the E-65 and E-77 programs were not significantly different from the previous findings and served to validate the MOVES Tier 2 permeation base rates. Tier 3 standards will be introduced in 2016, and phase in over model years 2016-2022. The Tier 3 permeation standard reflects a 40% reduction from the previous standard and the introduction of 10% Ethanol to the certification fuel. MOVES base rates exist as if the fuel contains no ethanol. As will be explained later in the fuel effects section, with other factors remaining constant, the presence of ethanol increases permeation emissions approximately twofold, therefore the resultant 0% ethanol base rate is approximately 80% less than the previous standard. Permeation base rates for are presented in Table 5 below.

Table 5: Base Permeation Rates at 72°F

Model year group	Age group	Base permeation rate [g/hr]
1971-1977	10-14	0.192
1978-1995	0-5	0.055
1996	0-5	0.046
1997	0-5	0.037
1998	0-5	0.015
1999-2015	All Ages	0.010
2016-2017	All Ages	0.007
2018-2019	All Ages	0.006
2020-2021	All Ages	0.004
2022+	All Ages	0.003

3.2.2 Temperature Adjustment

The E-65 permeation study found that permeation rates, on average, double for every 18°F increase in temperature. [23] This study tested 10 vehicle fuel systems (the vehicle body was cut away from the fuel system, which remained intact on a frame) 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 same temperature as the certification test.

Equation 5 is derived from this study and used to adjust the base permeation rate.

$$P_{adj} = P_{base}e^{0.0385(T_{Tank}-T_{base})} \tag{5}$$

Where:

P_{base} = Base Permeation Rate
T_{Tank} = Tank Temperature
T_{base} = Base Temperature for a given cycle (e.g. 72° for a federal diurnal test)

3.2.3 Fuel Adjustment

Ethanol affects evaporative emissions from gasoline vehicles due to the increased permeation of fuel species through tanks and hoses. This behavior highlights a key MOVES feature to account for independent fuel effects for each unique emissions process.

Permeation fuel effects were developed from the CRC E-65 and E-65-3 programs, which measured evaporative emissions from ten fuel systems that were removed from the vehicles and filled with E0, E5.7, and E10 fuels. This method assures that the emissions measured are purely from permeation (assuming the systems were not leaking). Additional data was provided from the CRC E-77-2 and E-77-2b programs, which measured evaporative emissions from sixteen intact vehicles. For this analysis, vehicles certified to enhanced-evaporative and Tier 2 standards are analyzed separately from vehicles certified to earlier standards. Enhanced evaporative standards were phased in from 1996-1999 and imposed a 2.0 g standard over a 24-hour diurnal test. Standards previously in effect applied a 2.0 g standard to a 1-hour simulated diurnal.

The ethanol effect is estimated with a mixed model developed in this report. The evaporative certification level, ethanol content, and RVP were modeled as fixed effects and the particular vehicle modeled as a random effect. The natural logarithm of the emission rates over the 65-105-65°F diurnal cycle provided a normally distributed dataset to the model. The dataset was not large enough to find a significant effect for three ethanol levels within each evaporative certification. Therefore, E5.7 and E10 test results were binned into one category of Ethanol-containing fuel. Ethanol was then seen to have a significant effect compared to E0 fuel. The percent difference between the Ethanol rate and the E0 rate is used in MOVES as the fuel adjustment. Due to the enhanced-evaporative certification standards phase in from 1996-1999 (20/40/90/100%), the two fuel adjustments must also be phased in for those model years. The fuel adjustment in MOVES is based on a variable called fuelModelYearID. Table 6 lists the fuel adjustments used for E5 through E85 for the fuelModelYearIDs used in MOVES.

Table 6: Ethanol effect for Permeation Emissions

Model Years	Percent increase due to Ethanol
1995 and earlier	65.9
1996	75.5
1997-2000	107.3
2001 and later	113.8

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

3.3 Tank Vapor Venting

Vapor generated in the tank can escape to the atmosphere during a process labeled Tank Vapor Venting (TVV). Hydrocarbons emitted by this process originate from a variety of sources. As tank temperature rises and vapor is generated within the tank, the vapors are forced out of the tank from increased pressure. Fully sealed gas tanks are rare as they must be constructed with metal to prevent bloating. Using metal as a tank material can be expensive, heavy, and difficult to shape into tightly packed modern vehicles. Instead, most vehicles are equipped with an activated charcoal canister to adsorb the vapors as they are generated. Later, the vapors are consumed as they purge to the engine (through the intake manifold) during vehicle operation. The canister is open (or vented) to the atmosphere to prevent pressure from building within the fuel system. Consequently, if the engine is not operated for a long period of time, (several days) fuel vapors can diffuse through the charcoal, or even freely pass through a completely saturated canister. Tampering, mal-maintenance, and system failure can result in excess evaporative emissions. Inspection and maintenance (I/M) programs can also influence how leaks and other problems are controlled over the life of a vehicle.

Integral to the understanding of Tank Vapor Venting (TVV) is the calculation of Tank Vapor Generated (TVG). This is a function of the rise in fuel tank temperature (F), ethanol content (vol.%), vapor pressure (RVP, psi) and altitude. Calculations in MOVES use the Wade-Reddy equation for vapor generation.

$$TVG = Ae^{B*RVP}(e^{CT_x} - e^{CT_1}) \tag{6}$$

Where:

T_1 = Initial temperature
T_x = Temperature at time x

In Equation 6, coefficients A,B,C vary by altitude and fuel ethanol content. These coefficients are shown in Table 7.

Table 7: TVG Constants for Equation 6

	E0 Gasoline		E10 Gasoline	
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 vapor venting emission process occurs during all three operation modes: running, hot soak, and cold soak. While running, vapors are generated as the fuel system is warming and active. During hot soak, vapor generation is caused by latent heat transfer due to fuel recirculation and other convective processes. Cold soak vapor generation is concurrent with ambient temperature increases.

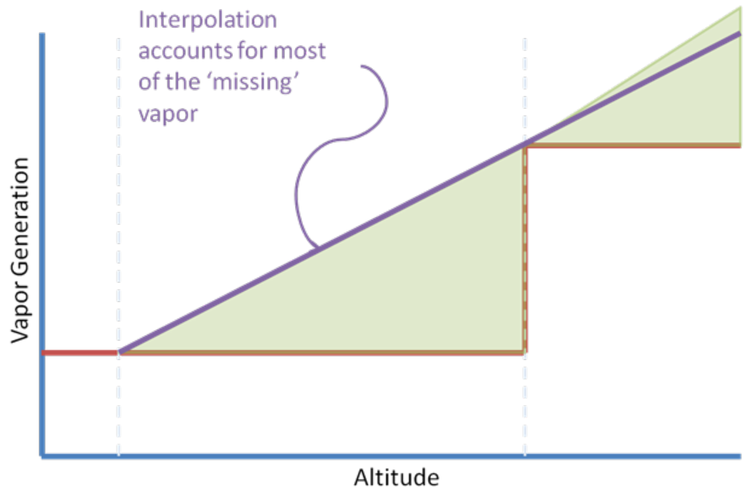
3.3.1 Altitude

Evaporative vapor generation is affected by the altitude (ambient pressure). MOVES accounts for this effect during the calculation of tank vapor generated. This process relies on the coefficients found in the tank vapor generation equation (Equation 6) for differing altitudes; a high altitude (Denver, CO) and a low altitude (Sea Level).

The MOVES database contains a binary flag for each county that determines which set of altitude coefficients to use. This either contains L or H for low or high altitude. Characterizing altitude this way creates a discontinuity in the calculation of evaporative emission rates.

In reality, evaporative vapor generation increases continuously as ambient pressure drops with increasing altitude. Counties with altitudes higher than sea level but lower than the cut-off for the

Figure 5: Illustration of Vapor Generation by Altitude



MOVES high altitude flag produce additional vapor not accounted for in MOVES2010, shown in Figure 5.

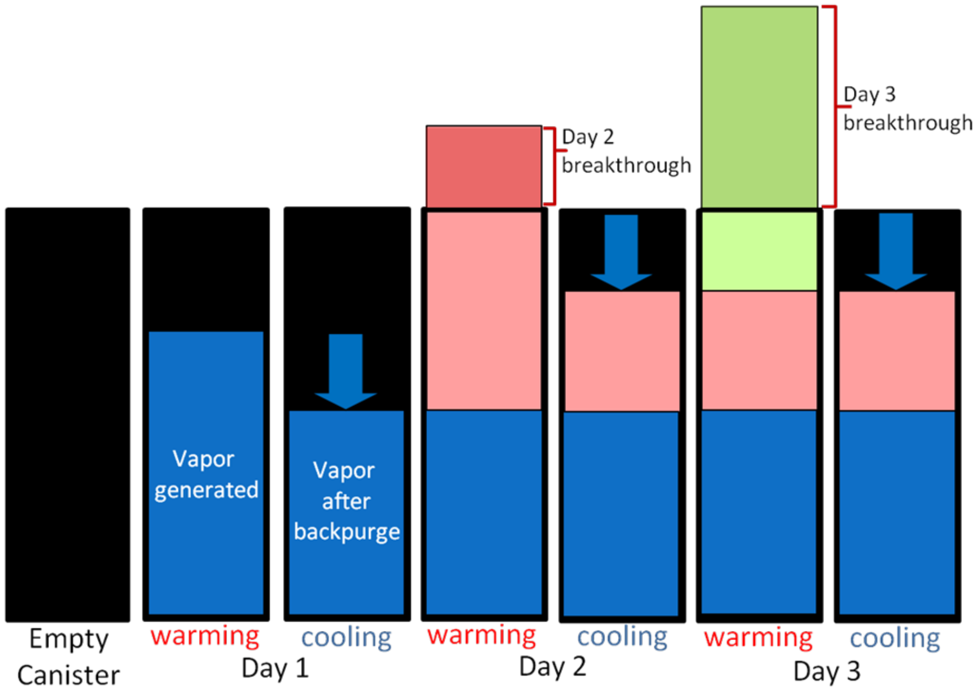
Update to MOVES Altitude Correction The tank vapor generated process has been updated from MOVES2010b to calculate evaporative emissions at all altitudes. A linear interpolation between sea level and Denver is performed to account for additional vapor generated between the low and high altitude equations. For counties with an altitude greater than that of Denver, an extrapolation is performed to calculate the additional vapor generation at higher altitude. This interpolation and extrapolation is show in Figure 5.

3.3.2 Cold Soak

Cold soak vapor emissions occur while a vehicle is not operating and the engine and fuel system have cooled to ambient temperature. Emissions occurring under these conditions are also referred to as diurnal emissions. For the first time, MOVES2014 introduces the modeling of multiple-day cold soaks and leaks. As a vehicle sits through multiple diurnal cycles, the carbon canister accumulates vapor every day. It can only adsorb vapor until it reaches its capacity; then it begins to vent to the atmosphere. A canister with degraded/damaged carbon may have reduced capacity, and eventually every canister will vent to the atmosphere once it reaches saturation. During cooling hours, a canister back purges to the fuel tank and regains some capacity. Then, during the subsequent warming period the canister is re-filled with vapor and any vapor generated beyond capacity will escape to the atmosphere.

The history of inventory quantification started with the measurement of emissions based on a standard regulatory test cycles. Examples included the FTP (tailpipe), 2 day diurnal/running loss test procedures (evap) etc. Over the years, as the emissions levels over the test cycles became more controlled with added technologies, there was concern over off-cycle emissions, i.e. emissions that occurred outside of the constraints of the test procedure. In MOVES2010, the model incorporated modal vehicle specific power (VSP) rates based on physical and causal mechanisms for tailpipe

Figure 6: Multiday Vapor Accumulation in Charcoal Canister

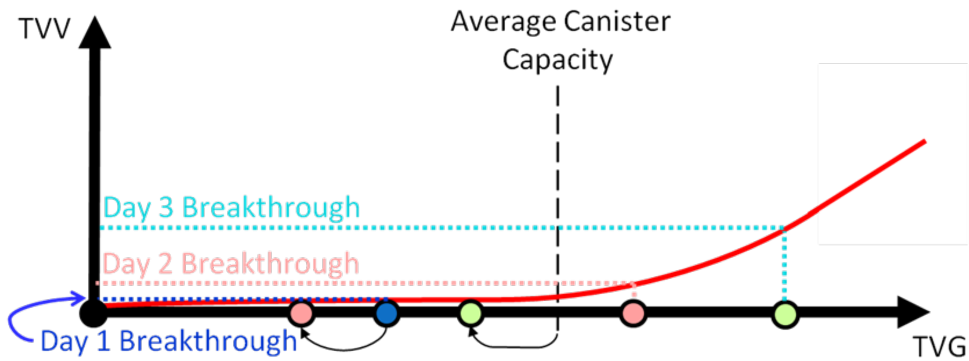


emissions formation. The higher VSP bins in this load-based model were designed to capture off-cycle emissions. In this instance, we attempt to quantify the evaporative emissions from off-cycle evaporative events, which we believe have the potential to significantly impact the emissions inventory. Off-cycle evaporative emissions occur during deviations from certification temperature ranges or fuel RVP, and also include multiple day diurnals emissions when a vehicle sits for longer than two or three days.

Figure 6 illustrates the dynamic behavior of vapor within a charcoal canister over three days of continuous cold soaking. During the first day, vapor accumulates within but does not exceed the canisters capacity. During the cooling period of day 1, we observe the backpurge behavior. Backpurge occurs when some of the fuel vapors that were previously adsorbed to the charcoal flow back into the cooling tank. The fresh air is drawn in through the canister vent while the vapor condenses in the tank during the cooling portion of the cycle. During warming on day 2, we see generated fuel vapors that exceed the canister capacity (though some canisters may be constructed to hold more than 2 days of vapor). These emissions are lost to the atmosphere, and only what remains in the canister can be backpurged during the subsequent cooling cycle. In day 3, more vapor is generated and consequently lost to the atmosphere. Any additional days without engine purge during normal driving (or as we call it: inactivity) will exhibit the same behavior as day 3. It should be mentioned that plug-in hybrid electric vehicles that are mainly driven on short (electric only) trips, may also exhibit similar breakthrough over time. However, modeling of these vehicles is beyond the scope of this effort at this time as the penetration rates of these technologies are quite low.

Modeling a fleet of vehicles involves a diverse population of canisters with differing capacities. A given amount of vapor will be fully contained by some vehicles but exceed the canister capacity in others. Figure 7 demonstrates the methodology for calculating the vapor vented (TVV) as a function of the vapor generated (TVG). Several factors accommodate this modeling approach. The

Figure 7: Vapor Vented Curve



importance of each variable will be explained along with relevant data sources and analysis. The following variables are included in the MOVES default database in the 'cumTvvCoeffs' table:

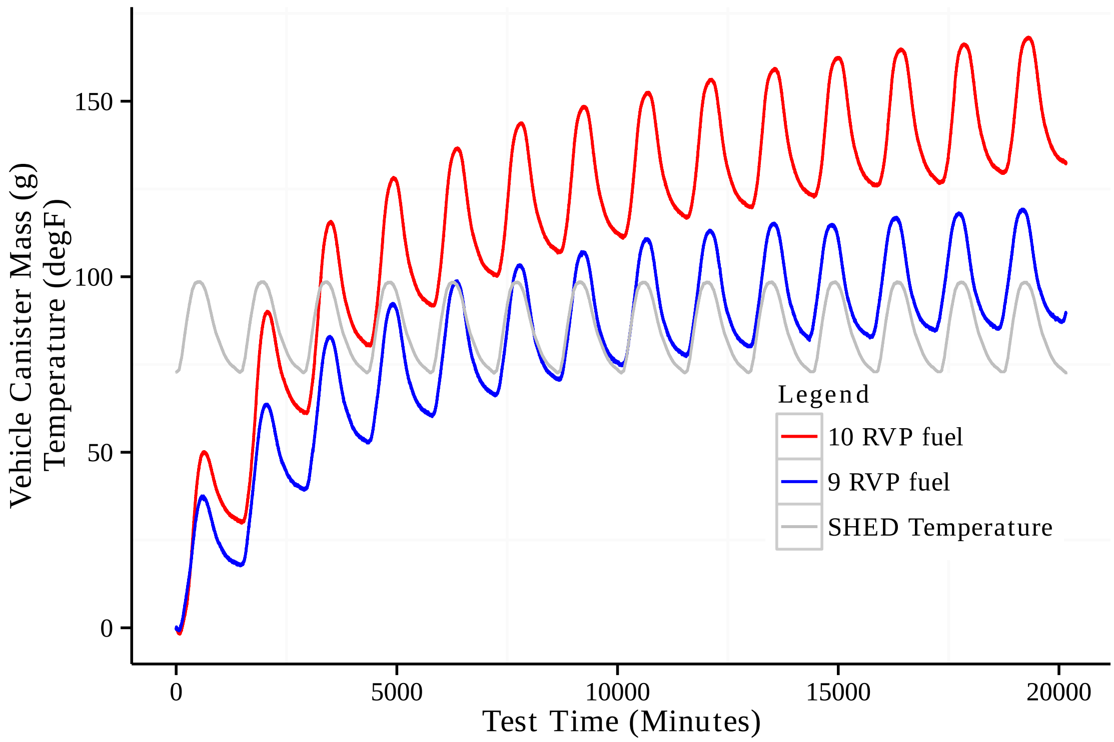
- Back Purge Factor
- Average Canister Capacity
- Tank Size
- Tank Fill Fraction
- Leak Fraction
- Leak Fraction IM
- TVV Equation
- Leak Equation

Back Purge Factor The back purge factor is the percent of hydrocarbon vapor that is desorbed from a vehicles canister during cooling hours. Pressure decreases within the tank, drawing ambient air in through the canister vent. In the real-world, this process occurs nightly as temperatures cool and restores some canister capacity. In the Multiday Diurnal Study, test vehicles soaked for 14 consecutive 72°F-96°F diurnals (the Federal Test Procedure temperature cycle). During this time, the vehicle canister mass was measured continuously. During the cooling period, the measured mass of the vehicle canisters decreased. This cyclical effect can be observed in Figure 8.

An average value of 23.8% backpurge was developed from these results and is used in the MOVES model. For example, a vehicle canister with 100 grams of hydrocarbons will backpurge 23.8 grams and begin the next day with 76.2 grams. A more complex model for backpurge was considered (similar to vapor generation) but would require a large computation demand and potentially slow model performance considerably. As diurnal temperatures are more or less symmetrical, heavy modeling on the front end (vapor generation) has already provided a high level of precision to the back end; justifying a simpler model.

Average Canister Capacity The canister capacity reflects how much vapor generated in the tank can be contained by the canister before breaking through. To calculate a sales-weighted average canister size, we used sales data [6] and EPA evaporation certification data [1]. Certification data includes the evaporative family code which contains the Butane Working Capacity (BWC) of the canister. It is found in digits 7, 8 and 9 for enhanced evap vehicles, and in digits 5,6 and 7 for pre-enhanced vehicles. The BWC represents the ability of a canister to capture butane vapor, rather

Figure 8: Vehicle X Canister Mass, 14-day Diurnal Test



than gasoline vapor, so it must be adjusted by a factor of 0.92 [25]. Exact matches between sales-data and cert-data are not possible for every vehicle make/model. Fortunately, canister size tends to correlate closely to tank size as onboard refueling vapor recovery (ORVR) also influences canister design. Since tank size is much more readily available information, an average tank-to-canister ratio for each model year is used for top-selling vehicle models with incomplete information.

Data is only available for model years 1990-2010. For years beyond 2010, the 2010 average canister capacity was used. Evaporative control was introduced in 1971, so for model years 1971-1989, a linear extrapolation is drawn backwards to 1971 through model years 1996-1990. The calculated average canister capacities for cars and trucks combined are listed in Table 8. A peak in average canister size at model year 2005 corresponds to greater sales of cars with larger fuel tanks.

Table 8: Average Canister Capacity by Model Year

Model Year Group	Average Canister Capacity (grams)
1960-1970	0
1971-1977	64.7
1978-1995	72.8
1996	78.7
1997	83
1998	115.4
1999-2003	122.9
2004	145
2005	150.7
2006	145.3
2007	142.9
2008	138.6
2009	136.2
2010+	137.5

Tank Size The average tank size for a given model year is an important facet of the vapor generation calculation because a larger tank will have more space in which vapor can accumulate. Both sales data [6] and tank size information [13], were required to calculated a sales-weighted average tank size for model years 1990-2010. For this analysis, car and truck sales, and tank sizes were combined. For vehicles with multiple trims with different tank sizes, the average available tank size was used as sales information is unavailable by trim. Data sources only span from 1990-2010 so past and future values must be projected. Vehicles in the 1990-2010 range have tanks with an average capacity of 1.25 times greater than a calculated 300 mile range, so this ratio is applied. With that, fuel economy becomes sufficient to estimate tank size, for which we have data to 1975 [14]. Vehicles pre-1975 use the 1975 fuel tank size. For future vehicles, tank size is assumed to stay constant from 2010 on. This is our current assumption, but will be revised as more information becomes available. The calculated sales-weighted tank sizes are in Table 9.

Table 9: Sales-Weighted Average Fuel Tank Size

Model Year Group	Tank Size (gal)
1960-1970	28
1971-1977	27.3
1978-1995	18.6
1996-1997	19.1
1998	19.5
1999-2003	19.9
2004	20.5
2005	20.3
2006	20
2007	19.7
2008	19
2009-2030	19.1
HD Vehicles	38

Tank Fill Fraction The tank fill fraction is an important input used in calculating tank vapor generation. The more vapor space above the liquid fuel, the more capacity there is for vapors to accumulate. The average tank fill fraction used in the model is 40% fill. This is a typical fill level for certification procedures and many of the test programs from which our data originates. It is also a figure supported by existing research on tank filling behavior by consumers [8].

Leak Prevalence In order to accurately quantify emissions from leaking vehicles, one must not only estimate emission rates from leaks of various sizes, but also the frequency of occurrence or the prevalence of leaks in the fleet. This corresponds to an emissions rate and its corresponding activity. Our estimates of leak prevalence are informed by the analysis of a field study which took place at the Ken Caryl IM Station in Denver, CO during the summer of 2009 [11]. In this study, a remote sensing device (RSD) was used to recruit high emitting vehicles which were then measured in a Portable Sealed Housing for Evaporative Detection (PSHED). The vehicles hydrocarbon emissions were measured over 15 minutes during hot-soak conditions, and vehicles were inspected to identify the cause/source of the leaks when possible. The set of hot-soak measurement from individual vehicles, with inverse-probability sampling weights and solicitation response weights applied to all vehicles, allows the prevalence of leaks in the fleet to be estimated.

Table 10 (Plotted in Figure 9) displays leak prevalence at various emission thresholds for what constitutes a "leak". Observing the difference between any two points determines how many vehicles fall into a particular range. For example, in model year group 1981-1995, 2.6% of vehicles are leaking at more than 20 g and 4.2% of vehicles are leaking at more than 10g. Subtracting these two values yields that 1.6% of vehicles in the model year group have a leak between 10g and 20g.

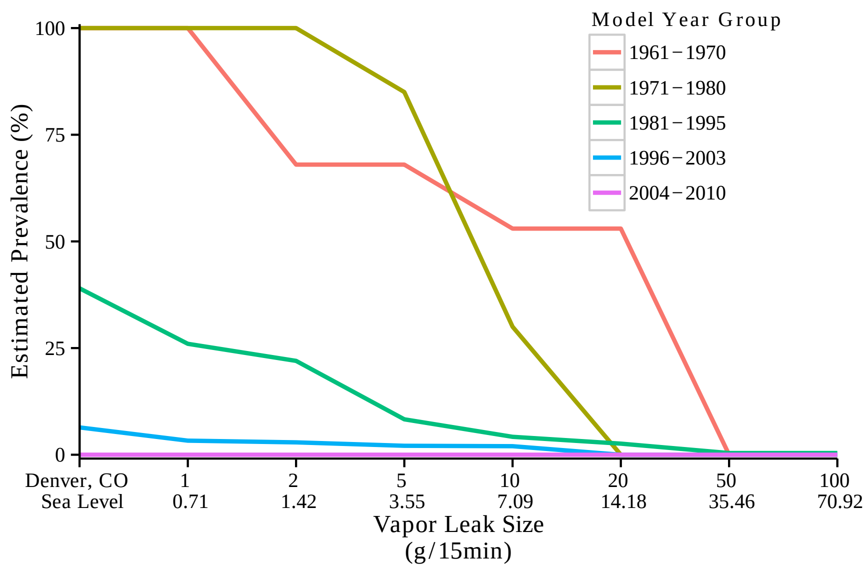
We have defined a vapor leaker as any vehicle that would fail the enhanced evaporative standard of 2 grams. The standard sums the emissions from the worst day of a 3-day diurnal test and the hot soak. To develop a surrogate standard for a 15-minute hot soak test, we used knowledge of

Table 10: Prevalence of Leaks above a given Threshold (g/15min)

Model Year Range **Sea Level Scale (MOVES)**	100 70.9	50 35.5	20 14.1	10 7	5 3.6	2 1.4	1 .7	0.3 .2
1961 - 1970	0	0	0.53	0.53	0.68	0.68	1	1
1971 - 1980	0	0	0	0.3	0.85	1	1	1
1981 - 1995	0.004	0.004	0.026	0.042	0.083	0.22	0.26	0.39
1996 - 2003	0	0	0	0.02	0.021	0.029	0.033	0.064
2004 - 2010	0	0	0	0	0	0	0	0

certification testing to attribute 0.4 grams (g) of the 2g standard to the hot soak portion, and, 76% of 0.4 g to the first 15 minutes of the hour-long hot soak test. This approach suggests that 0.3 g can be taken as a surrogate standard for a 15 minute hot soak.

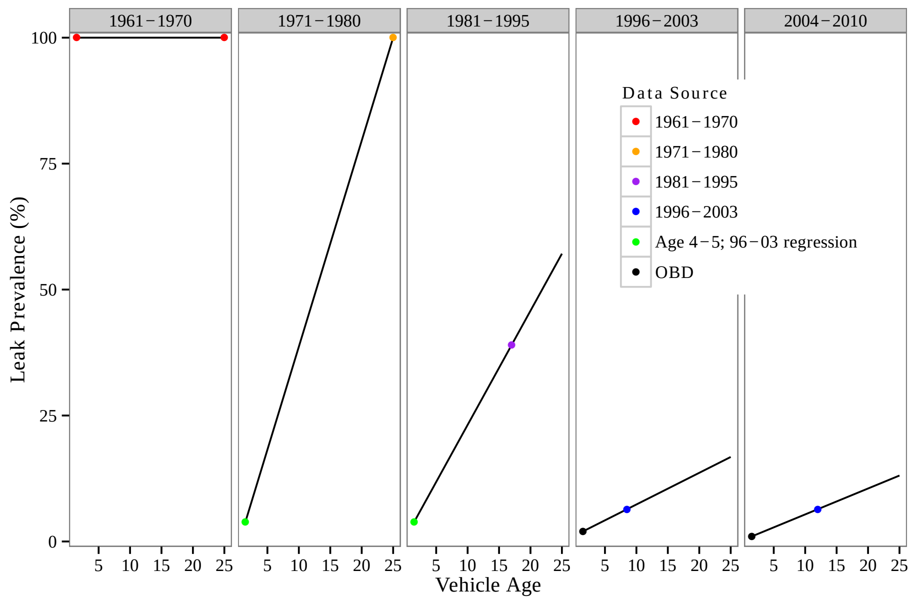
Figure 9: Prevalence of Vapor Leaks above a given Threshold in the 2009 Ken Caryl Fleet



The data only contain prevalence rates for PSHED measurements as low as 1.0g/15min. Failure rates are extrapolated to 0.3g/15min. Using aggregate data from the Ken Caryl station, it is found that 0.3g/15min PSHED measurements are 50% more prevalent than 1.0g/15min PSHED measurements.

Because the data used to estimate leak prevalence was collected in Denver, Colorado at an altitude of 5,280 feet above sea level, measurements must be adjusted to sea level. At sea level, the amount of vapor generated will be less, due to higher atmospheric pressure. To determine the appropriate correction factor, we performed the Wade-Reddy calculation and found that under identical conditions, the higher altitude will generate 41% more vapor. Colorado is a strategic location to perform a leak quantification program because a given vapor leak will produce higher levels of emissions at a higher altitude, therefore making it easier to detect. Each of the leak magnitude bins have been

Figure 10: Non-IM Vapor Leak Prevalence, Extrapolated from data



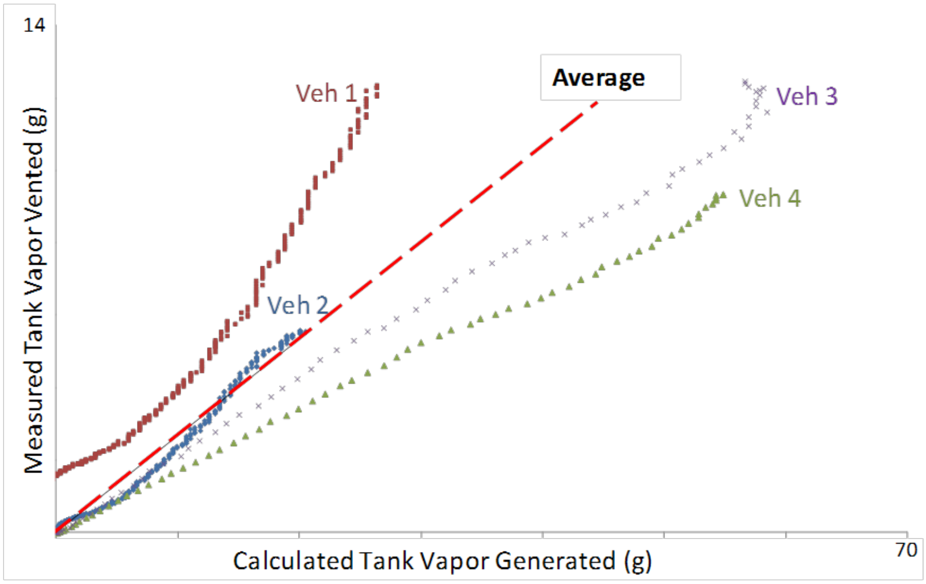
corrected for altitude by this factor. For example, the prevalence of leaks at 1g-2g levels in Denver will be the same prevalence of leaks at .71g-1.42g levels at sea level.

Because this was a cross-sectional study, many model year and age group combinations are not possible to measure, yet must exist in the model. A set of linear regressions is used to model vapor leak prevalence for ages and model years where data is not available. We divide model year groups in years when new technologies or standards were introduced. Modeling is based on the assumption that newer cars will have lower leak prevalence than older cars due to the advancing technology and use of more durable materials. Therefore, data from the 1996-2003 model year group is used as a surrogate for new vehicles in the 1971-1980 and 1981-1995 model year groups. However, because vapor leaks also occur due to tampering and mal-maintenance, deterioration is not the only factor involved in occurrence of vapor leaks. The regressions from the older model year show more rapid vehicle deterioration rates than newer model years.

Figure 10 shows the vapor leak prevalence as the percent of the vehicle fleet with a leak larger than 0.3g/15min. For model years 1996 and later, the estimate for leak prevalence at ages 0-3 was developed with I/M data from five states. The analysis revealed that 1-2% of vehicles consistently arrived at I/M stations with an evap Diagnostic Trouble Code (DTC) set. The vast majority of the DTCs set specifically indicated a vapor leak detected. The green diamonds in the 1971-1980 and 1981-1995 are an assumption made based on the 1996-2003 data to describe these vehicles leak rates when they were new. The slope of the 2004-2010 prevalence rates was developed by applying the 5-10 year old 1996-2003 data point to the 10-15 year old 2004-2010 point.

Leak Emissions Equation In MOVES2014, leak vapor emissions are a distinct emissions mode, separate from vapor emissions vented from the canister during normal operation. It is important to characterize leaking emissions separately because they can potentially be orders of magnitude higher than the other emissions modes described above. Unlike non-leak emissions, leak emissions

Figure 11: SHED Leak Emissions for one Severity Bin



can be modeled as a linear function with vapor generation. In Figure 11, measured vapor emissions are plotted on the y-axis against the calculated tank vapor generated. The average for four vehicles is overlaid and is used as the representative leak emission rate in MOVES.

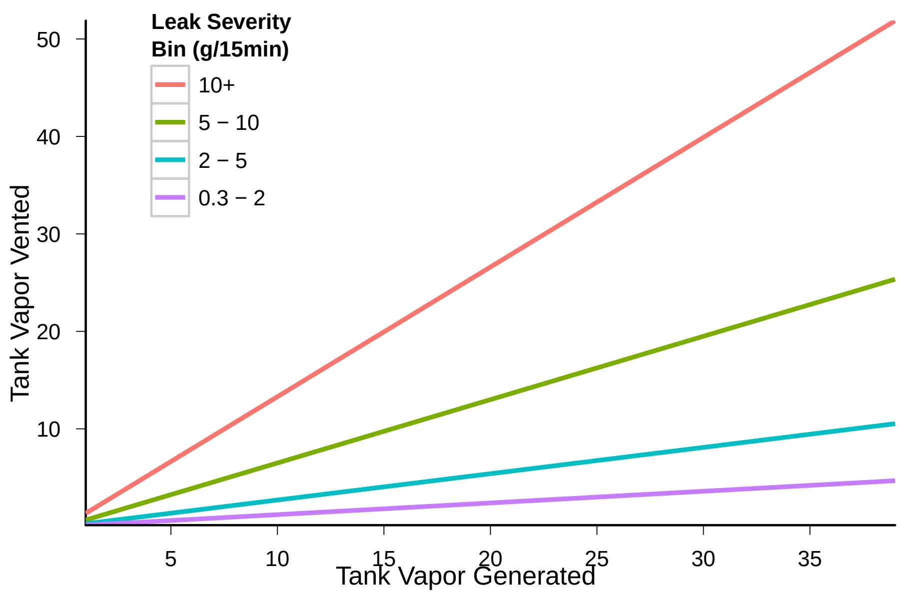
Vapor generated in the tank (TVG) is calculated using the Wade-Reddy equation, thus requiring fuel RVP, fuel ethanol content, and temperature data. Two datasets containing this information were used in developing leak emission rates. The E-77 suite of programs 8, 9, 10, 11 measured high-emitting vehicles, with known fuel properties and artificially implanted leaks on the California (65°F-105°F) diurnal cycle. In another effort, the Colorado Department of Public Health and Environment (CDPHE) carried out a repair effectiveness program during the summer of 2010 in collaboration with the Regional Air Quality Council (RAQC). This program [26] measured 16 vehicles with identified leaks. A 6-hour test was performed with a temperature increase of 72°F-96°F. This effort was less resource-intensive than the full diurnal procedure and still provides the necessary information to calculate TVG. The SHED measurements of Tank Vapor Vented (TVV) and calculated TVG form the basis for a linear regression of TVV vs. TVG for each vehicle. The resulting slope represents the mass of vapor vented per mass of vapor generated. The average of the regressions becomes the leak rate for that severity bin. This approach can be observed in Figure 11. Permeation and leak vapor emissions were indistinguishable using this testing procedure. However, for these vehicles permeation is assumed to be negligible during the 6 hour test given the severity of the leak emissions. In the E-77 program, TVV emissions were collected in a canister external to the SHED. The external canister was connected to the vent on the vehicle canister. No permeation was included in the measurement.

Because the emissions measured are highly variable; spanning several orders of magnitude, the emissions data for leaking vehicles are binned by magnitude. Accordingly, both emission rates and prevalence are calculated within these bins. As the leak prevalence estimates were measured at high altitude in Denver, it is essential to develop adjustments to apply the binning process at lower

Table 11: Leak Emission Rates by Bin

Denver bins (g/15min)	Sea Level bins (g/15min)	Grams vented / Grams generated
0.3 - 2	0.2 - 1.4	0.12
2 - 5	1.4 - 3.6	0.27
5 - 10	3.6 - 7.1	0.65
>10	>7.1	1.33

Figure 12: Leak Emission Rates by Leak Severity Bin



altitudes, such as sea level. Application of Equation 6 suggests that an E10 fuel in Denver generates 1.41 times as much vapor as at sea level. For example, a vapor leak at 0.3g/15min in Denver would have an equivalent rate of 0.21g/15min at sea level. The bins used to categorize leak severity as well as the average leak emission rate for that bin are listed in Table 11.

Each data point is binned by its hot soak measurement from the E-77 programs or PSHED (Portable SHED) measurement from the Denver program. The PSHED tests are 15 minute hot soak measurements.

Figure 12 illustrates the leak emission rates for each leak severity bin. The average emission rate for vehicles with 15-min hot soak measurements greater than 10g exceeds 1. It is possible to measure more fuel vapor in the shed than is calculated with Equation 6. It is known that the equation is less reliable at higher temperatures. Also, complicated factors such as fuel sloshing and tank geometry can influence vapor generation beyond the estimation capabilities of the Wade-Reddy equation.

Estimation of Tank Vapor Vented For normally operating non-leaking vehicles, tank vapor vented (TVV) from the canister is calculated. This quantity of vapor is calculated with Equation

6 calculates tank vapor generated in g/gal-headspace The model uses tank size and tank fill to calculate the headspace volume for a given vehicle. This information allows calculating the total vapor generated inside the tank. Equation 7 is the final calculation of TVG, where a, b, and c are the appropriate coefficients.

$$TVG = (ae^{b(RVP)}(e^{ct2} - e^{ct1})) * (tankSize * (1 - tankFill)) \tag{7}$$

With TVG as an input, the TVV equation estimates the amount of vapor vented. During a model run, MOVES2014 calculates vapor vented for consecutive days. The algorithm accounts for average canister capacity (ACC) and backpurge factor. Daily backpurge removes fuel vapors from the canister, increasing capacity to store vapor generated during successive days. Vapor generated above the ACC is lost to the atmosphere, therefore backpurge only applies to what remains in the canister.

$$If X_n < ACC, then X_{n+1} = ((1 - backpurgeFactor) * X_n) + TVG \tag{8a}$$

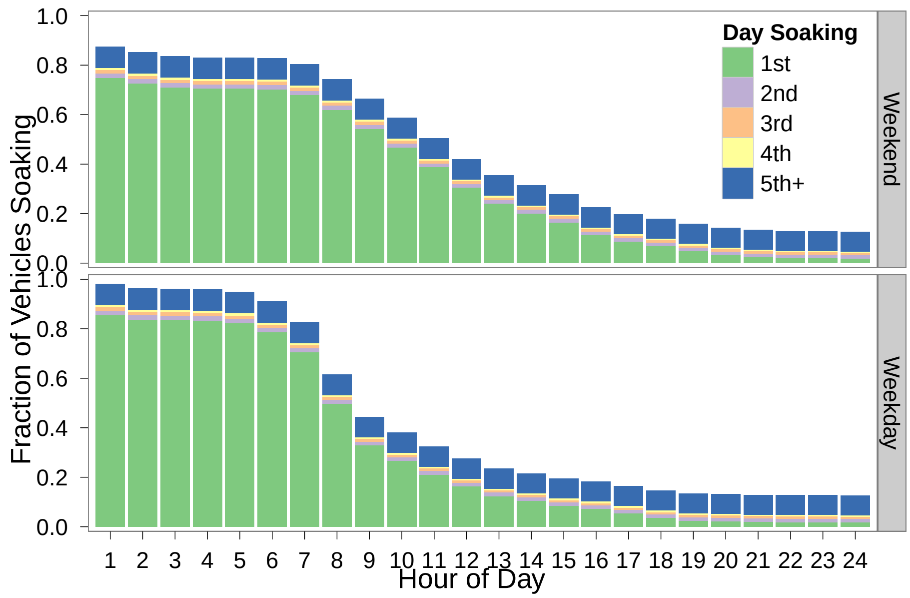
$$If X_n \geq ACC, then X_{n+1} = ((1 - backpurgeFactor) * ACC) + TVG \tag{8b}$$

In Equation 8a, Xn represents the TVG on Day n. The conditions in Equation 8a will determine the vapor generated for each day until n=5. To maintain model performance, emissions are calculated for a maximum of five successive days. Beyond five days, the algorithm assumes that breakthrough has occurred and that behavior over additional days has stabilized. The vapor emissions are fleet averages by model year group. Emissions rise as more vehicles are exceeding their canister capacities and begin venting fuel vapors. The development of the emission rates is covered in greater detail in the DELTA report. [7]

Activity Vehicles in MOVES2010 have trip and soak activity data for one day. However, as we have shown, diurnal evaporative emissions are dependent on number of consecutive days soaking. In order to properly account for these off-cycle emissions, MOVES must account for the different emissions rates of short (several hours) and long (multiple day) soaks. Because MOVES2010 only simulates activity for a single day, the fraction of vehicles soaking since midnight on a typical day include vehicles having soaked for less than one vehicles having soaked for one or more days. As vehicles begin starting throughout the day, the soaking population dwindles until only a small fraction remains soaking at the end of the day.

For any modeled day, there is a sub-population of vehicles exhibiting 1^{st}, 2^{nd}, 3^{rd}, n^{th} day diurnal emissions. The fractional allocations for 1^{st}, 2^{nd}, 3^{rd}, n^{th} day diurnals are calculated from the sampleVehicleTrip and sampleVehicleDays tables in MOVES. SampleVehicleTrip assigns numbers of first starts during each hour of the day. For the fraction of vehicles having soaked since at least midnight, the first engine start ends the cold soak episode. SampleVehicleDay contains the population of vehicles for each sourceTypeID. Combining information for both tables, it is simple to calculate the fraction of vehicles having soaked since midnight at any given hour. For example, at 1:00AM, some fraction of vehicles less than 100% have not yet started. The fraction continuously decreases throughout the day as more and more vehicles start. At 12:00AM, the fraction only represents vehicles that were not driven.

Figure 13: Passenger Car soak Distribution



Once the fraction of vehicles soaking at a given hour has been calculated, it must be estimated how many prior days each has been soaking. We classify vehicles as 1^{st} day, 2^{nd} day, 3^{rd} day, 4^{th} day, or 5+ days. We assume that after the 5^{th} day, vehicles will exhibit repeat emissions since the evaporative canister will either have broken through or be in conditions that will never cause breakthrough. Via an activity study performed by Georgia Technological University [17] and discussions with author, Randall Guensler, it was found that 16% of vehicles drive less than 3,000 miles per year. The MOVES inputs are based on the conservative estimate that 50% of these low-mileage vehicles, or 8% of all vehicles, have been soaking for more than 5 days on any given day.

The sampleVehicleSoakingDay table establishes the fraction of vehicles soaking for 5+ days. It contains 5 values, one for each soak day. The value for SoakDayID 1 is the percentage of vehicles soaking at the final hour of day 1. The product of SoakDayID=1 and SoakDayID=2 is the percent of vehicles soaking at the final hour of day 2. The product of all five values is the percent of vehicles soaking for five days or longer.

Figure 13 presents the fraction of soaking vehicles throughout the day. The majority of vehicles have driven the previous day, and are on their first day soaking. The fractions of vehicles on 2nd 4th day soaking are developed from the remainder of 1st day soaking vehicles at hour 24. The fraction of vehicles soaking for 5 days or longer is 8% at hour 24. This method models bimodal vehicle usage; with most vehicles being driven almost daily and the remaining vehicles being driven more intermittently.

3.3.3 Hot Soak

Hot-soak vapor emissions begin immediately after a car ceases operation and continue until the fuel tank reaches ambient temperature. In MOVES, the process of calculating hot-soak vapor emissions

Table 12: Recent Hot soak Evaporative Test Programs

Program	Location	Hot Soak Length	Fuel RVP	Altitude (ft)	No. Obs.
High Evap	Lipan IM station, CO	15 min	Fuel Supply	5130	100
High Evap	Ken Caryl IM station, CO	15min	Fuel Supply	5130	175
High Evap	Denver IM station, CO	15min, 1 hour	Fuel Supply	5130	100
E-77-2	Mesa, AZ	1 hour	7, 9, 10	1243	100

is simpler than that for cold soak. Base rates exist for each model year and age group and are expressed in units of grams per hour. They represent emissions at sea level with RVP assumed at 9.0 psi. In developing the rates, leak and non-leak rates are weighted together to form the base rate, similar to cold soak.

Hot soak data comes from several programs with diverse testing procedures, vehicle model years and technology, fuel Ethanol/RVP, and altitude. These programs include three summer programs in Colorado and the E-77-2 programs in Arizona.

There are many variables affecting hot soak emissions which need to be normalized into a uniform set of conditions native to the MOVES emission rate database.

These measurements differ from the default MOVES rates by length of test, fuel volatility (RVP), and altitude. Fifteen minute measurements need to be extrapolated to one hour totals. This translation cannot be made using a simple 4 multiplier due to non-linear cooling of engines and fuel systems. Measurements made on fuels with RVP higher or lower than 9.0 psi need appropriate corrections to estimate equivalent base values at 9.0 psi. Finally, measurements made thousands of feet above sea level need correction for the increased vapor generation occurring at higher altitudes.

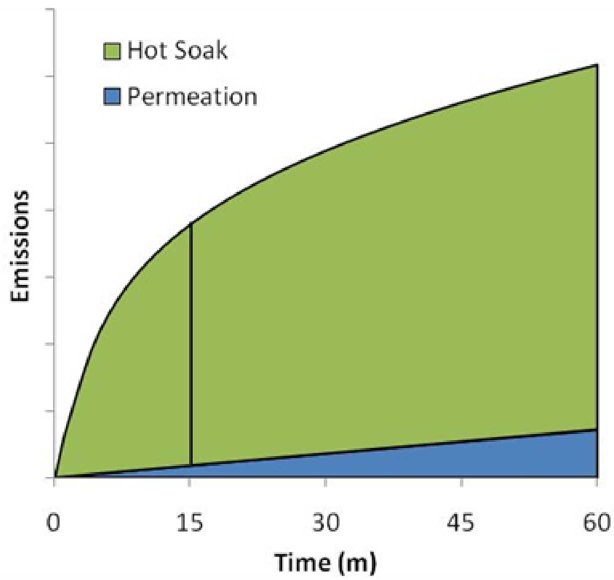
The vehicles in Colorado that participated in the studies were recruited in-situ and therefore were subject to a wide range of leak mechanisms. In the 2010 CDPHE study, it was observed that some vehicles emitting more than 50 grams in 15 minutes in the PSHED had liquid leaks present. All vehicles with a calculated 15 minute measurement greater than 50g/15min were removed from vapor leak analysis.

Vehicles in the E-77 program were tested multiple times with different fuels, whereas the Colorado population were each tested once. In order to not over-represent the E-77 vehicles in our sample, one measurement from each vehicle was selected with preference given to the measurements on 9 RVP, E10 fuels (where available).

First, it is necessary to develop a correction factor to translate 15-minute measurements to 1-hour equivalents and vice versa. Every datum requires a 15-minute mass and a one-hour mass. Base rates in the MOVES input table must be expressed in grams per hour; however, our method for distinguishing leaks from non-leaks uses the 15 minute rate. Furthermore, if a measurement is designated as from a leaking vehicle, the 15 minute measurement is used to project its rate of occurrence in the fleet.

Existing data is used to develop this correction factor. In the E-77 suite, the cumulative time series data for hot-soak tests on a minute-by-minute scale is readily available, enabling estimation

Figure 14: Hot Soak and Permeation Illustration



of vapor emissions over 15 minutes. Each set of vehicle data also contains a permeation rate. The permeation rate is subtracted from the 15 minute hot soak measurement. The result is the assumed vapor emissions during 15 minutes of hot soak. Similarly, hourly permeation is subtracted from the 1-hour hot soak measurement. After compiling the 15-min and 1-hour values, the fraction of emissions occurring in the first 15 minutes can be calculated.

All of the Denver testing programs provide similar vehicle measurements to augment the E-77 dataset. A subset of the vehicles was transported to a lab to receive a Hot Soak test. Readings were taken at both 15 and 60 minutes.

Figure 14 serves as an illustration of evaporative emissions occurring during a Hot Soak test. Vapor emitted by permeation is assumed to accumulate at a linear rate while vapor emissions attributed to the hot soak accumulate rapidly following engine shutoff but more slowly as the engine cools.

Using the combined data from E-77 and Denver testing, we developed the average fraction of emissions in the first fifteen minutes following engine shutoff. At first, it was thought that this fraction would vary among groups of vehicles certified to different evaporative standards. However, analysis of test results by certification groups did not seem to yield notably different results. This analysis resulted in a single fraction developed from all available data to be applied fleet-wide. It was estimated that 54% of emissions from a one-hour hot soak occur in the first 15 minutes. Conversely, emissions from a 15 minute hot soak must be multiplied by 1.85 to estimate an hours emissions.

Another correction must be applied to each measurement so that emission rates values are expressed as though measured using fuel with a vapor pressure of 9.0 psi. This value is simply the base level used as a reference in MOVES. Also, fuel effects for Hot Soak emissions are developed and applied on the assumption that the base rates reflect a fuel vapor pressure of 9.0 psi.

Results in the available datasets were measured at varying levels of RVP. Some programs recorded RVP, while other data has no explicit RVP information. Our first step is to estimate the RVP for all measurements that do not contain this information.

The majority of the data with unknown RVP was gathered in the summer months in locations with available fuel survey data. The mean RVP for June through August 2010 in Denver was 8.40 RVP (standard deviation 0.20 RVP), and this value was assumed for all vehicles tested from May through September. For non-summer months, RVP information was collected with a small subset of the vehicle measurements. In the case of a non-summer measurement without RVP information, the mean of all non-summer months is assumed. The mean RVP for non-summer vehicles is 10.67 (standard deviation 1.75 RVP). The testing at the Lipan station was all performed in the summer, so the RVP of the Lipan dataset is assumed to be 8.4.

Associating an RVP value with every measurement enables calculation of corrections for altitude. All vehicles were tested either in Colorado (Elev. = 5,130 ft) or Mesa, AZ (Elev. = 1,243 ft). Both locations are far enough above sea-level that it would be erroneous to assume their emissions are representative of sea-level emissions. Our approach is to apply Equation 9a for vapor generation to calculate the equivalent RVP (Equation 9b) at sea level that would generate the same amount of emissions. The E10 coefficients were used for this analysis.

$$TVG_{high} = A_{high} e^{B_{high} * RVP_{meas}} (e^{C_{high} * T_1} - e^{C_{high} * T_0}) \tag{9a}$$

$$RVP_{SeaLevel} = \frac{1}{B_{low}} * ln \left(\frac{TVG_{high}}{A_{low} * (e^{C_{low} * T_1} - e^{C_{low} * T_0})} \right) \tag{9b}$$

This application requires the assumption that vapor emissions will increase/decrease proportionally to vapor generation. As a rule, to generate the same amount of vapor at high altitude as generated at sea level, a fuel will have a lower RVP. Temperature values were also chosen arbitrarily for this calculation. However, after a monte-carlo analysis of varying starting and ending temperatures, the effect of either was found to be negligible within the conditions these vehicles are likely to experience during testing. Therefore, temperatures T0 = 60°F and T1 = 65°F were chosen for this analysis.

The Wade-Reddy equation provides no coefficients for Mesa, AZ elevation so the adjustment is a simple linear interpolation between Sea Level and Denver elevations. For example, to solve for the TVG_{high} used in Equation 9a corresponding to Mesa, Equation 10 was used.

$$TVG_{Mesa} = TVG_L + \left((TVG_H - TVG_L) * \frac{Elevation_{Mesa}}{Elevation_{Denver}} \right) \tag{10}$$

At this point in the analysis, every measurement is paired with an RVP value that would generate the same emissions at sea level. The next step is to estimate the equivalent result as though measured on fuel with 9.0 psi.

In order to calculate an adjustment for each measurement, the same assumptions were employed as above. Using the same temperature values, vapor generated at the sea level RVP and at 9.0 RVP was calculated. The ratio between these two values was applied to the original emissions measurement, in Equation 11a, and becomes the base MOVES emission rate.

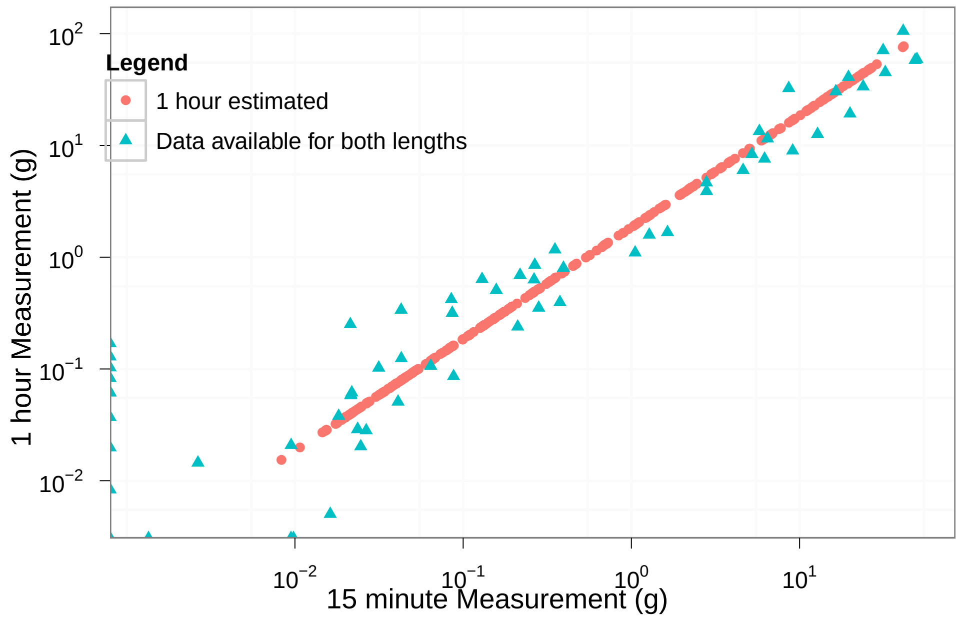
$$TVG_{measRVP} = A_{SeaLevel} e^{B_{SeaLevel} * RVP_{meas}} (e^{C_{SeaLevel} * T_1} - e^{C_{SeaLevel} * T_0}) \tag{11a}$$

$$TVG_{MOVES} = A_{Denver} e^{B_{Denver}*9.0} (e^{C_{Denver}*T_1} - e^{C_{Denver}*T_0}) \tag{11b}$$

$$HS_{MOVES} = HS_{Measured} * \left(\frac{TVG_{measRVP}}{TVG_{MOVES}} \right) \tag{11c}$$

At this point, for each measurement we have an emission rate for both 15 minutes and 60 minutes, at sea level, and with 9 RVP fuel. There were some necessary QA steps to be performed at this point. The result of our 15 minute emissions to 60 minute conversion and the results are plotted in Figure 15.

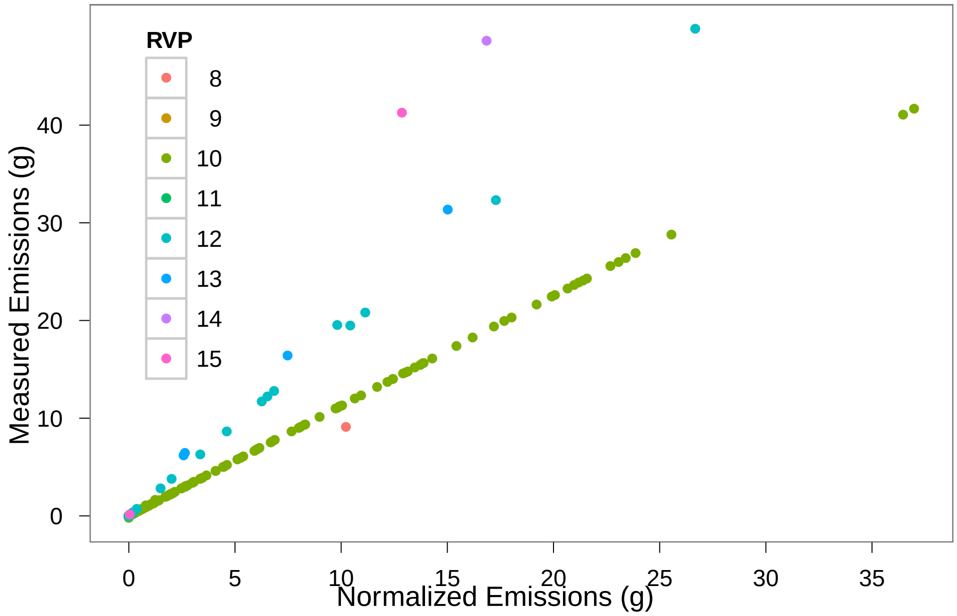
Figure 15: Hot Soak Measurement Test Length



As expected, the estimated hourly emissions (red circles) from the 15 minute measurements model the measurements (blue triangles) where data at both test lengths were available.

Quality assurance checks were also performed on the emissions values before and after calculating their equivalences at Sea Level and 9.0 psi fuel. As expected, the tests measured with higher RVP fuels at high altitude were reduced by wider margins under the influence of the two corrections.

Figure 16: Hot Soak Measurement Normalization to 9.0 RVP



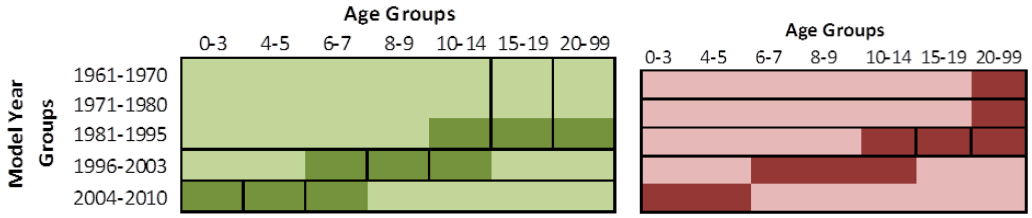
After normalizing the complete dataset, it was imported into the MOVES database. In the MOVES emission rates tables, emission rates must exist for all model year and age group combinations. As with most cross-sectional datasets, this requires additional modeling. For example, there is no data for 20 year old, model year 2010 vehicles, or brand new 1980 vehicles. To address this problem, we extrapolated the emission rate values. Table 13 describes the data.

In ranges where no data could be collected, leak and non-leak measurements are extrapolated from similar MY/age groups. In MY/age groups where very small amounts of data were collected, the measurements are combined with similar MY/age groups. Figure 17 illustrates how to populate model year and age group emission rates where there is no data.

Table 13: Hot Soak Measurements by Model Year and Age

		Age Group														
		0-3		4-5		6-7		8-9		10-14		15-19		20+		
	Leak?	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	**Total**
Model Year Group	1961-1970														5	5
	1971-1980														8	8
	1981-1995									6	15	46	55	8	39	169
	1996-2003			1		26	6	36	6	53	30					158
	2004-2010	12	3	26	2	5										48
	Total	12	3	27	2	31	6	36	6	59	45	46	55	8	52	388

Figure 17: Measurement Averaging



(a) Non-Leak

(b) Leak

- A darker shaded cell represents a bin where data is present.
- An enclosed area represents one rate. The rate is calculated by averaging all enclosed data.

For example, one non-leak rate exists for model years 1996-2003, ages 0-7. The rate is calculated by averaging available data, which only exists at age 6-7. For every model year and age group, there is a leaking rate and non-leaking rate. The two rates, weighted by leak prevalence, form the average hourly hot soak emission rate for a given bin. Figure 18 demonstrates how leak rates and non-leak rates are combined to form a final, weighted rate for a given model year, age combination.

For every model year and age group combination, the calculation outlined in Figure 18 is performed. Figure 19 compares the MOVES2014 rates to the rates in MOVES2010b. The inclusion of leaking vehicles has resulted in higher emissions, particularly for older model years where leaks are more prevalent.

Figure 18: Calculate Weighted Evaporative Emissions

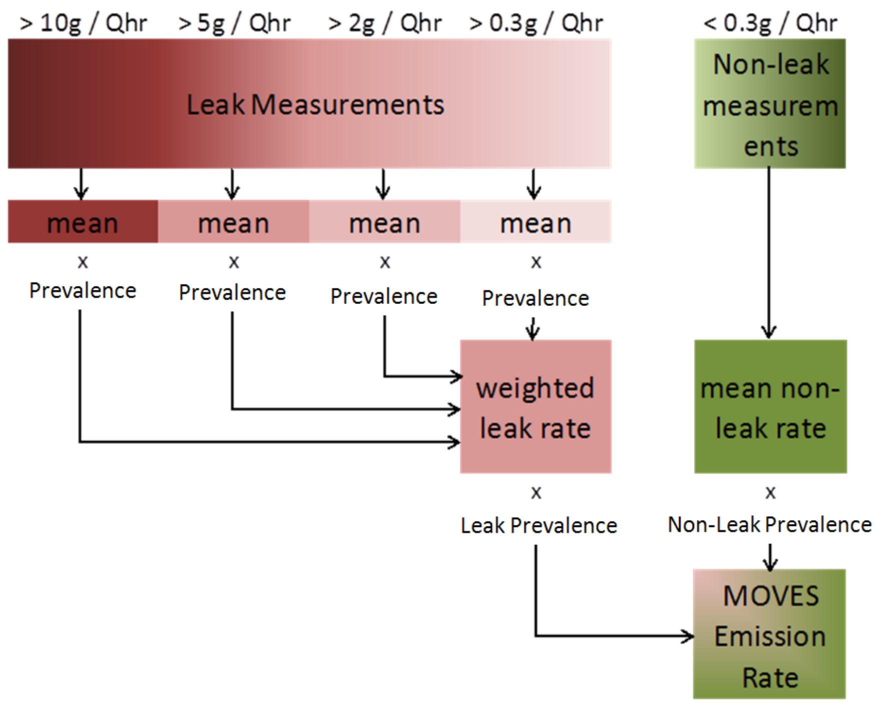
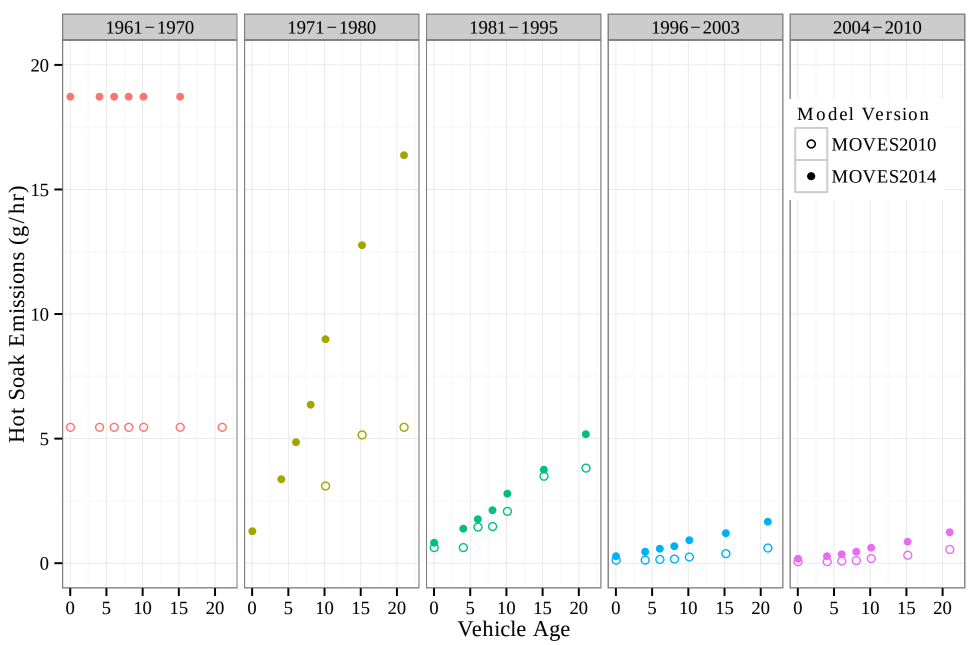


Figure 19: Hot Soak Emission Base Rates (9.0 RVP at Sea Level)



3.3.4 Running Loss

Running Loss emissions consist of vapor venting during vehicle operation. For running loss, MOVES currently only models vapor emissions from the canister as vapor leak data is not available at the time of release. Running loss leak emission data will be included in a future release and is expected to result in increased MOVES emission rates. Data used to develop running loss emission rates is from CRC E-35 [18] and CRC E-41 [3] [4]. These two programs tested 200 vehicles with model years ranging from 1971-1997.

For each vehicle, fuel tank temperature is calculated at the end of the running loss test using the fuel tank temperature algorithm (See Section 3.1). The running loss test performed in E-41 was the federal test procedure LA-4 NYCC NYCC LA-4 drive schedule, with two minute idle periods following the first LA-4, the second NYCC, and the final LA-4.

The data is filtered/reduced such that each test meets the following requirements:

- Non-liquid-leakers (emissions <137.2 g/hour32[3])
- As received vehicles (no retests)
- Fuel system pressure test result must be pass, fail, or blank

The average tank temperature is calculated by assuming a linear increase in temperature. Thus, the average is calculated by averaging the start temperature of the test and the final temperature. The average temperature is used to estimate the permeation rate using default permeation rates and the permeation temperature adjustment.

Gram/hour rates are calculated by dividing total emissions by the duration of the running loss test (4300 seconds). Permeation is subtracted for each hour to segregate tank vapor venting (TVV) emissions. After analysis of TVV data, running loss TVV rates are separated by model year only. Table 14 shows the results of the analysis.

An I/M effect is not observable from this data so the running loss TVV rates for I/M and non-I/M rates are the same.

[3] M6.EVP.009, Section 2.4, Table 2-1

Table 14: Measurment Counts by Model Year and Age

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

Running Loss Fuel & Temperature Effects Running Losses are affected by both temperature and fuel Reid Vapor Pressure (RVP). The adjustments used in MOVES2014 are taken from MOBILE6 and are applied to all model years and source types. MOBILE6 was run for a series of temperatures and RVP levels for passenger cars. A linear model was fit to the MOBILE6 results. The mean base emission rate for running losses in MOVES is located in the *'EmissionRateByAge'* table. Running loss rates were assumed to be measured at 9 RVP and 95°F. The results from MOBILE6 were normalized to the MOVES emission rates as multiplicative adjustments to the mean base rates. For example, a multiplicative adjustment of 1 would be applied to a 9RVP fuel at 95°F.

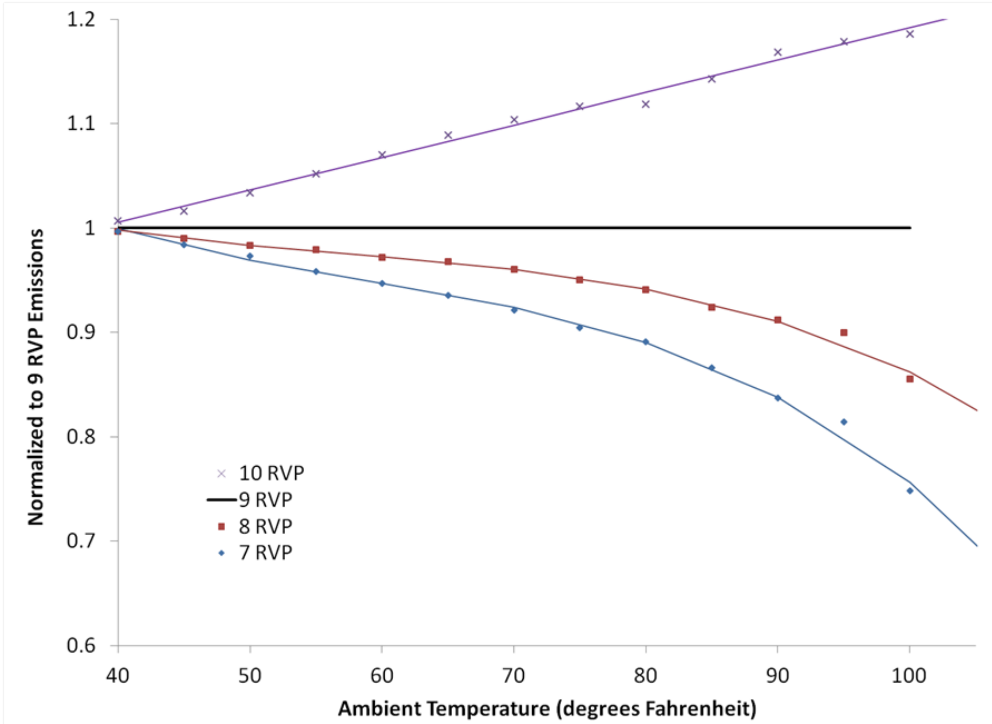
The running loss adjustments:

- Are multiplicative adjustments.
- Apply to all gasoline source types and model years.
- Are the same at temperatures below 40°F as at 40°F.
- Are applied as a function of both RVP and ambient temperature.
- Will use the 7 RVP coefficients for RVP values below 7 psi.
- Will use the 10 RVP coefficients for RVP values above 10 psi.
- Will not be applied for RVP at temperatures below 40°F.

$$AdjustedRunningLoss = RunningLoss * Adjustment(Temperature, RVP) \tag{12}$$

The adjustment coefficients are in a table in the default MOVES database, so that they can be changed without altering the MOVES code. The RVP adjustment range is dynamic; if new sets of coefficients for RVP values greater than 10 or less than 7 are added to the table, MOVES will use those values and set new minimum and maximum RVP values. Figure 20 illustrates the correction to base rates at 9RVP.

Figure 20: Running Loss Temperature and RVP Effect



3.4 Inspection/Maintenance (I/M) Program Effects

Inspection and Maintenance program efforts vary widely in their procedures for testing evaporative emissions. Some locations use a fill pipe pressure check and gas cap check, while others use just a scan of the onboard diagnostics (OBD) and others will use all three approaches. These types of tests do not guarantee the detection of a vapor leak within a vehicle.

MOVES assumes tank vapor venting is the only evaporative process where I/M benefits are realized. The types of evaporative tests performed in I/M programs do not affect permeation or liquid leaks.

I/M Factor An I/M factor describes the overall effectiveness of an I/M program and can be used as a basis to compare two separate programs. A higher I/M factor indicates a more effective I/M program. Data from four I/M programs were used in the development of MOVES I/M factors. The Phoenix, AZ program contained the most extensive data, for which reason we have used it to represent a reference condition, relative to which other programs can be assessed. Data from the programs in Tucson, AZ, Colorado, and North Carolina were used to adjust the Phoenix numbers for differences in I/M programs.

> *NOTE: In order to develop I/M factors, failure data was used from I/M. The failure frequencies are* **only** *used to estimate the effectiveness of differing evaporative I/M programs. They are* **not** *used to model the actual prevalence of evaporative leaks. For information on the modeling of leak prevalence please see Section 3.3.2.*

Table 15: Description of I/M Programs [29]

	Gas Cap Test	OBD	Pressure test	Frequency	Network	Years
Colorado	Y	Advisory	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

Table 16: OBD Evaporative Emission Trouble Codes

OBD Code	**Description**
P0440	Evaporative Emission Control System Malfunction
P0442	Evaporative Emission Control System Leak Detected (small leak)
P0445	Evaporative Emission Control System Purge Control Valve Circuit Shorted
P0446	Evaporative Emission Control System Vent Control Circuit Malfunction
P0447	Evaporative Emission Control System Vent Control Circuit Open
P1456	EVAP Emission Control System Leak Detected (Fuel Tank System)
P1457	EVAP Emission Control System Leak Detected (Control Canister System)

The Phoenix evaporative I/M program performed 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 assign evaporative failures are listed in Table 16 for all vehicle makes and additionally P1456 and P1457 for Honda and Acura vehicles. Vehicles with 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, the total number of failures is the sum of gas cap and pressure/OBD failures.

The I/M failure frequencies are developed from the Phoenix data using initial and final results for a vehicle in a given I/M cycle. For passing vehicles, the initial and final tests are the same. The initial and final failure frequencies were averaged to develop an I/M failure frequency for each model year and age group. Using the initial failure frequencies alone would neglect the required repairs occurring on most failing vehicles, and using only final failure frequencies would neglect the prior existence of failing vehicles. To develop non-I/M failure frequencies, the sample is restricted to vehicles registered in states that do not have any I/M programs.

The Tucson data was used to determine the effect of I/M program frequency (annual vs. biennial). For OBD-equipped vehicles, Tucson performs gas-cap and OBD tests annually, while Phoenix performs them biennially. Therefore, we were able to develop for the effectiveness ratio of Annual/Biennial programs by analyzing the Tucson data.

The North Carolina data was used to estimate the effectiveness of using the OBD scan as the sole test in a program. In North Carolina, expansion of I/M program boundaries has led to many vehicles being tested for the first time. These vehicles were effectively non-I/M until their first test. Vehicles were flagged as non-I/M tests if they were tested before the official start of the I/M program or were registered in new I/M county.

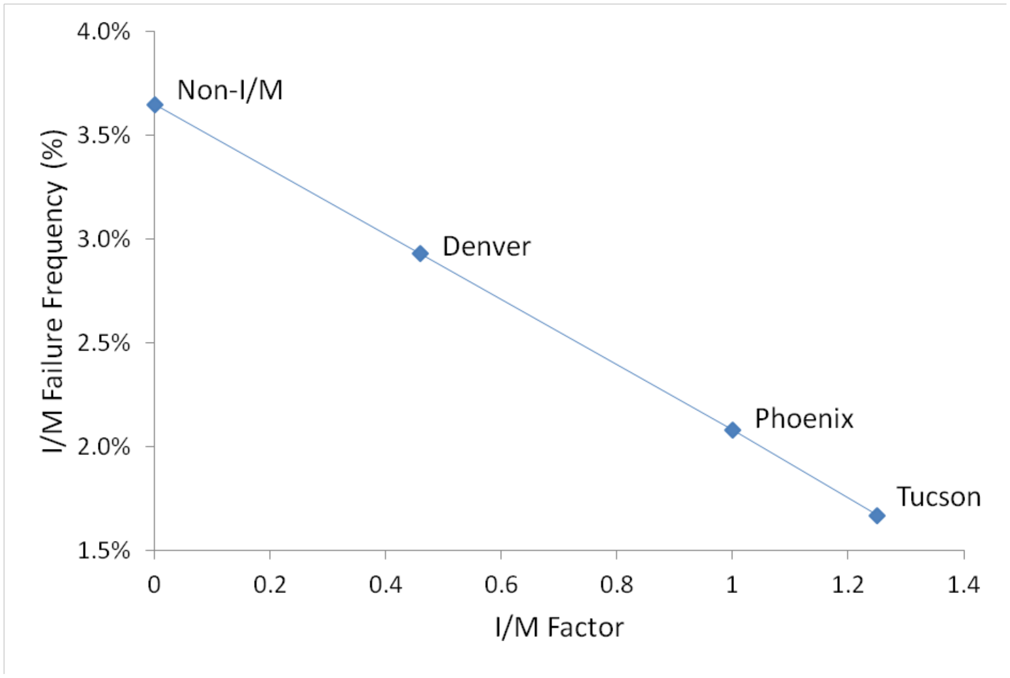
Failure frequencies of the non-I/M vehicles were compared to vehicles tested in I/M areas. The I/M effectiveness of an OBD only I/M program is estimated to be a 63% reduction in failures or a non-I/M to I/M failure ratio of 1.6. This ratio was then applied to Phoenix OBD and pressure test failure frequencies to determine non-I/M failure frequencies.

The Colorado data was used to determine the effectiveness of gas cap tests. In Colorado, the I/M data is primarily from the Denver and Boulder metropolitan areas. However, many residents are new to this area, having moved from non-I/M counties and states. These vehicles were effectively non-I/M until their first test. Vehicles were flagged as non-I/M if they were registered in a state without an I/M program, or in a non-I/M county within Colorado. Colorado OBD data was not used, because OBD in Colorado is only advisory and does not pass or fail a vehicle.

The failure rates of the non-I/M vehicles were compared to those in the I/M fleet. The effectiveness of a gas cap only I/M program is estimated to be a 45% reduction in failures or a non-I/M to I/M failure ratio of 1.2. This was then applied to gas cap failure frequencies to determine non-I/M failure frequencies.

The I/M factor in MOVES adjusts emission rates depending on the characteristics of a given county's I/M program. Our reference program, Phoenix, has an IM factor of 1. Non-I/M areas have an IM factor of 0. The failure frequencies from the other counties are used to calculate I/M factors for the diverse types of evaporative I/M procedures. The I/M factor is assumed to have a linear relationship with failure frequency. Figure 21 illustrates how the I/M factor varies with different I/M programs. Different programs fall on the line as determined by the analysis from above, based on specific evaporative tests performed. For the vehicles in Figure 21, Tucsons OBD and gas cap tests are annual, compared to Phoenixs biennial requirement, which gives Tucson a lower failure frequency, thus a higher I/M factor. Colorados frequency is biennial, but their OBD test is non-enforcing. As a result, their data shows a higher failure frequency, resulting in a lower I/M factor.

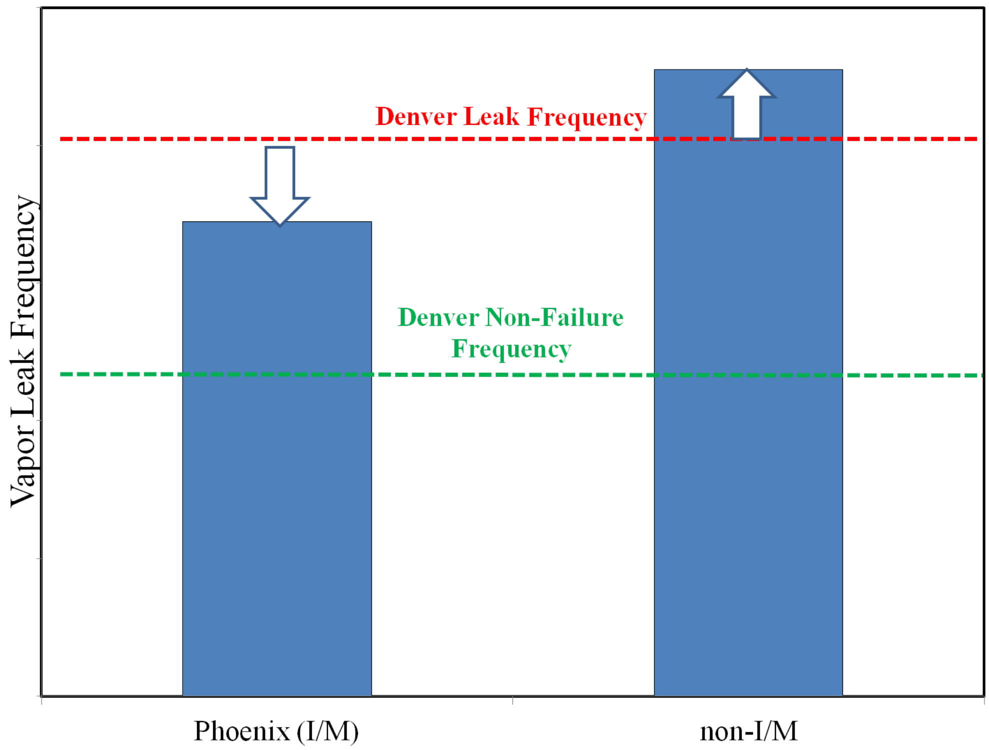
Figure 21: I/M Factor, MY 1999-2003, Age 4-5



3.4.1 Leak Prevalence

The I/M factor is applied to the leak prevalence rates developed in Section 3.3.2 Cold Soak. The leak prevalence rates were developed from a test program in the Denver, CO area. The MOVES default database contains non-IM and IM emission rates that represent I/M factors of 0 and 1. The I/M factor for Denver is a value of neither 0 (no I/M program) nor 1 (the reference I/M program). Therefore, the Denver leak prevalence rates, as-is, are not used as base prevalence rates in MOVES. From Figure 21, the I/M failure frequency in Denver is 30% less than non-IM (I/M factor = 0) and 30% higher than Phoenix (I/M factor = 1) so the leak prevalence rates developed from Denver data are adjusted accordingly before being added to the MOVES database.. This adjustment reflects the analysis described in the previous section and can be observed in Figure 21. For example, during a MOVES run for the Denver area, the Denver I/M factor will be applied and emissions will be modeled with the same prevalence rates originally estimated for Denver.

Figure 22: Adjusting Denver Leak Prevalence Data



3.5 Liquid Leaks

Liquid leaks include any non-vapor form of fuel escaping the fuel system. The average leaking rate is determined using the leaking vehicles excluded from the I/M analysis in section 3.4. Because the testing methods used did not distinguish the different evaporative emission processes, permeation and tank vapor venting are estimated using the calculation methods described in Section 3.2 and Section 3.3 and subtracted from the total measurement. The remaining emissions after permeation and vapor venting are subtracted are assumed to be caused by liquid leaks. Due to limitations in the data quality and quantity, the measurements are averaged across all vehicles by the three different modes, and shown in Table 17.

The liquid leak emission rates must be multiplied by the percentage of leakers in the fleet to get an average liquid leaking emission rate. The studies in Petroleum Industry [5] and API [28] provided

Table 17: Liquid Leak Emission Rates (g/hr)

Operating Mode	Liquid leak rate
Cold Soak	9.85
Hot Soak	19.0
Operating	178

Table 18: Percentage of Liquid Leaks by Age

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

this data. The estimates of liquid leak prevalence are shown in Table 18. It is assumed that most leaks do not occur until vehicles are 15 years or older.

Table 19 contains the fleet-weighted liquid leak rate. There is insufficient data to conclude that these rates change with model year or be affected by I/M programs.

Table 19: Weighted Liquid Leak Emissions (g/hr)

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	1.360
20+	0.235	0.452	4.230

3.6 Refueling

Refueling emissions are the displaced fuel vapors 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 estimated from the total volume of fuel dispensed (gallons). This volume is estimated from the average daily distance travelled (VMT) and estimated fuel consumption. Both the spillage and the vapor displacement associated with refueling events are in terms of grams spilled per gallon of fuel dispensed. Diesel vehicles are assumed to have negligible vapor displacement, but fuel spillage is included in the refueling emissions.

Uncontrolled and unadjusted, refueling emissions are the displaced grams of fuel vapor per gallon of liquid fuel, plus the grams per gallon for spillage. AP-42 Volume I Section 5.2.2.3 [5] lists the spillage as 0.7 lb/1000 gallons, which is 0.31g/gallon of dispensed fuel. The vapor displaced by refueling is a function of temperature and gasoline Reid Vapor Pressure (RVP) [10]:

$$E = e^{-1.2798-0.0049d_T+0.0203T_{DF}+0.1315RVP} \tag{13}$$

Where:

E = Displaced Vapor (non-methane grams)
RVP = Reid Vapor Pressure (psi)
T_{DF} = Dispensed gasoline temperature (degF)
T_{DF} = 20.30 + 0.81*T_{amb}
d_T = Temperature difference between tank and dispensed
d_T = 0.418*T_{DF} -16.6

Dispensed fuel temperature is the temperature of the fuel flowing from the pump. Based on a 2008 California study [32], this temperature is calculated as 20.30 + 0.81 * T, where T is the monthly average temperature, computed from the zone month hour table. The monthly average temperature must be between 45 and 90 degrees Fahrenheit. For ambient temperatures beyond those limits, the dispensed fuel temperature is set to the value calculated at the limit. Furthermore, the dT value cannot be greater than 20 degrees. The d_T equation is developed in an Amoco study. In that study, the difference in temperature was never greater than 20 degrees.

Two emission control strategies exist to limit fuel lost during refueling. First, there are programs designed to capture refueling vapors at the pump. These are often referred to as "Stage 2" vapor control programs. Second, vehicles manufactured since 2000 have onboard refueling vapor recovery (ORVR) systems that store refueling vapors in the vehicle's evaporative emission canister.

The implementations of Stage 2 systems vary from area to area and affect the displaced fuel vapors affected and the amount of reducing spillage. MOVES uses two factors to adjust the refueling losses and account for this variation.

1. The *refueling vapor program adjustment* is a value between zero and one indicating the percent reduction of total potential vapor losses by state or local programs (such as Stage 2 recovery programs).
2. The *refueling spill program adjustment* is a value between zero and one indicating the percent reduction of refueling spillage losses by state or local programs (such as Stage 2 recovery programs).

These program adjustments in MOVES are applied by county. Each county has a unique value for vapor and spillage program adjustments. The program adjustment values for each county and calendar year are stored in the default MOVES *'CountyYear'* table.

MOVES uses a separate factor to address the 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 for ORVR equipped vehicles. The effects of ORVR technology is phased in beginning in model year 1998.

1. The *refueling tech adjustment* 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 *'SourceTypeTechAdjustment'* table.

Table 20: Phase-In of Onboard Refueling Vapor Recovery

Model Year	Passenger 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%

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

Appendix A Notes on Evaporative Emission Data

Parameters: Vehicle Numbers, Test No., 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

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)
BL1A 1 hour Breathing Loss Evap. Test Gas Cap left On
BL1B 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 Relevant MOVES Evaporative Tables

Table 21: MOVES Pollutant IDs

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

Table 22: Base Permeation Rates at 72F

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	0-5	0.055
	6-9	0.091
	10-14	0.124
	15-19	0.148
	20+	0.201
1996	0-5	0.046
	6-9	0.075
	10-14	0.101
	15-19	0.120
	20+	0.163
1997	0-5	0.037
	6-9	0.059
	10-14	0.079
	15-19	0.093
	20+	0.125
1998	0-5	0.015
	6-9	0.018
	10-14	0.022
	15-19	0.024
	20+	0.029
1999-2015	All Ages	0.010
2016-2017	All Ages	0.007
2018-2019	All Ages	0.006
2020-2021	All Ages	0.004
2022+	All Ages	0.003

Table 23: MOBILE6 LDGV Running Losses (g/mi)

Temperature(F)	7 RVP (psi)	8 RVP (psi)	9 RVP (psi)	10 RVP (psi)
40	3.06	3.06	3.07	3.09
45	3.00	3.02	3.05	3.10
50	2.88	2.91	2.96	3.06
55	2.69	2.76	2.84	3.04
65	2.62	2.71	2.80	3.05
70	2.57	2.68	2.79	3.08
75	2.56	2.69	2.83	3.16
80	2.70	2.85	3.03	3.39
85	2.85	3.04	3.29	3.76
90	3.03	3.30	3.62	4.23
95	3.24	3.58	3.98	4.69
100	3.42	3.91	4.57	5.42

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