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U S. Environmental Protection Agency

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- Draft -

Determination of Start Emissions as a Function of Mileage and Soak Time for 1981-1993 Model Year Light-Duty Vehicles

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1.0 INTRODUCTION

MOBILE6 will allocate vehicle exhaust emissions to either the "extra" emissions associated with engine start (start emissions) or the "base" emissions associated with travel (running emissions). This distinction is to some extent an artifical constraint since in reality "start" emissions in part will be released while the vehicle is in motion. However, it is a useful constraint and not too far from physical reality, in at least summer conditions, when the extra emissions from a start end after only 1 or 2 minutes of driving. This split allows the separate characterization of start and running emissions for correction factors such as fuel effects and ambient temperature. It also allows a more precise weighting of these two aspects of exhaust emissions for particular situations such as morning commute, parking lots and freeways This document describes the methodology used to calculate start emissions as a function of mileage and soak time for use in MOBILE6 The results for model year 1981-1993 light-duty cars and light-duty trucks are presented. The deterioration of running emissions will be addressed in a separate document (Report Number M6.EXH 001)

This document is organized into six sections. The first section is the short introductory section. Section 2 describes the FTP data sources and the model year and technology groups which are used Section 3 provides a definition of start emissions in mathematical terms and shows the relationship between start emissions and the Federal Test Procedure (FTP) emissions. This includes a description of the FTP cycle, the Hot505 cycle, and a definition of cold start and hot start emissions Section 4 describes the methodology used to predict start emissions as a function of soak time. Section 5 shows the algorithm used to predict start emissions versus mileage. Section 6 contains an example of the final start emission results as used in MOBILE6 as a function of both deterioration and soak time.

2.0 DATA SOURCES USED

The basic datasets used to determine in-use deterioration are based on FTP testing. (I/M data from Dayton, Ohio were also used to correct the results for recruitment bias which EPA believes affects the FTP test samples - see Appendix A). Three FTP data sources were used: 1) the test results from the EPA laboratory in Ann Arbor, Michigan, 2) the data received from AAMA (American Automobile Manufacturers Association) based on testing conducted in Michigan and Arizona, and 3) the API (American Petroleum Institute) data collected in Arizona The model years in the dataset range from 1981 through 1993, and contain both cars and trucks. Table 1 gives a breakdown by vehicle type, model year, and technology for the three datasets combined.

Table 1
Distribution of Vehicles by Model Year and Technology*

MYR	Cars OPLP	Cars CL Carb	Cars TBI	Cars PFI	Cars ALL
81	367	657	15	29	1068
82	71	71	74	8	224
83	63	57	127	62	309
84	5	30	46	35	116
85	24	74	56	66	220
86	7	34	60	92	193
87	1	17	76	106	200
88		15	69	113	197
89		22	38	103	163
90			160	250	410
91			91	426	517
92			57	347	404
93			29	366	395
ALL	538	977	898	2003	4416

MYR	Trucks OPLP	Trucks CL Carb	Trucks TBI	Trucks PFI	Trucks ALL
81	124				124
82	45				45
83	8	3			11
84	26	22		1	49
85	33	30	13	6	82
86	14	9	23	41	87
87			6	4	10
88					0
89					0
90			144	1	145
91			141	144	285
92			92	92	184
93			90	93	183
ALL	250	64	509	382	1205

* No entry indicates no data available for that model year/technology type in the FTP dataset used for this analysis

In general, most of the 1990+ model year vehicle data were supplied by AAMA, and most of the pre-1990 data were supplied by the EPA laboratory testing. The API sample is a relatively small sample (99 cars and trucks). Its chief appeal is that the vehicles all have generally higher mileage readings than the rest of the sample (all over 100,000 miles). The other general trend in the data is toward PFI technology, and away from the others This is seen in the 1990+ vehicles which are predominately PFI with some TBI still present. The 1981 - 1989 model years start with a high percentage of carbureted and some open loop, but end with mostly TBI and PFI technology. Although not explicitly shown in the tables, new catalyst technology was phased slowly into the fleet starting in the mid 1980's.

For analysis, the cars and trucks were placed into the model year/technology groups shown below Trucks were separated into five different groups by pollutant due to differences in certification standards.

CARS MY Group / Technology Type	**TRUCKS** MY Groups / Technology Type
HC/CO/NOX	HC/CO/NOX
1988-93 PFI	1988-93 PFI
1988-93 TBI	1988-93 TBI
1983-87 FI	1981-87 FI
1986-93 Carb	1984-93 Carb
1983-85 Carb	1981-83 Carb
1981-82 FI	
1981-82 Carb	

The technology groups are closed-loop ported fuel injection (PFI), closed-loop throttle body injection (TBI), and carbureted (CARB). FI refers to a combination of PFI and TBI. CARB includes both closed-loop and open-loop vehicles which are carbureted. These model year/technology grouping boundaries were selected on the basis of changes in emission standards or the development/refinement of new fuel metering or catalyst technologies. It is assumed that as of 1990, carbureted technology had a very tiny market share, and are included with the previous carbureted group. Because of the relatively large amount of 1988-93 fuel injected data, the category was split into PFI technology and TBI technology for both cars and trucks. This produces separate deterioration functions based on this fuel delivery technology and allows the modeling of the future penetration of PFI technology into the in-use fleet.

3.0 DEFINITION OF START EMISSIONS

3.1 Overview of the Federal Test Procedure (FTP)

The Federal Test Procedure (FTP) is a test cycle which is used to certify new vehicles to emission performance standards (see 40 CFR Part 86, Subpart B, Section 86.144). The FTP consists of a cold start segment (Bag 1), a hot stabilized segment (Bag 2), and a hot start segment (Bag 3). Initially, the vehicle is stored for a minimum of 12 hours before testing to simulate a 12 hour overnight soak period. The vehicle is then driven over the cold start segment, which lasts 505 seconds over a length of 3.59 miles, and the emissions collected as Bag 1 The latter part of the driving in Bag 1 occurs with the engine and catalyst in a hot stabilized condition. Bag 2 emissions are then immediately collected from the hot stabilized segment, which lasts 867 seconds over a length of 3 91 miles. After a 10 minute soak, the 505 seconds of the start segment is then repeated and the emissions collected as Bag 3.

The FTP composite emission rate is a weighted combination of the three measured bags to represent two trips. The first trip is a cold start trip after a 12 hour soak, and the other is a hot start trip after a 10 minute soak. Each trip is a "LA4" cycle, which is a combination of the 505 cycle (either Bag 1 or Bag 3) and the Bag 2 cycle. In a typical FTP test, the Bag 2 is only measured once and the results are used for both trips. Since the 505 cycle is 3 59 miles long and the Bag 2 cycle is 3.91 miles long, each LA4 trip is 7 5 miles long. The cold start trip is weighted at 43% and the hot start trip weighted 57%. If the cold start trip is 43% of the driving, then the vehicle miles traveled (VMT) in Bag 1 (containing the cold start) is:

FTP Bag 1 VMT Weighting = 43% * (3.59 miles / 7.5 miles) = 0 206

The hot start trip is 57% of driving, and the VMT weighting for Bag 3 (containing the hot start) is:

FTP Bag 3 VMT Weighting = 57% * (3 59 miles / 7.5 miles) = 0.273

The remaining VMT is from stabilized driving, represented by Bag 2. Since Bag 2 is used for both the cold start and hot start trips, it uses VMT weighting from both.

FTP Bag 2 VMT Weighting = (43% + 57%) * (3.91 miles / 7 5 miles) = 0 521

The standard VMT weighting of the bags reported in grams per mile for the full FTP are·

FTP = (Bag 1 * 0.206) + (Bag 2 * 0.521) + (Bag 3 * 0.273)

where the fractions represent the amount of vehicle miles traveled within the three modes during the FTP trip, and Bag1, Bag2, Bag3 and the FTP emissions are in grams per mile (g/mi).

3.2 Overview of the Hot Running 505 and Its Use

The FTP testing method outlined above does not allow the precise separation of start and running emissions, since Bags 1 and 3 contain both start and running emissions. Bag 2 of the FTP does not contain an engine start; however, the driving cycle used in the second bag is significantly different from the cycle used for Bags 1 and 3. Thus, to estimate the amount of FTP emissions that can be allocated to engine start, the concept of the Hot Running 505 (HR505) is needed.

The HR505 is an extra 505 cycle performed immediately following bag 3 of the FTP. It uses an identical driving cycle as the first and third bags of the FTP, but does not include an engine start. For more information, refer to the document "The Determination of Hot Running Emissions from FTP Bag Emissions", report number M6.STE 002. With a HR505 emission result, it is possible to compare the results obtained from the HR505 to the results from Bags 1 and 3 of the FTP to determine the portions of Bags 1 and 3 attributable to start emissions following a 12 hour soak and start emissions following a 10 minute soak, respectively.

Since the HR505 has not historically been included in FTP test programs, a method of estimating the HR505 was developed, as described in report M6.STE.002. Briefly, HR505 emissions were measured from a sample of 77 vehicles tested under EPA contract. The results from this vehicle sample were used to develop a correlation between the HR505 and FTP bag data. This correlation was then used to estimate HR505 results for the FTP dataset used for this analysis.

3.3 Basic Start Emission Rate

For MOBILE6, the basic unit of engine start emissions is defined as a start after a 12 hour soak. The units for engine start emissions will be grams, instead of grams per mile, since start emissions will not be allocated by vehicle miles traveled. The engine start basic emission rate can be determined by subtracting the HR505 emission rate from the Bag 1 emission rate (in grams per mile) using the nominal distance traveled in the 505 driving cycle:

Basic Start Emission Rate (grams) = [Bag 1(g/mi) - HR505(g/mi)] * 3.59 miles

For illustration purposes, the average basic start emission rates (in grams) after a 12 hour soak were calculated for each model year and are shown in Tables 2 and 3 for cars and trucks.

Start emissions after a 10 minute soak can also be estimated from the Bag 3 and HR505 emission rates, analogous to the basic start emission rate:

Start Emissions after 10 minute soak (grams) = [Bag 3(g/mi) - HR505(g/mi)] * 3.59 miles

The average start emissions after a 10 minute soak are also shown in Tables 2 and 3 for each model year and for cars and trucks.

For some FTP tests of some cars, the predicted HR505 emissions are higher than Bag1 and/or Bag3 emissions. This causes the start emissions to be negative. This probably is due to intermittent emission control system defects. Except in some cases of very small samples, the negative values were retained in the analysis.

4.0 Basic Start Deterioration with Mileage

4.1 Definition of Categories

The basic modeling concept behind the start emission factor methodology is that the fleet can be represented as two types of vehicle emitter categories. These two types are termed "high" emitters, and "normal" emitters. The "high" emitters have FTP average emission levels which are considerably higher than the overall mean emission levels, and significantly higher than their FTP standards, indicating that they have problems with their emission control systems The "normal" emitters are low and average emitting vehicles with emission control systems which are generally functioning properly. The overall fleet emission factor is a weighted average of the high and normal emitters.

The high/normal emitter modeling concept is also used in the estimation of running emissions, and is discussed in depth in other reports. For both start and running emissions, the high/normal concept allows for corrections due to recruitment bias against higher emitting vehicles, and for more accurate estimates of the effects of I/M programs, fuel effects, temperatures, etc.

In the data analysis, vehicles were defined as normal emitters for a specific pollutant if their FTP HC emissions were less than twice the applicable new car certification standard, or their FTP CO emissions were less than three times the applicable new car

Table 2
Mean Estimated Start and FTP Emission Levels by Model Year for Light-Duty Cars in the FTP Dataset

Basic start (after 12 hour soak) grams				Start (after 10 min soak) grams				Composite FTP grams/mile			
MYR	**HC**	**CO**	**NOx**	**MYR**	**HC**	**CO**	**NOx**	**MYR**	**HC**	**CO**	**NOx**
81	4 002	46 419	1.373	81	0.610	5 115	0.041	81	0 706	9 667	0 897
82	2.445	36 378	1 237	82	0 373	4.843	-0 045	82	0 789	8 318	0.872
83	2.399	26 112	1 264	83	0 400	3 827	0 150	83	0.431	5 073	0.806
84	2.950	34 827	1 190	84	0 513	3 418	0 047	84	0.756	9 968	0 893
85	3 468	30 353	1 204	85	0 506	4 737	0.095	85	0 533	6 935	0 770
86	2 526	26 639	1 432	86	0 298	2 082	0.241	86	0 926	10.43	0 713
87	2.712	20 030	1 376	87	0 597	2.104	0 170	87	0 656	8 366	0.790
88	2 831	19 716	1 419	88	0 406	1.147	0 223	88	0 406	4 574	0.668
89	2.254	18.610	1 434	89	0 379	2 524	0 216	89	0 311	3.911	0.652
90	2 169	18 677	1.930	90	0.332	2 219	0.611	90	0.274	3 614	0 633
91	2 183	19 494	1 443	91	0 275	2 132	0 530	91	0.237	3 145	0.525
92	2 271	18.878	1 645	92	0.304	2 595	0 485	92	0 267	4 328	0 508
93	2 312	21.030	1 801	93	0.310	2 564	0 392	93	0 225	2 551	0 466

Table 3
Mean Estimated Start and FTP Emission Levels by Model Year for Light-DutyTrucks in the FTP Dataset

Basic start (after 12 hour soak) grams				Start (after 10 min soak) grams				Composite FTP grams/mile			
MYR	**HC**	**CO**	**NOx**	**MYR**	**HC**	**CO**	**NOx**	**MYR**	**HC**	**CO**	**NOx**
81	7 342	107 501	1.055	81	1 212	14 211	0 385	81	1 275	18.158	1.752
82	7 909	116 584	-0 119	82	1 489	14 189	0 006	82	1 732	16.774	1.732
83	6 537	104 817	0 796	83	1 577	18 657	-0 209	83	1 361	13.226	1 436
84	5 219	95.893	0 299	84	1.098	20.057	0.004	84	0.802	10.633	1 405
85	4 766	84 621	0.457	85	0.854	7 742	0 102	85	1 281	14 465	1 388
86	3.752	41 196	0 729	86	0 607	2.148	0 128	86	0 823	8.789	1.057
87	3 352	26 635	1 266	87	0 566	1 433	0 017	87	0 401	4 610	0.605
88				88				88			
89				89				89			
90	4 705	45 331	4 683	90	0 930	7 037	0 765	90	0 800	9 510	0 885
91	3 521	41.128	2 761	91	0 878	7 129	0 519	91			
92	3 656	41 446	3.054	92	0 654	5.746	0 656	92			
93	3 644	40 557	2 736	93	0 589	4 634	0 676	93	0 420	5 363	0.847

certification standard, or their FTP NOx emissions were less than twice the new car certification standard.

Vehicles were defined as high emitters for a specific pollutant if their FTP HC emissions or FTP CO emissions exceeded twice or three times the applicable new car certification standard, respectively, or their FTP NOx emissions were two times the new car certification standard. Because high NOx emissions often occur with low HC and/or low CO emissions, and sometimes even HC can be high and CO normal, the three categories were kept separate. Thus, a vehicle could be a high HC emitter, but a normal CO and NOx emitter.

4.2 Calculation of Start Emission Rates for Normal Emitters

Emission rates for normal emitters were calculated by least squares regression of the emissions of the normal emitters versus mileage. The regression was done for each pollutant / model year / technology group. The start emission regression coefficients for cars are shown in Table 4a and for trucks in Table 4b The column labeled ZML contains the zero mile coefficients, and the column DET contains the deterioration coefficients (slope) from the regressions.

Table 4a
Regression Coefficients for START Emissions from Normal Emitter CARS

MY Group	Tech Group	HC Coefficients		CO Coefficients		NOx Coefficients	
		ZML	DET	ZML	DET	ZML	DET
1988-93	PFI	1 9987	0 006830	18 972	0 00703	1 444	0 00220
1988-93	TBI	1 9019	0 002679	19 233	0 00000	2 300	0 00000
1983-87	FI	2 3589	0 001388	19 949	0 00000	1 461	0 00141
1986-89	Carb	1 4934	0 018238	24 698	0 10947	1 405	0 00000
1983-85	Carb	1 5892	0 009408	24 442	0 10577	0 748	0 00524
1981-82	FI	2 3543	0 008533	20 038	0 22673	1 530	0.00059
1981-82	Carb	2 1213	0 013610	28 637	0 22673	1 601	0 00000

Table 4b **Regression Coefficients for START Emissions from Normal Emitter Light Trucks**							
MY Group	Tech Group	HC Coefficients		CO Coefficients		NOx Coefficients	
		ZML	DET	ZML	DET	ZML	DET
1988-93	PFI	2 873	0 00000	32 178	0 0168	1 597	0 00000
1988-93	TBI	4 073	0 01309	42 456	0 1411	4 294	0 00324
1981-87	FI	2 599	0 00964	23 497	0 0613	1 384	0 00000
1984-93	Carb	3 916	0 00854	78.286	0 2564	0 143	0 00436
1981-83	Carb	6 817	0 00154	98 432	0 3240	1 082	0 00000

4.3 Calculation of Start Emission Rates for High Emitters

High emitters are the vehicles in the fleet which likely have problems with their emission control systems, as evidenced by emission levels which are considerably higher than the FTP standards. In the analysis they were defined as those vehicles exceeding either twice FTP standards for HC or NOX or three times FTP standards for CO. The emissions line is a flat horizontal line because the emissions of a high emitter were not a statistically significant function of mileage In addition, the relatively small sample sizes of high emitters make regression determined mileage coefficients unreliable indicators of actual behavior Table 5a shows the average emissions of the high emitters (cars only) for the pollutant / model year / tech groups, and Table 5b shows the analogous results for light trucks.

For NOX start emissions, the normals and the highs were combined together, and the emissions were regressed versus mileage This has the effect of eliminating the NOX high emitter group for start emissions. This combination was done for two reasons. First, for many of the model year / tech groups the average NOX start emissions were found to not be statistically significantly different from start emissions from the normals This was found to be the case even when different definitions of a high emitter were tried (1X FTP NOX, 1.5X FTP NOX, and 2X FTP NOX). This phenomenon is consistent with the mechanisms of NOX formation - higher emissions under lean high temperature / load FTP conditions, and lower during rich and cooler start conditions. Second, the sample sizes for NOX high emitters were smaller in both an absolute sense, and in comparison to the HC and CO high emitter sample.

Table 5a
Mean START Emissions of High Emitter CARS

MY Group	Tech Group	HC Mean	CO Mean	NOx Mean
1988-93	PFI	4 829	38 06	Same as Normals
1988-93	TBI	3 293	27 16	Same as Normals
1983-87	FI	5 313	65 31	Same as Normals
1986-89	Carb	10 520	92 82	Same as Normals
1983-85	Carb	10 520	92 82	Same as Normals
1981-82	FI	5 313	92 82	Same as Normals
1981-82	Carb	10 520	92 82	Same as Normals

Table 5b
Mean START Emissions of High Emitter Trucks

MY Group	Tech Group	HC Mean	CO Mean	NOx Mean
1988-93	PFI	5 212	83 862	Same as Normals
1988-93	TBI	5 212	83 862	Same as Normals
1981-87	FI	5.826	60 319	Same as Normals
1984-93	Carb	9 406	162 115	Same as Normals
1981-83	Carb	17 865	179 549	Same as Normals

The other anomally in the results was the HC and CO high emitter emission levels for the 1990-93 TBI group. In both of these cases the average start emission levels of the few cars tested were judged to be unrealistically low. For the case of CO, the value was -123.84 grams, and for HC it was 0.0356 grams. These low average levels are the result of small sample size, and the possibility of negative values when the hot running 505 on a particular car is greater than Bag1 of the FTP. Rather than insert negative values in the MOBILE6 model, the HC and CO high emitter emission levels from the 1988-93 PFI group were substituted in the 1988-93 TBI group. This is a reasonable assumption since these vehicles are generally about the same age and model year vintage, and have reasonably similar emission control technology.

4.4 Fraction of High and Normal Emitters in the Fleet

The basic start emission factor is computed from a weighted average of the highs and normals. The fraction of high emitters in the fleet is the weighting factor The fraction of high start emitters is the same fraction as the one used for the running emissions calculations Appendix A presents the fraction of HC and CO high emitters in the fleet at selected mileages / ages for each pollutant (see document M6.IM.001 for further details). The fraction of NOX high emitters is not shown because for NOX the Normals and Highs are assumed to have the same emission rate (no start NOX highs are assumed to exist).

4.5 Calculation of Basic Start Emission Rates

The basic start emission rate is calculated for each combination of vehicle type / pollutant / model year group / technology group. The units are start emissions in grams Equation 1 is used to calculate the basic (mean) start emission rate from the high and normal emitter emission values and the rate of high emitters in the fleet For NOX emissions a special case of this equation is used where the normal and high emission rates are set equal to each other.

$$START = ST\_High\_ave * Highs + ST\_Norm\_ave * Normals \qquad \text{Eqn 1}$$

Where:

Highs = fraction of High emitters
Normals = fraction of Normal emitters
START is the basic (mean) emission rate
ST_High_ave is the high emitter start emission average
ST_Norm_ave is the normal emitter start emission average

Where:

$$Highs + Normals = 1 \qquad \text{Eqn 2}$$

5.0 Start Emissions Versus Soak Time

Start emissions will be a function of soak time so that MOBILE6 will be able to account for the entire distribution of soak times observed in the fleet. This ranges from a minimum soak time of zero minutes up to a 12 hour soak period (720 minutes). Soak periods exceeding 12 hours will be assumed to be the same as for a 12 hour soak.

To develop the relationship between start emissions and soak time, the FTP database was used only to determine the engine start emissions after a 10 minute soak and a 12 hour (720 minute) soak (these are the only data points available). To predict start emissions for the entire range of soak duration, a model was developed from the two FTP points, and from testing done by California of the effect of soak time on engine start emissions (see CARB report "Methodology for Calculating and Redefining Cold and Hot Start Emissions")

The model which was developed uses the FTP start emission data from the two FTP soak times to adjust the curves presented in the California report. The start emission data points at 10 minutes and 720 minutes are derived from the FTP dataset described earlier and are a function of pollutant, technology, model year group, and mileage. The California interpolation curves (California Soak Function) is a function of pollutant and catalyst type

Mathematically, the start emissions of a given pollutant (in grams) as a function of soak time is shown as:

Start Emissions (@ soak time) = Basic Start Emissions (@ 12 hour soak) * Soak Function

where the Soak Function is a multiplicative factor used to calculate start emissions for other soak times. The Soak Function is calculated by dividing the grams for the soak time of interest by the grams for a soak time of 12 hours. Therefore, at a 12 hour (720 minute) soak time, the Soak Function is equal to 1.0.

Mathematically, for the first domain of the California Soak Function (see Table 6 for the two domains for each pollutant and catalyst type) the Soak Function is defined as:

Soak Function = California Soak Function * [Ratio+(1-Ratio)*((SoakTime-10)/(X-10))]

For the second domain of the California Soak Function (i e., HC for catalyst equipped vehicles the second domain is 90 minutes through 720 minutes) the Soak Function is

Table 6
Coefficients for Adjusting Engine Start Emissions for Soak Time

(from "Methodology for Calculating and Redefining Cold and Hot Start Emissions", CARB)

Non-Catalyst Vehicles						
	HC Curve 1	HC Curve 2	CO Curve 1	CO Curve 2	NOX Curve 1	NOX Curve 2
Constant	0 38067	0 43628	0 43803	-0 08541	1 31568	2 48061
minutes	-0 00163	0 00078	-0 00998	0 00303	0 02752	-0 00018
minutes^2	6 64E-05	0	7 01E-05	-2 11E-06	-0 00015	-2 6E-06
domain(min)	0-52	53-720	0-119	120-720	0-119	120-720
Catalyst Equipped Vehicles						
	HC Curve 1	HC Curve 2	CO Curve 1	CO Curve 2	Nox Curve 1	NOx Curve 2
Constant	0	0 57130	0	0 70641	0 11796	1 12983
minutes	0 01272	0 00072	0 01195	0 00033	0 02967	2 21E-05
minutes^2	-6 30E-05	-1 76E-07	-4 76E-05	1 00E-07	-0 00021	-3 04E-07
domain(min)	0-89	90-720	0-116	117-720	0-61	62-720
Electrically Heated Catalyst Equipped Vehicles						
	HC Curve 1	HC Curve 2	CO Curve 1	CO Curve 2	Nox Curve 1	NOx Curve 2
Constant (a)	0	0 50641	0	0 44733	1 05017	1 37178
minutes (b)	0 00561	0 00069	0 00707	0 00162	0 00362	0 00027
minutes^2 (c)	-5 09E-06	0	-1 33E-05	-1 18E-06	-5 57E-06	-1 09E-06
domain(min)	0-117	118-720	0-107	108-720	0-113	114-720

California Soak Function = a + b * minutes + c * minutes^2 (where minutes is time since last engine operation (i e , soak time))
The Soak Function is the grams per soak time i divided by the grams per overnight soak (720 minutes or 12 hours

defined as:

Soak Function = California Soak Function

where·

California Soak Function: The values developed by the California Air Resources Board to adjust the start emissions for soak times other than 12 hours. This is a function of soak time in minutes. The coefficients for catalyst vehicles, non-catalyst vehicles, and electrically heated catalyst vehicles are given in Table 6. The coefficients for catalyst-equipped vehicles are for the model year/technology groups examined in this report. For example, for HC on a catalyst equipped vehicle at a soak time of 100 minutes, the value is

$0\ 57130 + 0.00072*100 + (-1.76E\text{-}07)*(100)^2 = 0.64154$

Ratio: This parameter is calculated by dividing the EPA ratio of start emissions at 10 minutes to start emissions at 12 hours by the California Soak Function at 10 minutes. Mathematically, it is given by:

Ratio = (Start @10 minutes / Start @720 minutes) / California Soak Function @10 minutes

The numerator in the above equation (Start @10 minutes/ Start @720 minutes) was developed from FTP data using the equations in Sections 3.3, and dividing the Start @10 minutes by the Start @ 720 minutes. One value for each pollutant was developed that included all technologies and vehicle types These values, used in the numerator of the equation, are: HC= 0.160, CO = 0.112, and NOx = 0 204. The California Soak Function is the value obtained from the coefficients in Table 6 at a 10 minute soak point. The California Soak Function values at a 10 minute soak point for catalyst-equipped vehicles, used in the denominator of the equation, are. HC=0.1209, CO=0 1147, and NOx=0 3937. Therefore, the Ratios obtained are: HC=1.3234, CO=0 9765, and NOx=0.5182.

SoakTime: The time duration in minutes of the soak which is to be calculated (range zero minutes to 720 minutes).

X term: This term is defined to be zero for soak times from 0-10 minutes. For the range from 10 minutes to 720 minutes, it is set equal to the highest minute in the domain of the California Soak Function For example, HC emissions from catalyst equipped vehicles have two time domains in Table 6. These are 0-89 minutes and 90-720 minutes. Thus, for this example, X = 0 for times of 10 minutes or less, and X = 89 for times from 11 minutes through 89 minutes No soak adjustment is applied for the remaining soak period of 90 minutes through 720 minutes. Only the California Soak Function is used.

For all three pollutants, the difference between the MOBILE6 soak function and the California soak function will generally be small for the entire range of soak times. If any difference exists it will reach its highest magnitude in the range of 10 minutes to about 60 minutes.

6.0 START EMISSION RESULTS

Start emissions are both a function of vehicle deterioration represented by mileage, and soak time In previous sections the results were shown separately. In this section, examples of the results are shown with both effects combined.

Shown in the linked EXCEL spreadsheets (CAR_BER.xls and TR_BER.xls) is a sample calculation of the basic emission start factors for the various model year groups and pollutants It includes calculations for both start and running emissions The calculations in the spreadsheet use Equation 1 in this document, and show the magnitude of the start emission factors that will be used in MOBILE6.

The statistical results and output are too voluminous to present directly in this document. However, they are available in the linked document (stat.lst). The statistical software SPSS was used to perform the linear regressions and compute the means In general, the regression correlation coefficients (r-squared) are not high (< 0.10), and reflect the tremendous scatter in emissions data. However, virtually, all of the regression coefficients of the normal emitters are significant at least at a 90 percent confidence level On the other hand, the confidence intervals around the average start emission levels of the high emitters are quite large due to high scatter and small sample sizes.

Shown below for illustration purposes is a sample calculation of start emissions. It illustrates the soak function equations and methodology shown in Section 5.

Example: Calculate HC start emissions at a soak time of 88 minutes for a 1991 model year PFI-equipped car with 60,000 miles.

Start Emissions (@88min) = Basic Start Emissions (@12hr) * Soak Function

From Tables 4a, 5a and A-1:
Basic Start Emissions = High_ave * Highs + Norm_ave * Normals

START = 4.829*0.0987 + (1 999 + 0.00683*60)(1.0 - 0.0987) = 2.647 g HC

Soak Function = California Soak Funct * [Ratio+(1-Ratio)*((SoakTime-10)/(X-10))]

From Table 6, using the coefficients for catalyst-equipped vehicles:
California Soak Funct = 0.000 + (0.01272)*(88) + (-6.30E-05)*$(88)^2$ = 0.63149

Ratio = (Start@10min / Start@12hr) / California Soak Funct@10min
= 1.3234 for HC as given in Section 5.0

SoakTime = 88 minutes

X = 89 minute HC time domain (from Table 6).

Soak Function = 0.63149 * [1.3234 + (1-1.3234) * ((88-10) / (89-10))] = 0.63407

Start Emissions(@90min) = 2.647 * 0.63407 = 1.679g HC

Appendix A
Fraction of High and Normal Emitters in the Fleet

The fractions of high and normal emitters in the fleet were calculated based on the running emission estimates. For consistency, these fractions were also used for start emissions. The fractions were based on the running estimates, because the running estimates were corrected to account for the recruitment bias inherent in the FTP data.

A large amount of IM240 data from the Dayton, Ohio I/M program (211,000 initial tests) were used to correct the recruitment bias inherent in the FTP type data The recruitment bias is believed to exist in the EPA and AAMA FTP samples because of (1) their relatively small size in comparison to the likelihood of selecting a high emitter, (2) the belief that motorists with poorly maintained or tampered vehicles will be reluctant to volunteer them to a government entity like the EPA or even the vehicle manufacturer, and (3) the relatively low mileage levels of the EPA and AAMA sample (relatively few over 100,000 miles).

Since the Dayton sample contains virtually the entire vehicle fleet (or a randomly selected 50 percent) of the city these issues of recruitment bias should be minimal. For example, the sample size is quite large (211,000 vehicles). Even if high emitters are just a few percent of this sample, they should be well characterized Also, I/M is not a voluntary program in Ohio; thus, a motorist cannot simply decline to participate. Unless they have intentionally tampered the vehicle and have an expectation of failure, it is unlikely that they would seek to avoid the program since the data is from the first year of I/M testing in Dayton.

Although the mileage data from Dayton are highly suspect and not useful, the vehicles of a given model year vintage are older than the vehicles of the same model year vintage in the EPA and AAMA databases. Thus, they should provide a more representative cross-section of the in-use fleet. The derivation of the average running emission rates, with the adjustments based on the Dayton IM240 data, are discussed in EPA document M6.EXH 001.

Tables A-1 and A-2 show the fraction of HC and CO high emitters in the fleet. The use of these to develop start emission factors are discussed in Section 4 4 and Section 4.5. The derivation of these high emitter fractions is discussed in detail in EPA document M6 IM 001. However, a brief description and the mathematical equation is shown below.

The number of High and Normal emitters is calculated at each age point for each combination of vehicle type / pollutant / model year / technology group using the following general equations.

Where:

Highs is the fraction of High emitters.
Normals is the fraction of Normal emitters.
RLA4 is the average running emission rate, after adjustment based on IM240 data from Dayton, OH.
High_ave is the high emitter running emission average estimated from the FTP data.
Norm_ave is the normal emitter running emission average estimated from the FTP data.

$$\text{Highs} + \text{Normals} = 1 \qquad \text{Eqn A-1}$$

and

$$\text{RLA4} = \text{High\_ave} * \text{Highs} + \text{Norm\_ave} * \text{Normals} \qquad \text{Eqn A-2}$$

Solving for the variables Highs and Normals produces:

$$\text{Highs} = (\text{RLA4} - \text{Norm\_ave}) / (\text{Highave} - \text{Norm\_ave}) \qquad \text{Eqn A-3}$$

$$\text{Normals} = 1 - \text{Highs} \qquad \text{Eqn A-4}$$

Table A-1
Estimated Fraction of HC High Emitters in the Fleet

MILEAGE	HC 88-93 PFI	HC 88-93 TBI	HC 83-87 FI	HC 86-89 Carb	HC 83-85 Carb	HC 81-82 FI	HC 81-82 Carb
2 142	0 0184	0 0239	0 0223	0 0052	0 0232	0 0203	0 0282
12 823	0 0227	0 0251	0 0157	0 0197	0 0158	0 0654	0 0543
29 335	0 0422	0 0270	0 0406	0 0526	0 0047	0 1613	0 1580
50	0 0800	0 0386	0 1003	0 1042	0 0917	0 2861	0 2906
60 006	0 0987	0 0458	0 1298	0 1296	0 1348	0 3485	0 3560
74 239	0 1260	0 0561	0 1723	0 1661	0 1972	0 4393	0 4503
87 786	0 1525	0 0661	0 2078	0 2012	0 2578	0 5275	0 5416
100 01	0 1770	0 0753	0 2346	0 2334	0 3135	0 6094	0 6253
112 948	0 2036	0 0851	0 2634	0 2678	0 3737	0 6986	0 7152
124 625	0 2280	0 0940	0 2898	0 2992	0 4290	0 7812	0 7976
135 738	0 2518	0 1026	0 3153	0 3295	0 4826	0 8620	0 8772
146 315	0 2748	0 1110	0 3400	0 3586	0 5345	0 9407	0 9539
156 38	0 2972	0 1190	0 3638	0 3866	0 5847	1 0000	1 0000
165 96	0 3189	0 1267	0 3868	0 4135	0 6332	1 0000	1 0000
175 077	0 3398	0 1341	0 4089	0 4393	0 6801	1 0000	1 0000
183 753	0 3601	0 1412	0 4303	0 4641	0 7253	1 0000	1 0000
192 01	0 3798	0 1480	0 4508	0 4879	0 7690	1 0000	1 0000
199 869	0 3988	0 1546	0 4706	0 5108	0 8111	1 0000	1 0000
207 349	0 4171	0 1609	0 4896	0 5327	0 8516	1 0000	1 0000
214 466	0 4348	0 1669	0 5079	0 5537	0 8907	1 0000	1 0000
221 241	0 4519	0 1727	0 5255	0 5738	0 9284	1 0000	1 0000
227 688	0 4683	0 1782	0 5425	0 5931	0 9646	1 0000	1 0000
233 823	0 4842	0 1836	0 5587	0 6116	1 0000	1 0000	1 0000
239 663	0 4994	0 1887	0 5743	0 6293	1 0000	1 0000	1 0000
245 22	0 5141	0 1936	0 5893	0 6462	1 0000	1 0000	1 0000
250 509	0 5283	0 1982	0 6036	0 6624	1 0000	1 0000	1 0000

Table A-2
Estimated Fraction of CO High Emitters in the Fleet

	CO	CO	CO	CO	CO	CO	CO
MILEAGE	88-93 PFI	88-93 TBI	83-87 FI	86-89 Carb	83-85 Carb	81-82 FI	81-82 Carb
2 142	0 0093	0 0552	0 0180	0 0103	0 0130	0 0119	0 0508
12 823	0 0082	0 0553	0 0123	0 0388	0 0093	0 0511	0 1102
29 335	0 0241	0 0553	0 0357	0 0929	0 0473	0 1334	0 2441
50	0 0458	0 0554	0 0889	0 1741	0 1783	0 2466	0 4138
60 006	0 0566	0 0555	0 1150	0 2140	0 2430	0 3024	0 4969
74 239	0 0721	0 0555	0 1496	0 2715	0 3364	0 3830	0 6163
87 786	0 0872	0 0556	0 1765	0 3270	0 4271	0 4611	0 7312
100 01	0 1010	0 0556	0 2012	0 3778	0 5102	0 5327	0 8360
112 948	0 1159	0 0557	0 2276	0 4323	0 5998	0 6097	0 9479
124 625	0 1296	0 0558	0 2518	0 4822	0 6819	0 6802	1 0000
135 738	0 1429	0 0558	0 2751	0 5302	0 7614	0 7484	1 0000
146 315	0 1556	0 0559	0 2976	0 5764	0 8381	0 8141	1 0000
156 38	0 1680	0 0559	0 3193	0 6210	0 9121	0 8775	1 0000
165 96	0 1799	0 0560	0 3402	0 6638	0 9836	0 9387	1 0000
175 077	0 1914	0 0560	0 3602	0 7050	1 0000	0 9976	1 0000
183 753	0 2025	0 0561	0 3795	0 7445	1 0000	1 0000	1 0000
192 01	0 2132	0 0561	0 3981	0 7825	1 0000	1 0000	1 0000
199 869	0 2235	0 0561	0 4159	0 8191	1 0000	1 0000	1 0000
207 349	0 2334	0 0562	0 4330	0 8541	1 0000	1 0000	1 0000
214 466	0 2429	0 0562	0 4495	0 8877	1 0000	1 0000	1 0000
221 241	0 2521	0 0562	0 4653	0 9200	1 0000	1 0000	1 0000
227 688	0 2609	0 0563	0 4804	0 9510	1 0000	1 0000	1 0000
233 823	0 2693	0 0563	0 4949	0 9806	1 0000	1 0000	1 0000
239 663	0 2774	0 0563	0 5089	1 0090	1 0000	1 0000	1 0000
245 22	0 2852	0 0564	0 5222	1 0363	1 0000	1 0000	1 0000
250 509	0 2927	0 0564	0 5350	1 0623	1 0000	1 0000	1 0000