MEMORANDUM

DATE: May 31, 2000

SUBJECT: Changes to the NONROAD Model for the April 2000 Version Used in Support of the 2007 Heavy-Duty Diesel Engine Rule

FROM: The Nonroad Engine Emissions Modeling Team
Richard Wilcox, Team Leader

TO: Docket A-99-06

Introduction

For use in the air quality modeling for the 2007 HDD rulemaking, we have made various technical corrections and updates to the US EPA Nonroad Engine Emissions Model (NONROAD). These revisions update the version used for the Tier 2 light-duty vehicle and gasoline sulfur rulemaking, as published in the Federal Register on February 10, 2000 (Volume 65, Number 28). The Tier 2 version of NONROAD is described and documented in the EPA report, "Technical Report Addenda for Tier 2 Rulemaking Version," dated March 24, 1999 (EPA420-R-99-008).

This memo documents the subsequent model changes to NONROAD through April 2000 and reflected in the nonroad emission inventory estimates for the 2007 HDD final rule analyses. It is intended to allow initial public review and comment on the modeling methods used. More details of the specific modeling inputs will be provided in updated versions of the NONROAD technical reports in the coming months. The Regulatory Impact Analysis to be published with the final rule will also include more details of the modeling methods and inputs.

Overview of Changes

The most substantial changes are in the projected Tier 2 and Tier 3 diesel emission factors and recreational equipment inputs. Less substantial changes also affect all equipment types, such as updates to equipment population estimates obtained from the Power Systems Research (PSR) Partslink database. In this revision, 1998 values replace the 1996 data used previously. Other changes include revisions to activity (hours/year) and load factor inputs for certain equipment types based on either new PSR data or data provided by industry (e.g., load factors for chainsaws).

Diesel Emission Factors

Overview and Reasons for Revision

EPA has diesel engine emission factors used in the NONROAD model. Revisions reflect changes in steady-state emission factors and transient adjustment factors used to derive the emission factors used as inputs to the NONROAD model. We have revised steady-state emission factors for engines in Tiers 1-3 (MY 1996-2004) have revised transient adjustment factors for MY1988 and later engines. We have adopted deterioration factors for all engines (Tiers 0-3). The phase-in of diesel nonroad regulations by horsepower category is given in Table 1.

In previous versions of NONROAD, we based Tier 1 steady-state emission factors on either limited certification results collected by EPA or the California Air Resources Board (ARB), or in the absence of certification data, assumed that engines emitted at the applicable standard. Subsequently, a large number of Tier 1 engine certification test results have become available, especially for smaller engines (< 50 hp) for which the Tier 1 standards became effective in the 1999 or 2000 model year. These data provide an appropriate basis for revision of diesel emission factors for Tier 1 engines. For Tier 2 and Tier 3 emission factors in previous NONROAD versions, we similarly assumed that emissions remained at Tier 1 levels, or emitted at the applicable standard, whichever was more stringent. We have since refined this approach to also take into account certification compliance margins observed for highway diesel engines. Our new approach is described in more detail below.

We adopted deterioration factors to account for the tendency of engine emissions to increase over time, due to the effects of wear, poor maintenance or breakage. Deterioration data are unavailable for nonroad engines, but we believe that deterioration data for highway engines provide a reasonable surrogate. We adapted and applied the deterioration data reported for MOBILE6 and PART6 in USEPA (1999) for all pollutants, Tiers, and horsepower categories.

Transient adjustments apply to engines in Tiers 0-3 (MY1988-2004). Transient adjustments for pre-1988 engines are already incorporated, for selected applications, in the NEVES emission factors used in NONROAD. Recently available data allows us to develop new transient adjustments for 1988 and later model years.

Table 1 Phase-In of Nonroad Diesel Regulations by Engine Power Category

Power Range (hp)[1]	Model Year												
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
< 11					T1					T2			
11 - 25					T1					T2			
25 - 50				T1					T2				
50 - 100			T1						T2				T3
100 - 175		T1						T2				T3	
175 - 300	T1							T2				T3	
300 - 600	T1					T2					T3		
600 - 750	T1						T2				T3		
> 750	T1										T2		

[1] Horsepower category defined as: lower bound < hp ≤ upper bound.

Based on these variables the steady-state emission factor, transient adjustment factor and deterioration factor, the emission factors NONROAD uses to estimate emissions for a given cohorts of engines over time are derived using the following relationships. First, the transient-adjusted emission factor included in the input file is calculated as:

$$EF_{adj} = EF_{ss} \cdot TAF$$

where EF_{ss} is the 8-mode steady-state emission factor, determined in certification or in-use testing (g/hp-hr) and TAF is the transient adjustment factor (unitless). Second, within the model, the deterioration-adjusted emission factor for a given diesel application in a given year (EF_t) is given by

$$EF_t = EF_{adj} \cdot \left[DF_{rel} \cdot (0.01 \cdot \%\ \text{useful life}) \right]$$

where DF_{rel} is the relative deterioration factor (% emissions increase/% useful life expended) and % useful life is the proportion of equipment's useful life expended (%).

Revisions to Diesel Emission Factors (EF_{ss})

Tier 1

For Tier 1 nonroad engines, we have actual certification test results We averaged these data by horsepower category and adopted values as steady-state emission factors for all pollutants.

For engines less than 25 horsepower, certification data are reported in terms of combined "HC + NO_x" emissions because these pollutants are regulated under a combined standard in which the standard specifies the limit on combined emissions of both pollutants, rather than individual limits for NOx and hydrocarbons. For these horsepower categories, we averaged the HC + NO_x certification data and split the averages into pollutant-specific components for HC and NO_x, using fractions of 0.05 and 0.95, respectively. These fractions are averages calculated from a subset of MY96-00 nonroad certification test results that reported HC and NOx separately.

Tiers 2 and 3

Nonroad certification test results are not yet available for Tier 2 and Tier 3 engines, which are to be produced in model years 2001 and later. We recognize that engine manufacturers are unlikely to produce engines that emit at the exact levels codified in the Tier 2/3 standards. As a result, we developed three alternative options for calculating EF_{ss} for Tier 2/3 engines, and applied these options using the procedure described on pages 7-8.

(A) *Reduce the applicable nonroad standard by a compliance margin derived from certification test results for analogous highway engines*. The compliance margin is the percent difference between a standard and average emissions at certification for engines manufactured under that standard. We expect that the control of emissions from nonroad engines will follow a course similar to that experienced for highway engines, since we believe that as standards for nonroad engines become more stringent, manufacturers will adopt technologies similar to already introduced in highway engines. Based on this expectation, we calculated compliance margins using highway standards and corresponding certification test results. In this discussion, we will refer to compliance margins calculated for highway engines as "highway-certification compliance margins" (HCCM). This process is discussed in detail in Appendix A.

The Agency regulates HC and NO_x under a combined standard for all Tier 2 and Tier 3 engines. Thus, to enable calculation of HCCMs for these pollutants, we split the combined standard into pollutant-specific components for HC and NO_x (Table 2). We used HC and NO_x proportions developed for use in April-1999 draft NONROAD to derive pollutant-specific components for all Tier 2 and Tier 3 standards. Derivation of the split standards is described in Technical Report NR-009a.

(B) *Continue to use emission factors derived from MY96-00 nonroad certification data.* In this option we assume that manufacturers will maintain current emission levels, e.g., design technologies, if they appear adequate to achieve compliance while maintaining some margin of safety. Under this option, we would assume that emission factors remain at the same levels used for Tier 1engines . We refer to this option as “average nonroad certification” (ANC).

(C) *Apply a default compliance margin of 10%.* In this option we assume that on average, manufacturers will maintain a minimum compliance margin. This margin is based on average highway certification compliance margins for NOx, the pollutant appearing to drive measures to achieve compliance in highway diesel engines.

Table 2 Combined and Pollutant-Specific Emissions Standards for Nonroad Diesel Engines[1]

Power Range (hp)	Combined Standard HC+NOx (g/hp-hr)		Pollutant-Specific HC (g/hp-hr)		Pollutant-Specific NO_x (g/hp-hr)	
	Tier 2	Tier 3	Tier 2	Tier 3	Tier 2	Tier 3
< 11	5.6		0.6		5.0	
11-25	5.6		0.6		5.0	
25-50	5.6		0.6		5.0	
50-100	5.6	3.5	0.4	0.2	5.2	3.3
100-175	4.9	3.0	0.4	0.2	4.5	2.8
175-300	4.9	3.0	0.4	0.2	4.5	2.8
300-600	4.8	3.0	0.3	0.2	4.5	2.8
600-750	4.8	3.0	0.3	0.2	4.5	2.8
> 750	4.8		0.3		4.5	

[1] Pollutant-specific components have no regulatory significance and are derived to facilitate modeling analyses. For discussion, see text and Technical Report NR-009a.

Selection of Revised Steady-state Emission Factors for Individual Horsepower Categories

For each pollutant in Tiers 2 and 3, we evaluated one or more of these options (A,B,C above) for each horsepower category, and selected one option meeting the following criteria:

(1) Emission factors for a given pollutant will remain constant or decline across successive Tiers. Thus, we assume that gains in emission control will not retrograde or "backslide" over succeeding model years, and:

(2) The compliance margin between the revised emission factor and the applicable nonroad standard will be at least 10%. We based this lower bound (10%) on average highway-certification compliance margins for NO_x, assuming that it represents progressive highway certification experience for a "controlling pollutant," i.e., a pollutant for which the necessity to achieve compliance drives innovation in engine design or control technology.

Note that in Tier 2, 9 horsepower categories times 4 pollutants gives 36 combinations and in Tier 3, 5 horsepower categories times 4 pollutants gives 20 combinations, for a total of 56 combinations.

For each combination of horsepower category, Tier and pollutant, we executed the following steps:

(1) Calculate the HCCM-based emission factor (Option A, see Appendix A). We adopted this emission factor if:

(a) the HCCM is greater than or equal to 10% and less than 75% ($0.10 \leq HCCM < 0.75$) (Table 3), AND,

(b) the resulting emission factor is less than or equal to that used for the previous Tier ($EF_{T1} \geq EF_{T2} \geq EF_{T3}$).

If either of these criteria is not met, then evaluate Option B:

(2) Adopt the average nonroad certification level (ANC, option B) as the emission factor EF_{ss} if the nonroad compliance margin (NCM) is greater than 10%.

The NCM is defined as the percentage difference between the applicable nonroad standard (Tier 2 or Tier 3) and the average emissions level for engines certified under the Tier 1 standard:

$$NCM = \frac{NS - ANC}{NS}$$

where NS is the nonroad standard for a given pollutant, horsepower category and Tier, (Tiers 2 or 3) (e.g., NO_x, 50-100 hp, Tier 2).

If this criterion is not met, then apply Option C:

(3) Apply a default compliance margin of 10% (Option C):

Under this option, we calculated the emission factor EF_{ss} as

$$EF = 0.90 \cdot NS$$

Revised Steady-State Emission Factor Selections by Pollutant

Based on the steps outlined above, specific options selected for each pollutant and Tier are presented in Table 4 and summarized below:

HC: *Tier 2*: We applied MY 96-00 nonroad certification results (option B) or the default compliance margin (option C) on an individual basis by horsepower category to give nonroad compliance margins of at least 10%. We did not use the highway-certification compliance margins because they were unrealistically large (> 80%), and achieved in relation to highway standards that are several times higher than their pollutant-specific nonroad counterparts.

Tier 3: We applied the default compliance margin of 10% (option C) for all horsepower categories. The nonroad certification data (option B) gave insufficient compliance margins, i.e., < 10%. We ruled out use of highway-certification compliance margins (option A) for the same reason as for Tier 2.

CO: We applied MY1996-2000 nonroad certification data (option B) for all horsepower categories in Tiers 1-3. Highway-certification compliance margins (option A) were very large (>90%), and as with HC, give implausibly low emission factors in Tiers 2 and 3.

Table 3 Highway-Certification Compliance Margins by Horsepower Category

Nonroad Engine Power Categories (hp)	Highway Model-Year Group (MYG)	Corresponding Heavy-Duty Highway Vehicle Weight Class (VWC), Emission Standards (HS), Certification Test Results (AHC) and Compliance Margins (HCCM)			
		NOx			
		VWC[1]	**HS**	**AHC** [2]	**HCCM**
			(g/hp-hr)	**(g/hp-hr)**	**(% HS)**
< 11	1991-93	LHDD	5.0	4.28	14
11-25	1991-93	LHDD	5.0	4.28	14
25-50	1991-93	LHDD	5.0	4.28	14
50-100	1998-2003	MHDD	4.0	4.54	9.0
100-175	1998-2003	MHDD	4.0	3.78	5.5
175-300	1998-2003	MHDD	4.0	2.58	10.5
300-600	1998-2003	HHDD	4.0	2.92	2.0
600-750	1998-2003	HHDD	4.0	3.84	4.0
>750	1998-2003	HHDD	4.0	3.84	4.0
		PM			
< 11	1988-89	LHDD	0.6	0.44	27
11-25	1988-89	LHDD	0.6	0.44	27
25-50	1988-89	LHDD	0.6	0.44	27
50-100	1991-93	MHDD	0.25	0.20	20
100-175	1991-93	MHDD	0.25	0.20	20
175-300	1994-97	MHDD	0.10	0.08	20
300-600	1994-97	HHDD	0.10	0.08	20
600-750	1994-97	HHDD	0.10	0.08	20
>750	1994-97	HHDD	0.10	0.08	20

[1] LHDD = "light heavy-duty diesel," MHDD = "medium heavy-duty diesel," and HHDD = "heavy heavy-duty diesel."

[2] Source: USEPA (1999), for NO_x, Table 10 or MY 1997-2001 highway certification data; for PM, Table 11 or MY 1997-2001highway certification data.

NO_x: *Tier 2*: We applied highway-certification compliance margins (option A), nonroad certification results (option B) or the default compliance margin (option C) on an individual basis by horsepower category to give compliance margins of at least 10%.

Tier 3: We applied the highway certification compliance margin (option A) or the default compliance margin (option C) for all horsepower categories. Nonroad certification results (option B) did not satisfy their selection criterion.

PM: We applied highway-certification compliance margins (option A) for all horsepower categories in Tiers 2 , with the exception of one horsepower category (11-25 hp), for which Option A resulted in higher emission factors than those observed from certificaiton data. For this category, we applied the average nonroad certification level (Option B). Emission factors do not change between Tiers 2 and 3, because the standards remain constant.

Revised steady-state emission factors for all Tiers and pollutants are shown in Table 4.

Table 4 Revised Zero-Hour Steady-State Emission Factors for Nonroad Diesel Engines by Pollutant, Power Range and Regulatory Tier

Power Range		Emission Factor (g/hp-hr)			
(hp)	**(kW)**	**Tier 0**	**Tier 1**	**Tier 2**	**Tier 3**
			HC[1]		
< 11	< 8	1.5	0.30	0.30 (B)	
11-25	8-19	1.7	0.20	0.20 (B)	
25-50	19-37	1.8	0.13	0.13 (B)	
50-100	37-75	1.0	0.56	0.36 (C)	0.18 (C)
100-175	75-130	0.7	0.40	0.36 (C)	0.18 (C)
175-300	130-225	0.7	0.35	0.35 (B)	0.18 (C)
300-600	225-440	0.7	0.22	0.22 (B)	0.18 (C)
600-750	440-560	0.7	0.20	0.20 (B)	0.18 (C)
>750	> 560	0.7	0.20	0.20 (B)	
			CO[2]		
< 11	< 8	5.0	4.1	4.1	
11-25	8-19	5.0	1.3	1.3	
25-50	19-37	5.0	1.8	1.8	
50-100	37-75	3.5	2.0	2.0	2.0
100-175	75-130	2.7	1.1	1.1	1.1
175-300	130-225	2.7	0.8	0.8	0.8
300-600	225-440	2.7	0.8	0.8	0.8
600-750	440-560	2.7	1.2	1.2	1.2
>750	> 560	2.7	1.1	1.1	

[1] HC: Tier 0: Represents MY 1988-Tier 1. Documented in NR-009a.
Tier 1: MY 1996-2000 nonroad diesel engine certification test results (8-mode emissions).
Tier 2: MY 1996-2000 certification test results (B) or a default compliance margin of 10% (C), as indicated by superscript.
Tier 3: Default compliance margin of 10% (C), as indicated by superscript.

[2] CO: Tier 0: Represents MY 1988-Tier 1. Documented in NR-009a.
Tier 1: MY 1996-2000 nonroad diesel engine certification test results (8-mode emissions).
Tier 2: MY 1996-2000 nonroad diesel engine certification test results (8-mode emissions).
Tier 3: MY 1996-2000 nonroad diesel engine certification test results (8-mode emissions).

Table 4 Revised Emission Factors for Nonroad Diesel Engines (continued).

Power Range (hp)	Power Range (kW)	Tier 0	Tier 1	Tier 2	Tier 3
		Emission Factor (g/hp-hr)			
		NOx[1]			
< 11	< 8	10.0	5.6	4.3[(A)]	
11-25	8-19	8.5	4.0	4.3[(B)]	
25-50	19-37	6.9	4.8	4.3[(A)]	
50-100	37-75	6.9	5.3	4.7[(C)]	3.0[(C)]
100-175	75-130	8.4	5.9	4.1[(C)]	2.5[(C)]
175-300	130-225	8.4	5.8	4.0[(A)]	2.5[(A)]
300-600	225-440	8.4	5.8	4.1[(C)]	2.5[(C)]
600-750	440-560	8.4	5.8	4.1[(C)]	2.5[(C)]
>750	> 560	8.4	5.8	4.1[(C)]	
		PM			
< 11	< 8	1.00	0.52	0.44[(A)]	
11-25	8-19	0.90	0.36	0.36[(B)]	
25-50	19-37	0.80	0.38	0.32[(A)]	
50-100	37-75	0.72	0.37	0.24[(A)]	0.24[(A)]
100-175	75-130	0.40	0.22	0.18[(A)]	0.18[(A)]
175-300	130-225	0.40	0.19	0.12[(A)]	0.12[(A)]
300-600	225-440	0.40	0.12	0.12[(A)]	0.12[(A)]
600-750	440-560	0.40	0.14	0.12[(A)]	0.12[(A)]
>750	> 560	0.40	0.13	0.12[(A)]	

[1] NOx Tier 0: Represents MY 1988-Tier 1. Documented in NR-009a.

Tier 1: MY 1996-2000 nonroad diesel engine certification test results (8-mode emissions).

Tier 2: Pollutant-specific component of the Tier 2 HC+NO_x standard (Table 2), minus the corresponding highway-certification compliance margin (A) (Table 3), or the default compliance margin (C), as indicated by superscript.

Tier 3: Pollutant-specific component of the Tier 2 HC+NO_x standard (Table 2), minus the corresponding highway-certification compliance margin (A) (Table 3), or the default compliance margin (C), as indicated by superscript.

[2] PM: Tier 0: Represents MY 1988-Tier 1. Documented in NR-009a.

Tier 1: MY 1996-2000 nonroad diesel engine certification test results (8-mode emissions).

Tier 2: Highway-certification compliance margin (Table 3) .

Tier 3: Highway-certification compliance margin (Table 3).

Deterioration Factors (DF_{rel})

As with the revised steady-state emission factors, we based the deterioration factors adopted for nonroad engines on highway certification data (zero-mile levels and lifetime deterioration) presented in USEPA (1999) and used in development of the Tier 2/3 nonroad diesel engine emission factors. Correspondence between highway weight class (light, medium, heavy), highway model-year group, and nonroad horsepower categories is identical to that used for the steady-state emission factor analysis.

We converted the highway engine deterioration estimates into a format applicable to nonroad engines, following two steps:

(1) We calculated absolute deterioration rates DF_{abs} using the zero-mile emission factors and lifetime deterioration estimates presented in USEPA (1999).

(2) We converted the absolute deterioration rates DF_{abs} (g/hp-hr^2) to relative deterioration rates DF_{rel} (% emissions increase/% useful life expended). We discuss these two calculations in greater detail below.

We calculated a separate DF_{rel} for each combination of pollutant**,** Tier, and horsepower category. Then to derive a single value for each Tier and pollutant, we calculated a weighted average DF_{rel} using the proportion of emissions by pollutant as a weighting variable. We discuss these calculations in greater detail in the following subsection.

Derivation of Highway-Certification Based Deterioration Factors

To adapt highway-certification deterioration rates for application to nonroad engines, it was necessary to convert them from an absolute basis (emissions increase over engine's useful life (g/hp-hr)) to a relative basis (% emissions increase/% useful life expended). This conversion involves relating the emissions increase over the engine's useful life to the zero-hour emission factor, in proportional terms.

We achieved this conversion as follows. To begin, if we assume linear deterioration with the intercept at the zero-mile emission factor, (0 deterioration increase at 0 miles (0 hours useful life)), it is possible to calculate the absolute slope of the line, i.e., the absolute deterioration rate DF_{abs} (g/hp-hr^2) (Figure 1). The required data are the absolute emissions increase D_T (g/hp-hr) over engine's useful life L (years) and the zero-mile emission factor EF_{zm} (g/hp-hr):

$$\mathrm{DF}_{abs} = \frac{\Delta y}{\Delta x} = \frac{(\mathrm{EF}_{zm} + D_T) - \mathrm{EF}_{zm}}{L - 0} = \frac{D_T}{L} \qquad (7)$$

Dividing the numerator and denominator by EF_{zm} and L, respectively, and multiplying each by 100 expresses the deterioration factor in percentage terms with respect to emissions increase and useful life, giving a relative deterioration rate DF_{rel} (% emissions increase/% useful life):

$$DF_{rel} = \frac{\left(\frac{D_T}{EF_{zm}}\right) \cdot 100}{\left(\frac{L}{L}\right) \cdot 100} = \frac{D_T}{EF_{zm}} \qquad (8)$$

Thus, the relative deterioration rate is the quotient of the absolute emissions increase and the zero-mile emission factor. Tables 5-8 present estimates of DF_{rel} for each combination of pollutant, Tier and horsepower category. To derive individual values of DF_{rel} for each pollutant and Tier, we calculated weighted averages, using the proportion of emissions in each horsepower category as the weighting variable (Table 9). We calculated the proportions using NONROAD predictions of emissions for each pollutant, apportioned by horsepower category. The April-1999 draft version of NONROAD generated the predictions. Weighted-average relative deterioration factors for each pollutant and Tier are presented in Table 10.

Table 5 Hydrocarbon (HC) Deterioration Factors by Tier and Horsepower Category

Nonroad Engine Power Categories (hp)	Corresponding Highway Vehicle Weight Class[1]	Corresponding Highway Model-Year Group	Corresponding Highway Certification Test Results and Deterioration Factors		
			EF_{ZM}[2] (g/hp-hr)	D_T[3] (g/hp-hr)	DF_{rel}[4] (%increase/% useful life)
				Tier 0	
< 11	LHDD	1988-89	0.64	0.02	0.031
11-25	LHDD	1988-89	0.64	0.02	0.031
25-50	LHDD	1988-89	0.64	0.02	0.031
50-100	MHDD	1988-89	0.66	0.05	0.068
100-175	MHDD	1988-89	0.66	0.05	0.068
175-300	MHDD	1988-89	0.66	0.05	0.068
300-600					0.043
600-750					0.043

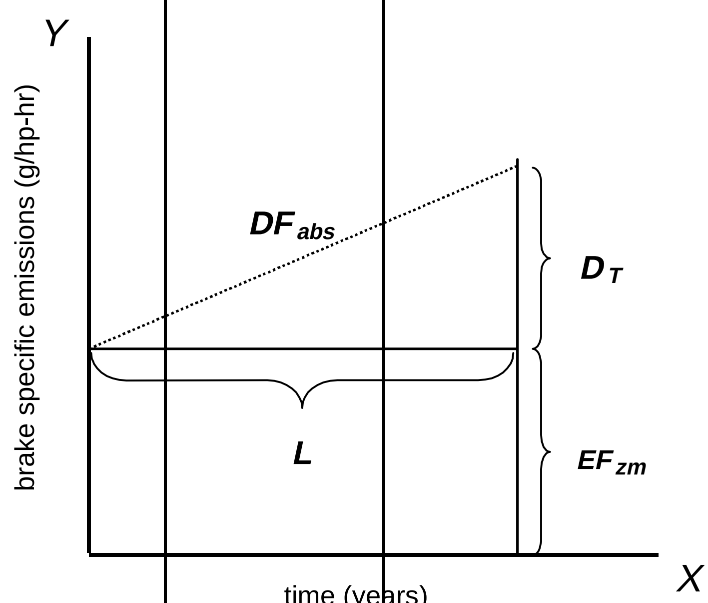

Figure 1. Conceptual representation of absolute linear emissions deterioration over the useful life of a diesel engine.

>750	HHDD	1988-89	0.47	0.02	0.043
				Tiers 1-3	
< 11	LHDD	1994-97	0.26	0.01	0.038
11-25	LHDD	1994-97	0.26	0.01	0.038
25-50	LHDD	1994-97	0.26	0.01	0.038
50-100	MHDD	1994-97	0.31	0.00	0.000
100-175	MHDD	1994-97	0.31	0.00	0.000
175-300	MHDD	1994-97	0.31	0.00	0.000
300-600	HHDD	1994-97	0.22	0.02	0.068
600-750	HHDD	1994-97	0.22	0.02	0.068
>750	HHDD	1994-97	0.22	0.02	0.068

[1] LHDD = "light heavy-duty diesel," MHDD = "medium heavy-duty diesel," and HHDD = "heavy heavy-duty diesel."

[2] Zero-mile emission factor, Source: USEPA 1999, Table 8.

[3] Lifetime Deterioration (cumulative deterioration over vehicle useful life), Source USEPA 1999, Table 8.

[4] Relative Deterioration Factor, calculated as D_T/EF_{zm}. For discussion, see text.

Table 6 CO Deterioration Factors by Tier and Horsepower Category[1]

Nonroad Engine Power Categories (hp)	Corresponding Highway Vehicle Weight Class[1]	Corresponding Highway Model-Year Group	Corresponding Highway Certification Test Results and Deterioration Factors		
			EF_{ZM}[2] (g/hp-hr)	D_T[3] (g/hp-hr)	DF_{rel}[4] (%increase/% useful life)
				Tier 0	
< 11	LHDD	1988-89	1.22	0.24	0.198
11-25	LHDD	1988-89	1.22	0.24	0.198
25-50	LHDD	1988-89	1.22	0.24	0.198
50-100	MHDD	1988-89	1.70	0.33	0.195
100-175	MHDD	1988-89	1.70	0.33	0.195
175-300	MHDD	1988-89	1.70	0.33	0.195
300-600	HHDD	1988-89	1.36	0.22	0.162
600-750	HHDD	1988-89	1.36	0.22	0.162
>750	HHDD	1988-89	1.36	0.22	0.162
				Tiers 1-3	
< 11	LHDD	1994-97	1.20	0.03	0.021
11-25	LHDD	1994-97	1.20	0.03	0.021
25-50	LHDD	1994-97	1.20	0.03	0.021
50-100	MHDD	1994-97	0.88	0.17	0.189
100-175	MHDD	1994-97	0.88	0.17	0.189
175-300	MHDD	1994-97	0.88	0.17	0.189
300-600	HHDD	1994-97	1.07	0.10	0.093
600-750	HHDD	1994-97	1.07	0.10	0.093
> 750	HHDD	1994-97	1.07	0.10	0.093

[1] LHDD = "light heavy-duty diesel," MHDD = "medium heavy-duty diesel," and HHDD = "heavy heavy-duty diesel."

[2] Zero-mile emission factor, Source: USEPA 1999, Table 9.

[3] Lifetime Deterioration (cumulative deterioration over vehicle useful life), Source USEPA 1999, Table 9.

[4] Relative Deterioration Factor, calculated as D_T/EF_{zm}. For discussion, see text.

Table 7 NOx Deterioration Factors by Pollutant and Horsepower Category[1]

Nonroad Engine Power Categories (hp)	Corresponding Highway Vehicle Weight Class[1]	Corresponding Highway Model-Year Group	Corresponding Highway Certification Test Results and Deterioration Factors		
			EF_{ZM}[2] (g/hp-hr)	D_T[3] (g/hp-hr)	DF_{rel}[4] (%increase/% useful life)
				Tier 0-1	
< 11	LHDD	1988-89	4.34	0.02	0.005
11-25	LHDD	1988-89	4.34	0.02	0.005
25-50	LHDD	1988-89	4.34	0.02	0.005
50-100	MHDD	1988-89	6.43	0.16	0.025
100-175	MHDD	1988-89	6.43	0.16	0.025
175-300	MHDD	1988-89	6.43	0.16	0.025
300-600	HHDD	1988-89	6.28	0.28	0.044
600-750	HHDD	1988-89	6.28	0.28	0.044
>750	HHDD	1988-89	6.28	0.28	0.044
				Tier 2	
< 11	LHDD	1991-93	4.28	0.01	0.003
11-25	LHDD	1991-93	4.28	0.01	0.003
25-50	LHDD	1991-93	4.28	0.01	0.003
50-100	MHDD	1998-2003	4.67	0.03	0.006
100-175	MHDD	1998-2003	4.67	0.03	0.006
175-300	MHDD	1998-2003	4.67	0.03	0.006
300-600	HHDD	1998-2003	4.70	0.05	0.011
600-750	HHDD	1998-2003	4.70	0.05	0.011
>750	HHDD	1998-2003	4.70	0.05	0.011
				Tier 3	
50-100	MHDD	1998-2003	4.67	0.03	0.006
100-175	MHDD	1998-2003	4.67	0.03	0.006
175-300	MHDD	1998-2003	4.67	0.03	0.006
300-600	HHDD	1998-2003	4.70	0.05	0.011
600-750	HHDD	1998-2003	4.70	0.05	0.011

[1] LHDD = "light heavy-duty diesel," MHDD = "medium heavy-duty diesel," and HHDD = "heavy heavy-duty diesel."
[2] Zero-mile emission factor, Source: USEPA 1999, Table 10.
[3] Lifetime Deterioration (cumulative deterioration over vehicle useful life), Source USEPA 1999, Table 10.
[4] Relative Deterioration Factor, calculated as D_T/EF_{zm}. For discussion, see text.

Table 8 PM Deterioration Factors by Pollutant and Horsepower Category[1]

Nonroad Engine Power Categories (hp)	Corresponding Highway Vehicle Weight Class[1]	Corresponding Highway Model-Year Group	Corresponding Highway Certification Test Results and Deterioration Factors		
			***EF**$_{ZM}$*[2] (g/hp-hr)	***D**$_T$*[3] (g/hp-hr)	***DF**$_{rel}$*[4] (%increase/% useful life)
				Tier 0-1	
< 11	LHDD	1988-89	0.44	0.01	0.023
11-25	LHDD	1988-89	0.44	0.01	0.023
25-50	LHDD	1988-89	0.44	0.01	0.023
50-100	MHDD	1988-89	0.44	0.03	0.068
100-175	MHDD	1988-89	0.44	0.03	0.068
175-300	MHDD	1988-89	0.44	0.03	0.068
300-600	HHDD	1988-89	0.44	0.02	0.045
600-750	HHDD	1988-89	0.44	0.02	0.045
>750	HHDD	1988-89	0.44	0.02	0.045
				Tier 2	
< 11	LHDD	1988-89	0.44	0.01	0.023
11-25	LHDD	1988-89	0.44	0.01	0.023
25-50	LHDD	1988-89	0.44	0.01	0.023
50-100	MHDD	1991-93	0.20	0.01	0.050
100-175	MHDD	1991-93	0.20	0.01	0.050
175-300	MHDD	1994-97	0.08	0.000	0.000
300-600	HHDD	1994-97	0.08	0.000	0.000
600-750	HHDD	1994-97	0.08	0.000	0.000
>750	HHDD	1994-97	0.08	0.000	0.000
				Tier 3	
50-100	MHDD	1991-93	0.20	0.01	0.050
100-175	MHDD	1991-93	0.20	0.01	0.050
175-300	MHDD	1994-97	0.08	0.000	0.000
300-600	HHDD	1994-97	0.08	0.000	0.000
600-750	HHDD	1994-97	0.08	0.000	0.000

[1] LHDD = "light heavy-duty diesel," MHDD = "medium heavy-duty diesel," and HHDD = "heavy heavy-duty diesel."

[2] Zero-mile emission factor, Source: USEPA 1999, Table 11.

[3] Lifetime Deterioration (cumulative deterioration over vehicle useful life), Source USEPA 1999, Table 11.

Table 9 Weights Applied to Deterioration Factors by Criteria Pollutant[1]

Power Category (hp)	HC	CO	NOx	PM
< 11	0.005	0.011	0.002	0.007
11-25	0.048	0.046	0.027	0.061
25-50	0.110	0.123	0.059	0.096
50-100	0.342	0.251	0.269	0.382
100-175	0.192	0.205	0.241	0.183
175-300	0.191	0.212	0.240	0.162
300-600	0.069	0.084	0.088	0.058
600-750	0.014	0.026	0.024	0.019
> 750	0.029	0.043	0.050	0.031

[1] Proportion of emissions by horsepower category, as calculated by April-1999 Draft NONROAD.

Table 10 Proposed Deterioration Factors for Nonroad Diesel Engines

Pollutant	Relative Deterioration Factor (DF_{rel}) (% increase/%useful life)[1]			
	Tier 0	Tier 1	Tier 2	Tier 3
HC	0.06	0.01	0.01	0.01
CO	0.19	0.14	0.14	0.18
NOx	0.03	0.03	0.01	0.01
PM	0.06	0.06	0.03	0.04

[1] Weighted averages for each Tier, calculated using weights by horsepower category and pollutant, as shown in Table 10.

Transient Adjustment Factors (TAFs)

We have revised transient adjustment factors (TAFs) applied to diesel emission factors for nonroad MY1988 and later. As with deterioration factors, the purpose of this revision is to reflect recently available test data, which supplements the set of test data used to develop the transient adjustment factors for the April1999 draft version of NONROAD.

We apply transient adjustments because baseline emission factors are based on steady-state emission tests. However, transient conditions characterize some or all of the actual operation of many types of nonroad equipment, some of which experience frequent or continuous changes in speed and load. Thus, we apply TAFs to compensate for the effects of such transient operation on diesel emissions.

We have derived transient adjustment factors from sets of laboratory test data specifically collected for this purpose. We test a set of selected engines using a standard steady-state test cycle and several transient test cycles. A transient test cycle varies speed and load so as to simulate the actual operation of a particular type of nonroad equipment, such as agricultural tractor, backhoe loader, etc. We then calculate transient emission factors (EF_{trans})from the transient test results.

For each pollutant and operating cycle, we calculate the TAF as the ratio of the transient emission factor (EF_{trans}) to the corresponding steady-state emission factor (EF_{ss}):

$$TAF = \frac{EF_{trans}}{EF_{ss}}$$

Transient adjustment factors may be greater than or less than 1.0.

In the April1999 draft version of NONROAD, we applied one set of adjustment factors to some engines in 1988 and later model years,. Baed on test results for a set of nine engines are the basis for these TAFs. The test engines included eight Tier 0 engines produced in model years 1988-1995, and one Tier 1 engine, produced in 1997. We tested each engine on the ISO C1 standard 8-mode steady-state cycle, and three transient cycles (agricultural tractor, backhoe loader, and crawler dozer). TAFs based on these results range from 0.42 to 2.31, depending on test cycle and pollutant (Table 11). We assigned one of the TAF to each application where we considered its use appropriate.

For the April 2000 draft version of NONROAD, we developed separate adjustment factors for Tier 0 (1989-1995) and Tier 1 and later engines. We recalculated transient adjustment factors for Tier 0 engines after removing results for the single Tier 1 engine originally included with the results for the Tier 0 engines. We calculated transient adjustment factors for Tier 1 and later engines using results for four Tier 1 engines, one of which was the single Tier 1 engine previously tested for development of the original set of TAFs. We tested all four engines on the original three transient cycles, and two of the engines on an additional 3 transient cycles (arc welder, rubber-tire loader, skid-steer loader). Based on these results, six TAFs are available for each pollutant for Tier 1 engines (Table 12).

We revised TAF assignments to some equipment applications, based on further evaluation of their operating patterns. For Tier 0 engines, we reassigned TAF for 5 applications out of 43 applications for which TAF were used previously For example, we changed the assignment for off-highway trucks from “backhoe” to “dozer.” For an additional nine applications, we introduced TAFs where none had been used previously. Thus, for Tier 0 engines, we now apply TAFs to a total of 52 applications (Table 13).

For Tier 1 engines, we have modified some TAF assignments to equipment applications for Tier 1 and later engines to take advantage of the three new transient cycles. We reassigned one of the recently developed alternative TAFs to thirteen applications assigned one of the original 3 TAFs. We introduced TAFs for an additional fifteen applications. In total, for Tier 1 engines, we apply TAF to 67 of 80 diesel applications (Table 13).

Table 11 Prior and Revised Diesel Transient Adjustment Factors for Tier 0 Engines

Test Cycle	version	HC	CO	NOx	PM	BSFC
Agricultural Tractor	prior[1]	0.89	0.42	0.99	0.64	0.98
	revised	0.88	0.42	1.00	0.61	0.98
	% difference	-1.00	0.00	1.00	-5.00	0.00
Backhoe	prior[1]	2.19	2.31	1.03	2.04	1.18
	revised	2.19	2.32	1.02	1.96	1.18
	% difference	0.00	0.00	-1.00	-4.00	0.00
Crawler Dozer	prior[1]	0.93	1.27	0.99	1.21	0.98
	revised	0.92	1.27	0.99	1.17	0.98
	% difference	-1.00	0.00	0.00	-3.00	0.00

[1] Used in April-1999 Draft NONROAD.

Table 12 Revised Diesel Transient Adjustment Factors for Tier 0 and Tier 1+ Engines

Test Cycle	Tier	HC	CO	NOx	PM	BSFC
Agricultural Tractor	Tier 0	0.88	0.42	1.00	0.61	0.98
	Tier 1+	0.91	0.65	0.94	0.82	0.99
	% difference	4.0	55	-6.0	34	1.0
Backhoe	Tier 0	2.19	2.32	1.02	1.96	1.18
	Tier 1+	1.81	2.26	1.13	1.87	1.13
	% difference	-17	-2.0	11	-4.0	-5.0
Crawler Dozer	Tier 0	0.92	1.27	0.99	1.17	0.98
	Tier 1+	0.87	1.52	0.96	1.30	1.00
	% difference	-5.0	20	-4.0	11	2.0
Arc Welder	Tier 1+	2.76	3.22	1.31	2.12	1.29
RT Loader[1]	Tier 1+	0.94	3.73	0.96	2.03	1.04
SS Loader[2]	Tier 1+	1.29	1.85	0.95	1.75	1.09

[1] Rubber-Tire Loader.

[2] Skid-Steer Loader.

Table 13 Assignment of Diesel Transient Adjustment Factors by Nonroad Application, Model Version and Tier [1]

Use Category	Application	Prior[2]	Revised: Tier 0	Revised: Tier 1+
Agricultural	Agricultural Mowers	Ag Tractor	Ag Tractor	Ag Tractor
	Agricultural Tractors	Ag Tractor	Ag Tractor	Ag Tractor
	Balers	Ag Tractor	Ag Tractor	Ag Tractor
	Combines	Ag Tractor	Ag Tractor	Ag Tractor
	Other Agricultural	Ag Tractor	Ag Tractor	Ag Tractor
	Sprayers	Ag Tractor	Ag Tractor	Ag Tractor
	Swathers	Ag Tractor	Ag Tractor	Ag Tractor
	Tillers > 6 hp	Ag Tractor	Ag Tractor	Ag Tractor
	Two-wheel Tractors	Ag Tractor	Ag Tractor	Ag Tractor
	Hydro Power Units	None	None	Arc Welder
	Irrigation Sets	None	None	Arc Welder
Airport Service	Airport Support Equipment	Backhoe	Backhoe	RT Loader
	Terminal Tractors	Backhoe	Backhoe	Backhoe
Commercial	Air Compressors	None	Dozer	Arc Welder
	Gas Compressors	None	Dozer	Arc Welder
	Generator Sets	None	None	Arc Welder
	Pressure Washers	None	None	Arc Welder
	Pumps	None	None	Arc Welder
	Welders	None	None	Arc Welder
Construction	Dumpers/Tenders	Backhoe	Backhoe	Backhoe
	Excavators	Backhoe	Backhoe	Backhoe
	Off-Highway Tractors	Backhoe	Dozer	Dozer
	Off-Highway Trucks	Backhoe	Dozer	Dozer
	Plate Compactors	Backhoe	Backhoe	Arc Welder
	Rough Terrain Forklifts	Backhoe	Backhoe	RT Loader
	Rubber Tire Loaders	Backhoe	Backhoe	RT Loader
	Skid Steer Loaders	Backhoe	Backhoe	SS Loader
	Tractor/Loader/Backhoes	Backhoe	Backhoe	Backhoe
	Trenchers	Backhoe	Dozer	Dozer
	Bore/Drill Rigs	Dozer	Dozer	Arc Welder
	Concrete/Industrial Saws	Dozer	Dozer	Dozer
	Cranes	Dozer	Dozer	Arc Welder
	Crawler Dozer	Dozer	Dozer	Dozer
	Crushing/Processing	Dozer	Dozer	Arc Welder
	Graders	Dozer	Dozer	Dozer
	Other Construction	Dozer	Dozer	Dozer
	Pavers	Dozer	Dozer	Dozer
	Paving Equipment	Dozer	Dozer	Dozer
	Rollers	Dozer	Dozer	Dozer

Use Category	Application	Prior[2]	Revised: Tier 0	Revised: Tier 1+
	Rubber Tire Dozers	Dozer	Dozer	Dozer
	Scrapers	Dozer	Dozer	Dozer
	Surfacing Equipment	Dozer	Dozer	Dozer
	Cement/Mortar Mixers	None	None	Arc Welder
	Signal Boards	None	None	Arc Welder
Industrial	Sweepers/Scrubbers	Ag Tractor	Backhoe	Backhoe
	Forklifts	Backhoe	Backhoe	RT Loader
	Other Material Handling	Backhoe	Backhoe	Backhoe
	Aerial Lifts	Dozer	Backhoe	Backhoe
	AC/Refrigeration	None	None	Arc Welder
	Other General Industrial	None	None	None
Lawn & Garden	Chippers/Stump Grinders	None	None	None
	Chippers/Stump Grinders (Commercial)	None	None	Arc Welder
	Commercial Turf Equipment	None	Backhoe	Arc Welder
	Front Mowers	None	Backhoe	Backhoe
	Front Mowers (Commercial)	None	Backhoe	Backhoe
	Lawn & Garden Tractors	None	Backhoe	Backhoe
	Lawn & Garden Tractors (Commercial)	None	Backhoe	Backhoe
	Leafblowers/Vacuums	None	None	Arc Welder
	Other Lawn & Garden	None	None	None
	Rear Engine Riding Mowers	None	Backhoe	Backhoe
	Shredders < 6 hp	None	None	Arc Welder
	Shredders < 6 hp (Commercial)	None	None	Arc Welder
	Snowblowers	None	None	None
	Snowblowers (Commercial)	None	None	None
Logging	Fellers/Bunchers	Backhoe	Backhoe	RT Loader
	Skidders	Dozer	Dozer	RT Loader
	Chain Saws > 6 hp	None	None	RT Loader
	Shredders > 6 hp	None	None	RT Loader
Oil Field	Other Oil Field	None	None	Arc Welder
Railroad	Railway Maintenance	Backhoe	Backhoe	Backhoe
Recreational Marine	Pleasure Craft, Outboards	None	None	None
	Sailboat Aux., Outboards	None	None	None
	Pleasure Craft, Inboards	None	None	None
Recreational Vehicle	Speciality Vehicle Carts	Backhoe	Backhoe	Backhoe
Underground Mining	Underground Mining	Backhoe	Backhoe	Backhoe

[1] For numerical values associated with transient cycles, see Table 12.

[2] Assignment used in April-1999 Draft NONROAD.

Recreational Equipment

In the April 2000 draft version of NONROAD, estimates of emissions from snowmobiles and off-road motorcycles/ATVs have decreased considerably from the estimates developed for the Tier 2 rulemaking using the April 1999 version of the model. For instance, estimated snowmobile exhaust VOC, CO, and PM emission inventories are 85-90% lower, and NOx is about 75% lower than prior estimates. Similarly, revised estimates of off-road motorcycle/ATV emission inventories are lower by about 65% for VOC, 88% for CO and NOx, and 45% for PM. These changes are based on updated estimates of the typical usage patterns of these vehicles and updated emission factors based on emission test results from more current snowmobiles. The reductions in estimated emissions, average activity and load factor more than offset an increase in estimated motorcycle/ATV population, as shown in Table 14.

Small Spark-Ignition Lawn and Garden Engines

For engines less than 25 horsepower (19 kilowatts) that power lawn and garden equipment and are covered by the recently- finalized Hand-Held Small Spark-ignition Engine Rule (Classes III, IV, and V), we revised several inputs to NONROAD, based on information supplied by the manufacturers of these engines. Specifically, we revised the mix of technologies to reflect the manufacturers' projected responses to the new phase-in schedule for the rule.

We have revised the residential/commercial population proportions for commercial chainsaws, trimmers/edgers/brush cutters, and blowers/vacuums. We now classify all equipment powered by Class III two-stroke engines as residential. Equipment powered by Class IV two-stroke engines is now predominantly classified as residential. All equipment powered by Class V two-stroke engines is now classified as commercial.

Independently of the final handheld spark-ignition rule, we have revised the residential and commercial proportions for four-stroke blowers/vacuums and trimmers/edgers/brush cutters to reflect information from the manufacturers. In the June 1998 and April 1999 draft versions of NONROAD, the population proportions for these equipment types were independent of engine size. Based on the new manufacturer information, engine size is now a factor. We now classify all blowers/vacuums and trimmers/edgers/brush cutters powered by four-stroke engines over 6 horsepower as commercial equipment. The residential/commercial proportions for comparable engines under 6 horsepower remains unchanged.

We have also revised the median life at full load and load factors for engines powering both residential and commercial (Classes III, IV, and V) chainsaws, trimmers/edgers/brush cutters, and blowers/vacuums, based on recent information from industry. The updated median life and load factor values are shown in Table 15.

Table 14 Revised Recreational Equipment Two-Stroke Emission Factors (g/hp-hr), Activity, Load Factors, and Population

Equipment	Factor	**Prior** (4/99)	**Revised** (4/00)	% Change
Snowmobile	Emission Factor			
	THC	154	110	-29%
	CO	390	300	-23%
	NOx	0.47	0.86	+83%
	PM	2.4	2.7	+13%
	Activity (hours/year)	121	30	-75%
	Load Factor	0.81	0.34	-58%
	Population	1,276,538*	Unchanged	N/A
Motorcycle/ATV	Emission Factor			
	THC	154	110	-29%
	CO	390	300	-23%
	NOx	0.47	0.86	+83%
	PM	2.4	2.7	+13%
	Activity (hours/year)	135	34	-75%
	Load Factor	0.72	0.34	-53%
	Population	1,726,536	5,106,000	196%

* Source: 1996 snowmobile registration data provided by the International Snowmobile Manufacturers Association (ISMA).

Table 15 Revised Median Life and Load Factors for Hand Held Equipment (≤ 25 hp)			
Equipment Type	**Median Life Residential**	**Median Life Commercial**	**Load Factor**
Chainsaws	39.2 hours	191.0 hours	0.70
Trimmers/Edgers/Brush Cutters	35.3 hours	286.8 hours	0.91
Blowers/Vacuums	40.4 hours	609.7 hours	0.94

Appendix A: Derivation of Tier 2/3 Diesel Emission Factors (EF_{ss}) Using Highway-Certification Compliance Margins

Here below, we describe the derivation of the highway-certification compliance margins in greater detail. The highway certification results used for this purpose in derivation of Tier 2/3 emission factors (option A) are summarized in a report updating emission levels for heavy-duty highway diesel engines for use in MOBILE6 (USEPA 1999). The report presents results for light, medium, and heavy vehicle classes in model years 1988-1989 and 1991-1994. For this analysis, we supplemented these certification data with more recent highway certification data from model years 1997-2001.

As described previously, we used the highway certification results to calculate compliance margins (HCCM) for some highway engines for MY 1988-2001. The procedure followed several steps (Table 3):

(1) We assigned highway model-year groups, (e.g., 1991-93) to each nonroad horsepower category (e.g., 50-100 hp). These assignments vary for each pollutant and individual horsepower category. The assignments attempt to associate similar highway and nonroad engine technologies. We averaged results for multiple years within a model-year group.

(2) We assigned nonroad engines less than 50 horsepower to the light heavy-duty diesel vehicle weight class (LHDD), engines in the range of 50-250 hp to the medium heavy-duty diesel vehicle weight class (MHDD), and engines greater than 250 hp to the heavy heavy-duty diesel vehicle weight class (HHDD). Within a model-year group, these assignments identified subsets of certification data to represent specific nonroad horsepower categories. Correspondence between highway weight class (light-duty, medium-duty, heavy-duty) and nonroad horsepower categories follows relationships established by the California Air Resources Board (CARB 2000).

(3) We used the highway certification data described above and assigned to the appropriate nonroad horsepower categories to calculate compliance margins for highway engines at certification:

$$HCCM_{i,j} = \frac{HS_{i,j} - AHC_{i,j}}{HS_{i,j}}$$

where $HCCM_{i,j}$, $HS_{i,j}$ and $AHC_{i,j}$ are the highway-certification compliance margin, highway standard and average certification emissions level, respectively, for pollutant *i*, and horsepower category *j* (e.g., NOx, 50-100 hp).

(4) We calculated steady-state emission factors for Tier 2 nonroad engines as the applicable nonroad standard $NS_{i,j,T2}$, reduced by the compliance margin $HCCM_{i,j}$:

$$EF_{i,j,T2} = NS_{i,j,T2} \cdot (1 - HCCM_{i,j})$$

Similarly, we calculated steady-state emission factors for Tier 3 engines as the applicable Tier 3 standard reduced by $HCCM_{i,j}$:

$$EF_{i,j,T3} = NS_{i,j,T3} \cdot (1 - HCCM_{i,j})$$

While we calculated the highway-certification compliance margins for all pollutants and horsepower categories, note that Table 3 presents results only for NO_x and PM. We do not present compliance margins for HC and CO because we did not use them in estimation of Tier 2/3 emission factors.

References

United States Environmental Protection Agency. Update of Heavy-Duty Emission Levels (Model Years 1988 - 2004+) for Use in MOBILE6. Office of Air and Radiation, Office of Mobile Sources, Assessment and Modeling Division. EPA420-R-010 / M6.HDDE.001. April, 1999.