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U. S. EPA NONROAD Model
Technical Report Addenda

for Tier 2 Rulemaking Version

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Introduction

Various technical corrections and updates have been made to the US EPA Nonroad Engine Emissions Model (NONROAD) since the last release of the technical reports for public review. This is intended to document all those changes that occurred prior to EPA's use of NONROAD in December 1998 to generate nonroad emission inventory estimates for the Tier 2 NPRM. It also documents changes that we have made to the model since the Tier 2 modeling runs were done, plus certain additional changes planned for the final release of NONROAD.

The reports are all listed below in order of report number. In some cases there are no updates, corrections or changes applicable to a given report. Such cases are noted below.

NR-001
Temperature and RVP Effects on Diurnal Emissions for Nonroad Engine Modeling

In addition to effects on diurnal emissions, NONROAD also includes effects of ambient temperature on exhaust emissions. This has been true in every release of the model including the 1997 beta, but it was not mentioned in the technical report. The method used in NONROAD is taken directly from the MOBILE5a highway emission factor model. Only effects on 4-stroke gasoline engine exhaust hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NOx) are included. We are not aware of any data that could be used to estimate temperature effects on the other pollutants in NONROAD, so no such effects are currently modeled.

The details of the temperature correction method are as follows:

TCF = EXP [A * (Tambient -75)]

where:

TCF = multiplicative Temperature Correction Factor

Tambient = Ambient Temperature, in degrees Fahrenheit

"A" = The coefficient "A" is taken from MOBILE5a for "Bag 2" effects on uncontrolled light-duty gasoline vehicles (LDGV's). "Bag 2" refers to the hot stabilized portion of the test sequence, so no cold-start effects are present. The value of "A" in the above equation depends on high or low temperature (relative to 75F) and on pollutant (HC/CO/NOx). Values for A are:

"A"	Tambient>75	Tambient<75
HC (4-stroke)	-.00240	+.00132
CO (4-stroke)	+.00158	+.00375
NOx (4-stroke)	-.00892	-.00873

For two-stroke engines, conditions differ significantly from those of on-road motor vehicles. Therefore, the 4-stroke corrections from MOBILE are not applied to 2-stroke or diesel engines in NONROAD. Due to lack of data for these engine types, temperature effects on exhaust emissions from 2-stroke and diesel engines are not currently included in NONROAD. However, we have recently become aware of some limited test data on 2-stroke snowmobile engines at somewhat reduced temperatures. These data will be investigated and may allow modeling of 2-stroke temperature effects in the final release of NONROAD.

NR-002
Conversion Factors for Hydrocarbon Emission Components

There are no updates, corrections or changes to these aspects of the model.

NR-003
Exhaust Emission Effects of Fuel Sulfur and Oxygen on Gasoline Nonroad Engines

There are no updates, corrections or changes to these aspects of the model. Temperature effects on exhaust emissions are now covered in NR-001 above.

NR-004
Seasonal and Monthly Activity Allocation Fractions For Nonroad Engine Emissions Modeling

The only addition to the information provided in NR-004 is that the NONROAD model now has the ability to model seasonal and monthly emissions for a nationwide scenario. Previously, nationwide modeling runs could only be done for an "annual total" or "typical annual day." Since then, we have used the monthly activity allocations to calculate national average seasonal and monthly activity allocations. These are now included in the SEASON.DAT input data file with the region designation of "US."

The national average seasonal allocations were calculated as follows:

1) Do twelve 50-state model runs (one for each month of the year) including all equipment types to generate emission estimates for any exhaust pollutant (HC, CO or NOx) for each state for each month for every type of equipment. Use the same temperature and fuel properties for all runs, since the seasonality allocation factors are just meant to allocate activity, regardless of emissions. In this exercise the emissions are being used as a surrogate for activity.

2) Do one annual total model run including all equipment types, using same temperature and fuel properties as in step 1.

3) For each of the 65 equipment types listed in SEASON.DAT find the ratio of each month's emissions total from step 1 to the annual total from step 2.

4) In the /MONTHLY/ packet of SEASON.DAT add another 65-line block for the US total allocations, putting in the twelve monthly ratios from step 3 into each appropriate line.

NR-005a
Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling

We have made changes to recreational marine activity and median life as well as forklift activity and median life.

The annual activity values for recreational marine engines have been changed to match the values used in the 1996 US EPA final rule. [1] The "Tech Report" values contained in the June 1998 draft release of NONROAD were based on back-calculation from data on fuel consumption and average power level (estimated from boat length) in a 1992 Price Waterhouse survey conducted for the U.S. Fish and Wildlife Service and the U.S. Coast Guard. Depending on comments received, we may switch back to using the "Tech Report" values in the final release of NONROAD.

Recreational Marine Activity (hours/year)	Tech Report	1996 Final Rule (currently in model)
Inboard (4-stroke)	75	47.6
Outboard (2-stroke)	45	34.8
Personal Watercraft	73	77.3

Median Life and Load Factor

In the original technical report median life was based on the values in Table 1 of that report ("Expected Engine Life in Hours at Full Load") combined with Load Factors. The recreational

marine load factor used in all cases in both the tech report and in the current NONROAD is 0.21 (rounded from 0.207 in the technical report).

The analysis described in technical report NR-005a had assumed increasing engine life with increasing engine size, but the rulemaking regulatory impact analysis used the opposite assumption according to data submitted by marine engine manufacturers. Since deterioration is assumed to be zero for 2-strokes, these differences should have no effect on base year emission inventory comparisons. In looking at future controlled years, median life differences would become important. NONROAD currently uses the rulemaking RIA median life estimates, since sticking to the numbers in tech report NR-005a would mean that outboard engines and PWC over 50 hp have a median life of 66 years, which seems a bit excessive. Note that the power vs engine life relationship used in the rulemaking RIA and now used in NONROAD is opposite from what is used for other equipment in NONROAD as covered in the tech report NR-005a, which is based on values from the CARB OFFROAD model. Comments on the median life determination for recreational marine engines and any supporting data would be very welcome.

Median Life - Spark Ignition Recreational Marine Engines

Power Range		Tech Report (June 1998 draft)	NONROAD (revised July 1998)	1996 Final Rule RIA (FRMCURVE*)
HP min	HP max	hours	hours	hours
Outboard				
0	3	200	194	194 = 27 yrs
3	6	200	194	194
6	11	200	191	187-194
11	16	200	177	173-180
16	25	750	162	158-166
25	40	1500	148	130-151
40	50	1500	140	130-151
50	100	3000	126	122-130
100	175	3000	108	101-115
175	999	3000	97	94-101 = 13-14 yrs
PWC				
16	25	750	160	= 10 yrs
25	40	1500	160	
40	50	1500	160	
50	100	3000	160	
100	175	3000	160	

Inboard				
3	6	200	197	= 20 yrs
6	11	200	197	
11	16	200	197	
25	40	1500	197	
50	100	3000	197	
100	175	3000	197	
175	300	3000	197	

* FRMCURVE median life = useful life yrs*(hrs/yr)*load factor. i.e., useful life at full load.

The spark ignition forklift inputs for annual activity and median life have been changed from the PSR estimates based on a 1991 study. [2] The 4500 hour median life value is based on the nine year life given in that study multiplied by the average activity of 1664 hours/year divided by the load factor.

Forklift Activity, Life, and Load Factor

	Tech Report (June 1998 draft)	NONROAD (revised Nov 1998)
Activity (hrs/yr)	1800	1664
Median Life (hrs)	750 - 3000*	4500
Load Factor	0.30	0.30

* depending on engine power rating.

NR-006a
Nonroad Engine Population Estimates

One enhancement to the model which affects all equipment types is the ability to input an average horsepower for each power range for each equipment type. As an example, for agricultural tractors (SCC 2270005015) in the 300-600 hp range the model used to simply compute emissions using the midpoint of the power range (450 hp), but the model now uses an average power of 350 hp based on PSR estimates of the in-use population of agricultural tractors. All of the average horsepower inputs come from 1996 PSR estimates, except for four of the most significant lawn & garden equipment types -- lawn mowers, trimmers, chainsaws, and leafblowers -- for which average horsepowers were determined from EPA engine emission certification records.

Other updates to the engine populations described in the tech report affect the following equipment types: snowmobiles, snowblowers, lawn mowers, trimmers, chainsaws, leafblowers, forklifts and certain other spark-ignition commercial/industrial equipment. In some cases

changes have also been made to the distribution of engines among fuel types (gasoline, LPG, CNG).

The snowmobile population inputs have been updated from the previous PSR estimates based on state snowmobile registration data compiled by the International Snowmobile Manufacturers Association (ISMA). This increased the estimated population by about 60% to a total of 1,276,538. Since the ISMA registration data did not include engine horsepower information, the PSR data was still used to set the fraction of engines within each horsepower range.

Large spark ignition engine (greater than 25 hp) populations have been changed from the PSR estimates based on early information collected for EPA's February 28, 1999, Notice of Proposed Finding. [3] Specifically, the total 1996 population of spark-ignition forklifts greater than 25 hp (19 KW) was increased from about 158,000 to 370,000. This change occurred in early November 1998 and was included in the NONROAD model runs done for the Tier 2 proposed rule and for the small spark ignition engine final rule. [4] However, based on the two final reference documents [5, 6] that were used for the February 28 Finding, a more correct number to use for total SI forklifts is 420,000. Thus, we plan to switch to this higher number for the final release of NONROAD.

The LPG/CNG fractions of certain large (greater than 25 hp) SI equipment were also changed from the PSR estimates. For forklifts the LPG fraction was increased to 95%. For refrigeration/air conditioning equipment the CNG fraction was set to 100%. For many other large SI engines, such as generator sets, pumps, air compressors, welders, etc., the LPG/CNG fraction was increased to 50%. Details of these LPG/CNG fractions are found in the January 28, 1999, EPA memorandum by Alan Stout. [5]

As of 1998, engines less than 25 horsepower used in gasoline-fueled nonroad equipment (such as lawn and garden equipment) were required to meet the first set of Federal emission standards, known as Phase 1 standards. Using sales estimates submitted to EPA by manufacturers of small nonroad engines as part of their Phase 1 certification, EPA estimated the total number of engines sold in 1998 in four of the highest sales volume small engine applications: lawnmowers, trimmers/edgers/cutters, chainsaws, and leaf blowers/vacuums. For 1993 and earlier years EPA used sales estimates that had been submitted for those years by manufacturers during the development of EPA's Phase 1 rulemaking. For the years 1994 to 1997 EPA linearly interpolated between the 1993 and 1998 sales estimates for each application. Using this year by year sales information and the expected scrappage of small nonroad equipment, EPA estimated the total 1996 calendar year population for the four applications noted above. In order to determine the power category specific populations, EPA relied on the fractions of engines in each engine class based on the certification sales estimates for all categories other than lawnmowers. For lawnmowers, nearly all of which were certified as Class I engines, EPA used the power category fractions in the PSR database. The resulting 1996 base year populations, by power category, for the four applications noted above are shown in the following table.

1996 Base Year Populations for Select Nonroad Small SI Equipment Applications

Application	0-1 hp	1-3 hp	3-6 hp	6-11 hp
4-stroke lawnmowers (residential)	0	636,892	31,652,672	10,436
4-stroke lawnmowers (commercial)	0	29,577	1,469,938	485
2-stroke chainsaws (residential)	0	4,770,000	530,000	0
2-stroke chainsaws (commercial)	0	540,000	60,000	0
2-stroke trimmers (residential)	3,400,000	10,094,600	105,400	0
2-stroke trimmers (commercial)	450,000	1,336,050	13,950	0
2-stroke leaf blowers (residential)	517,500	6,210,000	172,500	0
2-stroke leaf blowers (commercial)	52,500	630,000	17,500	0

NR-007
Calculation of Age Distributions in the Nonroad Model: Growth and Scrappage

There are no updates, corrections or changes to these aspects of the model.

NR-008
Nonroad Engine Growth Estimates

Technical report NR-008 explained that for the draft version of NONROAD, released in June 1998, we projected future populations by fitting an exponential curve to the historical populations and extrapolating from that curve to future years. This approach resulted in very large projected increases in equipment populations in 2010 and beyond for certain equipment categories. In response to comments received about this approach, we reviewed the data again and concluded that extrapolating from a simple linear regression of the historical populations would give more reasonable estimates of future populations. This change was implemented in the model in October 1998 and is more fully documented in the paper "Geographic Allocation and Growth In EPA's NONROAD Emission Inventory Model," written for the December 1998 Air and Waste Management Association Conference, by Gary Dolce, Greg Janssen, and Richard Wilcox.

As described in that paper, there are two exceptions to the use of linear growth extrapolations: oil field equipment and aircraft ground support equipment (GSE). The PSR database indicates a sharp decline in oil field equipment population over the period from 1989 to 1996, which is not unreasonable given trends in the domestic oil production industry over that period. However, if this trend is extrapolated linearly, it implies that oil field equipment would disappear completely by 2006. Because there is no indication that domestic oil production will cease by 2006, we have chosen to use BEA economic estimates of gross state product from

domestic oil production to estimate growth in this equipment category. This change was implemented in the NONROAD model in October 1998.

In the case of aircraft ground support equipment, we have become aware that the Federal Aviation Administration has a detailed database that tracks aircraft takeoffs and landings for commercial aviation. Since the activity of ground support equipment is directly related to commercial aviation takeoff and landing events, we believe that this database may provide a more accurate basis than the PSR database for estimating ground support equipment population, activity, and growth. However, we have not yet completed this analysis, so this change has not yet been implemented in the model. Growth of the aircraft ground support equipment population is currently handled using PSR-based linear growth extrapolations, as is the case for all equipment types other than oil field equipment.

NR-009a
Exhaust Emission Factors for Nonroad Engine Modeling -- Compression-Ignition

The pollutants covered by this report include exhaust total hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NOx), total particulate matter (PM), and brake specific fuel consumption (BSFC). For nonroad engines all PM emissions are assumed to be smaller than 10 microns (PM10), and 92% of the PM from gasoline and diesel fueled engines is assumed to be smaller than 2.5 microns (PM2.5). For gaseous fueled engines (LPG/CNG) 100% of the PM emissions are assumed to be smaller than PM2.5. The NONROAD Reporting Utility allows the user to select the desired size range. These PM size fractions existed in the June 1998 draft release of NONROAD but were not mentioned in the technical report.

The CI engine emission factors and phase-in schedule listed in Table 1 of technical report NR-009a were changed in July 1998 to reflect the provisions of the Final Rule published October 23, 1998. [7] This means that there are no standards for underground mining equipment, and the phase-in schedule depends only on engine power rating and not application.

One correction that still needs to be made for the final release of NONROAD is an adjustment to the exhaust hydrocarbon emission factors for Tier 1, 2, and 3 controlled engines. The emission factors used in the model and listed in the technical report are really nonmethane hydrocarbons (NMHC), whereas the model assumes all inputs are total hydrocarbons (THC). Therefore, we expect the input THC values for these CI engines in the final release will be about 1.6% lower than those currently in the model.

NR-010a
Exhaust Emission Factors for Nonroad Engine Modeling -- Spark Ignition

The corrections and updates to NR-010a are so extensive that a revised version of NR-010 is being issued with the name NR-010b. The major changes included in the new version are listed below.

- The section of NR-010a presenting "Effect of the Federal Rulemaking on SI Recreational Marine Engines" included tables labeled (incorrectly) as Table 6 through Table 11 for 2-stroke and direct injection engines. The emission factors shown in those tables were incorrect, since they were simply copied from the baseline emission factors in Table 2. NR-010b contains corrected tables.

- The recreational marine emission factors have been changed from the sales-weighted averages used in NR-010a and in the June 1998 release of NONROAD to be straight averages of the M1 - M4 engine type emission factors used in the 1996 rulemaking, to be consistent with the method used for the controlled engine types (M5 - M15). For the final version of NONROAD, we may return to using sales-weighted averages of the baseline data for engine types M1 - M4. We may also switch to using sales-weighted averages for engine types M5 - M15 if sufficient sales data by engine type become available for them.

- The small SI engine emission factors and phase-in schedule have been changed per the provisions of the Phase 2 final rule. [4]

- The large SI engine (and snowblower) emission factors have been changed per new test data reported in the 1998 CARB/SwRI report [8] and used in the Large SI Findings Notice [3].

NR-011
Emission Deterioration Factors for the NONROAD Emission Model

Based on the analysis done for the small spark ignition engine Phase 2 final rule [4], all small (and large) spark ignition engine NOx deterioration factors were changed to zero (i.e., no deterioration), for all applications and engine sizes. Also as a result of that analysis, handheld 2-stroke catalyst (tech type G2HxC2) exhaust hydrocarbon deterioration factors were updated as shown below.

Engine Tech Type	Class Description	HC Deterioration Factor A
G2H3C2 (Phase 2 with catalysts)	Class 3 (< 20 cc)	0.72
G2H4C2 (Phase 2 with catalyst)	Class 4 (20cc - 50 cc)	0.77
G2H5C2 (Phase 2 with catalyst)	Class 5 (≥ 50cc; <25 HP)	0.626

NR-012
Basic Evaporative Emission Rates for Nonroad Engine Modeling

In the section "Diurnal: Other possible methods and data" the report mentions the possibility of switching to gram/day emission factors for certain types of equipment. The core model has been modified to allow use of gram/day diurnal inputs, but the input files have not yet been changed to those inputs. The gram/day inputs may be used in the final release of NONROAD depending on comments and any additional data that we receive.

Regarding crankcase emissions the technical report stated: "All pre-1997 chippers and stump grinders are assumed to have open crankcases." However, this assumption has not yet been reflected in the model's CRANK.EMF input file, so the June 1998 draft release and updates through February 1999 (including model runs for the Tier 2 proposed rule) treated chippers/stump grinders (SCC 226x004066) as other lawn & garden equipment and assumed that only 21% of them had open crankcases. The final release of NONROAD will model 100% of pre-1997 chippers and stump grinders to have open crankcases.

NR-013
Refueling Emissions for Nonroad Engine Modeling

There are no changes to this report. The tank size inputs are still handled as they were in the June 1998 draft, since the model has not yet been changed to allow specific gallon size inputs as described in the tech report. We still plan to change the tank size methodology for the final release of NONROAD to incorporate the method from NEVES which uses specific tank sizes for certain types of equipment, rather than using a regression of tank size versus horsepower.

NR-014
Geographic Allocation of State Level Nonroad Engine Population Data to the County Level

As described in this technical report, snowmobile and snowblower populations at the state and county levels were set to zero in the June 1998 draft version of the model to avoid misallocation problems. In October 1998, we changed these allocations to use state snowmobile populations provided to EPA by the International Snowmobile Manufacturers Association (ISMA) to allocate both snowmobiles and snowblowers to the state level. Within each state, snowmobiles are allocated to counties using the same indicator as other recreational equipment -- number of recreational vehicle parks. Snowblowers are allocated to counties using the same indicator as other lawn and garden equipment -- number of single and double (duplex) family housing units for residential snowblowers and number of employees in landscape and horticultural services for commercial snowblowers. Note that neither of these changes were mentioned in the December 1998 Air and Waste Management Association paper "Geographic Allocation and Growth In EPA's NONROAD Emission Inventory Model."

Other corrections to the NONROAD allocation data files have been made as follows:

- November 1998: Added missing Alaska counties to AK*.ALO files.

- November 1998: Added missing human population allocation file for Hawaii (HI_POP.ALO).

- January 1999: Changed the allocation indicator for refrigerated truck trailers (SCC 22xx003060) to human population as specified in the technical report. Prior to that it had used the same indicator as other 22xx003000 equipment types -- number of employees in manufacturing.

- February 1999: Changed the allocation indicator for golf carts (SCC 22xx001050) to number of golf course establishments as specified in the technical report. Prior to that it had used the number of golf course employees.

- February 1999: Changed the allocation indicator for recreational equipment (SCC 22xx0010xx other than 22xx001050) to number of recreational vehicle park establishments as specified in the technical report. The June 1998 draft release of NONROAD actually had the correct data file, but all the modeling runs done by EPA prior to February 1999 used the number of RV park employees.

No changes have been made yet to the allocation method for Aircraft Ground Support Equipment. For the final release of NONROAD we still plan to change from using the number of people employed in air transportation to using the number of landings and take-offs (LTOs) by airport to allocate ground support equipment populations.

References

[1] "Regulatory Impact Analysis: Control of Air Pollution - Emission Standards for New Spark-Ignition Marine Engines," U.S. EPA, October, 1996.

[2] "Forklift Comparative Cost Study," Arnold Schneider, Ph.D., CPA, for the National Propane Gas Association, June 1991.

[3] Notice of Proposed Finding: Control of Emissions From New Nonroad Spark-Ignition Engines Rated Above 19 Kilowatts and New Land-Based Recreational Spark-Ignition Engines, February 28, 1999, 64 FR 6008.

[4] Final Rule: Phase 2 Emission Standards for New Nonroad Spark-Ignition Nonhandheld Engines At or Below 19 Kilowatts, signed March 1999.

[5] "Emission Modeling for Large SI Engines," Alan Stout, U. S. Environmental Protection Agency, Office of Mobile Sources, supporting memorandum for February 8, 1999, proposed finding for large spark-ignition engines, January 28, 1999.

[6] "The Role of Propane in the Fork Lift/Industrial Truck Market: A Study of its Status, Threats, and Opportunities," Robert E. Myers for the National Propane Gas Association, December 1996.

[7] Final Rule: Control of Emissions of Air Pollution From Nonroad Diesel Engines, October 23, 1998, 63 FR 56967.

[8] "Three-Way Catalyst Technology for Off-Road Equipment Powered by Gasoline and LPG Engines; Volume 2, Cost-Effectiveness Analysis," Jeff J. White, Melvin N. Ingalls, Lit-Mian Chan, Southwest Research Institute, May 1998.