United States Environmental Protection Agency
Air and Radiation
EPA420-P-02-019
April 2002
NR-011a

Spark-Ignition Engine Emission Deterioration Factors for the Draft NONROAD2002 Emissions Model

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Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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For the draft NONROAD2002 Emissions Model

Report No. NR-011a

revised April 24, 2002

Assessment and Standards Division
EPA, Office Transportation and Air Quality

I. <u>Purpose</u>

This report addresses the emission deterioration rates for spark-ignition engines currently being used in the draft NONROAD2002 model. The specific deterioration inputs used in NONROAD and their basis will be addressed for spark-ignition engines at or below 25 horsepower and over 25 horsepower, as well as liquid petroleum gas (LPG) and compressed natural gas engines (CNG). Deterioration inputs for compression-ignition (diesel) engines are addressed in the report, Exhaust Emission Factors for Nonroad Engine Modeling - Compression Ignition (NR-009b). The EPA welcomes comments and suggestions concerning our approach to modeling nonroad engine emissions deterioration.

The previous version of this report contains discussions of the deterioration inputs used in the original 1998 draft of the NONROAD model and sources of deterioration rates which have been considered by EPA. It has been included as an appendix in this report for ease of reference.

II. <u>Background</u>

As used here, the term "deterioration" refers to the degradation of an engine's exhaust emissions performance over its lifetime due to normal use or misuse (i.e., tampering or neglect). Engine deterioration increases exhaust emissions, usually leads to a loss of combustion efficiency, and can in some cases increase nonexhaust emissions. The amount of emissions increase depends on an engine's design, production quality, and technology type (e.g., spark ignition two-stroke and four-stroke, compression ignition). Other factors, such as the various equipment applications in which an engine is used, usage patterns, and how it is stored and maintained, may also affect deterioration.

The term "deterioration rate" refers to the degree to which an engine's emissions increase per unit of activity. Nonroad engine activity is expressed in terms of hours of use or fraction of median life. The term "deterioration factor" refers to the ratio of an engine's emissions at its median life divided by its emissions when new.

The terms *useful life* and *median life* are used in the following manner in this report in order to avoid confusion. *Useful life* is a regulatory term used to indicate the amount of time during the life of a nonroad engine that a manufacturer must certify to the U.S. EPA that the engine meets a required emission standard as defined by a regulation. *Median life,* as used in this report, refers to the age at which 50 percent of the engines sold in a given year have ceased to function and have been scrapped.[1]

III. <u>Core Challenge</u>

The core challenge associated with estimating nonroad engine deterioration is the development of reasonably accurate deterioration rates for the enormous range of nonroad engine types and applications from the limited amount of nonroad emission deterioration data that exist at this time. To estimate deterioration, the emission performance of engines at various ages is required. Such information can be obtained from a longitudinal study that examines the same set of engines periodically as they age, or from a sampling study that tests engines of various ages but the same basic design. In either case, the engines studied should be selected randomly from the population of engines actually being used in the field.

Given the limited available test data, EPA is currently unable to develop unique deterioration rates based on actual engine test data for the myriad of applications and power levels covered by NONROAD. The Office of Transportation and Air Quality has conducted emissions testing on several dozen small spark ignition lawn & garden engines and a few large compression-ignition engines. The nonroad engine industry and a few States have also conducted some nonroad engine emissions testing. However, the nonroad engine emissions data currently available are still limited when compared to the large number of nonroad engine types and applications for which these engines are used, particularly for the purposes of evaluating emission deterioration as engines age. The EPA has obtained extensive data on the emissions deterioration of light-duty highway engines, but these engines are unlikely to deteriorate in a fashion typical of nonroad engines due to fundamental differences in engine and emission control technology design, maintenance, and operation. Deterioration in emissions from light-duty vehicles (LDVs) is thought to be due in large part to gross failures of emission control after-treatment systems, which nonroad engines do not have at this time.

A related challenge is that the EPA has essentially no data on the incidence of tampering and/or neglect of proper maintenance and only limited data that distinguish the effect of such malmaintenance from the effects of normal usage. These data are based on emission tests of two lawnmower engines that had various components, including the sparkplug, air filter, and oil, manipulated to simulate bad maintenance practices (i.e., not changing the sparkplug, air filter and oil on a regular basis, as recommended by the manufacturer). The results of this effort were inconclusive, suggesting that intentional disablement of engine components does not adequately simulate emissions deterioration from normal usage. The EPA requests that state and industry stakeholders share any data regarding the incidence of tampering and neglect of proper maintenance they may have. The EPA also requests that stakeholders share any data they have regarding the relationship between emissions deterioration due to normal usage and emissions deterioration due to intentional disablement of engine components.

IV. Method of Applying Deterioration In NONROAD

Generally, the NONROAD model addresses the effects of deterioration in the inventory calculation by multiplying a zero hour emission factor for each category of engine by a deterioration rate as the engine ages. The following formula describes the basic form of the calculation:

$$EF_{aged} = EF_o * DF \qquad (1)$$

where: EF (aged) is the emission factor for an aged engine
EF_o is the emission factor for a new engine
DF is the deterioration factor.

In order for the NONROAD model to be compatible with the EPA's small nonroad spark ignition engine rulemaking process and also be able to calculate deterioration for other engines, the NEEMT has derived the following multi-purpose deterioration function:

$$DF = 1 + A * (\text{Age Factor})^b \quad \text{for Age Factor} \leq 1 \qquad (2)$$
$$DF = 1 + A \quad \text{for Age Factor} > 1$$

$$\text{where Age Factor} = \frac{[\text{Cumulative Hours * Load Factor}]}{\text{Median Life at Full Load, in Hours}}$$

A, b = constants for a given technology type; $b \leq 1$.

The constants A and b can be varied to approximate a wide range of deterioration patterns. "A" can be varied to reflect differences in maximum deterioration. For example, setting A equal to 2.0 would result in emissions at the engine's median life being three times the emissions when new. The shape of the deterioration function is determined by the second constant, "b." This constant can be set at any level between zero and 1.0; currently, the NONROAD model sets "b" equal to either 0.5 or 1.0. The first case results in a curvilinear deterioration rate in which most of the deterioration occurs in the early part of an engine's life. The second case results in a linear deterioration pattern in which the rate of deterioration is constant throughout the median life of an engine. In both cases, the EPA decided to cap deterioration at the end of an engine's median life, under the assumption that an engine can only deteriorate to a certain point beyond which it becomes inoperable. For spark ignition engines at or below 25 horsepower, NONROAD uses the regulatory useful life values in Appendix F of the Phase 1 regulatory support document for median life values. For other engines, NONROAD uses the median life values from the Power Systems Research (PSR) database.[2] These functions can be used to provide a close approximation to the shape of the deterioration curves used in

NSEEM1 and NSEEM2 (regulatory models for the Phase 1 and 2 Small Spark-Ignition Rules) for spark ignition engines less than 25 horsepower.

SI engines have a wide range of designs that affect their emissions deterioration. To model these different deterioration patterns, NONROAD categorizes SI engines into "technology types" by their design and emission control equipment. A given technology type can apply to one or more horsepower-application categories, and a given horsepower-application category can be divided into more than one technology type. NONROAD applies a given deterioration function (that is, a given A and b value) to all engines of a given technology type, regardless of their application or power range. As a result, a single technology type may be applied to engines with very different median lives, but this difference is handled by expressing engine age in terms of the "Age Factor" defined above. The EPA believes this approach is reasonable, since deterioration patterns should be more closely related to the design of the engine and its emission control technology than to the kind of application in which it is used. Furthermore, the available data on emissions deterioration of nonroad SI engines is insufficient to develop separate deterioration functions for the many combinations of application, horsepower range, and technology type.

NONROAD's technology type feature allows each horsepower-application category to be divided into as many as ten technology types, each with its own deterioration pattern. The technology type feature gives the model flexibility to handle the full range of engine designs used in nonroad equipment. For example, the technology type feature can handle the 33 distinct engine types that are defined by EPA's Phase 1 and 2 Small Engine Rules, as shown in Tables 1 through 5. However, deterioration data for each technology type across different applications are not available at the present time. Thus, the NONROAD model does not apply different deterioration patterns to engines of the same technology type used in different applications. Instead, the model applies different deterioration patterns to engines within each engine type (i.e., two-stroke and four-stroke spark ignition) based on the more detailed engine classes defined in the Phase 1 and 2 Small Engine Rules, the proposed Large Spark-Ignition Equipment, Recreational Marine and Recreational Equipment Rule, instead of by application. In other words, NONROAD models deterioration for a tiller and a lawn mower equipped with engines of the same technology type using the same deterioration pattern.

V. Deterioration Inputs For Engines At or Below 25 Horsepower

A. Deterioration Inputs Used In NONROAD For Spark Ignition Engines Less than 25 Horsepower

In the draft NONROAD2002 model, the constant ‘b’ is set at 0.5 for four-stroke engines, resulting in a square root relationship between age and deterioration. The constant ‘b’ is set at 1.0 for two-stroke engines, which produces a linear relationship between age and deterioration. This use of a curvilinear deterioration pattern for four-stroke engines and a linear deterioration pattern for two-stroke engines is similar to the approach used in the NSEEM2 model used for the Phase 2 Small Engine Rule.

The inputs for the variable ‘A’ of the NONROAD deterioration function are shown in Tables 1-5 for the small engine classes defined in the Phase 1 and 2 Small Engine Rules. EPA derived the deterioration values for Phase 2 engines with catalysts (G2HxC2) and set NOx deterioration values to zero based on analyses done during the development of the Phase 2 rule.[3] For the other types of small engines included in the Phase 1 and 2 rulemakings, the values came from the Phase I Regulatory Support Document for maximum life emission factors and new engine emission factors. It should be noted the HC deterioration ‘A’ value (0.201) for snowblowers (G2GT25) is the same as that used for baseline Class 1 and 2 two-stroke nonhandheld engines (G1N1 and G2N2).

For each pollutant and each engine type, variable ‘A’ represents the maximum deterioration rate reached at one median life. It should be noted that particulate matter (PM) standards were not considered or included in the Phase 1 and Phase 2 Small Engine Rules, and little data exists for PM deterioration rates. Based on EPA’s best judgement at this time, PM deterioration in two and four-stroke engines are equated to that of HC in the draft NONROAD2002 model. The EPA requests stakeholders with information about the PM emissions deterioration of two-stroke engines to submit such data.

The deterioration rates used in NONROAD for small engines covered under the Phase 1 and 2 Small Engine Rules approximate the levels of deterioration found in testing, including the testing summarized in NEVES and the testing done to support the Phase 1 and 2 Small Engine Rules. Where these test results differ, the EPA has chosen to give greater weight to data taken from engines which have experienced usage patterns that reflect expected field conditions. The test data submitted to EPA for the Phase 2 Small Engine Rule, for example, reflects testing of engines that have undergone accelerated aging which EPA does not believe to be representative of the aging experienced by engines in use. After evaluating all available data, the EPA has determined that the level of deterioration used in NSEEM1 and Phase 1 Small Engine Rule provides a reasonable basis for the deterioration rates used in NONROAD. These deterioration rates are generally higher than the deterioration rates used for regulatory purposes in NSEEM2 and the Phase 2 Small Engine Rule, but are generally smaller than those used in NEVES. The EPA believes that the deterioration rates used in NONROAD are more reflective of the deterioration rates that one would expect to find out in the field when equipment powered by small spark ignition engines is used by the average person than are the deterioration rates found in NSEEM2 and the Phase 2 Small Engine Rule.

It should be noted that EPA increased HC deterioration rates for two-stroke engines with catalysts that small engine manufacturers plan to use in handheld equipment (Classes 3, 4, and 5) based on additional analyses for the final Phase 2 Rule. However, the EPA did not update the PM deterioration rates for these engines to match the revised HC deterioration rates. This was an oversight and will be in the next update of the model. EPA welcomes any comments or information concerning PM deterioration rates for these types of engines.

There are some small engine applications that are not covered by the Phase 1 or 2 Small Engine Rules. These include marine engines (SCC 2282xxxxxx) and certain recreational equipment such as snowmobiles (226x001020), off-road motorcycles, all-terrain vehicles (226x001030), and specialty vehicle carts (226x001060). In NONROAD the two-stroke versions of the recreational equipment engines are assigned deterioration values equal to the G2N2 tech type shown in Table 2, but they use a tech type name of R12S since the emission factors differ from the other engine applications. Four-stroke versions of these recreational equipment engines use deterioration rates based on pre-1978 uncontrolled four-stroke on-highway motorcycles from the MOBILE model.[4]

Recreational marine engines are handled differently from the recreational equipment engines. Based on information gathered for the recreational marine engine rulemaking (61 FR 52087, October 4, 1996), two-stroke marine engines are modeled as having no deterioration. We request comment on whether this should be changed to model two-stroke marine engine deterioration similarly to other two-stroke engines or possibly use some other deterioration rate.

Table 1
Class 1 (Displacement < 225 cc) Nonhandheld Deterioration Factor A

Engine Tech Type	HC	CO	NOx	PM	BSFC
G2N1 (gas 2-stroke nonhandheld Class 1, baseline)	0.201	0.199	0	0.201	0
G4N1S (gas, side-valve, 4-stroke nonhandheld Class 1, baseline)	1.1	0.9	0	1.1	0
G4N1O (gas, overhead valve, 4-stroke nonhandheld Class 1, baseline)	1.1	0.9	0	1.1	0
G2N11 (2-stroke, Phase 1)	0.266	0.231	0	0.266	0
G4N1S1 (Phase 1 side-valve, 4-stroke)	5.103	1.109	0	5.103	0
G4N1O1 (Phase 1 overhead valve, 4-stroke)	1.753	1.051	0	1.753	0
G4N1SC1 (Phase 1 side-valve, 4-stroke with catalyst)	5.103	1.109	0	5.103	0
G4N1S2 (Phase 2 side-valve, 4-stroke)	5.103	1.109	0	5.103	0
G4N1O2 (Phase 2 overhead valve, 4-stroke)	1.753	1.051	0	1.753	0

Table 2
Class 2 (Displacement ≥225 cc; Power Rating < 25 hp) Nonhandheld Deterioration Factor A

Engine Tech Type	HC	CO	NOx	PM	BSFC
G2N2 (gas 2-stroke nonhandheld Class 2, baseline)	0.201	0.199	0	0.201	0
G4N2S (gas, side-valve, 4-stroke nonhandheld Class 2, baseline)	1.1	0.9	0	1.1	0
G4N2O (gas, overhead valve, 4-stroke nonhandheld Class 2, baseline)	1.1	0.9	0	1.1	0
G4N2S1 (Phase 1 side-valve, 4-stroke with catalyst)	1.935	0.887	0	1.935	0
G4N2O1 (Phase 1 overhead valve 4-stroke)	1.095	1.307	0	1.095	0
G4N2S2 (Phase 2 side-valve)	1.935	0.887	0	1.935	0
G4N2O2 (Phase 2 overhead valve)	1.095	1.307	0	1.095	0

Table 3
Class 3 (Displacement < 20cc) Handheld Deterioration Factor A

Engine Tech Type	HC	CO	NOx	PM	BSFC
G2H3 (gas 2-stroke handheld Class 3, baseline)	0.2	0.2	0	0.2	0
G2H31 (Phase 1)	0.24	0.24	0	0.24	0
G2H3C1 (Phase 1 with catalyst)	0.24	0.24	0	0.24	0
G2H32 (Phase 2)	0.24	0.24	0	0.24	0
G2H3C2 (Phase 2 with catalysts)	0.72	0.24	0	0.24	0

Table 4
Class 4 (20cc ≤ Displacement < 50 cc) Handheld Deterioration Factor A

Engine Tech Type	HC	CO	NOx	PM	BSFC
G2H4 (gas 2-stroke handheld Class 4, baseline)	0.2	0.2	0	0.2	0
G2H41 (Phase 1)	0.29	0.24	0	0.29	0
G2H4C1 (Phase 1 with catalyst)	0.29	0.24	0	0.29	0
G4H41 (Phase 1 4-stroke)	1.1	0.9	0	1.1	0
G2H42 (Phase 2)	0.29	0.24	0	0.29	0
G2H4C2 (Phase 2 with catalyst)	0.77	0.24	0	0.29	0
G4H42 (Phase 2 4-stroke)	1.1	0.9	0	1.1	0

Table 5
Class 5 (Displacement ≥ 50cc; Power Rating <25 HP) Handheld Deterioration Factor A

Engine Tech Type	HC	CO	NOx	PM	BSFC
G2H5 (gas 2-stroke handheld Class 5, baseline)	0.2	0.2	0	0.2	0
G2H51 (Phase 1)	0.266	0.231	0	0.266	0
G2H5C1 (Phase 1 with catalyst)	0.266	0.231	0	0.266	0
G2H52 (Phase 2)	0.266	0.231	0	0.266	0
G2H5C2 (Phase 2 with catalyst)	0.626	0.231	0	0.266	0

VI. Deterioration Inputs for Spark Ignition Engines Greater than 25 Horsepower (19 kilowatts)

Spark-ignition engines greater than 25 horsepower are primarily found in recreational, commercial, recreational marine, and industrial equipment. The deterioration rates discussed in this section can be found in Table 6.

A. Recreational Equipment

Due to a lack of deterioration data for large two-stroke spark-ignition engines found in snowmobiles, all-terrain vehicles, and off-road motorcycles, EPA has chosen to use deterioration rates associated with Class 1 and 2 Nonhandheld 2-stroke lawn and garden equipment (Tables 1 and 2) in the draft NONROAD2002 model. The 'b' value for these engines is 1.0, resulting in a linear deterioration rate. The deterioration rates are the same for uncontrolled and controlled engines.

For 4-stroke ATVs and off-road motorcycles, EPA uses deterioration factors based on pre-1978 uncontrolled 4-stroke on-highway motorcycles from the MOBILE model. The 'b' value for these engines is 0.5, resulting in a curvilinear deterioration rate. The deterioration rates are the same for uncontrolled and controlled engines.

It should be noted that PM has not been addressed in the rulemaking process for large 4-stroke spark-ignition engines used in recreational equipment and little or no data exist for PM deterioration associated with this type of equipment. Based on EPA's best judgement at this time, PM deterioration has been equated with HC deterioration rates. EPA welcomes any comments or information that stakeholders may have concerning PM deterioration.

B. Other Large Spark-Ignition Engines

The deterioration rates for large four-stroke spark-ignition engines used in sterndrive and inboard recreational marine, industrial, commercial, agricultural, and aircraft support equipment can be found in Table 6.

At this time, EPA still does not have any deterioration data on large spark-ignition engines. However, EPA now believes that larger uncontrolled carbureted gasoline nonroad engines would likely deteriorate more similarly to on-highway light-duty gasoline truck engines from the 1960's and 1970's.[5] These older on-highway engine models used similar technology as today's carbureted SD/I marine engines and large nonroad gasoline engines.

MOBILE5 includes emission factors and deterioration and tampering rates for on-highway heavy-duty gasoline engines. From this information, we can calculate the "A" value in Equation 2 by dividing the deteriorated emission factor at 100,000 miles by the new engine emission factor (and subtracting 1). To capture carbureted engines, we looked at the 20-year average for the 1960 through 1979 model years. Also, MOBILE5 uses linear deterioration for heavy-duty gasoline engines which translates to a "b" value of 1.0 in Equation 2.

As a check on these deterioration rates, we reviewed emission data from ten 1969 light-duty gasoline trucks in an EPA report titled "Procurement and Emissions Testing of 1969 and 1972/1973 Model Year Gasoline Powered Light Duty Trucks" (EPA-460/3-80-11). These trucks were emission tested in 1980 before and after engine maintenance. The ratio of the emissions before and after maintenance gives some insight into the emission deterioration of the engines. These data showed equivalent A values of 0.11 to 0.58 for HC, 0.31 to 0.39 for CO, and 0.05 to 0.10 for NOx. These data are consistent with the deterioration rates used in the draft NONROAD2002 model (see Appendix 1). The ranges of A values from the test data are due to reporting the averages with and without one truck that appeared to be an outlier.

At this time, we do not have any information on the deterioration of fuel-injected gasoline engines (without catalysts). MOBILE does not include emission rates for non-catalyzed engines with fuel injection because catalysts were introduced before fuel-injection into the on-highway market. Anecdotal information suggests that deterioration is low from these engines compared to deterioration in a catalyst. For instance, accepted emission deterioration test methods for current on-highway engines are performed by aging the catalyst to full life but using a relatively new engine. Because we do not have better information, EPA used the same deterioration coefficients for fuel-injected engines (without catalysts) as for carbureted engines.

To estimate the Phase 1 deterioration factors, we relied upon deterioration information for current Class IIb heavy-duty gasoline engines developed for the MOBILE6 emission model. Class IIb engines are the smallest heavy-duty engines and are comparable in size to many Large SI engines. They also employ catalyst/fuel system technology similar to the technologies we expect to be used on Large SI engines.[6]

To estimate the Phase 2 deterioration factors, we relied upon the same information noted above for Phase 1 engines. The technologies used to comply with the proposed Phase 2 standards are expected to be further refinements of the technologies we expect to be used on Phase 1 Large SI engines. For that reason, we are applying the Phase 1 deterioration factors to the Phase 2 engines.[7]

It should be noted that PM is not addressed in the rulemaking process for large SI engines used in recreational marine, commercial, industrial, and other types of equipment and little or no data exist for PM deterioration associated with these types of equipment. Based on EPA's best judgement at this time, PM deterioration has been equated with HC deterioration rates for these types of engines. EPA welcomes any comments or information stakeholder may have concerning PM deterioration.

Table 6
NONROAD Deterioration Rates for Spark-Ignition Engines Greater Than 25hp (19 kW)

Equipment	**Engine Type**	**Tech Type**	**HC**	**CO**	**NOx**	**PM**	**BSFC**
Off-road Motorcycle, ATVs, Snowmobiles	2-stroke	R12S	0.2	0.2	0	0.2	0
Off-road Motorcycle, ATVs	4-stroke	R142	0.15	0.17	0	0.15	0
Recreational Marine and Other Large SI	4-stroke						
Base		G4GT25	0.26	0.35	0.03	0.26	0
Phase 1		G4GT251	0.64	0.36	0.15	0.64	0
Phase 2		G4GT252	0.64	0.36	0.15	0.64	0

VIII. Liquid Petroleum and Compressed Natural Gas Spark-Ignition Engines

Because liquid petroleum gas (LPG) and compressed natural gas (CNG) engines are primarily four-stroke engines, the EPA decided to assume that they would deteriorate at the same rate as the corresponding gasoline-powered four-stroke SI engines for all pollutants. The EPA is not aware of any deterioration data available for LPG and CNG engines and requests that commenters submit any such data they may have to EPA. If such data become available, EPA will revise the deterioration rates for these engines in NONROAD accordingly.

Endnotes

1. Median life is defined as the midpoint of the scrappage curve at which half of the engines in a given population cease to function and are scrapped. For more information, please refer to the technical report on activity, load factors and median life (NR-005a) and the technical report about scrappage (NR-007a).

2. See endnote 1.

3. U.S. EPA NONROAD Model Technical Report Addenda for Tier 2 Rulemaking Version, March 24, 1999.

4. “Emission Modeling for Recreational Equipment,” EPA Memorandum From Linc Wehrly to Docket A-98-01, November 13, 2000.

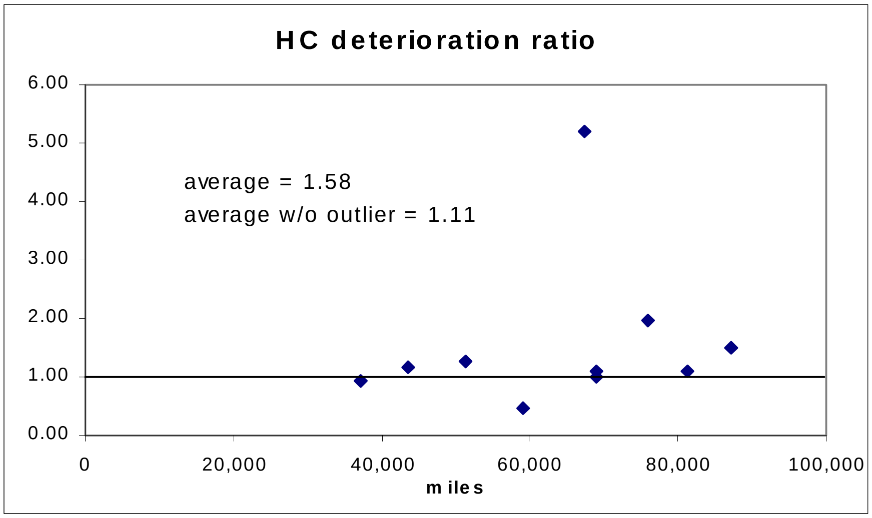
5. "Revisions to the June 2000 Release of NONROAD to Reflect New Information and Analysis on Marine and Industrial Engines," EPA memorandum from Mike Samulski to Docket A-98-01, November 2, 2000, Docket A-2000-01, Document II-B-08.

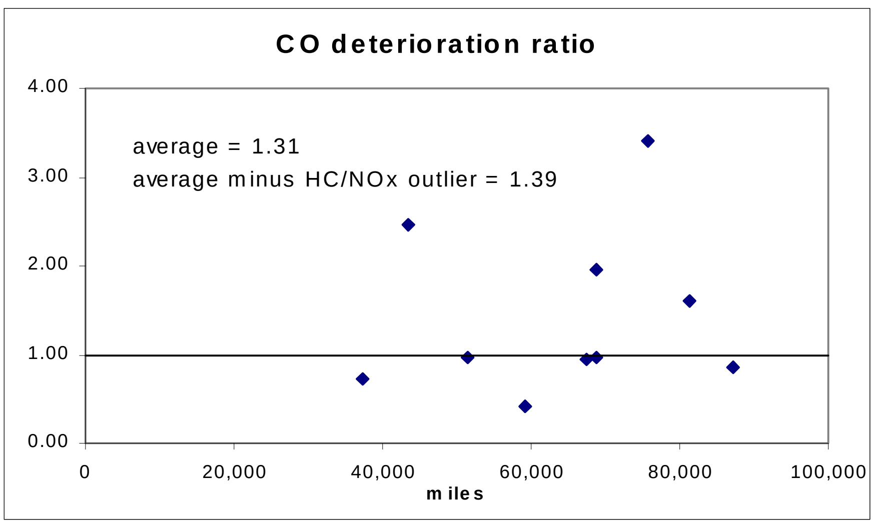
6. Proposed Control of Emissions from Nonroad Large Spark Ignition Engines, Recreational Engines (Marine and Land-based), and Highway Motorcycles, Regulatory Support Document, EPA420-D-01-004, September 2001, Chapter 6.

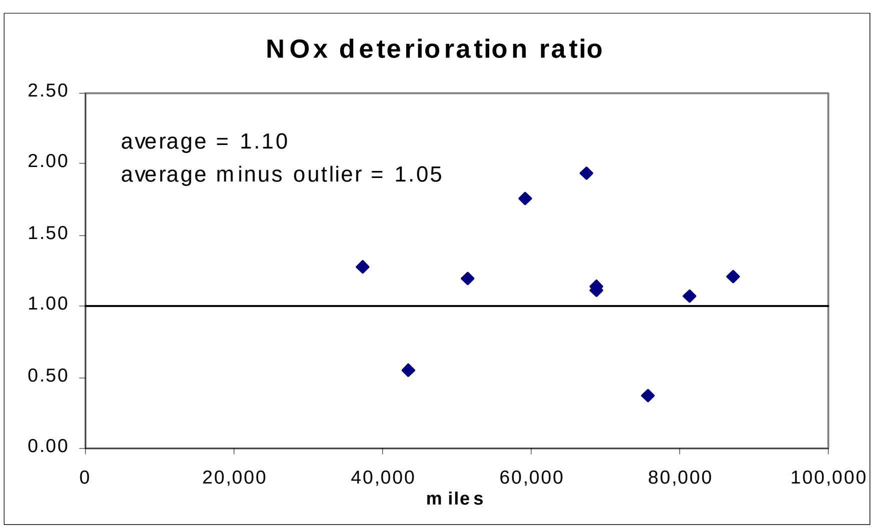
7. See endnote 6.

Appendix 1

Deterioration Ratio Data for 1969 MY LDGTs







Appendix 2

Emission Deterioration Factors For the NONROAD Emissions Model

Report No. NR-011

September 4, 1998

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I. <u>Purpose</u>

This report addresses the emission deterioration rates currently being used in the draft version of NONROAD and discusses other sources of emission deterioration estimates. The Nonroad Engine and Emissions Modeling Team (NEEMT) welcomes comments and suggestions concerning our approach to modeling nonroad engine emissions deterioration.

II. <u>Background</u>

As used here, the term "deterioration" refers to the degradation of an engine's exhaust emissions performance over its lifetime due to normal use or misuse (i.e., tampering or neglect). Engine deterioration increases exhaust emissions, usually leads to a loss of combustion efficiency, and can in some cases increase nonexhaust emissions. The amount of emissions increase depends on an engine's design, production quality, and technology type (e.g., spark ignition two-stroke and four-stroke, compression ignition). Other factors, such as the various equipment applications in which an engine is used, usage patterns, and how it is stored and maintained, may also affect deterioration.

The term "deterioration rate" refers to the degree to which an engine's emissions increase per unit of activity. Nonroad engine activity is expressed in terms of hours of use or fraction of median life. The term "deterioration factor" refers to the ratio of an engine's emissions at its median life divided by its emissions when new.

The terms *useful life* and *median life* are used in the following manner in this report in order to avoid confusion. *Useful life* is a regulatory term used to indicate the amount of time during the life of a nonroad engine that a manufacturer must certify to the U.S. EPA that the engine meets a required emission standard as defined by a regulation. *Median life,* as used in this report, refers to the age at which 50 percent of the engines sold in a given year have ceased to function and have been scrapped.[1]

III. Core Challenge

The core challenge associated with estimating nonroad engine deterioration is the development of reasonably accurate deterioration rates for the enormous range of nonroad engine types and applications from the limited amount of nonroad emission deterioration data that exist at this time. To estimate deterioration, the emission performance of engines at various ages is required. Such information can be obtained from a longitudinal study that examines the same set of engines periodically as they age, or from a sampling study that tests engines of various ages but the same basic design. In either case, the engines studied should be selected randomly from the population of engines actually being used in the field.

Given the limited available test data, the NEEMT is currently unable to develop unique deterioration rates based on actual engine test data for the myriad of applications and power levels covered by NONROAD. The Office of Mobile Sources has conducted emissions testing on several dozen small spark ignition lawn & garden engines and a few large compression-ignition engines. The nonroad engine industry and a few States have also conducted some nonroad engine emissions testing. However, the nonroad engine emissions data currently available are still limited when compared to the large number of nonroad engine types and applications for which these engines are used, particularly for the purposes of evaluating emission deterioration as engines age. The EPA has obtained extensive data on the emissions deterioration of light-duty highway engines, but these engines are unlikely to deteriorate in a fashion typical of nonroad engines due to fundamental differences in engine and emission control technology design, maintenance, and operation. Deterioration in emissions from light-duty vehicles (LDVs) is thought to be due in large part to gross failures of emission control after-treatment systems, which nonroad engines do not have at this time.

A related challenge is that EPA has essentially no data on the incidence of tampering and/or neglect of proper maintenance and only limited data that distinguish the effect of such malmaintenance from the effects of normal usage. These data are based on emission tests of two lawnmower engines that had various components, including the sparkplug, air filter, and oil, manipulated to simulate bad maintenance practices (i.e., not changing the sparkplug, air filter and oil on a regular basis, as recommended by the manufacturer). The results of this effort were inconclusive, suggesting that intentional disablement of engine components does not adequately simulate emissions deterioration from normal usage. The NEEMT requests that state and industry stakeholders share any data regarding the incidence of tampering and neglect of proper maintenance they may have with EPA. The NEEMT also requests that stakeholders share any data they have regarding the relationship between emissions deterioration due to normal usage and emissions deterioration due to intentional disablement of engine components with EPA.

This report explicitly addresses the compatibility of NONROAD's estimates of deterioration with the estimates of deterioration produced by other nonroad emission models. These models include the nonroad compression ignition regulatory Nonroad Emissions Model (NEM), the Phase 1 Nonroad Small Engine Emission Model (NSEEM1), the Phase 2 Nonroad Small Engine Emission Model (NSEEM2), and the California Air Resources Board (ARB) OFFROAD model. EPA used the NEM to support the proposed compression ignition (diesel) engine rule, the NSEEM1 to support the Phase 1 Small Spark Ignition Engine Rule, and the NSEEM2 to support the proposed Phase 2 Small Spark Ignition Engine Rule. During the development of NONROAD, the NEEMT has used many of the same data sources and modeling assumptions used in these earlier models. Once the final version of NONROAD is released, the EPA expects to rely on NONROAD as its primary emission inventory model for future rulemaking and inventory modeling activities.

A discussion of the calculation methods used in each of the earlier models can be found in Section IV, **Methods of Applying Deterioration**. The specific deterioration inputs used in NONROAD and their basis will be addressed for spark ignition engines at or below 25 horsepower; over 25 horsepower; liquid petroleum gas (LPG) and compressed natural gas engines (CNG), and compression ignition (diesel) engines in subsequent sections.

IV. Methods of Applying Deterioration

A. NONROAD Method

Generally, the NONROAD model addresses the effects of deterioration in the inventory calculation by multiplying a zero hour emission factor for each category of engine by a deterioration rate as the engine ages. The following formula describes the basic form of the calculation:

$$EF_{aged} = EF_o * DF \qquad (1)$$

where: EF (aged) is the emission factor for an aged engine
EF_o is the emission factor for a new engine
DF is the deterioration factor.

In order for the NONROAD model to be compatible with the EPA's small nonroad spark ignition engine rulemaking process and also be able to calculate deterioration for other engines, the NEEMT has derived the following multi-purpose deterioration function:

$$DF = 1 + A * (\text{Age Factor})^b \quad \text{for Age Factor} \leq 1 \qquad (2)$$
$$DF = 1 + A \quad \text{for Age Factor} > 1$$

where Age Factor = $\frac{\text{[Cumulative Hours * Load Factor]}}{\text{Median Life at Full Load, in Hours}}$

A, b = constants for a given technology type; $b \leq 1$.

The constants A and b can be varied to approximate a wide range of deterioration patterns. "A" can be varied to reflect differences in maximum deterioration. For example, setting A equal to 2.0 would result in emissions at the engine's median life being three times the emissions when new. The shape of the deterioration function is determined by the second constant, "b." This constant can be set at any level between zero and 1.0; currently, the NONROAD model sets "b" equal to either 0.5 or 1.0. The first case results in a deterioration curve in which most of the deterioration occurs in the early part of an engine's life; the second case results in a linear deterioration pattern, in which the rate of deterioration is constant throughout the median life of an engine. In both cases, the NEEMT decided to cap deterioration at the end of an engine's median life, under the assumption that an engine can only deteriorate to a certain point beyond which it becomes inoperable. For spark ignition engines at or below 25 horsepower, NONROAD uses the regulatory useful life values in Appendix F of the Phase 1 regulatory support document for median life values. For other engines, NONROAD uses the median life values from the Power Systems Research (PSR) database.[2] These functions can be used to provide a close approximation to the shape of the deterioration curves used in NSEEM1 and NSEEM2 for spark ignition engines less than 25 horsepower.

SI engines have a wide range of designs that affect their emissions deterioration. To model these different deterioration patterns, NONROAD categorizes SI engines into "technology types" by their design and emission control equipment. A given technology type can apply to one or more horsepower-application categories, and a given horsepower-application category can be divided into more than one technology type. NONROAD applies a given deterioration function (that is, a given A and b value) to all engines of a given technology type, regardless of their application or power range. As a result, a single technology type may be applied to engines with very different median lives, but this difference is handled by expressing engine age in terms of the "Age Factor" defined above. The NEEMT believes this approach is reasonable, since deterioration patterns should be more closely related to the design of the engine and its emission control technology than to the kind of application in which it is used. Furthermore, the available data on emissions deterioration of nonroad SI engines is insufficient to develop separate deterioration functions for the many combinations of application, horsepower range, and technology type.

NONROAD's technology type feature allows each horsepower-application category to be divided into as many as ten technology types, each with its own deterioration pattern. The technology type feature gives the model flexibility to handle the full range of engine designs used in nonroad equipment. For example, the technology type feature can handle the 33 distinct engine types that are defined by EPA's Phase 1 and proposed Phase 2 Small

Engine Rules, as shown in Tables 1-5. However, deterioration data for each technology type across different applications are not available at the present time. Thus, the NONROAD model does not apply different deterioration patterns to engines of the same technology type used in different applications. Instead, the model applies different deterioration patterns to engines within each engine type (i.e., two-stroke, four-stroke spark ignition, compression ignition) based on the more detailed engine classes defined in the Phase 1 and proposed Phase 2 Small Engine Rules instead of by application. In other words, NONROAD models deterioration for a tiller and a lawn mower equipped with engines of the same technology type using the same deterioration pattern.

B. Methods of Applying Deterioration in Other Models

1. California ARB OFFROAD Model

The California ARB OFFROAD model applies deterioration based on a linear relationship. Emissions are modeled to increase by a fixed amount for every hour that the engine is used, up to a fixed limit. The function used by OFFROAD is as follows:

$$EF_{aged} = EF_{new} + DR * CumHours_{\text{at in-use load}}$$

where EF_{aged} = deteriorated emission factor
EF_{new} = zero hour emission factor
DR = fraction of the maximum deterioration added to the zero hour emission factor (EF_{new}) for each hour of age the engine accumulates
$CumHours_{\text{at in-use load}}$ = Engine Age * Hours of use per year

Without the emission rate cap, the linear function presented above could show an engine deteriorating indefinitely beyond one median life. This projection may not be a realistic or accurate one, since an engine can only deteriorate to a certain point beyond which it ceases to function and is scrapped. Like the NONROAD model, the OFFROAD model reflects the limit on how much an engine’s emissions can deteriorate before the engine ceases to function by capping deterioration once an engine has reached one median life.

2. Phase 1 Nonroad Small Engine Emission Model (NSEEM1) for Small Gasoline Four and Two-Stroke (<25 hp) Engines

The Phase 1 Small Engine Rule calculates deterioration using the following exponential function for both two and four-stroke spark ignition engines:

$$DF = 1 + [(EF_f - EF_o)/EF_o] * [1 - \exp(-3 * \{\text{Age Factor}\})] \qquad (3)$$

where EF_f = emission factor for a fully aged engine
EF_o = zero hour emission factor
Age = Age in years/Median life in years.

The deterioration function (3) in the NSEEM1 model results in 95% of the deterioration occurring at an age of one median life. As stated above, the equation (2) used in NONROAD closely approximates the Phase I deterioration curve, but caps deterioration after one median life. The relationship between the deterioration in NONROAD and NSEEM1 at one median life is given below.

$$A = [(EF_f - EF_o)/EF_o] \quad (4)$$

for Age Factor = 1

3. Proposed Phase 2 Nonroad Small Engine Emission Model (NSEEM2) for Small Gasoline Four and Two-Stroke (< 25 hp) Engines

The proposed Phase 2 Small Engine Rule and its supporting model (NSEEM2) use the following equations to calculate deterioration for small two and four-stroke engine HC, CO, and NOx emissions. It should be noted that the following deterioration functions were used to recalculate the original Phase 1 deterioration rates as well as calculate the Phase 2 deterioration rates. Also, particulate matter (PM) emissions and deterioration were not considered in either the first or second phase of the Small Engine Rule.

The deterioration function for spark ignition two stroke engines is linear and is given by equation (5):

$$DF = 1 + C * (Hours_{total}) \quad (4)$$

where C = A constant derived from a best-fit regression based on EPA and manufacturer test data[3]
$Hours_{total}$ = Engine age * Annual hours of use

For four-stroke engines, the deterioration function is a square root function and is given by equation (6):

$$DF = 1 + C * (Hours_{total})^{0.5} \quad (6)$$

where C = A constant derived from a best-fit regression based on manufacturer test data
$Hours_{total}$ = Engine Age * Annual hours of use

This function produces a curvilinear plot similar in shape to the NSEEM1/Phase 1 curve, where most of the deterioration occurs toward the early part of an engine's median life. This function is based on manufacturer's emissions testing data from engines undergoing accelerated aging in the laboratory and in the field.[4]

4. Compression-Ignition Nonroad Engine Model (NEM)

The NEM does not contain a deterioration function, since EPA assumes that compression ignition engines do not significantly deteriorate. This assumption is discussed in more detail later in this report, under the section addressing compression ignition engines.

C. Using the NONROAD Deterioration Function to Represent Other Deterioration Patterns

The NONROAD deterioration function can be modified to give results consistent with the Phase 1 and proposed Phase 2 Small Engine Rules. The NONROAD deterioration function also has the ability to describe other curvilinear or linear deterioration patterns, such as the California ARB deterioration rates, by changing the inputs for the function in equation (2).

V. Deterioration Inputs For Engines At or Below 25 Horsepower

A. Deterioration Inputs Used In NONROAD For Spark Ignition Engines Less than 25 Horsepower

The NONROAD deterioration function is given by equation (2):

$$DF = 1 + A * (\text{Age Factor})^{b} \qquad \text{for Age Factor} \leq 1$$
$$DF = 1 + A \qquad \text{for Age Factor} > 1$$

where $\text{Age Factor} = \dfrac{[\text{Cumulative Hours * Load Factor}]}{\text{Median Life at Full Load, in Hours}}$

A, b = constants for a given technology type; $b \leq 1$.

In NONROAD, the constant 'b' is set at 0.5 for four-stroke engines, resulting in a square root relationship between age and deterioration. The constant 'b' is set at 1.0 for two-stroke engines, which produces a linear relationship between age and deterioration. This use of a curvilinear deterioration pattern for four-stroke engines and a linear deterioration pattern for two-stroke engines is similar to the approach used in the NSEEM2 model.

The inputs for the variable ‘A’ of the NONROAD deterioration function are shown in Tables 1-5 for the small engine classes defined in the Phase 1 and proposed Phase 2 Small Engine Rules. These values were derived from the values provided in the Phase I Regulatory Support Document for maximum life emission factors and new engine emission factors. For each pollutant and each engine type, variable ‘A’ represents the maximum deterioration rate reached at one median life. It should be noted that particulate matter (PM) standards were not considered or included in the Phase 1 and proposed Phase 2 Small Engine Rules. For the present time, PM deterioration in four-stroke engines will be equated to that of HC in NONROAD, and PM deterioration for two-stroke engines will assumed to be zero. The NEEMT believes this assumption is reasonable, since two-stroke engines are unlikely to experience the high PM deterioration rates seen in four-stroke engines given the high PM emission rates of new two-stroke engines. The NEEMT requests stakeholders with information about the PM emissions deterioration of two-stroke engines to submit such data to EPA.

There are some small engine applications that are not covered by the Phase 1 or proposed Phase 2 Small Engine Rules. These include marine engines (SCC 2282xxxxxx) and certain recreational equipment such as snowmobiles (226x001020), off-road motorcycles and all-terrain vehicles (226x001030), and specialty vehicle carts (226x001060). In NONROAD the two-stroke versions of the recreational equipment engines are assigned deterioration values equal to the G2N2 tech type shown in Table 2, but they use a tech type name of R12S since the emission factors differ from the other engine applications. Four-stroke versions of these recreational equipment engines are simply included in the G4N2O tech type since there are no different emission factors.

Recreational marine engines are handled differently from the recreational equipment engines. Based on information gathered for the recreational marine engine rulemaking (61 FR 52087, October 4, 1996), two-stroke marine engines are modeled as having no deterioration for the same reasons mentioned above regarding particulate matter (PM) emissions. We request comment on whether this should be changed to model two-stroke marine engine deterioration similarly to other two-stroke engines or possibly use some other deterioration rate. NONROAD assigns four-stroke marine engines deterioration values equal to the G4N2O tech type shown in Table 2, but they use different tech type names such as M3, M10, M11, M12, and M16 depending on the specific control technology and application (outboard, personal water craft or inboard).

Table 1
Class 1 (Displacement < 225 cc) Nonhandheld Deterioration Factor A

Engine Tech Type	**HC**	**CO**	**NOx**	**PM**	**BSFC**
G2N1 (gas 2-stroke nonhandheld Class 1, baseline)	0.201	0.199	0	0	0
G4N1S (gas, side-valve, 4-stroke nonhandheld Class 1, baseline)	1.1	0.9	-0.6	1.1	0
G4N1O (gas, overhead valve, 4-stroke nonhandheld Class 1, baseline)	1.1	0.9	-0.6	1.1	0
G2N1 (2-stroke, Phase 1)	0.266	0.231	0	0	0
G4N1S1 (Phase 1 side-valve, 4-stroke)	5.103	1.109	-0.33	5.103	0
G4N1O1 (Phase 1 overhead valve, 4-stroke)	1.753	1.051	-0.30	1.753	0
G4N1SC1 (Phase 1 side-valve, 4-stroke with catalyst)	5.103	1.109	-0.33	5.103	0
G4N1S2 (Phase 2 side-valve, 4-stroke)	5.103	1.109	-0.33	5.103	0
G4N1O2 (Phase 2 overhead valve, 4-stroke)	1.753	1.051	-0.30	1.753	0

Table 2
Class 2 (Displacement ≥225 cc; Power Rating < 25 hp) Nonhandheld Deterioration Factor A

Engine Tech Type	**HC**	**CO**	**NOx**	**PM**	**BSFC**
G2N2 (gas 2-stroke nonhandheld Class 2, baseline)	0.201	0.199	0	0	0
G4N2S (gas, side-valve, 4-stroke nonhandheld Class 2, baseline)	1.1	0.9	-0.6	1.1	0
G4N2O (gas, overhead valve, 4-stroke nonhandheld Class 2, baseline)	1.1	0.9	-0.6	1.1	0
G4N2S1 (Phase 1 side-valve, 4-stroke with catalyst)	1.935	0.887	-0.274	1.935	0
G4N2O1 (Phase 1 overhead valve 4-stroke)	1.095	1.307	-0.599	1.095	0
G4N2S2 (Phase 2 side-valve)	1.935	0.887	-0.274	1.935	0
G4N1O2 (Phase 2 overhead valve)	1.095	1.307	-0.599	1.095	0

Table 3
Class 3 (Displacement < 20cc) Handheld Deterioration Factor A

Engine Tech Type	HC	CO	NOx	PM	BSFC
G2H3 (gas 2-stroke handheld Class 3, baseline)	0.2	0.2	0	0	0
G2H31 (Phase 1)	0.24	0.24	0	0	0
G2H3C1 (Phase 1 with catalyst)	0.24	0.24	0	0	0
G2H32 (Phase 2)	0.24	0.24	0	0	0
G2H3C2 (Phase 2 with catalysts)	0.24	0.24	0	0	0

Table 4
Class 4 (20cc ≤ Displacement < 50 cc) Handheld Deterioration Factor A

Engine Tech Type	HC	CO	NOx	PM	BSFC
G2H4 (gas 2-stroke handheld Class 4, baseline)	0.2	0.2	0	0	0
G2H41 (Phase 1)	0.29	0.24	0	0	0
G2H4C1 (Phase 1 with catalyst)	0.29	0.24	0	0	0
G4H41 (Phase 1 4-stroke)	1.1	0.9	-0.6	1.1	0
G2H42 (Phase 2)	0.29	0.24	0	0	0
G2H4C2 (Phase 2 with catalyst)	0.29	0.24	0	0	0
G4H42 (Phase 2 4-stroke)	1.1	0.9	-0.6	1.1	0

Table 5
Class 5 (Displacement ≥ 50cc; Power Rating <25 HP) Handheld Deterioration Factor A

Engine Tech Type	HC	CO	NOx	PM	BSFC
G2H5 (gas 2-stroke handheld Class 5, baseline)	0.2	0.2	-0.031	0	0
G2H51 (Phase 1)	0.266	0.231	0	0	0
G2H5C1 (Phase 1 with catalyst)	0.266	0.231	0	0	0
G2H52 (Phase 2)	0.266	0.231	0	0	0
G2H5C2 (Phase 2 with catalyst)	0.266	0.231	0	0	0

B. Other Sources of Deterioration Rates for Spark Ignition Engines At or Below 25 Horsepower

The NEEMT considered several sources of information regarding deterioration factors. These sources included the Nonroad Engine and Vehicle Emissions Study[5] (NEVES), the technical documentation for the California ARB OFFROAD model, and the small engine regulatory impact analysis and support documents for the Phase 1 and proposed Phase 2 Small Spark Ignited Engine Rules.

1. California ARB

To estimate deterioration rates for pre-control, Tier 1, and Tier 2 two and four-stroke engines, the California ARB uses deterioration factors for HC, CO, and NOx derived from analysis of manufacturer emissions data submitted to EPA for consideration during the regulatory negotiation process for small engine standards, as well as additional manufacturer data submitted to the California ARB during its small engine rulemaking process.[6,7] These data include the testing of engines that have undergone accelerated aging under both field and laboratory conditions. The deterioration rates for two-stroke engines appear in Table 6a and the rates for four-stroke engines appear in Table 6b. It should be noted that the four-stroke deterioration rates are weighted averages of the deterioration rates for side and overhead valve engines. At this time, the NEEMT has not received sufficient information from the California ARB to show the separate deterioration rates for side and overhead valve engines. However, all other things being equal, side-valve engines usually deteriorate significantly more than overhead valve engines, based on tests conducted by both EPA and the Equipment Manufacturers Association (EMA).

Table 6a
Small Engine (<25hp) Spark Ignition Two-Stroke OFFROAD Deterioration Rates

Standards	Model Yr.	HP	HC DR	CO DR	NOx DR	PM DR
Uncontrolled	pre-95	0-2	0	0	0	0
Tier 1	1995-99		0	0	0	0
Tier 2	2000+		0.2513	0	0	0.01117
Uncontrolled	pre-95	2-15	0	0	0	0
Tier 1	1995-99		0	0	0	0
	2000+		0.2513	0	0	0.00808
Uncontrolled	pre-95	15-25	0	0	0	0
Tier 1	1995-99		0	0	0	0
Tier 2	2000+		0.2513	0	0	0.00808

Table 6b
Small Engine (<25hp) Spark Ignition Four-Stroke OFFROAD Deterioration Rates

Standards	Model Yr.	HP	HC DR	CO DR	NOx DR	PM DR
Uncontrolled	pre-95	0-5	0.0948	0.5196	0.0002	0.0026
Tier 1	1995-96		0.0565	-0.067	0.0031	0.0026
	1997-99		0.0565	-0.067	0.0031	0.0026
Tier 2	2000-03		0.0144	-0.3849	0.0065	0.0026
Uncontrolled	pre-95	5-15	0.0178	0.0337	0.0013	0.0002
Tier 1	1995-96		0.0207	0.0895	0	0.0002
	1997-99		0.0207	0.0895	0	0.0002
Tier 2	2000-03		0.0047	0	0.0035	0.0002
Uncontrolled	pre-95	15-25	0.0141	0.0276	0.0011	0.0002
Tier 1	1995-96		0.0166	0.0345	0	0.0002
	1997-99		0.0166	0.0345	0	0.0002
Tier 2	2000-03		0.0049	0	0.0032	0.0002

2. <u>EPA Phase 1 Small Engine Model (NSEEM1)</u>

For both uncontrolled and controlled four-stroke spark ignition engines, the maximum deterioration derived from the NSEEM1 model occurs at the end of one median life for HC, CO, and NOx. The deterioration rates in the two models, expressed in terms of the absolute increase in g/bhp-hr emission rates over the course of the engine's life, are the same and can be found in the regulatory impact analysis and support document for EPA's Phase 1 Small Engine Rule for engines at or below 25 horsepower (19 kw).[8] The NSEEM1 model uses the same deterioration rates found in the NEVES report for small four-stroke engines less than 20 horsepower (discussed in section 4 below).[9] These deterioration rates were originally based on tests done by Southwest Research Institute (SwRI) on three different four-stroke engines.

The two-stroke spark-ignition deterioration factors for HC, CO, and NOx used by the Phase 1 Small Engine Rule Team used can be found in the regulatory impact analysis and support document for EPA's Phase 1 Small Engine Rule for engines at or below 25 horsepower (19 kw). The two-stroke engine deterioration factors represent the ratio between the emission rates at one median life (when emissions reach their maximum level) and the emission rates at zero hours of age. The two-stroke maximum deterioration rates are 1.2, 1.9, and 1.0 for HC, CO, and NOx, respectively. This translates into a 20 percent HC increase, a 90 percent CO increase, and no change in NOx emissions over the engine's life. The deterioration rates used in the Phase 1 Small Engine Rule were based on information from SAE technical papers and industry-supplied data. The OMS analysis of this information during the development of the Phase 1 Small Engine Rule supported changing the deterioration rates for two-stroke spark ignition engines from the ones found in the NEVES report.

3. <u>EPA Phase 2 Small Engine Model (NSEEM2)</u>

As discussed above, the Phase 2 Small Engine Model uses a linear function for two-stroke engines and a curvilinear square root function for four-stroke engines to define deterioration as the engine ages. The Small Engine Rule Team used these functions to derive deterioration rates for Phase 2 small engines, and they also revised the Phase 1 deterioration rates originally calculated for the Phase 1 Small Engine Rule. However, the uncontrolled deterioration rates remain unchanged from the original ones used in the Phase 1 Small Engine Rule.

As shown above in the "Methods of Applying Deterioration" section (Section IV.A), the two and four-stroke Phase 2 deterioration functions employ a unique constant for HC, CO, and NOx for each class of small engines, as shown in Table 7.

Table 7
Constants Used in the Phase 2 Small Engine Rule Deterioration Function

	G2H3	G2H4	G2H5	G2N1	G2N2	G4N10	G4N1S	G4N20	G4N2S	G4H4
Phase 1 Res.										
HC	0.002	0.002	0.002	0.000	0.000	0.050	0.1300	0.0800	0.0400	0.1840
CO	0.002	0.002	0.002	0.002	0.000	0.022	0.0220	0.0110	0.0110	0.0020
NOx	0.000	0.000	0.000	0.000	0.000	0.030	0.0200	0.0200	0.0200	0.0230
Phase 1 Com.										
HC	0.0003	0.0003	0.0003	*0.000*	0.000	0.0245	0.0637	0.0566	0.0283	0.0751
CO	0.0003	0.0003	0.0003	*0.002*	0.000	0.0110	0.0110	0.0080	0.0080	0.0008
NOx	0.0000	0.0000	0.0000	*0.000*	0.000	0.0147	0.0098	0.0141	0.0141	0.0094
Phase 2 Res.										
HC	0.002	0.002	0.002	0.000	0.000	0.050	0.1300	0.0280	0.0400	0.1840
CO	0.002	0.002	0.002	0.000	0.000	0.022	0.0220	0.0110	0.0110	0.0020
NOx	0.000	0.000	0.000	0.000	0.000	0.030	0.0200	0.0060	0.0200	0.0230
Phase 2 Com.										
HC	0.0003	0.0003	0.0003	0.000	0.000	0.0245	0.0637	0.0198	0.0283	0.0751
CO	0.0003	0.0003	0.0003	0.000	0.000	0.0110	0.0110	0.0080	0.0080	0.0008
NOx	0.0000	0.0000	0.0000	0.000	0.000	0.0147	0.0098	0.0042	0.0141	0.0094

The other input used in the deterioration functions is the median life in hours for each equipment type. This value is derived by multiplying the annual hours of activity by the half-life (B50 value) in years of each equipment type. The half-life in years is the point on the NSEEM2 scrappage curve when 50 percent of the equipment from a given model year are no longer functioning. These values are included in Tables F-05 by F-06 in the Phase 2 Small Engine Rule Regulatory Support Document and are reprinted here in Table 8.[10]

Table 8

Phase 2 Small Engine Rule Average Annual Use and Load Factor

Equipment	Use	Hr/Year*Load Factor	Hr/Year	B50
LN MOWERS	res	8.38	25.4	5.8
LN MOWERS	prof	134.12	406.42	2
TRIM/EDGE CUTTER	res	4.55	9.1	4.3
TRIM/EDGE CUTTER	prof	68.64	137.29	2.3
CHAINSAWS	res	6.25	12.5	4.3
CHAINSAWS	prof	151.25	302.5	0.9
LEAF BLOW/VAC	res	4.8	9.59	4.3
LEAF BLOW/VAC	prof	141.14	282.29	2.3
GENERATOR SETS	res	6.08	8.95	5.8
GENERATOR SETS	prof	97.36	143.18	2.3
TILLERS	res	6.69	16.73	5.8
TILLERS	prof	188.64	471.6	4.4
SNOWBLOWERS	res	2.97	8.48	4.4
SNOWBLOWERS	prof	47.49	135.68	4.4
COMM TURF	res	NA	NA	NA
COMM TURF	prof	340.85	681.69	2.9
REAR ENG RIDER	res	13.5	35.54	5.8
REAR ENG RIDER	prof	216.07	568.6	2.9
LN/GROUND TRACTOR	res	19.84	45.08	5.8
LN/GROUND TRACTOR	prof	317.37	721.31	2.9
PUMPS	res	9.34	13.54	5.8
PUMPS	prof	149.44	216.58	2.3
ALL OTHER EQUIPMENT	prof	7.3	14.61	5.8
ALL OTHER EQUIPMENT	res	116.84	233.68	2.3

4. Nonroad Engine and Vehicle Emissions Study (NEVES)

Four-Stroke SI Engines

The deterioration rates used in the NEVES for four-stroke engines at or below 20 horsepower were applied to zero-hour emission factors to generate an in-use emission factor. These deterioration rates were derived from tests done by Southwest Research Institute (SwRI) on three four-stroke engines.[11] A table of the SwRI testing results can be found in Appendix 1 of this report. For four-stroke engines, the maximum deterioration factor at the engine's average useful life based on the SwRI tests are multiplicative factors of 2.1, 1.9, and 0.4 for exhaust hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NOx), respectively (i.e., 110 percent increase for HC, 90 percent increase for CO, and 60 percent decrease for NOx at the median life of this type of engine). The particulate matter (PM) deterioration factor taken from the NEVES report is 3.6, which translates into a 260 percent increase in emissions at the median life for this engine category.[12] The decrease in NOx emissions was not seen as being unreasonable, given that wear and tear on small engines tends to cause the fuel to air ratio to become more fuel-rich, thereby increasing products of incomplete combustion such as hydrocarbons, particulate matter, and carbon monoxide emissions while suppressing NOx formation.[13] The authors of NEVES assumed that four-stroke LPG and CNG engines deteriorated the same amount as their gasoline counterparts, since design differences between the gasoline and LPG/CNG engines were negligible.

Two-Stroke SI Engines

With the exception of recreational marine engines, the NEVES report equated all two-stroke SI engine deterioration rates for HC and CO to the four-stroke SI engine deterioration rates in NEVES for below-25 horsepower (19 kw) engines. The authors of NEVES used this approach because the available two-stroke SI emissions testing data from Southwest Research Institute (SwRI) provided inconclusive results. As discussed in the NEVES report, SwRI tested two small (at or below 20 hp), aged two-stroke SI engines , but these results differed widely for HC and CO. The SwRI deterioration data for small four-stroke SI engines fell between the results for the two two-stroke engines, and the authors of the NEVES report decided to use this four-stroke deterioration rate for all small SI engines (both two- and four-stroke). This approach was considered to be preferable to basing the small two-stroke engine deterioration estimates on two data points that differed so greatly. For two-stroke recreational marine engines the NEVES report used a multiplicative deterioration factor of 1.2 (20 percent) that was based on data submitted by the National Marine Manufacturers Association (NMMA).

For NOx, both of the two-stroke SI engines tested by SwRI showed almost equal or slightly higher emissions compared to new engine emission factors for two-strokes. These consistent test results prompted NEVES' authors to use a deterioration factor of 1.0 (zero percent deterioration) for NOx emissions from all small two-stroke SI engines (including recreational marine engines), instead of using the four-stroke SI engine NOx deterioration factor.

For PM, the NEVES report set the PM deterioration factors for all two-stroke spark-ignition engines to a multiplicative factor of 1.0 (zero percent) due to the perceived inappropriateness of applying the four-stroke spark-ignition deterioration rate (3.6 or 260 percent over the median life of the engine) to two-stroke engines. PM emission rates from new two-stroke SI engines are already so high that the NEVES authors believed that they could not experience such a large increase in emissions and remain operational. In the absence of other information, they chose to assume no deterioration in PM emissions. A copy of the table containing these deterioration rates can be found in Appendix 2.

C. Discussion of Deterioration Factor Data for Spark-Ignition Engines At or Below 25 Horsepower

The deterioration rates used in NONROAD approximate the levels of deterioration found in testing, including the testing summarized in NEVES and the testing done to support EPA's Phase 1 and proposed Phase 2 Small Engine Rules. Where these test results differ, the NEEMT has chosen to give greater weight to data taken from engines which have experienced usage patterns that reflect expected field conditions. The test data submitted to EPA for the proposed Phase 2 Small Engine Rule, for example, reflects testing of engines that have undergone accelerated aging which the NEEMT does not believe to be representative of the aging experienced by engines in use. After evaluating all available data, the NEEMT has determined that the level of deterioration used in NSEEM1 and Phase 1 Small Engine Rule provides a reasonable basis for the deterioration rates used in NONROAD. These deterioration rates are generally higher than the deterioration rates used for regulatory purposes in NSEEM2 and the proposed Phase 2 Small Engine Rule, but are generally smaller than those used in NEVES. The NEEMT believes that the deterioration rates used in NONROAD are more reflective of the deterioration rates that one would expect to find out in the field when equipment powered by small spark ignition engines is used by the average person than are the deterioration rates found in NSEEM2 and the proposed Phase 2 Small Engine Rule.

VI. Deterioration Inputs for Spark Ignition Engines Greater than 25 Horsepower

A. Deterioration Factors Used in NONROAD for Spark-Ignition Engines Greater Than 25 Horsepower (19 kilowatts)

Currently, there are few emission testing data concerning dedicated nonroad four-stroke spark ignition engines over 25 horsepower. Both the NEVES and the California ARB used deterioration rates for these types of engines that originated from on-highway spark-ignition engine emissions data. These approaches will be discussed later in this document.

For the purpose of the draft release of NONROAD, the NEEMT has decided to equate deterioration of four-stroke SI engines over 25 horsepower to that of the Class 2, non-handheld four-stroke engines, which are the largest class of engines found in the Phase 1 and proposed Phase 2 rules. Since four-stroke engines over 25 horsepower are not currently regulated, have overhead valve technology, and have no catalytic technology applied to them, the NEEMT will use the baseline deterioration factors found in Table 2 listed next to the label "G4N2O" (i.e., gasoline, four-stroke, non-handheld, Class 2, overhead valve engines). The deterioration rate for the large ones will be curvilinear, using 0.5 for the 'b' constant, as is the case for small four-stroke engines.

Two-stroke SI engines over 25 horsepower are also unregulated at this time. For these engines, the NEEMT has decided to use the pre-control deterioration inputs being used in NONROAD for the largest class of small engines in the Phase 1 and proposed Phase 2 Small Engine Rules. These can be found in table 2 next to the label "G2N2" (i.e., gasoline, two-stroke, non-handheld, Class 2 engines). The deterioration rate for the large ones will be linear, using 1.0 for the 'b' constant in the NONROAD deterioration function, as is the case for small two-stroke engines.

B. Other Sources of Deterioration Factors for SI Engines Greater than 25 Horsepower

1. <u>NEVES Deterioration Factors for Gasoline Spark Ignition Engines Greater than 20 Horsepower</u>

The data for the large four-stroke SI deterioration rates in the NEVES report were developed by a 1983 joint testing program by EPA and the Equipment Manufacturers Association (EMA) to test heavy-duty on-highway engines, including both spark-ignition and compression-ignition engines. For heavy-duty, four-stroke, spark-ignition engines, the program used an unknown number of 1979 to 1982 pre-controlled highway engines. EMA's calculation of the deterioration rates used regression equations based upon a number of assumptions, most notably that the engines had logged 55,000 miles. Based on this assumption, the engines had reached the halfway point of their median life in relation to the existing heavy-duty on-highway gasoline engine regulations, which defined the median life of such engines to be 110,000 miles. Deterioration rates for HC and CO were calculated by dividing in-use engine emissions by those of new heavy duty gas engines. The deterioration factor for HC was calculated to be 1.5 (a 50 percent increase), while the deterioration factor for CO was calculated to be 1.3 (a 30 percent increase). NOx emissions did not show a significant increase in emissions, so a deterioration factor of 1.0 (zero percent increase) was used. No testing was done to measure PM deterioration. The NEVES report assumed that large nonroad four-stroke SI engines experienced similar deterioration patterns, in part because of the similarities in engine design between such nonroad engines and the uncontrolled highway engines tested by EMA and EPA.

The NEVES report equated the large two-stroke spark ignition deterioration rates to the deterioration rates for the greater than 20 horsepower (19 kW) four-stroke spark-ignition engines in NEVES for HC, CO, and NOx. As stated in section V.B.4, the NEVES report assumed no deterioration in PM emissions for all two-stroke spark ignition engines.

2. California ARB's Deterioration Factors for Spark Ignition Nonroad Engines Greater than 25 Horsepower

The California ARB nonroad model, OFFROAD, uses deterioration rates for gasoline four-stroke spark-ignition engines over 25 horsepower that are based on pre-control on-highway engine deterioration rates found in EMFAC7E, the California ARB on-highway emissions model. These deterioration rates, in the form of percent deterioration per percent of median life, are shown in Table 9.[14] The California ARB matched nonroad and on-highway engines as closely as possible by horsepower and used a ratio to convert the on-highway deterioration rates based on gram/10,000 miles traveled to rates based on number of hours an engine has been used. This ratio is shown below, with the median life for off-road engines expressed in terms of hours and the median life for on-highway engines expressed in terms of miles traveled. The deterioration factors are expressed as the percent increase in emissions per percent of median life. Since there were no equivalent on-highway engines for the 25 to 50 horsepower category of nonroad engines, the California ARB set the deterioration rate for these engines equal to that used for the 50 to 120 horsepower engines. No data were available for PM.

$$\frac{\text{Off-Road d.f.} * \text{Median Life}}{\text{Off-Road Zero Hour Factor}} = \frac{\text{On-Highway d.f.} * \text{Median Life}}{\text{On-Highway Zero Mile Factor}}$$

Table 9
California ARB Deterioration Rates For Four-Stroke
Spark-Ignition Engine Over 25 Horsepower
(Percent increase per percent of median life)

HP Category	Equivalent On-hwy.	On-hwy. MYR	On-hwy. Useful Life	Off-hwy. HC d.f.	Off-hwy. CO d.f.	Off-hwy. NOx d.f.
25 to 50	None	N/A	N/A	1.38%	0.83%	0.064%
50 to 120	LDGT	1969 NCAT	120,000	1.38%	0.83%	0.064%
120+	HDGV	1970 NCAT	120,000	0.37%	0.56%	0.140%

The technical support document for the California ARB's OFFROAD model stated that baseline deterioration rates for two-stroke SI engines had been set equal to the two-stroke deterioration rates contained in the NEVES report, with the exception of two-stroke nonroad motorcycles, all terrain vehicles (ATVs) and snowmobiles. For nonroad motorcycles and ATVs, the California ARB calculated deterioration rates based on data from pre-control on-highway motorcycle engines. Snowmobile deterioration rates in OFFROAD were set to zero percent because the California ARB believed that it did not have sufficient data concerning their emissions.

C. Discussion of Deterioration Factors for Spark Ignition Engines Greater Than 25 Horsepower

The NEEMT has several misgivings about using the on-highway engine deterioration rates derived from the EPA/EMA testing program and used in NEVES. Nonroad and highway engines are used in different applications and on different operating cycles, experience different maintenance patterns, and are operated at different power levels. Highway SI engines also may be tuned to run differently or be configured differently than those used in nonroad applications. These differences are likely to result in significantly different rates of deterioration for nonroad engines when compared to highway engines of similar rated power levels. The cycles used in the EPA/EMA test program were not documented in the NEVES report and supporting documentation, but it is likely that the program used highway testing cycles since it used highway engines and since EPA had not yet developed representative test cycles for nonroad applications at that time. The NEEMT also has reservations about using the California ARB deterioration factors, and its general approach for deriving nonroad deterioration rates from highway engine test data, for similar reasons. Furthermore, neither the EPA/EMA test program nor the California program measureed PM emissions, although PM deterioration could be assumed to be equal to HC deterioration, as the California ARB did for small four-stroke SI engines.

Given the paucity of actual nonroad testing data for spark-ignition engines greater than 25 horsepower and the concerns with the deterioration factors used in NEVES report and the OFFROAD model, the NEEMT has chosen to equate spark-ignition engine deterioration for large (>25 hp) engines to the deterioration of Class 2 SI engines in its draft version of NONROAD. Class 2 engines are the largest class of under-25 horsepower spark-ignition engines, and there is sufficient test data on such engines to permit estimation of their deterioration rates without having to use data taken from tests of highway engines. The NEEMT requests comments regarding the appropriateness of this approach and welcomes suggestions regarding more appropriate alternatives. The NEEMT also requests that commenters submit any additional data that could be used to assess deterioration for large spark-ignition engines (both two and four-stroke).

VIII. Liquid Petroleum and Compressed Natural Gas Spark-Ignition Engines

Because liquid petroleum gas (LPG) and compressed natural gas (CNG) engines are primarily four-stroke engines, the NEEMT decided to assume that they would deteriorate at the same rate as the corresponding gasoline-powered four-stroke SI engines for all pollutants. The NEEMT is not aware of any deterioration data available for LPG and CNG engines and requests that commenters submit any such data they may have to the NEEMT. If such data become available, the NEEMT will revise the deterioration rates for these engines in NONROAD accordingly.

IX. Diesel Engines

In the draft version of NONROAD, the NEEMT has chosen to assume that no deterioration takes place in compression ignition nonroad engines. This approach is consistent with the approach used by EPA in modeling emissions from highway compression ignition engines. However, recent preliminary test results suggest that nonroad diesel engines may experience significant rates of deterioration. In a 1997 test program conducted by Southwest Research Institute for OMS [15], nine late-model, in-use nonroad diesel engines were tested. Four of the engines had significant problems necessitating repairs. Manifold or turbocharger leaks were found in all four of the malmaintained engines; two of the engines also required other repairs to the fueling system in addition to the leaks. Leaks in the manifold or turbocharger would affect the functionality of the turbocharger and would likely increase emissions. The manifold leaks made it impracticable to perform emission measurements on these engines, so repairs were required before emissions testing. Therefore, it is likely that the measured emissions and fuel consumption of these engines underestimated their in-use emissions. EPA expects to have a testing program commencing soon that will investigate deterioration rates in nonroad compression ignition engines. The NEEMT hopes to incorporate the data from this testing program in future versions of NONROAD and, if time and resources allow, in the final version of NONROAD.

The EPA/EMA testing program mentioned above in Section VI.B.1 tested on-highway heavy-duty diesel engines as well as heavy duty gasoline engines. The results of this testing showed no increase in HC or NOx and only a slight increase in PM as engines aged. These results are reflected in EPA's MOBILE emissions models and the Nonroad Emissions Model (developed to support EPA's 1997 proposed nonroad diesel engine standards), both of which assume that diesel engines experience no emissions deterioration. The California ARB incorporates diesel engine deterioration rates in its OFFROAD model that were derived from on-highway data in the California ARB's EMFAC model. The same concerns regarding the relevance of highway engine emissions testing data to nonroad engine deterioration rates discussed in Section VI.C also apply to nonroad diesel engines. The NEEMT is not aware of any nonroad diesel emissions testing programs that were designed to isolate the effects of deterioration and that could be used to confirm or refute the EPA/EMA and California ARB test results.

<u>Endnotes</u>

1. Median life is defined as the midpoint of the scrappage curve at which half of the engines in a given population cease to function and are scrapped. For more information, please refer to the technical report on activity, load factors and median life (NR-005) and the technical report about scrappage (NR-007).

2. See endnote 1.

3. <u>Regulatory Impact Analysis and Regulatory Support Document, Control of Air Pollution; Emission Standards for New Nonroad Spark-Ignition Engines At or Below 19 Kilowatts</u>, Office of Air and Radiation, Office of Mobile Sources, A-93-25, May 1995, section C.1.1, p. C-4.

4. <u>Regulatory Impact Analysis and Regulatory Support Document, Control of Air Pollution; Emission Standards for New Nonroad Spark-Ignition Engines At or Below 19 Kilowatts</u>, Office of Air and Radiation, Office of Mobile Sources, A-93-25, May 1995, Section 5.4.2.

5. <u>Nonroad Engine and Vehicle Emission Study - Report and Appendices</u>, USEPA, Office of Air and Radiation, Office of Mobile Sources, 21A-2001, November 1991.

6. <u>Documentation of Input Factors For The New Off-Road Mobile Source Emissions Inventory Model</u>, Prepared for the California Air Resources Board by Energy and Environmental Analysis, Inc., August 1995, p. 6-21.

7. Fax sent to NEEMT on 4/3/98 from Archana Agrawal of the California Air Resources Board. The fax contains tables of the official adopted deterioration rates in the California OFFROAD model as of 3/26/98.

8. <u>Regulatory Impact Analysis and Regulatory Support Document, Control of Air Pollution; Emission Standards for New Nonroad Spark-Ignition Engines At or Below 19 Kilowatts</u>, Office of Air and Radiation, Office of Mobile Sources, A-93-25, May 1995, Appendix C.

9. A slight discrepancy exists between NEVES and the small engine nonroad regulation concerning the classification of small versus large spark ignition engines. The NEVES report divided smaller and larger

four-stroke and two-stroke engines at 20 horsepower. The regulations that have been promulgated since the publishing of NEVES set the dividing point at 25 horsepower (19 kilowatts).

10. EPA Regulatory Support Document, Phase 2: Emission Standards for New Nonroad Spark-Ignition Engines At or Below 19 Kilowatts, Appendix F: Nonroad Small Engine Emission Model Tables, Tables F-05 and F-06, December 1997.

11. Nonroad Engine and Vehicle Emissions Study, November 1991, Appendix I, Table I-14, p. I-61.

12. The first and second phases of the small engine rule did not address PM emissions.

13. Nonroad Engine and Vehicle Emission Study, USEPA, Office of Air and Radiation, Office of Mobile Sources, 21A-2001, November 1991, Appendix I, p. I-12, Section 2.2.1.

14. Recreated from Table 6-9, p. 6-22, in Documentation of Input Factors For The New Off-Road Mobile Source Emissions Inventory Model, Prepared for the California Air Resources Board by Energy and Environmental Analysis, Inc., August 1995

15. Fritz, S. G., Emission Factors for Compression Ignition Nonroad Engines Operated on Number 2 Highway and Nonroad Diesel Fuel, Southwest Research Institute. EPA EPA 420-R-98-001, March 1998.

Appendix 1

SwRI In-Use Small Utility Engine Test Results

Engine	Test	HC g/hp-hr	HC test/EF	CO g/hp-hr	CO test/EF	NOx g/hp-hr	NOx test/EF	PM g/hp-hr	PM test/EF
4-Stroke									
2 yr. WBM	1A	67.9	1.80	650	1.51	0.94	0.47	1.35	1.80
4 yr. WBM	1A	83.9	2.23	928	2.16	0.37	0.18	1.11	1.48
	2A	112.6	2.99	1033	2.40	0.47	0.23	2.05	2.73
8 yr. WBM	1A	VOID	VOID	VOID	VOID	VOID	VOID	VOID	VOID
	2A	77.3	2.05	835	1.94	0.90	0.45	6.27	8.36
	3A	74.9	1.99	829	1.93	0.71	0.35	4.08	5.44
New Engine EFs		37.7		430		2.02		0.75	
In-use adjustment (avg. test/EF)			2.10		1.90		0.40		3.60
2-Stroke									
11 yr. WBM	1	187	0.90	415	0.85	0.51	1.76	5.75	0.75
	2	177	0.85	418	0.86	0.52	1.79	6.61	0.86
New Engine EFs		208		486		0.29		7.7	
4 yr. String Trimmer	1	1369	6.11	2244	3.11	0.77	0.86	61.3	15.36
	2	1205	5.38	1936	2.68	0.69	0.77	54.3	13.61
New Engine EFs		224		722		0.90		3.99	

Appendix 2

Baseline and In-Use Emissions Numbers from EPA's 1991 Nonroad Study

Equipment Category	Baseline (g/kw-hr)			In-Use (g/kw-hr)			In-Use Factor			Adjusted In-Use Factors		
	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx
4-Stroke Engines							2.1	1.9	0.4	2.1	1.9	0.4
Lawnmowers	50.5	576.4	2.71	106.13	1095.17	1.09						
Trimmers/Edgers/Brush Cutters	32.41	527.27	2.71	68.07	1001.81	1.09						
Chainsaws	NA	NA	NA	NA	NA	NA						
Leaf Blower/Vacuum	26.01	509.79	2.72	54.61	968.59	1.09						
Generator Sets	12.73	473.19	2.72	26.74	899.06	1.09						
Tillers	50.54	576.41	2.71	106.13	1095.17	1.09						
Snowblowers	50.54	576.41	2.71	106.13	1095.17	1.09						
Commercial Turf	12.6	474.53	2.83	26.46	901.61	1.13						
Rear Engine Riders	12.47	473.19	2.72	26.18	899.06	1.09						
Lawn and Garden Tractors	12.6	474.53	2.83	26.46	901.61	1.13						
Pumps	12.47	473.19	2.72	26.18	899.06	1.09						
All Other Equipment							2.1	1.9	1.0	**1.2**	1.9	1.0
2-Stroke Engines												
Lawnmowers	278.82	486	0.39	585.52	1237.8	0.39						
Trimmers/Edgers/Brush Cutters	301.1	728.22	1.22	632.14	1854.72	1.22						
Chainsaws	399.46	699	1.29	842.9	1780.29	1.29						
Leaf Blower/Vacuum	288.59	716.81	1.29	606.05	1825.66	129						
Generator Sets	278.82	486	0.39	585.52	1237.8	0.39						
Tillers	278.82	486	0.39	585.52	1237.8	0.39						
Snowblowers	278.82	486	0.39	585.52	1237.8	0.39						
Commercial Turf	278.82	486	0.39	585.52	1237.8	0.39						
Rear Engine Riders	NA	NA	NA	NA	NA	NA						
Lawn and Garden Tractors	NA	NA	NA	NA	NA	NA						
Pumps	5.74	113	9.44	12.05	287.8	3.78						
All Other Equipment												

N/A=Not Applicable

Note: All Other Equipment includes the following: Distributed Loose Engines, Commercial Turf Equipment, Other Lawn and Garden, Wood Splitters, Pressure Washers, Front Mowers, Welders, Specialty Vehicles and Carts, Shredders, Cement/Mtr Mixers, Golf Carts, Paving Equipment, Air Compressors, and Sprayers.