UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
NATIONAL VEHICLE AND FUEL EMISSIONS LABORATORY
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OFFICE OF
AIR AND RADIATION

June 15, 2004

CCD-04-12 (HD)

Dear Manufacturer:

Subject: Non Road Compression Ignited Engines: Guidance on Reporting Maximum Allowable Off-cycle Emissions

Enclosed with this letter is a guidance document which addresses the reporting of Maximum Allowable Off-cycle Emissions (MAEL) in non road compression ignited engines for purposes of certification under Title II of the Clean Air Act. This document establishes the MAEL as a voluntary objective screening tool to assist manufacturers and EPA in evaluating off-cycle emissions from base emission control strategies as they relate to the prohibition of defeat devices.

If you have any questions about this guidance, please contact your certification team representative.

Sincerely,

Merrylin Zaw-Mon, Director
Certification and Compliance Division
Office of Transportation and Air Quality

Enclosure

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June 15, 2004

Nonroad Compression Ignited Engines: Guidance on Reporting Maximum Allowable Off-Cycle Emissions

I. Purpose

This guidance document establishes the Maximum Allowable Emissions Limit (MAEL) as an objective screening tool to assist nonroad Compression Ignition (CI) engine manufacturers and EPA in evaluating off-cycle emissions from base emission control strategies as they relate to the prohibition of defeat devices. As described in previous EPA guidance, base emissions control calibrations meet the definition of an auxiliary emissions control device (AECD). See EPA Guidance Document VPCD 98-13 (VPCD-98-13) and Advisory Circular 24-3 (A/C 24-3). This guidance explains how EPA will use MAEL data voluntarily submitted by manufacturers to evaluate base emissions control calibrations not substantially included in the Federal Test Procedure (FTP) for compliance with the defeat device provisions in 40 CFR Part 89 Section 107. The MAEL is intended to assure engines are calibrated to provide emissions control similar to that demonstrated over the 8-mode certification test cycle across the operating range, and not just at the 8 pre-defined test points.

EPA has adapted the MAEL protocol designed for on-highway heavy-duty diesel engines to the nonroad CI engine test cycles. The MAEL for on-highway heavy-duty diesel engines is defined in EPA guidance document VPCD-98-13 and in the 2004 and 2007 heavy-duty diesel final rules.

EPA is issuing this guidance in response to manufacturer requests for an alternative to EPA's traditional means of evaluating base emissions control strategies which heavily relied on case-by-case design reviews. Manufacturers of nonroad CI engines have expressed concern about the time required of these labor-intensive design reviews. Further, manufacturers have suggested that a more objective performance criteria such as the MAEL could be more clearly and consistently integrated into the engine design process as well as enable compliance monitoring to be more consistently implemented across nonroad engine designs and manufacturers. As stated in previous guidance for heavy-duty engines, EPA prefers to rely on emission performance rather than design specifications in determining whether a manufacturer's proposed product offering qualifies for emissions certification. This guidance is being issued now because of the anticipated complexity of the design reviews that would need to accompany the increasingly sophisticated electronic control strategies manufacturers are expected to introduce for Tier 3 compliance. Exhaust gas recirculation (EGR) is one such example.

This guidance applies to 2004 and later model year new, non-carryover nonroad CI engines required to comply with the Tier 1, 2, or 3 requirements contained in 40 CFR Part 89. EPA does not expect MAEL test results to be submitted for certification applications where the certification test results were generated prior to the issuance of today's guidance.

II. Background

Emissions control system parameters such as fuel injection timing are commonly modulated as engine speed and load change during normal operation. The designs of these modulations are contained in base emissions control maps which are defined as a function of engine speed and load. The only portion of the base emissions control strategy where emissions performance is demonstrated during the emissions certification process is that portion which activates over the engine speed and load prescribed by the official EPA certification test.

However, the nonroad steady-state certification test does not cover a large portion of typical engine operation. The nonroad CI certification test cycles consist of, at most, eight distinct test modes, each defined by a unique pairing of engine speed and load.[1] Consistent with the defeat device provisions

[1] As described in Appendix B to 40 CFR Part 89 Sub-Part E, the Table 1 test cycle for variable speed

contained in 40 CFR Part 89 Section 107, emissions control for operation outside of and between the official test modes is expected to be similar to the emissions control demonstrated at the test modes.

EPA has recently been investigating the calibration of nonroad base injection timing maps for compliance with the defeat device provisions. Those investigations involved comparing the calibration of the base map represented over the FTP to the calibration at loads and speeds not included in the FTP. The investigations have uncovered instances of inappropriate base map designs. As a result, manufacturers have been seeking guidance on what constitutes appropriate off-cycle base emissions control. EPA has reiterated its position that control between and beyond emissions test points should be similar to the emissions control demonstrated at the test modes.

The MAEL test designed for on-highway heavy-duty diesel engines embodies the principal of linear control between test points. The MAEL uses a four-point linear interpolation to define the emissions limit for any operating point not covered by the certification test. The MAEL was introduced by the Commission of the European Union as part of the Euro III steady-state emissions test for on-highway diesel engines[2]. EPA is adopting a slightly revised version of the Euro III steady-state and MAEL tests as part of the emissions requirements for 2007 on-highway diesel engines. In the interim, EPA is using the MAEL in tandem with the Euro III and Not-To-Exceed as defeat device screening tools for heavy-duty diesel engines. See VPCD-98-13 and AC 24-3.

The MAEL for nonroad CI engines described in this guidance is derived from the non-idle points of the 8-mode test in a manner similar to the way the on-highway MAEL relies on the emissions results from the non-idle Euro III test points to interpolate MAEL values. The on-highway MAEL procedure was not directly applicable to nonroad CI engines due to differences between the nonroad and on-highway emissions tests. In particular, the nonroad certification test includes test points at lower engine loads than the Euro III. Further, the nonroad test consists of only two test speeds (intermediate and rated) in contrast to the three test speeds required by the Euro III. As a result, the nonroad MAEL requires additional emissions information to be generated prior to performing the 4-point linear interpolation. First, emissions must be measured or estimated at one point outside of the 8-mode test so MAEL values can be interpolated for operation below 50 percent load. Second, the MAEL values for operation beyond rated speed must be estimated from the 8-mode test values at rated speed.

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engines consist of 8 modes; the Table 2 cycle for constant speed engines 5 modes.

[2] Proposal adopted by the Commission of the European Union on December 3, 1997, for presentation to the European Council and Parliament, titled “Draft Proposal for a Directive of the European Parliament and the Council Amending 88/77/EEC of 3 December 1987 on the Approximation of the Laws of the Member States Relating to the Measures to be Taken Against the Emission of Gaseous and Particulate Pollutants From Diesel Engine for Use in Vehicles.”

III. Applicability

The MAEL will be used to screen for defeat devices in nonroad CI engines certified to the Table 1 and Table 2 test cycles in 40 CFR Part 89 Subpart E and covered by the Tier 1, 2, and 3 emissions standards described in 40 CFR Part 89. The MAEL is only applicable under the testing conditions specified in 40 Part 89 Subparts D & E. Within an engine family, MAEL data generated from the engine configuration selected as the certification test engine per 40 CFR §89.117(a), i.e. the parent engine, may be used to demonstrate that the remaining configurations within the engine family also do not exceed the MAEL screening thresholds provided that 1) those configurations share the same emissions control strategies as the parent engine and 2) the manufacturer includes the compliance statement language referenced in Section VII of this guidance.

MAEL results from an engine family may be used for subsequent model year production of that family, i.e. carryover engine families, provided that the certification data and the engine and emissions control system are identical across each model year for those families. The engine and emissions control system includes both hardware design and software calibration. A carryover engine family may include minor changes which reflect a new component vendor and/or part number provided the basic design of the hardware and calibration of the software are identical.

The AECD reporting guidelines and design screening thresholds contained in VPCD-98-13 and AC 24-3 will continue to apply to nonroad CI engines. A copy of an AECD reporting template is provided in Attachment 1 of this guidance document. EPA will use other relevant information and test results to determine compliance with the defeat device requirements if an engine does not meet the MAEL emission criteria or design screening thresholds.

Given MAEL data is intended to assist EPA in evaluating AECDs for compliance with the defeat device provisions during the certification process, MAEL data generation is not applicable to selective enforcement audits where the focus is evaluating the emissions variability resulting from the manufacturing process.

IV. Definitions

For nonroad compression ignited engines, the following regulatory definitions apply:

1. Auxiliary Emission Control Device (AECD). An AECD is any element of design that senses temperature, vehicle speed, engine RPM, transmission gear, or any other parameter for the purpose of activating, deactivating, or modulating the operation of any part of the emission control system. See 40 CFR Part 89 Section 2.

2. Defeat Device. A Defeat Device means any device, system, or element of design which senses operation outside normal emission test conditions and reduces emissions control effectiveness.

A defeat device includes any auxiliary emission control device (AECD) that reduces the effectiveness of the emission control system under conditions which may reasonably be expected to be encountered in normal vehicle operation and use, unless such conditions are included in the test procedure. Defeat device does not include such items which either operate only during engine starting or are necessary to protect the engine (or equipment in which it is installed) against damage or accident during its operation. See 40 CFR Part 89 Section 107 (b).

For the purpose of this guidance document, the following definition applies:

1. Base emissions control calibration. A base emissions control calibration is any parameter, element of design, or strategy that is designed to modulate as a function of engine load and speed in a manner that effects the emissions performance of the engine. Examples include, base fuel injection timing, EGR, and fuel pressure modulation.

V. Using the MAEL to Assist in Evaluating Base Emissions Control Maps

1. General

EPA will evaluate MAEL information voluntarily submitted by nonroad CI engine manufacturers during the certification process. Each engine shall have its own Maximum Allowable Emission Limits for any intermediate test points selected by EPA. The MAEL values are generated from a combination of 1) the measured emissions at the 7 non-idle test modes of the 8 mode test cycle for variable speed engines, 2) the estimated or measured emissions at Mode 9 (intermediate speed /10% load), 3) application of the emissions offsets (from the standard-to-weighted average emissions ratio and the 1.20 multiplier) to the measured (and Mode 9) emissions, and 4) the four-point linear interpolation procedure specified below.

NOx (Tier 1), NOx+NMHC (Tier 2/Tier 3), and CO emissions are subject to the MAEL screening criteria; PM and smoke emissions are not. CO emissions will be phased into the MAEL screening criteria. For 2004 model year engine families either certified for the first time, i.e. non-carryover, or required to meet pull-ahead requirements contained in consent decrees, EPA will evaluate voluntarily submitted CO data to identify general trends, establish baseline information for use in subsequent model years, and determine the general appropriateness of the CO screening threshold. Assuming the CO screening threshold proves to be appropriate, EPA will evaluate the CO data from subsequent model year engines against the screening threshold with the exception of engine families which meet the carry over criteria described previously.

The engine manufacturer is to conduct MAEL testing immediately after completing the 8^{th} mode of the nonroad test cycle. If the manufacturer chooses to measure emissions at Mode 9 (see V.3.), this measurement is done immediately after completing Mode 8. Emissions testing is then conducted at the intermediate test points. Manufacturers are to submit a request for EPA to select intermediate test points prior to conducting certification emissions testing. EPA will select three intermediate operating points, i.e., mystery points, within 2 EPA business days of the receiving the manufacturer's request. In the event a manufacturer does not receive a response from EPA within the 2 business-day period, it should make its own random selection of intermediate test points.

The emissions generated at each of the three intermediate test points are compared to the corresponding interpolated or extrapolated MAEL value. If the intermediate emissions are equal to or below their respective MAEL value, the engine satisfies the MAEL screening criteria.

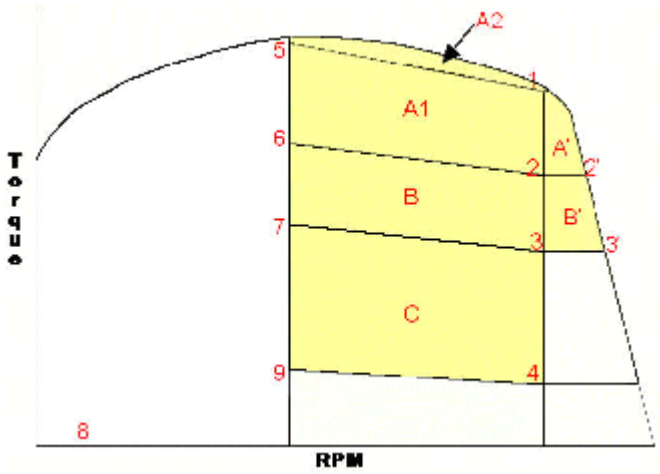
2. MAEL operating zone

The MAEL screening will be performed in the following engine operating areas:

a) above 10% load between intermediate and rated speed, and
b) above rated speed and above 50% of rated speed torque

As seen in Figure 1, the engine operating range has been subdivided into six zones (A1, A2, B, C, A', and B') to illustrate the areas of interpolation and extrapolation. Each non-idle test mode of the 8-mode cycle is included as well. Zones A2 and A' are extrapolated from zone A1. Similarly, zone B' is extrapolated for zone B. Alternatively, manufacturers may choose to use constant NOx + NMHC and CO emissions for the MAEL values above rated speed (Zones A' and B'). In other words, the same emission level that occurs at rated speed would extend into the area beyond rated speed along lines of constant power. With this approach, the NOx +HC and CO MAEL are held constant with power.

Figure 1.



The following operating areas are not be subject to MAEL screening:

a) below intermediate speed at all loads
b) below 10% load at all speeds, and
c) below 50% load and above rated speed

As seen above, the MAEL does not cover all engine operation, although manufacturers are still responsible for appropriate emissions control during those operating modes as required by the defeat device provisions. For engine operation below the intermediate engine test speed, EPA will consider a manufacturer's demonstration of emissions performance or control similar to the emissions results at the intermediate test points to be adequate evidence that a defeat device does not exist for the purposes of this guidance. In situations where similar emissions performance or control cannot be demonstrated (for example, when emissions data for operation below the intermediate engine test speed does not exist and base control in that region does not follow the trends established in the region of operation covered by the MAEL), a manufacturer should provide a detailed explanation why the modulation of the emissions control system within the base map is appropriate via the AECD reporting process (see reporting template in Attachment 1).

A robust, detailed AECD report should, at a minimum, explain or describe 1) why a strategy which modulates the emissions control system within the base map is necessary (e.g. EGR shut-off for turbocharger surge protection), 2) the conditions which give rise to the need for the strategy and why (e.g. low engine speed/high engine load and/or low air density because each requires a higher compressor ratio for a given volumetric air flow, which moves compressor operation into the surge region), 3) why there is no reasonable alternative means to achieve the stated purpose of the strategy (e.g. a larger turbocharger), 4) why it is not appropriate for the strategy to be removed from the base map and contained as a separate engine protection AECD, 5) how each modulated parameter of the emissions control system achieves the stated purpose of the strategy, 6) the process used to ensure that the modulation is limited to the conditions where the stated purpose of the strategy arises and to calibrate the modulation to be the minimum necessary to achieve that stated purpose, 7) the estimated emissions impacts of the strategy (e.g. brake specific emissions and/or tons emitted lifetime), and 8) the estimated frequency that the strategy will be activated (e.g. percent of overall engine operation). In general, EPA would accept such detailed AECD report(s) as

an adequate means to explain any nonlinear emissions behavior in the portions of the base map not subject to MAEL screening.

Accordingly, in situations where the AECD reporting process adequately demonstrates that a strategy within the base map is needed for engine protection and the resulting modulation of the emissions control system is calibrated to the minimum necessary, EPA does not intend to pursue further investigation of the strategy for the purposes of certification with respect to the prohibition against defeat devices absent other information suggesting the existence of a defeat device.

3. Determining Mode 9 emissions

Since Mode 9 is not a test point in the 8 mode test cycle, a value for emissions at this mode must be determined and used for the purposes of making the necessary interpolations. The manufacturer may generate the emissions at mode 9 through actual testing. Alternatively, any of the following criteria may be used to determine the Mode 9 emissions value used in the MAEL calculations:

a) The NOx (Tier1) or NOx+NMHC (Tiers 2 and 3) and CO level at Mode 4.

b) A value computed using the same delta in NOx (Tier 1) or NOx+NMHC (Tiers 2 and 3) and CO from Mode 7 as the delta from Modes 3 to 4. This delta is an absolute difference (g/kWh) not a ratio or percentage difference.

c) A value 10% higher than the minimum NOx (Tier 1) or NOx+NMHC (Tiers 2 and 3) and CO that could be achieved by adjusting engine emission control parameters at the intermediate speed /10% load point while still achieving acceptable engine operation and adequate control of other emission parameters

While it is not necessary that actual emissions testing be conducted to determine the Mode 9 emissions value for the purposes of interpolation, the estimated value from options a) through c) will serve as a cap on the actual Mode 9 emissions. EPA reserves the right to select Mode 9 as one of its three intermediate "mystery" points at the time of certification.

4. Generating Intermediate Point Emissions and Corresponding MAEL Values

a) Intermediate point emissions. For the three test points selected by EPA per the General section above, the emissions at each test point must be measured and calculated using the procedures for the 8-mode test cycle as described in 40 CFR Part 89 Subparts D and E. The measured emissions values must then be compared to the interpolated MAEL values according to the procedure described below.

b) MAEL offsets. The MAEL value for any point within the MAEL operating zone is determined by first multiplying the emissions at each of these modes by the ratio of the standard (or FEL) to the weighted average emissions value for the 8 mode test, and then by 1.10 for modes 1,2,3,5,6, and 7, and 1.20 for modes 4 and 9. The emissions values adjusted by these offsets at the corners of zones A1, B, or C serve as the basis for the 4-point interpolation (or extrapolation) and should be reported to the same number of significant digits as the applicable emissions standards. The interpolated/extrapolated values are determined from the modes of the test cycle closest to the respective test point according to the procedure below.

c) Interpolating or extrapolating MAEL emission values from the test cycle. In general terms, the gaseous emissions for each regulated pollutant for each of the control points (Z) must be interpolated from the four closest modes of the test cycle that envelop the selected control point Z as shown in Figure 2 of this below.

For these four closest modes (R, S, T, U), the following definitions apply:

(A) Speed (R) = Speed (T) = n_{RT} = Intermediate speed.
(B) Speed (S) = Speed (U) = n_{SU} = Rated speed.
(C) Percent load (R) = Percent load (S).
(D) Percent load (T) = Percent load (U).

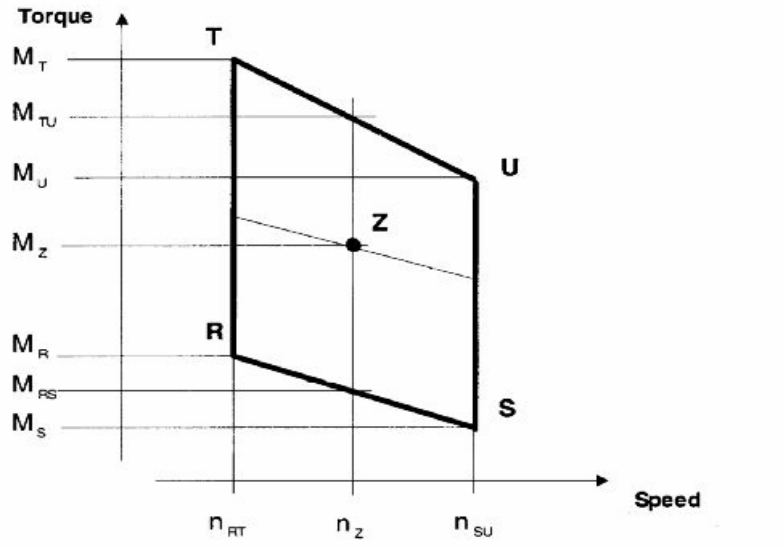
The interpolated or extrapolated value of the brake specific gaseous emissions at the selected control point $Z(E_Z)$ must be calculated as follows:

$$E_Z = E_{RS} + (E_{TU}-E_{RS}) * (M_Z-M_{RS}) / (M_{TU}-M_{RS})$$
$$E_{TU} = E_T + (E_U-E_T) * (n_Z-n_{RT}) / (n_{SU}-n_{RT})$$
$$E_{RS} = E_R + (E_S-E_R) * (n_Z-n_{RT}) / (n_{SU}-n_{RT})$$
$$M_{TU} = M_T + (M_U-M_T) * (n_Z-n_{RT}) / (n_{SU}-n_{RT})$$
$$M_{RS} = M_R + (M_S-M_R) * (n_Z-n_{RT}) / (n_{SU}-n_{RT})$$

Where:

E_R, E_S, E_T, E_U = for each regulated pollutant, brake specific gaseous emissions of the enveloping modes adjusted according to the offset factors described previously.
M_R, M_S, M_T, M_U = engine torque of the enveloping modes.
M_Z = engine torque of the selected control point Z.
n_Z = engine speed of the selected control point Z.

Figure 2.



d) Comparing measured emissions values to interpolated or extrapolated emission values. If the measured brake specific emissions (NOx, NOx +NMHC, CO) of the control point Z (X_Z) is less than or equal to the interpolated value (E_Z), the MAEL guidance screening criteria are satisfied. The enclosed spreadsheet

(Attachment 2) contains a template for the calculating interpolated or extrapolated MAEL values and comparing them to the measured emissions at their respective intermediate test points. The same equations apply to interpolation (zones A1, B, and C) and extrapolation (zones A2, A', and B'). As mentioned previously, zone A1 is an interpolation of Modes 1, 2, 5, and 6. Zone B is an interpolation of Modes 2, 3, 6, and 7. Zone C is an interpolation of Modes 3, 4, 7, and 9. Zones A2 and A' are defined by an extrapolation of zone A1 (Modes 1, 2, 5, and 6). Zone B' is an extrapolation of zone B (Modes 2, 3, 6, and 7). Note that data points 2' and 3' are on the governor droop curve at the same absolute torque (not percent torque) as Modes 2 and 3.

5. Constant Speed Engines

The approach for variable-speed engines certified to the eight-mode cycle when tailored for constant speed engines collapses to a one-dimensional linear interpolation. For constant speed engines, the screening will take place along a line between Modes 1, 2, 3, 4, and 5 of the 5-mode test cycle. A one-dimensional interpolation is performed between any two test modes after adding the 10% offset for Modes 1, 2, 3, and 4, the 20% offset for Mode 5, and the offset for every mode determined by the ratio of standard or FEL to the weighted emission result from the five-mode test. No new modes are created to do this MAEL analysis, nor is any extrapolation necessary.

VI. Defeat Device Evaluations of Base Emissions Control Calibrations

If an engine manufacturer demonstrates to EPA's satisfaction that an engine family satisfies the previous mentioned AECD reporting and design screening criteria, and these MAEL criteria, then absent other information suggesting the existence of a defeat device, EPA does not intend to pursue further investigation of the engine family for the purposes of certification with respect to the prohibition against defeat devices. The base emissions control calibrations of engines failing to satisfy the MAEL screening criteria will be evaluated further on a case-by-case basis. For base emissions control calibrations which cause emissions to exceed the MAEL performance criteria, EPA will evaluate the need for the base emissions control calibration design based upon the information supplied by the manufacturer in its application for certification. EPA may conduct additional testing or may request the manufacturer supply additional information if necessary to make a defeat device determination.

EPA reserves the right use its authority at 40 CFR Part 89 Section 119 to test certification engines according to MAEL procedures referenced above, when appropriate, to evaluate the emission impacts of any base emissions control calibration which the Agency is concerned may result in increases in emissions during operation not well represented by the FTP. Any such testing that the Agency deems necessary in order to complete its defeat device evaluation may, according to 40 CFR Part 89 Section 119, be conducted at a site of EPA's choice including the manufacturer's test facility.

VII. Reporting MAEL Screening Results

The emissions test results at each intermediate test point selected by EPA must be reported with the certification test results in the manufacturers' application for a certificate of conformity. The data may be included in the Supplemental Data section of EPA's Large Engine Certification templates. Any manufacturer which chooses to conduct MAEL testing must include the following statement in its certification application:

> "All engines in this engine family meet the Maximum Allowable Emissions Limit screening criteria for nonroad engines as specified in EPA guidance CCD-04-12."

AECD Reporting Template
Version 3
June 15, 2004

1. AECD title

2. Why the AECD is necessary

    a. Chemistry/physics behind the problem
    b. Design limits or operating condition thresholds which trigger the problem
    c. Basis for the design limits (theory, supplier information, real failure experiences, etc...)
    d. Summary of real world and lab experiences that identified the problem and confirmed the solution
    e. Impact of not using the AECD i.e., resulting engine damage, including the failure mechanisms or chain of events which lead to the engine damage
    f. Other approaches considered given current state of technology, why not selected

3. How the AECD works

    a. Parameters sensed to activate the AECD (provide summary list)

        i. type and location of sensors used to directly measure design parameter or operating conditions for which limits may be exceeded

        ii. complete description of any parameters sensed as a surrogates to estimate the design parameter for which limits may be exceeded

        iii. provide the rationale or relationship between the surrogates and the design parameters being held within limits i.e. correlation data between the parameters sensed and the design parameter being protected

    b. Parameters controlled (provide summary list)

        i. describe the relationship between each parameter sensed and each parameter controlled

        ii. explain why/how modulation of the controlled parameters avoid an exceedance of the design limit, avoid the operating consequence of concern, or generally protect the engine from damage

    c. Calibration info (tables, graphs)

        i. summary of operational conditions expected to activate the AECD; i.e. range of altitudes, temperatures, loads, speeds, etc...

        ii. tables and/or graphs illustrating how parameters controlled respond/react to parameters sensed or estimated

iii. a brief description of and reason for basic trends contained with in the control maps, tables, or graphs

iv. actual software code or narrative description of the code

4. Environmental impacts

a. Indicate whether the AECD is substantially included in the FTP, or the Euro III or Not-to-Exceed (NTE) when emissions information is voluntarily provided for those emissions tests.

b. Indicate whether the AECD reduces the effectiveness of the emissions control system.

c. Provide empirical data and/or engineering judgement describing:
i. Emissions rates when AECD activated
ii. Frequency of activation (i.e.VMT)

d. The information in 4 c. is not necessary if one of the "substantially included" conditions in 4 a. have been met, or if the AECD does not reduce the effectiveness of the emissions control system (see 4 b. above).

5. Justification that AECD is calibrated to be the minimum strategy necessary

a. Describe process used during engine development to limit AECD activation only to the conditions which require protection (or otherwise achieve the stated purpose of the AECD).
b. Describe process used to calibrate the strategy so that modulation of the emissions control system is limited only to what is required to protect the engine (or otherwise achieve the stated purpose of the AECD)
c. Provide an engineering explanation or empirical data demonstrating why lesser frequency of use or modulation of controlled parameters would not solve the problem in question
d. The information in item 5 above is not necessary if one of the "substantially included" conditions in 4 a. have been met, or if the AECD does not reduce the effectiveness of the emissions control system (see 4 b. above).

6. Interaction with other AECDs

a. Explain hierarchy of control and indicate when multiple AECDs impact a controlled parameter
b. Justify any possible redundancy
c. Describe plans for evaluating possible, but not yet understood, interaction of new AECDs

7. Future approaches to minimize or avoid AECD given expected evolution of technology

a. Status of development work
b. Key hurdles to be overcome
c. Expected timing of development