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OFFICE OF
AIR AND RADIATION

May 12, 2014

CD-14-10 (HDNR)

SUBJECT: Certification of Nonroad Diesel Engines Equipped with SCR Emission Controls

Dear Manufacturer:

The purpose of this letter is to provide certification guidance to manufacturers of nonroad diesel engines equipped with selective catalytic reduction (SCR) emission controls. Since there are unique operational considerations associated with the commonly used reductant, diesel exhaust fluid or DEF, EPA believes it important to clarify our expectations for emission control effectiveness and how this can be demonstrated at the time of certification. This letter does not represent final agency action. Rather, final decisions regarding the adequacy of a manufacturer's design will occur at the time of certification.

Background

In July 2011, EPA presented materials focused primarily on certification considerations for SCR-equipped nonroad diesel engines.¹ The content of that presentation was largely based on prior certification experience with similar SCR-equipped heavy-duty on-highway diesel engines and addressed the following topics:

- DEF replenishment as critical emission-related maintenance
- DEF quality as an adjustable parameter
- Tampering with SCR components
- DEF thawing provisions
- Unregulated pollutants

The materials also provided guidance for preventing engine/equipment operation with low or no DEF and focused on a series of operator warnings and engine or equipment-based performance inducements that would reasonably assure against such circumstances occurring in-use. Separately, in January 2012 EPA published a Federal Register Notice announcing the minimum approved maintenance intervals for DEF replenishment for nonroad diesel engines.² These

¹ See <http://www.epa.gov/otaq/cert/documents/nrci-scr-web-conf.2011-07-25.pdf>, presented July 26, 2011.

² See 77 FR 497 (January 5, 2012).

items have largely stood as the main sources of guidance to assist nonroad diesel engine manufacturers in preparing for certification. This letter is intended to supplement our prior guidance and provide clarification in two areas: 1) compliance with the adjustable parameter provisions as they apply to DEF quality and 2) adequacy of final inducement approaches.

Adjustable Parameter Provisions and DEF Quality

Adjustable Parameter Provisions of 40 CFR Part 1039

The provisions that govern adjustable parameters in 40 CFR Part 1039 authorize EPA to determine which parameters are adjustable for emission testing purposes, the adequacy of the limits, stops, or other means used to inhibit adjustment, and the resulting physically adjustable range for such a parameter (40 CFR §§ 1039.115(e) and 1039.205(s)). Any parameter on any engine which is physically capable of being adjusted and may significantly affect emissions may be considered adjustable (40 CFR §§ 1039.801 and 1039.235(c)(3)). In determining the parameters subject to adjustment, EPA will generally consider the likelihood that settings other than the manufacturer's recommended setting will occur during in-use operation. Manufacturers may ask EPA to exclude a parameter that is difficult to access if it cannot be adjusted in a way that affects emissions without significantly degrading engine performance. Once a parameter has been determined to be adjustable, EPA then determines the range of adjustment for emission testing based on whether the means used to inhibit improper adjustment (*e.g.*, physical limits, stops, or other means) are effective in preventing adjustment on in-use engines to settings outside the intended physically adjustable range. Finally, the resulting physically adjustable range for any such parameter is established based on whether the parameter is determined to be adequately inaccessible or sealed, or is otherwise restrained in adjustment outside the intended physically adjustable range.

The provisions governing adjustable parameters are of particular relevance for the certification of diesel engines using SCR technology to comply with the NO_x emission standards of 40 CFR §§ 1039.101 and 1039.102. SCR technology in use with certified engines today relies upon injection of an aqueous urea solution, DEF, into the exhaust to control NO_x emissions. DEF is stored in a tank on the equipment and must be replenished routinely by the operator with DEF meeting the engine manufacturer's recommended specification. Engine manufacturers predominantly recommend use of DEF meeting the industry-recognized ISO 22241-1 quality standard, which specifies a 32.5 percent by weight urea concentration for the solution. SCR systems are calibrated to the 32.5 percent urea concentration to ensure optimum NO_x reduction during operation. Given the need for operator intervention to replenish the DEF, there exists the possibility that the operator can put fluids other than the manufacturer's recommended DEF in the tank, either accidentally or intentionally. Using fluids other than the manufacturer's recommended DEF could contribute to a significant increase in NO_x emissions.

In a related guidance letter to heavy-duty on-highway diesel engine manufacturers, EPA described the financial motivation that exists for operators to refill the DEF tank with fluids other than the manufacturer's recommended DEF.³ Given an operator's ability to physically adjust DEF quality, the increase in NO_x emissions that would result if they do so, and the significant

³ See CD-13-13 (November 22, 2013).

possibility that they could be tempted to make such adjustments on in-use equipment, EPA has previously determined that DEF quality is an adjustable parameter.⁴

Range of DEF Quality Adjustment

At the time of certification, EPA will review the manufacturer's engine design to assess the adequacy of the means used to inhibit DEF quality adjustment (*e.g.*, physical limits, stops, or other means) by reviewing the likelihood that it will be circumvented, removed, or exceeded on in-use vehicles or engines. EPA can determine that a physical limit, stop, or other means used to inhibit adjustment of a parameter is adequate based on the effect of settings beyond the limit, stop, or other means on equipment or engine performance characteristics other than emission characteristics. In our July 2011 presentation, we provided the example of an engine design that incorporates the ability to detect DEF quality and activate engine or equipment-based performance inducements in a timely manner as one that could represent an adequate restraint on adjustability. We continue to believe that such an approach represents one example of an adequate restraint on adjustability. Manufacturers may, however, devise alternate restraints.

Upon establishing that adequate restraints on adjustability exist, EPA will next review the manufacturer's engine design to determine the physically resulting range of DEF quality adjustment for emission testing. EPA generally considers the range of adjustment for emission testing to span the change in urea concentration from 32.5 percent (unadulterated DEF) to the point at which poor DEF quality can be detected. This point represents the limit for DEF quality adjustment because it is the first point at which a manufacturer is able to implement inducements to prevent sustained engine or equipment operation with poor quality DEF. Poor DEF quality is any urea concentration at which the engine is unable to comply with the relevant NO_x standard over an applicable test cycle, including operating points within the not-to-exceed (NTE) zone. For example, an engine that first detects poor quality when DEF is diluted with water by 50 percent would be subject to emissions testing at any urea concentration ranging from 32.5 percent (unadulterated DEF) down to, but not including, 16.25 percent (DEF diluted with water by 50 percent). Over the full span of this range, the engine would need to comply with the relevant NO_x standard over all applicable test cycles. In this example, if the engine will exceed the NO_x standard on one or more test cycles when DEF quality drops below 24 percent urea concentration, the engine will exceed the NO_x standard within the adjustable range for emissions testing purposes. In this case, the manufacturer should improve their detection capability to restrain adjustment between 32.5 percent and 24 percent urea concentration. Such an adjustable range could be appropriate for certification. Manufacturers should describe the DEF quality range of adjustment in their application for certification.

It is possible that in a specific case, EPA may determine that it is acceptable to certify an engine design that detects poor DEF quality such that there is a very small range where poor DEF quality will not be detected and the engine will not comply with a specific emission standard, and where the manufacturer can prove to EPA that the adjustable range where noncompliance is found is so small that it is highly unlikely an operator would adjust to that setting in-use. As in the example above, if the manufacturer improved their detection capability to restrain adjustment between 32.5 percent and 23 percent urea concentration (*i.e.*, the range contains a "non-

⁴ See <http://www.epa.gov/otaq/cert/documents/nrci-scr-web-conf.2011-07-25.pdf>, presented July 26, 2011.

compliant” setting that represents a one percent span in urea concentration, or a roughly 3 percent increment of dilution with water), the manufacturer might be able to sufficiently demonstrate that such a narrow setting is so difficult for an operator to target in-use that it is highly unlikely that they will attempt to make such an adjustment. EPA notes that a manufacturer is unlikely to be able to make such a demonstration where its engine’s level of detection has a noncompliance margin that is large enough to possibly be targeted by consumers. EPA also notes that any evidence of such targeting by consumers, even in situations not including the manufacturer’s products, would make such demonstration increasingly unlikely. Any manufacturer contemplating certification of such an engine design should be prepared to justify the claim that there is a low likelihood of such adjustment in-use and approach EPA well in advance of submitting an application for certification.

EPA recognizes that technological challenges exist for detecting poor DEF quality instantaneously. In our July 2011 presentation, EPA described a reasonable time frame for detecting poor DEF quality of one hour. In the test cell, this can be demonstrated by running replicate test cycles, such as the NRTC, with poor DEF quality while checking for detection within one hour of continued engine operation. To confirm detection during NTE operation in the test cell, the engine manufacturer should use good engineering judgement to select NTE points or a sequence of operation within the NTE zone which can demonstrate detection over the entire NTE zone. Also in our July 2011 presentation, EPA noted its recommendation that the engine should implement appropriate inducements to prevent sustained operation with poor DEF quality and with final inducement occurring within 4 hours of detection.

DEF Quality Detection

For 2013 and earlier model years, EPA has certified engines that demonstrate an approach using NO_x sensor-based strategies for detecting some, but not all, DEF dilution levels. These strategies monitor NO_x concentration in the exhaust stream and determine SCR catalyst efficiency by measuring changes in NO_x across the catalyst. Significant deviations in NO_x conversion across the SCR catalyst from the expected or modeled conversion rate can be an indication of poor DEF quality. In most applications, NO_x sensors have been able to detect poor DEF quality for many, but not all, DEF dilution scenarios. The Agency approved certification for these engines because at the time we concluded NO_x sensors were the best available technology to detect in-use adjustments and other technology was not readily available to detect all DEF dilution levels that would result in non-compliance with the applicable emission standard. Some manufacturers continue to make refinements to their DEF dosing strategies to enable NO_x sensors to detect lesser amounts of dilution. For some manufacturers with excess DEF dosing capability and sufficient control of ammonia storage on the SCR catalyst, it may be possible to eventually achieve this level of performance with only NO_x sensors. Such an approach could be acceptable under the adjustable parameter provisions.

As early as 2007, EPA recognized urea quality sensors as one example for detecting DEF quality for SCR-equipped diesel engines.⁵ Through direct measurement of urea concentration, these sensors offer the quickest and most accurate measurement of DEF quality across the full spectrum of DEF dilution. They are able to measure urea concentrations at a resolution ranging

⁵ See CISD-07-07.

from 1-5 percent and have response times as rapid as 30 seconds. In our July 2011 nonroad presentation, EPA noted that these enhanced capabilities would become increasingly important for ensuring compliance with the transition to the Tier 4 final NO_x standards in the 2014 engine model year. While we were hopeful that the sensors would be ready for implementation with the 2014 model year, we understood at the time they were still in development for mobile applications and engine manufacturers were still evaluating durability and system integration issues with them. For the 2013 engine model year, two heavy-duty on-highway engine manufacturers certified their SCR-equipped engines with urea quality sensors. About half of the nonroad diesel engine manufacturers have already certified their SCR-equipped engines with urea quality sensors in the 2014 engine model year. These sensors will enable engine manufactures to further restrain the adjustment of DEF quality, especially DEF quality adjustment accomplished by dilution with water.

EPA Expectations for DEF Quality Monitoring In-Use

At this time, neither of the above technologies (NO_x sensors or urea quality sensors) can monitor DEF quality continuously. NO_x sensor technology relies on the calculation of conversion efficiency across the SCR catalyst to determine DEF quality. This measurement cannot be made unless DEF dosing is occurring, which typically requires a minimum exhaust temperature of 190°C. Urea quality sensors may have accuracy errors at high DEF temperatures, or for certain sensor types, when excessive bubbles are present in the DEF tank. Neither NO_x sensors nor urea quality sensors can monitor DEF quality when the fluid is frozen. While these problems prevent continuous monitoring, a manufacturer can design a DEF quality monitoring strategy that prevents maladjustment of DEF while avoiding monitoring under problematic conditions. For example, urea quality signals could be monitored during discrete intervals, such as shortly after DEF refill, or ignored if DEF temperature is too high. Manufacturers should describe their DEF quality monitoring strategy in their application for certification.

Compliance with the Adjustable Parameter Provisions

For the 2013 model year, two heavy-duty on-highway engine manufacturers have certified engines using urea quality sensors that allow for conformance to the adjustable parameter provisions regarding inhibition of adjustment at all DEF quality levels that would lead to noncompliance. Additionally, about half of the nonroad engine manufacturers have already certified engines using urea quality sensors for the 2014 engine model year. As such, we are now concluding that at least one technology, urea quality sensors, is available that can detect DEF dilution at all levels of concern. Given these circumstances, we think it appropriate for nonroad engine manufacturers to implement urea quality sensors, or otherwise be able to detect poor DEF quality in a manner such that it is highly unlikely for noncompliance to occur without triggering the appropriate inducements, no later than the 2017 engine model year.

Through parallel discussions with urea quality sensor suppliers, we understand that production capacity is rapidly developing to meet anticipated demand from engine manufacturers around this timeframe. However, some level of uncertainty remains about meeting the entire demand for the industry if it comes forward all in one model year. To help alleviate this situation, we encourage engine manufacturers planning to incorporate urea quality sensors to begin

implementing them on some portion of their certified engine families in the 2015 and 2016 engine model years. In pre-certification discussions for the 2015 model year, engine manufacturers should be prepared to describe their plans to the Agency.

Final Inducement Approaches⁶

A key element of preventing operation with either no DEF or poor quality DEF is to provide an adequate limit on the range of adjustments operators can make in-use to ensure continued functioning of the SCR system as intended by the engine manufacturer. As referenced in the DEF quality section of this letter, we have previously provided the example of an engine design that incorporates the ability to detect DEF level or DEF quality and activate engine or equipment-based performance inducements in a timely manner as one that could represent an adequate restraint on adjustability. The adequacy of such a restraint is dependent in part on the effectiveness of the inducement at preventing the engine or equipment from accomplishing the work it is designed to perform when an engine parameter is adjusted to a noncompliant setting. For heavy-duty on-highway vehicles, “preventing work” has generally been accepted to mean limiting a vehicle’s speed to 5 mph or less. The analog for nonroad equipment is somewhat more difficult to define given the diverse array of equipment that even a single engine family can be installed into, let alone the breadth of the sector as a whole. For example, some nonroad equipment is designed to perform work while stationary or moving at very low speed.

In our July 2011 nonroad presentation, we outlined that equipment should not be able to functionally operate once DEF dosing is no longer capable or following identification of poor DEF quality. We provided examples of approaches that could represent effective final inducements, including shutting the engine down or limiting the engine to idle with no power. Since that time, engine manufacturers have made broad interpretations about what the term “preventing work” represents, some of which have been inconsistent with EPA’s expectations. Therefore, to preserve competitive equity across the sector and provide clarity with respect to system performance expectations, EPA is offering further guidance on how we will review the adequacy of final inducements at the time of certification.

Once it becomes necessary to implement final inducement, the functioning of the equipment should be reduced to a level at which it cannot accomplish the work it is designed to perform and service intervention becomes absolutely necessary.⁷ In the most basic sense, this could be accomplished through completely shutting the engine down. Alternatively, idle-only operation of the engine with torque limited to a level that is only sufficient to maintain idle speed (no net torque available to do work) could achieve the same ends. In an expanded sense, there may be applications where the minimum engine speed and torque required to keep the engine running when installed in the equipment may not be coincident with traditional engine low-idle speed and torque values. Provided the engine idle speed and torque values necessary to idle the equipment

⁶ Note that while this section discusses the adequacy of final inducements relative to DEF level and DEF quality as adjustable parameters, the same general principles should serve as guidance for how EPA will review the adequacy of final inducements for tampering with SCR components. See July 2011 nonroad presentation for further detail.

⁷ For inadequate DEF level, EPA maintains that a final inducement should be applied once the DEF level has reached a point where dosing is no longer capable. For DEF quality faults, we also maintain that final inducement should be applied four hours from fault detection. See July 2011 nonroad presentation for further detail.

are not sufficient to allow the equipment to accomplish the work it is designed to perform, these alternate engine idle-speed and torque values could represent an appropriate final inducement. For example, if the engine installed in a direct-coupled rotary screw air compressor was limited to low-idle speed, it could permanently damage the screw compressor due to differential vibration at low compressor rotational speeds. At the slightly higher engine idle speed necessary to maintain idle mode for the equipment, if the equipment were not able to respond to any load demand, the equipment would be effectively prevented from accomplishing its work. Such a final inducement approach could be acceptable.

EPA has been presented with the example where an engine manufacturer has the capability to detect machine inputs such as parking brake engagement, transmission in neutral, implements locked out, or zero vehicle speed for determining when the equipment is in a “non-work” mode. When in a “non-work” mode, the equipment cannot accomplish the work it is designed to perform. For diagnostic or other purposes, the engine would be allowed to operate during “non-work” mode over broader speed and torque ranges than would otherwise be available at low-idle. Should the machine re-enter a “work” mode, it then transitions to idle-only operation of the engine with torque limited to a level that is only sufficient to maintain idle speed (no net torque available to do work). While we expect that capability to employ such an approach would be limited to vertically-integrated engine/equipment manufacturers, and even then only to specific equipment models where a “non-work” mode can reasonably be defined, such a final inducement approach might be acceptable.

Manufacturers may devise alternate final inducement approaches to the examples provided above so long as they are equally robust in preventing the equipment from performing work. In these cases, manufacturers are encouraged to approach the Agency early in the planning process to present evidence showing that the equipment cannot perform its intended function once the engine enters into final inducement. Please note that we are not likely to consider a final inducement approach consisting solely of derating the engine across the full torque curve to be equally robust to the examples provided above. A manufacturer is unlikely to be able to demonstrate that such an engine derate is adequate to prevent the equipment from performing work under all in-use operating conditions, especially with engines produced for a multitude of disparate equipment applications. EPA believes that any alternate final inducement approaches should include equipment limitations. For example a final inducement for a combine harvester which completely disables use of any implements may be an acceptable method of preventing work from being done. An alternative inducement for a combine harvester which attempts to demonstrate a 40% derate across the available engine torque curve alone is sufficient to prevent work from being accomplished would not likely be acceptable.

Manufacturers have also raised the question of whether a limited (or unlimited) number of restarts can occur with full or partial power available to perform work after final inducement has been applied to allow for fault diagnosis and repair (e.g., self-healing of faults after a repair action) or moving of the equipment. While we agree that time with full or partial power available to perform work should be allowed for these purposes, EPA has already allowed continued operation of the equipment with full engine power for four hours after a fault has been detected. We allowed for this time so that operators could safely correct the problem before experiencing final inducement. In our discussions with manufacturers during pre-certification

meetings, we believed manufacturers were only allowing full power restarts after the four hour window if the equipment was otherwise being restricted from performing work. We have since learned that some manufacturers allow full power restarts with no restriction on the ability to perform work.

To ensure all manufacturers will be employing the same restart strategy, and to allow time to redesign software to limit full power restarts, manufacturers may continue to present strategies for certification through the 2015 model year that include full power restarts after final inducement.⁸ We anticipate manufacturers will make software changes as they address the adjustable parameter provisions for DEF quality outlined above, and think they should be able to make relatively concurrent changes to eliminate full power restarts after final inducement. Prior to the 2016 model year, EPA believes full power should only be restored after final inducement in the rare instances when DEF dosing is necessary to determine if a fault has been corrected. Many issues which trigger inducements can be diagnosed at idle. For example, low DEF or poor quality DEF cannot be corrected without the operator first attempting a DEF tank refill. In these scenarios, full power should only be restored once a DEF refill is detected. Similarly, continuity checks can be performed on failed components without full power. Once the checks have passed, the fault can be cleared and full power restored. In 2016 and subsequent model years, it is unlikely that EPA would find an inducement to be an adequate inhibition to adjustment if full power restarts are allowed following final inducement.

Should you have any questions concerning this guidance, please contact your certification representative or Justin Greuel, Director of the Diesel Engine Compliance Center at greuel.justin@epa.gov or (202) 343-9891.

Sincerely,



Byron J. Bunker, Director
Compliance Division
Office of Transportation and Air Quality

⁸ Industry has commented that software changes, such as eliminating restarts after final inducement take time to develop and deploy into production engines. For the same reason, EPA expects manufacturers who are not currently allowing restarts beyond final inducement to keep their current strategies. If manufacturers start changing software to add more restarts after final inducement, EPA will consider revising the date to remove the restarts.