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Environmental Technology Verification Protocol

DETERMINATION OF EMISSIONS REDUCTIONS FROM SELECTIVE CATALYTIC REDUCTION CONTROL TECHNOLOGIES FOR HIGHWAY, NONROAD, AND STATIONARY USE DIESEL ENGINES

Prepared by:

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GENERIC VERIFICATION PROTOCOL FOR DETERMINATION OF EMISSIONS REDUCTIONS FROM SELECTIVE CATALYTIC REDUCTION CONTROL TECHNOLOGIES FOR HIGHWAY, NONROAD, AND STATIONARY USE DIESEL ENGINES

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ABBREVIATIONS AND ACRONYMS

APCT	air pollution control technology
APCTVC	Air Pollution Control Technology Verification Center
BSFC	brake-specific fuel consumption
CARB	California Air Resources Board
CBI	confidential business information
CFR	Code of Federal Regulations
CI	confidence interval
CO	carbon monoxide
CO_2	carbon dioxide
CTM	conditional test method
DEC	diesel exhaust catalyst
DQO	data quality objective
EGR	exhaust gas recirculation
EPA	Environmental Protection Agency
ETV	environmental technology verification
FTIR	Fourier transform infrared
FTP	federal test procedure
g/bhp-hr	grams per brake horsepower-hour
g/kWh	grams per kilowatt-hour
GVP	generic verification protocol
HAP	hazardous air pollutant
HCs	hydrocarbons
hp	horsepower
NH_3	ammonia
NMHC	non-methane hydrocarbon
NO_x	nitrogen oxides
NPRM	Notice of Proposed Rulemaking
ORD	Office of Research and Development
OTAQ	Office of Transportation and Air Quality
PM	particulate matter
ppm	parts per million
QA	quality assurance
QC	quality control
QMP	quality management plan
RTI	Research Triangle Institute
SAC	stakeholders advisory committee
SCR	selective catalytic reduction
SET	Supplemental Emissions Test (40 CFR 86.1360)
SOP	standard operating procedure
VDRP	Voluntary Diesel Retrofit Program
VOC	volatile organic compound
VR	verification report
VS	verification statement

1.0 INTRODUCTION

This protocol describes the Environmental Technology Verification (ETV) Program's considerations and requirements for verification of emissions reduction provided by selective catalytic reduction (SCR) technologies. The basis of the ETV will be comparison of the emissions and performance of well maintained engines or vehicles to the same engines or vehicles equipped with SCR. This protocol applies to heavy duty highway, nonroad, and some stationary source diesel engines. In keeping with ETV requirements, this protocol is implemented to test a specific technology and test engine(s) at a specific testing organization through an ETV-approved test/quality assurance (QA) plan.

ETV provides verified emissions reduction data for SCR technologies. It may be part of an overall process that leads to inclusion of SCR technologies on the U.S. Environmental Protection Agency (EPA) mobile sources retrofit emissions reduction verified technology list. This protocol describes the ETV portions of that process in detail. Table 1 provides an overview of mobile source ETV and its interface with the EPA retrofit emissions reduction program.

Table 1. Overview of Mobile Source ETV Process and Participants' Responsibilities

		ETV			
Step in Process	**Applicant**	**APCTVC**	**Test Org.**	**OTAQ**	**ORD**
Preparation of preliminary application (w/o ETV data)	Primary	None	None	Advise	Access
Preliminary test dialog	Participate	Organize & participate	Participate	Participate	Access
Test/QA plan	Review	Shared preparation, APCTVC approve		Review	Review & approve
Acceptance of ETV test/QA plan, and terms and payment	Primary	Advise	Advise	Access	Access
Conduct ETV test	Access	Audit	Primary	Access	Audit
Prepare test report	Access	Review	Primary	Access	Access
Publish ETV report & statement	Review	Primary	Review	Access	Review & approve

APCTVC = Air Pollution Control Technology Verification Center at RTI.
OTAQ = EPA's Office of Transportation and Air Quality.
ORD = EPA's Office of Research and Development, the ETV sponsor.

1.1 Environmental Technology Verification

EPA, through its Office of Research and Development (ORD), has instituted the ETV Program to verify the performance of innovative and improved technical solutions to problems that threaten human health or the environment. EPA created the ETV Program to accelerate the entrance of new and improved environmental technologies into the marketplace. It is a voluntary, nonregulatory program. Its goal is to verify the environmental performance characteristics of commercially ready technologies through the production of objective and quality-assured data so that potential purchasers and permitters are provided with an independent and credible assessment of what they are buying and permitting.

The ETV Program does not conduct technology research or development. ETV test results are always publicly available, and the applicants are strongly encouraged to ensure, prior to beginning an ETV test, that they are satisfied with the performance of their technologies. Within the ETV Program, this state of development is characterized as "commercially ready."

The provision of high-quality performance data on a commercial technology encourages more rapid implementation of that technology and consequent protection of the environment with better and often less expensive approaches. The ETV Program is conducted by six ETV centers that span the breadth of environmental technologies.

1.2 Air Pollution Control Technology Verification Center

EPA's partner in the Air Pollution Control Technology Verification Center (APCTVC) is RTI International,[1] a nonprofit contract research organization with headquarters in Research Triangle Park, NC. The APCTVC verifies the performance of commercially ready technologies used to control air pollutant emissions. The emphases of the APCTVC are currently on technologies for controlling particulate matter (PM), volatile organic compounds (VOCs), nitrogen oxides (NO_x), and hazardous air pollutants (HAPs) from both mobile and stationary sources. The activities of the APCTVC are conducted with the assistance of stakeholders from various interested parties. Overall, APCTVC guidance is provided by the stakeholders advisory committee (SAC), while the detailed development of individual technology ETV protocols is conducted with input from technical panels focused on each technology area.

The APCTVC develops generic verification protocols (GVPs) and specific test/QA plans, conducts independent testing of technologies, and prepares ETV test reports and statements for broad dissemination. Testing costs are ultimately borne by the technology applicants, although initial tests within a given technology area may be partially supported with government funds.

1.3 The APCTVC Mobile Sources Verification Program

The various retrofit technologies have been divided into three groups to facilitate ETV:

- SCR systems,
- retrofit diesel mobile source control devices, and
- fuel and lubricant technologies.

Selective catalytic reduction is an emissions control technology that reduces NO_x by injecting a controlled amount of a reductant (usually urea or ammonia) into the gaseous exhaust stream ahead of a catalyst. In its simplest form, an SCR system includes a reductant storage and injection system, a control unit, and one catalyst.

[1]RTI International is a trade name of Research Triangle Institute.

This GVP provides the requirements for APCTVC's verification of the performance of SCR applied to mobile and stationary source diesel engines. Other organizations (e.g., EPA's Office of Transportation and Air Quality [OTAQ] and the California Air Resources Board [CARB]) also verify the performance of SCR to meet the needs of those organizations. The technology applicant should discuss the intended application of the SCR with OTAQ to determine the most suitable path for verification.

This GVP is intended to apply only to SCR. The APCTVC reserves the right to evaluate each technology submitted for verification and to determine the applicability of this protocol to that specific technology. Regulatory authorities (OTAQ and others) may also have different requirements. Special testing may be required in some cases to maintain the integrity, credibility and, therefore, the value of verifications. The critical data quality objectives (DQOs) in this document were chosen to provide emissions measurements sufficient to support the vendor's application for emissions credits under the Voluntary Diesel Retrofit Program (VDRP).

This protocol was developed and has been reviewed by a technical panel composed of a broad group of stakeholders who have expertise in mobile source controls and come from the vendor, user, and regulatory spheres. Technical panel membership is dynamic, and its composition is expected to change over time as technical emphases change. The APCTVC will maintain membership balance on the panel.

The basic SCR verification will measure and report baseline emissions concentrations and rates using the federal test procedures (FTPs) applicable to a particular engine or vehicle on a baseline fuel compared to that same engine or vehicle equipped with SCR. The number of engines and the test requirements will differ depending on the engine applicability and nature of the SCR. The tests will be conducted at an independent, third-party testing organization that has been qualified and audited by the APCTVC. The data quality requirements of this GVP will be applied at approved testing organizations through the preparation of an SCR-specific test/QA plan. Other organization-, application-, or technology-specific information may also need to be addressed in the test/QA plan, which is described in Section 10.0. Because specific technology areas may require special expertise or emphasis, input and review will be obtained from an ad hoc subcommittee of the technical panel or outside experts when deemed appropriate by the APCTVC. Test results will be presented as ETV reports and statements.

This GVP will be revised as necessary. Changes to the protocol will not affect products that have been verified. However, such changes will be reflected in test/QA plans not yet finalized, regardless of the applicant's application status. Test/QA plans that are being carried out when a protocol change is enacted will be examined to determine whether any modifications must be made.

Retrofit mobile diesel control devices include exhaust treatment emission control devices, other retrofit devices, and engine modifications. Some require no mechanical changes to engines, while others will involve some modification of the engine or its control system. Filters for PM control and diesel exhaust catalysts (DECs) may make use of or require some integration with engines. Engine modifications, in this context, refer to pollution reduction technologies integral to the

engine or the engine control systems. All of these technologies have the potential to affect engine performance, and the concurrence of the engine manufacturer that the changes are compatible with safe, efficient, and reliable operation in the engine is an important element in demonstrating commercial readiness and suitability for ETV. ETV of these technologies is guided by *Generic Verification Protocol for Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Engines* (APCTVC, 2002a).

Retrofit fuels and lubricant technologies include fuel formulations, fuel and lubricant additives, and alternative fuels. Generally, no modification of the engine is necessary. All of these technologies have the potential to affect engine performance, and the concurrence of the engine manufacturer that the changes are compatible with safe, efficient, and reliable operation in the engine is an important element in demonstrating commercial readiness and suitability for ETV. ETV of these technologies is guided by *Draft Generic Verification Protocol for Determination of Emissions Reductions Obtained by Use of Alternative or Reformulated Liquid Fuels, Fuel Additives, Fuel Emulsions, Lubricants, and Lubricant Additives for Highway and Nonroad Use Diesel Engines and Light-Duty Gasoline Engines* (APCTVC, 2002b).

1.4 Quality Management Documents

Management and testing in this APCTVC program are performed in accordance with procedures and protocols defined by the following:

1) EPA's ETV Quality Management Plan (ETV QMP) (EPA, 2002a or the quality management plan current at the time of testing);
2) the APCTVC Quality Management Plan (QMP) (APCTVC, 1998 or the quality management plan current at the time of testing);
3) the *Generic Verification Protocol for Selective Catalytic Reduction Control Technologies for Highway, Nonroad, and Stationary Use Diesel Engines* (this document); and
4) the test/QA plan prepared for each specific test or group of tests.

EPA's ETV QMP lays out the definitions, procedures, processes, interorganizational relationships, and outputs that will ensure the quality of both the data and the programmatic elements of the ETV Program. Part A of the ETV QMP contains the specifications and guidelines that are applicable to common or routine quality management functions and activities necessary to support the ETV Program. Part B of the ETV QMP contains the specifications and guidelines that apply to test-specific environmental activities involving the generation, collection, analysis, evaluation, and reporting of test data.

The APCT QMP describes the quality systems in place for the overall APCTVC. It was prepared by RTI and approved by EPA. Among other quality management items, it defines what must be covered in the GVPs and test/QA plans for technologies undergoing ETV testing.

A GVP is prepared to describe the general procedures to be used for testing a type of technology and to define the critical DQOs. The GVPs for retrofit air pollution control technologies for

highway and nonroad use engines were written by the APCTVC with input from a technical panel and approved by EPA.

A test/QA plan is prepared for each test or group of tests. The test/QA plan describes, in detail, how the testing organization will implement and meet the requirements of the GVP. The test/QA plan also sets DQOs for any planned measurements for a particular technology that were not set in the GVP. The test/QA plan addresses issues such as the test organization's management structure, the test schedule, test procedures and documentation, analytical methods, recordkeeping requirements, and instrument calibration and traceability, and it specifies the QA and quality control (QC) requirements for obtaining ETV data of sufficient quantity and quality to satisfy the DQOs of the GVP. Testing organizations will be audited by the APCTVC against the approved GVP and test/QA plan they are expected to follow. Section 10 of this GVP addresses requirements for the test/QA plan.

Because multiple testing organizations may be conducting the tests, the APCTVC will develop a prototype test/QA plan (not part of this GVP) for each type of technology to ensure comparability. This prototype will be customized by the testing organization to meet its specific implementation of the FTPs as defined in 40 Code of Federal Regulations (CFR) Parts 86 and 89, and the secondary measurements, subject to approval by the APCTVC and EPA-ORD. Testing arrangements that do not meet the requirements of the FTP will not be approved, and test instrumentation or test procedures that the APCTVC determines will compromise data reliability or comparability between testing organizations will not be approved.

2.0 OBJECTIVE AND SCOPE

2.1 Objective

The objective of this GVP is to establish the parameters within which SCR control technologies for highway, nonroad, and some stationary source diesel engines will be tested to verify their performance with uniform and consistent methodologies within the APCTVC. The protocol addresses the requirements for technology submission, outlines the test conditions and procedures to be used, and states the critical DQOs for ETV and the reporting requirements. The control technologies will be verified within a specified range of applicability, and ETV reports and statements will be produced for dissemination to the public.

2.2 Scope

This protocol describes the considerations and requirements for ETV of emissions reductions attributable to the use of SCR on an engine-by-engine basis. Although SCR may achieve similar emissions reductions on many engines, each ETV test is conducted on and reported for the actual test conditions: engine (vehicle), base fuel, and SCR test conditions. The base engine (vehicle) will be well maintained and will produce emissions at levels consistent with a well maintained engine (vehicle) of its age and use. SCR may be combined with other technologies for verification testing as a single entity emissions control system. Before combined technologies can be accepted for verification,

- the controlling interests in each technology must be in agreement to pursue ETV (in this context, low-sulfur diesel fuels are not considered technologies but as commodities available to all, and therefore no permission is required),
- the applicant must be a single organization with authority to pay for the applicant's cost, and
- the applicant must show that each technology in the combination has a credible impact on reducing emissions.

Verification testing for a system will incorporate in the test/QA plan elements from the protocols applicable to the individual technologies. In general, the test for a system will include the more stringent aspects of each protocol, where they differ. Each test may be different, and the APCTVC should be consulted for assistance.

Emissions testing under this protocol is based on the FTPs for emissions certification of highway diesel engines (40 CFR Part 86) and nonroad diesel engines (40 CFR Part 89); the Supplemental Emissions Test (SET) for highway diesel engines (40 CFR 86.1360); and Conditional Test Method CTM-038 for ammonia slip measurement (EPA, 2003). For diesel nonroad engines, emissions testing under this protocol may also include the transient nonroad test cycle as published in the Notice of Proposed Rulemaking (NPRM) for "Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel" on May 23, 2003.

(New test procedures become standardized and are incorporated into the FTPs from time to time. Verifications are to be conducted under the current applicable FTP and related amendments published in the Federal Register.)

2.3 Applicability

2.3.1 Applicability of ETV Results to Other Engines and Engine Families

The basic ETV test remains the same for all SCR and engines; however, the SCR may interact differently with the various engines. The extension of emissions reductions from one engine or engine family to another requires engineering analysis of the data and may require additional testing. Determination of the applicability of single-engine tests to other engines is an OTAQ decision and not part of ETV.

2.3.2 Relationship of ETV Program to OTAQ VDRP Verified Technology List

OTAQ is charged with establishing a verified technology list of technologies capable of providing emissions reductions. The test results OTAQ will use to evaluate a technology may be generated following the ETV process, with the ETV report and verification statement submitted by the vendor as the data package to OTAQ. Other paths to the verified technology list also exist. The VDRP program is described and appropriate contacts are identified at http://www.epa.gov/otaq/retrofit/. The technology applicant should discuss the intended application of the technology with OTAQ to determine the most suitable evaluation path for the applicant's technology.

2.3.3 Assignment of Emissions Benefits to SCR

The emissions from engines vary as engines age and progress through the cycle of routine maintenance. The intent of ETV under this GVP is to determine the emissions reductions provided by SCR, exclusive of oil and filter changes, engine tune-ups, and similar scheduled maintenance that, by themselves, may provide emissions benefits. The ETV test will be designed to isolate the effects of the SCR from coincident engine adjustments and tune-ups to the extent possible. Baseline engines will be tuned and set up to the engine manufacturer's recommendations, and the baseline emissions are expected to be consistent with the age and usage history of the engine (near certification levels for diesel engines; in conformance with the expected model year standard for gasoline vehicles.)

2.4 Data Quality Objectives

The data of primary interest in this verification are the reductions in emissions of the FTP primary pollutants: NO_x, hydrocarbons (HC), PM, and carbon monoxide (CO). The DQOs of this GVP are the requirements of the test methods specified in 40 CFR Part 86 (highway diesel engines) or 89 (nonroad diesel engines) when conducting the number and type of tests called for by the approved test/QA plan for the SCR. ETV tests that do not meet the FTP and SET QA requirements are invalid.

The number of and type of FTP tests (cold- or hot-start) required for ETV is determined from the following criteria:

> First, a minimum of three tests is required to provide the basic ETV result of a mean emission reduction and the 95 percent confidence interval on that mean based on measured variability for each of the measured emissions and test parameters. For highway engines, this minimum is satisfied with one cold start test and three hot start tests. For nonroad engines, three replicates of the appropriate test sequence (i.e., three 8-mode tests or three 6-mode tests) are required. A three-test minimum is currently the same as is required by the State of California for its program.
>
> Second, additional tests may be required to meet the ETV requirement that the test/QA plan provide a 90 percent probability of detecting the expected emissions reductions when computed using the expected experimental errors for the various measurements. These criteria become controlling for low emissions reductions and/or high test variability. This is a planning requirement for the test/QA plan.
>
> Third, additional tests may be desired by the applicant to reduce the width of the 95 percent confidence interval on the mean emission reduction. This third criterion is a consequence of applying standard statistical procedures to the ETV test design and data analysis. At a fixed measurement variability, normal statistical procedures lead to a small number of tests giving a broader 95 percent confidence interval than would a larger number of tests. To any regulator or potential

technology user, an emission reduction of 40 ± 5 percent is better than 40 ± 20 percent and will be given more credence.

Noncritical measurements, including ammonia slip, will also be made as described in later sections. These are not considered critical, and the methods and DQOs for them will be stated in the test/QA plan.

The FTP tests referenced above are conducted following test cycles specified in 40 CFR. As discussed in Section 5, other test cycles may also be required for verification of an SCR. A single data set for highway engines will consist of at least one FTP cold start cycle, plus three FTP hot start cycles and one SET. A single data set for nonroad engines will consist of triplicate multimode FTP tests.

An applicant may conduct privately sponsored tests at a testing organization for development purposes with the same test engine prior to and/or after conducting ETV tests. Such testing is understood to be common and important to ensure that the technology is properly adjusted and tuned to the application. The ETV DQOs do not apply to privately sponsored testing. However, the applicant and testing organization must coordinate the entire testing effort with the APCTVC so that

- preparation for the ETV test (submittal of the technology to the APCTVC, discussion of engine selection, and preparation of the test/QA plan) is completed prior to conducting the ETV test itself;
- the APCTVC is notified of the ETV test dates in time to schedule QA activities at the discretion of the APCTVC; and
- declaration of the test run that is to be the ETV test is made prior to starting the test, the engine is brought to a starting point in accordance with the test/QA plan, and the results of that test are documented and reported in accordance with the test/QA plan.

An applicant may desire to run the baseline ETV test, conduct private developmental testing, and then complete the ETV tests following the private testing. This approach may be acceptable provided the baseline run is considered to remain valid for the duration of and for the activities that occur during the private testing. If not, the baseline case will have to be rerun.

The data from all ETV tests will be retained and reported to the APCTVC, including invalid FTP test results. Data that meet the QA requirements of the FTP are considered valid and will be used to compute emissions reductions for ETV purposes.

The SCR emissions reduction performance will be reported both as absolute emissions in the appropriate units (per applicable FTP) for the baseline and SCR cases and as percentage emissions reduction for a specific engine or engine family. The percentage emissions reduction reported will be the mean emissions reduction (relative to the baseline emission) with attendant upper and lower 95 percent confidence limits on that mean.

3.0 ETV TESTING RESPONSIBILITIES

The primary responsibilities for each organization involved in the SCR ETV verification program were summarized in Table 1. Additional comments are provided below:

- The technology applicant provides the complete, commercially ready product for ETV testing, and logistical and technical support, as required, during the ETV testing. The applicant's responsibilities are defined by a contract or letter of agreement with the APCTVC (RTI). The preliminary application (Table 1, Row 1) provides relevant background data and technology information to facilitate test/QA plan development. The applicant must pay the portion of the ETV verification cost required at the time that its contractual relationship with the APCTVC begins.
- In addition to the items in Table 1, the APCTVC prepares the GVP (this document); qualifies and approves and audits the testing organization and provides a template for test/QA plans; prepares the ETV reports and statements from the organization test reports; and, jointly with ORD, reviews and approves the ETV reports and statements.
- The qualified testing organization conducts ETV verifications under contract to the APCTVC. The order of activities in Table 1 is mandatory, with the test/QA plan being prepared and approved before testing. The testing organization also conducts internal QA on test results and reports.

4.0 APPLICATION AND TECHNOLOGY DESCRIPTION

The ETV applicant is the basic source of technology information, which is provided to the APCTVC and OTAQ through an application form. This information is used by the testing organization and APCTVC to prepare and review a test/QA plan that meets the requirements of the applicant and by OTAQ and other users of the verification data. In keeping with the voluntary nature of ETV, the applicant must control the technology within the United States to submit it for verification.

For the applicant's convenience, the application form used by the OTAQ retrofit program can also be used for ETV. The applicant should complete the form and submit it to OTAQ and the APCTVC. The applicant should provide available preliminary test data which supports the claimed emissions reduction. ETV will provide test data generated under the approved test plan that will allow completion of the form for submission to OTAQ and participation in the VDRP. The form can be obtained from the APCTVC and is also posted on the OTAQ retrofit Web site at http://www.epa.gov/otaq/retrofit/retrofittech.htm. Both Microsoft Excel and Lotus 123 versions are provided. Alternatively, an applicant who is not participating in the VDRP can use the APCTVC's shorter general application form.

The VDRP application consists of four worksheets: (1) Manufacturer Information, (2) Product Information, (3) Test Information, and (4) Component Information. There is a separate spreadsheet that contains directions and examples for completing the forms. This guidance document begins with a page of general instructions for using the entire form. Since no general form can anticipate the data requirements for all possible SCR systems, the applicant should use

only the applicable portions of the form. Additional information will be requested to supplement the form, if needed.

The mobile sources ETV program is intended to provide independent and quality-assured performance data to potential users of technologies through a documented public process. Existing data (whether Confidential Business Information [CBI] or not) cannot be used to substitute for ETV tests, although they can be used to help design the ETV test. The ETV documents (protocol, test/QA plans, reports, and verification statements) are publicly available. For these reasons, the submittal of CBI to the APCTVC is unlikely to be necessary. The application form **is not** intended to convey CBI to the APCTVC, and none should be included in the form. It should be noted that all information submitted on the application is subject to the Freedom of Information Act.

4.1 Manufacturer Information

The first page of the application requests background and contact information for the applicant who is seeking product verification. Guidance and examples supporting its use are provided on the second page of the guidance form.

4.2 Technology Descriptive Information

The second page of the application is used to describe the SCR system fully and concisely. It will be used to prepare the test/QA plan and serves as a more complete description of the technology in the ETV report. It requires a concise (300 words or less) description of the SCR system being verified and requests a number of operating details that summarize the emissions control performance expected, along with the product's operation. All questions may not apply. Instructions for completing this page can be found in the "Explan_Prod" page of the guidance document.

If combinations of independent technologies are being submitted for ETV, the description of the combined technology should completely identify and describe those technologies being combined and fully state the nature of the combined test and expected result.

4.3 Test Information

Results of verification testing on the applicant SCR are to be detailed on the third sheet of the application form. Completion of this page is not required for application to the APCTVC for verification of a technology; the APCTVC will be providing the test results. However, the applicant is encouraged to report all available test data, which can be used by the APCTVC to better plan the ETV test program for the applicant's technology. These existing test data will not be included in the verification report. The Explan_Tests page of the guidance document provides information for completing this page.

4.4 Component Information

The last page of the application form, Component Information, lists the major components of the technology system. For SCR systems, it is expected that the major components of the reductant dosing system, including the electronic control unit, all catalysts, and major components of monitoring systems, will need to be listed here. Directions are given in the Explan_Components page of the guidance document.

5.0 ETV TESTING

This section gives the test requirements for verification of SCR technologies. It also describes reduction of the data to produce the emissions reduction measures that are the product of the tests. Section 5.1 gives an overview of the testing requirements and statistical analysis as they apply to all SCR. Section 5.2 gives a more detailed description of the test parameters, conditions, and data analysis.

5.1 Test Design and Data Analysis for ETV of SCR

5.1.1 Overview of Testing Requirements

The data of primary interest in this verification testing are the reduction in emissions of NO_x, HC, PM, and CO. Emissions reductions are defined as the percentage reduction obtained between a base case and the SCR candidate case. For all engine and vehicle types, emissions measurements are made using the FTP certification test cycle applicable to the engine or vehicle for which the SCR is intended and the SET test cycle for highway engines. The details of the tests are different for different engines and vehicles and are given below.

A single test of an engine without a control system installed, followed by one with the system installed, is not considered to be adequate for all SCR ETVs. Emissions from engines or vehicles may increase if changes in the product performance occur as the SCR system ages. These characteristics require that the ETV for SCRs be designed to provide emissions reductions over the projected life of the system.

Testing conducted under this protocol utilizes individual FTP and special tests that measure emission rates of various pollutants. Replicate tests are conducted at a particular test point in the service life, defined in either hours or miles, of an engine or vehicle. The FTP and special tests are combined to give a combined emissions rate for each pollutant. The complete ETV test includes a minimum of two test points over the projected service life, each of which gives a combined tests emissions rate for either the base or the candidate SCR. The combined emissions rates are then used to estimate the emissions reduction for each pollutant. The decision to assign a single engine emissions reduction to a technology for the OTAQ verified technology list is made by OTAQ based on the ETV verification.

5.1.2 Test Design Requirement for Single Engine Verification

Minimizing the cost of ETV testing is important, and limiting the amount of testing required is one way to lower costs. However, if too few tests are conducted, normal experimental variability could prevent the ETV from finding a significant result. All ETV test/QA plans for SCR are required to include sufficient tests to have a high probability of detecting the emissions reductions expected by the applicant. In addition to other requirements, each SCR ETV test plan must be designed to have at least a 90 percent probability of detecting the emission reductions expected by the applicant. This requirement was adopted to ensure, as much as practical, that the ETV test would accomplish the applicant's goals.

In this context, "detecting" means that the 95 percent confidence interval on the emission reduction does not include zero. (This requirement is for test design purposes only and does not require that the test/QA plan be modified, should actual test data show that the assumptions that went into the calculation were incorrect. However, insufficient replication can result in the inability to verify any emissions reduction and publication of an ETV report that states that a technology had no statistically significant benefit.) The test/QA plan prepared for the SCR will reflect this requirement, based on the applicant's knowledge of its product and the testing organization's estimates of test variability.

At each test point, a minimum of three tests are required. The definition of a data set depends on the application. For highway diesel engines, for instance, one complete FTP cold start cycle, plus three FTP hot start cycles and one SET are considered three tests.

5.1.3 Data Analysis for Single-Engine Tests of SCR

ETV of SCR requires a single base case test point (multiple tests) followed closely in time by a single candidate SCR test point (multiple tests), and is very similar to that used to test retrofit devices. This section describes the data analysis procedure that will be used to calculate the emission reductions for SCR.

The first step is the calculation of the composite emission rate for each pollutant for each of the base and candidate SCR tests. E_B and E_S are understood to refer to the composite emission rates of a single pollutant in the equations below. Calculation of E_B and E_S from individual test results is described in Section 5.2.6. Once the E values for the test points are available, the sample means and standard deviations (s_B and s_S) are computed using Equations 1 and 2.

$$\overline{E_B} = \frac{\sum_{1}^{n_B} E_{B,i}}{n_B} \qquad \textit{and} \qquad \overline{E_S} = \frac{\sum_{1}^{n_S} E_{S,i}}{n_S} \tag{1}$$

$$s_B = \sqrt{\sum_{1}^{n_B} \left(E_{B,i} - \overline{E_B}\right)^2 \Big/ \left(n_B - 1\right)} \quad \textit{and} \quad s_S = \sqrt{\sum_{1}^{n_S} \left(E_{S,i} - \overline{E_S}\right)^2 \Big/ \left(n_S - 1\right)} \tag{2}$$

where:

$\overline{E_B}$ = mean emission rate for base for a single pollutant,
$\overline{E_S}$ = mean emission rate for SCR for a single pollutant,
$E_{B,i}$ = composite emission rate for a single base (B) i[th] test for a single pollutant,
$E_{S,i}$ = composite emission rate for a single SCR (S) i[th] test for a single pollutant,
n_B and n_S = number of base (B) and SCR (S) tests, and
s_B and s_S = standard deviations of base (B) and SCR (S) tests.

The raw emission reduction for each pollutant, ER_{RAW}, is then computed as the difference between the mean emission rates for the base and candidate SCR cases, divided by the base case mean emission rate, as shown in Equation 3.

$$ER_{RAW} = \left(\overline{E_B} - \overline{E_S}\right) \Big/ \overline{E_B} \tag{3}$$

The upper and lower bounds of the approximate confidence interval (*CI*) around E_{RAW} are computed using Equations 4a and 4b.

$$CI\ (upper\ bound) = ER_{RAW} + \left\{ \left(t_{\alpha/2} \cdot \sqrt{\frac{s_B^2}{n_B} + \left(1 - ER_{RAW}\right)^2 \frac{s_S^2}{n_S}} \right) \Big/ \overline{E_B} \right\} \tag{4a}$$

$$CI\ (lower\ bound) = ER_{RAW} - \left\{ \left(t_{\alpha/2} \cdot \sqrt{\frac{s_B^2}{n_B} + \left(1 - ER_{RAW}\right)^2 \frac{s_S^2}{n_S}} \right) \Big/ \overline{E_B} \right\} \tag{4b}$$

where $t_{\alpha/2}$ is $t_{0.025}$ in tables of the critical values (alternatively, tail area probability) of the t-distribution, with degrees of freedom, υ, given by Equation 5 (rounded down.)

$$\upsilon = \frac{\left[s_B^2 / n_B + \left(1 - ER_{RAW}\right)^2 s_S^2 / n_S \right]^2}{\left[\left(s_B^2 / n_B\right)^2 / \left(n_B - 1\right) \right] + \left(1 - ER_{RAW}\right)^4 \left[\left(s_S^2 / n_S\right)^2 / \left(n_S - 1\right) \right]} \tag{5}$$

The fractional values of emission reduction and the confidence intervals are converted to percentages by multiplying by 100 percent.

5.2 ETV Testing for Diesel SCR

Unless specified otherwise, the general test considerations in this section will apply to all technologies covered by this protocol.

5.2.1 Diesel Base Fuels

The standard diesel test fuel for highway engines should meet the EPA specifications outlined in 40 CFR Part 86.1313-98 with the exception of the sulfur content, which the applicant should specify. For nonroad engines, the test fuel should be that described in 40 CFR Part 89.330 or another fuel as specified by the control technology applicant. For stationary source engines, the permitting authority may dictate fuel requirements. Therefore, applicants may wish to use test fuel other than the 40 CFR Part 89.330 test fuel. If this is the case, manufacturers will provide the specifications of the test fuel chosen.

Because the performance and durability of many types of diesel retrofit technologies are affected by the sulfur content of the diesel fuel, applicants should specify the maximum sulfur level of the fuel for which their technologies are designed. The sulfur content of the ETV test fuel should be no less than 66 percent of the stated maximum sulfur content. (Because refinery and blending operations are such that very low sulfur content control is difficult, test fuel with a sulfur content of 15 ppm or below is not constrained by the "66 percent rule". The actual sulfur content of the test fuel batch is to be reported.) Other test fuels should meet the applicable EPA specifications outlined in 40CFR Part 86.1313. It is permissable for testing organizations to add sulfur to the fuel if doing so is necessary to achieve the required fuel sulfur content for either baseline or controlled engine tests. During ETV testing, baseline engines should be fueled with the standard fuels that are representative of nominal in-use fuels and controlled engines with low sulfur versions of the standard fuels that are representative of the applicant's recommended or required fuel.

5.2.2 Selection of Engine for ETV Testing

The applicant may select a specific test engine for the candidate diesel SCR. A candidate SCR ETV can be conducted on any single engine meeting the requirements below. The decision to apply ETV test results from a single engine to multiple engines of different manufacturers is reserved to EPA-OTAQ.

Test engines must be in good operating condition and representative of in-use engines. Standard engines proposed for testing must be in a certified configuration. The engines are to be "as delivered, without any added technologies, and are to be tuned to the manufacturer's specifications." (Specially prepared engines, such as future technology engines that are not commonly available, may also be tested under this protocol and will be identified as such. However, the acceptability of such a verification to OTAQ must be explored by the applicant with OTAQ.) For engines manufactured before implementation of emission standards, the engine must be representative of normal production engines.

Engines must have a minimum of 125 hours of use before beginning an ETV test and must exhibit stable operation. In the baseline condition, the test engine must not exceed 110 percent of its applicable emission standards. For engines manufactured before emission standards, the engine must not exceed 150 percent of the first standards for that engine category.

Rebuilt engines will be allowed so long as they represent a certified configuration, produce emissions at the certification standard in the baseline condition (within limits given above), and meet any other applicable criteria.

5.2.3 SCR Technology

The application of SCR to diesel vehicles requires that a number of components be utilized. These include a reductant storage system, reductant delivery system, SCR converter, and an integrated control system capable of detecting or predicting the NO_x content of the engine exhaust and controlling the reductant injection rate appropriately. Current technology generally utilizes "maps" of NO_x emissions as a function of engine operation to predict the required reductant injection rates. This map is known to be a complex response surface that must be evaluated over a wide range of engine operating conditions if the engine is to be used over a range of conditions. Lower NO_x conversion occurs if the reductant rate is low, and ammonia slip can increase when it is high.

5.2.3.1 Degreening. For many hardware technologies, a brief period of use (degreening) is needed to achieve a stable emissions reduction that allows representative testing. The degreening time period required varies for different technologies but is on the order of 25 to 125 hours. In all cases, the technology applicant must propose and justify the extent of the degreening process in the ETV application. The APCTVC office will review and comment on this proposal, advise regarding the documentation requirements, and append the degreening process description to the technology test/QA plan. When complete, the actual process used must be documented. A description of the degreening process will be included in the ETV report.

For purposes of this protocol, the degreening time requirement will be specified by the technology applicant as indicated by either previous testing or the requirements of the data user. To allow flexibility for the applicant, degreening is not required to be conducted at the testing organization. It may be performed and documented by the applicant or conducted by the testing organization by arrangement with the applicant. In either case, the applicant will ensure that degreening activity documentation such as start and stop date and time, engine and fuel description, and operating conditions are available and signed by the person responsible for the activity.

Degreening may occur in a laboratory or during in-use field operations on an engine that is equivalent to the proposed ETV test engine, or another engine of the same size which utilizes the same engine technology (and thus falls within the range of the technology's stated applicability).

Table 2. Minimum Durability Demonstration Periods

Engine Type	Minimum Durability Demonstration Period
Highway	50,000 miles or 1,000 hours
Nonroad (mobile and some stationary engines)	1,000 hours
Stationary Emergency Generator	500 hours

5.2.3.2 Durability. Durability is the ability of the control system to function over the service life of the engine without significant deterioration. To

measure durability, a control system is aged by subjecting it to operating conditions that cause normal wear equivalent to 100 percent of the Minimum Durability Demonstration Period. Table 2 provides the demonstration periods that were current as of the date of this protocol. The applicant should verify that the durability period is current at the date of the verification.

For participation in the VDRP, additional testing of an aged control system is required by EPA-OTAQ. If performed as part of the ETV program, the aged system test will meet the same data requirements as a new system test. The aging process details are not part of this protocol. Provided for information only, the description below is current as of April 2002 and may change. The details should be confirmed prior to ETV.

The technology applicants must conduct the aging process on their technology. They have discretion to tailor this process to product requirements. It is expected that applicants will submit identical parts (one in a degreened state, one aged to 100 percent demonstration period) so that testing with one baseline may occur sequentially. However, applicants may conduct the degreened and aged technology tests as separate tests, in which case the baseline engine test must be repeated. All aging protocols must accompany the ETV application and explain the technical basis for stating the aging protocol results in 100 percent demonstration period aging. If real-world aging is performed, the application must describe and provide documentation of the usage and maintenance history of the aged unit as well as the engine with which it was aged.

5.2.3.3 Functional testing of monitoring and notification systems. In addition to emission reduction performance, it is important to ensure that the operator of SCR-equipped engines is notified if the reductant supply is low; if there is a leak, particularly when ammonia is used; or if the system is malfunctioning. Functional testing of the reductant level monitoring and notification system, the reductant leak monitoring and notification system, and other SCR system malfunction monitoring systems will be conducted. Generic test procedures are attached as Appendix B. These procedures require that the SCR applicant identify the monitoring and notification methodology used for the systems mentioned above, list the criteria designed to cause operator notification to occur, and then record the actual criteria values necessary to cause operator notification to occur during the test. It is not necessary to have the entire monitoring and notification system present if functionality can be demonstrated with a portion – a buzzer or warning light may be missing. This modification to the monitoring/notification system must be included in the test plan and agreed upon between the applicant and EPA ahead of time.

5.2.4 Test Procedures—General Requirements

5.2.4.1 Engine maintenance. All equipment used in the testing must be maintained and operated in accordance with applicable FTP testing regulations. To the extent practical, the engine and test conditions should be maintained the same between the base and candidate SCR tests. This consideration applies to all aspects of engine operation and maintenance. Routine engine maintenance must be performed before beginning a verification test, and once testing has started, routine engine maintenance is not allowed. If use of an SCR technology requires any engine adjustments beyond tuning, this requirement must be detailed in the test/QA plan and will be included in the report as a requirement for use of this technology. Resumption of testing

following engine or test stand breakdown and repair should generally follow EPA guidelines (40 CFR Part 86.1336-84), will be evaluated by the APCTVC on a case-by-case basis, and will be allowable only for brief shutdowns for which no emissions impact is considered likely.

5.2.4.2 Test data format and retention. Raw test results will be retained by the testing organization in electronic format required for EPA certification tests and made available to the APCTVC on request. Results for cold and hot starts will be reported both separately and as an appropriately weighted composite. Emissions during steady-state testing are to be reported mode-by-mode as well as in the final weighted form. Torque curves will be provided electronically for each engine map. Brake-specific fuel consumption (BSFC) will be measured during each engine map and provided with the map.

5.2.4.3 ETV test procedures. For highway engines, the FTP is described in 40 CFR Part 86, and the SET is specified in 40 CFR 86.1360. The FTP is a transient test cycle and the SET is a 13-mode steady-state test cycle. For SCR on a highway diesel engine, the minimum ETV testing at a single test point consists of one FTP cold start cycle, three FTP hot start cycles, and one SET. The weighted cold start results will be applied to each of the weighted hot start results to provide three transient sets of data for each regulated pollutant and BSFC. Additional testing at each test point may be required to detect the expected emissions reduction, as described in Section 5.1.2. The test parameters will be derived from the baseline engine mapping procedure.

For nonroad engines, the FTP is described in 40 CFR Part 89. Nonroad engines will be verified with both the applicable steady-state cycle and the nonroad transient cycle as published in the Federal Register. For SCR on a nonroad diesel engine, the minimum ETV test at a single test point consists of triplicate multimode FTP tests. Additional testing at each test point may be required to detect the expected emissions reduction, as described in Section 5.1.2. The test parameters will be derived from the baseline engine mapping procedure.

Stationary engines will generally follow the same ETV test procedure as similar nonroad engines. For SCR on a stationary diesel engine, the minimum ETV test at a single test point consists of triplicate multimode FTP tests. Additional testing at each test point may be required to detect the expected emissions reduction, as described in Section 5.1.2. The test parameters will be derived from the baseline engine mapping procedure.

Unless otherwise described in this document or identified in the approved test/QA plan, the FTP is to be followed in its entirety. In accordance with this protocol, any deviations from the test/QA plan will be noted and throughly documented by the testing organization in its report. Existing data of any kind and chassis or in-use field (e.g., on-road testing systems) data are not acceptable as the basis for ETV verification.

5.2.4.4 Engine performance and power. Engine performance and power will be measured and reported for both the baseline engine (without the control system installed) and the engine with the control technology. Engine performance measurements will be made with the engine operating at maximum power (rated conditions) and at peak torque as defined in the applicable FTP.

5.2.4.5 Fuel consumption. Fuel consumption will be measured for both the baseline engine (without the control system installed) and the engine with the control system installed to determine the effect of the technology on fuel consumption. The engine fuel consumption measurements will be made at maximum power at rated conditions and at peak torque at intermediate speed. Results of multiple tests, if available, will be averaged. The averaged results of multiple tests will be reported as a fractional increase or decrease relative to the baseline engine. Also reported will be fuel economy and BSFC from testing by the applicable FTP.

5.2.4.6 Back-pressure. Within the test cell, baseline engine back-pressure will be set to the value required by the applicable FTP (highway or nonroad). Once retrofit control technology is installed for the ETV test, the resulting back-pressure may be greater than the FTP requirement. If so, the ETV test will be conducted without adding additional back-pressure; if not, the test cell will be adjusted to meet the FTP requirements.

Because back-pressure of a retrofit control technology may affect the performance of an engine, the ETV test will measure and report back-pressure with the control system at full load and rated speed. Back-pressure will be measured and reported for both the baseline engine (as set for the FTP test without the technology installed) and the engine with the degreened or aged control technology installed.

5.2.4.7 Control technology operating temperature. At a minimum, the engine exhaust gas and SCR catalyst inlet temperatures must be measured for technologies, such as SCR, that are either dependent on specific operating temperature ranges or affected by engine or exhaust temperatures.

5.2.4.8 Other measurements and conditions. Ammonia slip is a concern with SCR systems, and therefore, ammonia will be measured using CTM-038, based on 40 CFR 63 Appendix A, Test Method 320 *Measurement of Vapor Phase Organic and Inorganic Emissions by Extractive Fourier Transform Infrared (FTIR) Spectroscopy*. This will provide an average ammonia slip over the test cycle. Technologies that may produce secondary pollutants or have other secondary effects must include measurement of those pollutants in the ETV test. Carbon dioxide (CO_2) emissions, while not primary ETV test pollutants, must be measured using instrumentation or estimated from a carbon balance from the fuel usage. ETV must include the appropriate measurements for technologies that require other specific operating conditions or affect emissions over only a limited range of a particular pollutant. For example, because the long-term operation of DECs and PM filters is affected by the soluble organic fraction (SOF) of the PM, SOF must be measured during ETV testing for filters and similar technologies. The details of these non-critical measurements and their QA goals will be part of the test/QA plan.

5.2.5 Example Test Sequence for Highway Engines

Table 3 outlines the minimum highway diesel engine SCR verification test for a single engine. The technology being evaluated in Table 3 is assumed to be one whose expected emissions reduction is large enough that the minimum data set (one FTP cold start cycle, three FTP hot start cycles, and one SET) at each test point provides a sufficiently narrow confidence interval. Other

diesel engine applications may run the appropriate FTP test sequence with additional SET testing as required.

5.2.6 Data Reduction for SCR

Table 3.
Minimum ETV Test Program for Highway Diesel Engine SCR on Single Engine

1. Select representative engine and stabilize in baseline condition.
2. Map engine in baseline condition and practice cycles.
3. Conduct one FTP cold start cycle, three FTP hot start cycles, and one SET on base engine.
4. Install degreened SCR system, and operate and stabilize engine.
5. Practice cycles using baseline condition map.
6. Conduct one FTP cold start cycle, three FTP hot start cycles, and one SET on SCR-equipped engine.

(Optional: To avoid repeating the base test, repeat steps 4–6 with aged SCR immediately following degreened SCR test.)

7. Compare baseline and SCR-equipped engine emissions results for emissions reductions.

For highway diesel engines, emissions test results are recorded at each test point for HC, CO, NO_x, PM, and the other measured pollutants. For each pollutant, the single cold start emission measurement (E_C) is combined with each of up to three hot start tests (e_H) to obtain up to three composite emissions rates following the normal fractional calculation for highway engines:

$$(E_{comp})_m = \frac{(1/7)(e_c) + (6/7)(e_H)_m}{(1/7)(W_c) + (6/7)(W_H)_m} \quad (6)$$

where:

(E_{COMP}) = weighted mass emission level in grams per brake horsepower-hour and, if appropriate, the weighted mass total hydrocarbon equivalent, in grams per brake horsepower-hour,

m = hot start test 1, 2, or 3,

e_C = mass emission level in grams or grams carbon mass equivalent, measured during the cold start test,

e_H = mass emission level in grams or grams carbon mass equivalent, measured during the hot start test,

W_C = total brake horsepower-hour (brake horsepower integrated over time) for the cold start test,

W_H = total brake horsepower-hour (brake horsepower integrated over time) for the hot start test.

Hot start tests that are combined with a cold start test must be obtained sequentially following that cold start, and no more than three hot starts may be combined with a single cold start or single SET. The composited FTP highway transient emission for each pollutant, E_{COMP}, is combined

with a single SET as follows to obtain the combined tests emission rate, E_i, for each pollutant for each of the n tests at the test point:

$$E_i = 0.85 \bullet (E_{COMP})_i + 0.15 \bullet E_{SET} \text{ for } i = 1 \text{ to } n \text{ tests required at test point} \quad (7)$$

As an example, as stated by Equation 6, $(E_{COMP})_1$, $(E_{COMP})_2$, and $(E_{COMP})_3$ would be computed from the first cold start and first three valid hot starts following the cold start. Then the SET results would be combined with each E_{COMP} value to obtain three E values, for $n = 3$ according to Equation 7. (The APCTVC recognizes that the emissions results generated in this way are not fully independent. This approach is a compromise allowed to reduce cost.)

The same process would be applied to both the base case and the candidate SCR case.

The same general approach is applied to nonroad engines. Instead of combining a cold and hot start test result, E_{COMP} for nonroad tests is obtained from the multimode nonroad test following the weightings in Appendix B to Subpart E of 40 CFR Part 89 as appropriate for the intended nonroad use as shown in Equation 8.

$$(E_{COMP})_i = \sum_{j=1}^{k} f_j \bullet E_{MODE_j} \quad (8)$$

where: $(E_{COMP})_i$ = combined emissions rate for test ith of n tests required at test point,
f_j = mode weighting factor from 40 CFR 89, Subpart E, Appendix B for jth mode,
$E_{MODE\,j}$ = pollutant emissions rate during mode j, and
k = total number of modes for intended application per 40 CFR 89.

The emissions reductions for both highway and nonroad engines are then calculated using Equations 1 through 6 from Section 5.1.3.

6.0 REPORTING AND DOCUMENTATION

This section describes the procedures for reporting data in the verification report (VR) and verification statement (VS). The specifics of what data must be included and the format in which the data must be included are addressed in this section (e.g., QA/QC summary forms, raw data collected, photographs/slides/video tapes). The VR for each technology will include near the beginning a VS that summarizes the ETV results. A sample draft VS is attached as Appendix A. The VR, including the VS, will be written by the APCTVC based on the test report submitted by the testing organization. The VR and VS will be reviewed by the APCTVC and the technology applicant before being submitted to EPA for review and approval as specified in the ETV QMP.

6.1 Reports

Based on the test report from the testing organization, the APCTVC will prepare the draft VR, which includes the following topics:

1. VS;
2. Introduction;
3. Description and identification of product tested;
4. Procedures and methods used in testing;
5. Statement of operating range over which the test was conducted;
6. Summary and discussion of results as required to:
    a. support the VS,
    b. explain and document necessary deviations from the test plan, and
    c. discuss QA issues;
7. References;
8. Appendices:
    a. QA/QC activities and results,
    b. Raw test data, and
    c. Equipment calibration results.

The VS will include the following:

1. Technology applicant's name and technology's descriptive information;
2. Summary of ETV test program;
3. Results of the ETV test;
4. Notice of control system warranty and any limitations of the ETV results; and
5. Brief QA statement.

Review and approval of the draft ETV report and statement are described in Section 3.0.

6.2 Data Reduction

Data from measurements made as part of the ETV test will be reported as emissions rates in grams/kilowatt hour (grams/brake horsepower) and as percentage emission reductions from the baseline engine. Emissions specific to a particular technology (e.g. ammonia) may be reported in units of concentration as well as grams/kilowatt hour (grams/brake horsepower). The confidence limits will be presented as well as the mean emissions reduction, as discussed in Section 5.1.2. When they would be helpful to the mobile sources community because of established usage, the appropriate English engineering units will be supplied parenthetically.

7.0 DISSEMINATION OF ETV REPORTS AND STATEMENTS

After a retrofit control technology has been tested and the draft VR and VS prepared by the APCTVC, the APCTVC will send a draft of both to the applicant for review prior to submission to the EPA and release of the approved report to the public. This gives the applicant the

opportunity to review the results, test methodology, and report terminology while the drafts remain working documents and are not publicly accessible. The applicant may submit comments and revisions on the draft statement and report to the APCTVC. The APCTVC will consider these comments and may suggest revisions of its own.

After incorporating appropriate revisions, the draft final VR and VS will be submitted to the EPA for review and approval. A signed original VS within the VR will be filed and retained by the APCTVC, and signed originals will also be provided in VRs to the applicant and EPA. Three additional paper copies of the ETV report will be provided to the applicant. Further distribution of the ETV report, if desired, is at the applicant's discretion and responsibility. However, approved VSs and VRs will be posted on the ETV Web site for public access without restriction. The VR report appendices will not be posted on the Web site but will be publicly available from the APCTVC.

8.0 APPLICANT'S OPTIONS SHOULD A TECHNOLOGY PERFORM BELOW EXPECTATIONS

The ETV Program is not a technology research and development program; technologies submitted for ETV are to be commercially ready with well understood performance. Tests that meet the ETV data quality requirements (a valid FTP test) are considered valid and suitable for publishing; however, a technology may fail to meet the applicant's expectations. Based on limited testing, for instance, the applicant might expect an emission reduction of 30 ± 7 percent result. However, the actual ETV result from the more complex FTP test cycle might be 20 ± 15 percent. The APCTVC will use its experience to avoid this situation, but test results cannot be guaranteed to meet an applicant's expectations. In this case, the applicant may choose to schedule additional tests, may accept the result and complete the verification, or request that a VS not be issued. However, ETV reports are always in the public domain and will be posted on the ETV Web site. VRs will be written and will be available from the EPA for review by the public regardless of an applicant's request not to issue a verification statement.

As another example, an applicant might expect a mean of 10 percent reduction with a confidence interval of ±5 percent, but testing results in an actual verification may show a mean reduction of 5 percent with a confidence interval of ±7 percent. In this case, the ETV data are insufficient to verify that the technology provides any reduction at all. Additional tests must be scheduled and a statistically significant reduction obtained for a VS to be issued. Inability to detect a statistically significant emission reduction (or failure to have sufficient tests) will prevent a positive completion of the ETV, and the results of the ETV will be reported publicly stating that performance could not be distinguished from 0 percent reduction. A VS will not be issued in the VR in this case.

In either of the above cases, the applicant may improve the product and resubmit it under a new model identification for ETV testing. ETV reports and statements for acceptable tests of the new product will be issued as they are processed by the APCTVC and EPA (except that the results for several identical tests performed in rapid succession will be released simultaneously).

9.0 LIMITATIONS ON TESTING AND REPORTING

To avoid having multiple ETV reports for the same product and to maintain the ETV testing as a cooperative effort with the applicant, the following restrictions apply to ETV testing under this protocol:

- Applicants may submit only products that they manufacture or whose distribution they control. Applicants may not submit for ETV testing control systems whose use is not in their control, except with the agreement of the manufacturer or vendor.
- For a given product (e.g., brand and model), APCTVC policy is that only one ETV report and statement will be issued for any single application.
- Air pollution control technology frequently performs differently in different applications. Applicants may request additional tests of essentially identical technology if it is being applied to pollution sources that are clearly different from those for which verifications have been obtained.

10.0 REQUIREMENTS FOR TEST/QA PLAN

10.1 Quality Management

All testing organizations participating in this ETV Program must meet the QA/QC requirements defined below and have an adequate quality system to manage the quality of work performed. Documentation and records management must be performed according to the *Environmental Technology Verification Program, Quality Management Plan* (EPA, 2002a) or its superceding document. Testing organizations must also perform assessments and allow audits by the APCTVC (headed by the APCT QA Officer) and EPA corresponding to those in Section 11.

All testing organizations participating in the Retrofit Air Pollution Control Technologies for Highway and Nonroad Use Diesel Engines Program must have an ISO 9000-accredited (ISO, 1994) or ANSI E4-compliant (ASQC, 1994) quality system and an EPA- or APCTVC-approved QMP.

10.2 Quality Assurance

All ETV testing will be done following an approved test/QA plan that meets *EPA Requirements for Quality Assurance Project Plans* (EPA, 2001a) and EPA's ETV QMP (EPA, 2002a). These documents establish the requirements for test/QA plans, and the common guidance document, *Guidance for Quality Assurance Project Plans* (EPA, 2002b), provides guidance on how to meet these requirements. The APCT Quality Management Plan (APCTVC, 1998) implements this guidance for the APCTVC.

ETVs conducted under this generic protocol utilize test procedures described in the FTP (40 CFR Part 86 for highway engines and 40 CFR Part 89 for nonroad engines). The test/QA plan must describe in adequate detail how the FTP test methods are implemented by the testing organization. Replication of the FTP text is neither expected nor desired. The test/QA plan

should reference the FTP in detail, by section and subsection, as appropriate for the topic under consideration. Any deviations from the FTP must be identified and explained. Internal standard operating procedures (SOPs) may be referenced provided they are available for audit review. (SOPs need not be incorporated into the test/QA plan except by reference. If considered proprietary to the test organization, they should be clearly marked.) When the FTP offers alternative test procedures or equipment, the test/QA plan must identify the alternative implemented. Similarly, if a range of operating parameters is allowed by the FTP, the specifics of the particular implementation must be provided. For a test organization with multiple test cells, these details may be tabulated and incorporated by attaching a table and identifying the test cell on the test report. Steps that the testing organization will take to ensure acceptable data quality in the test results are also identified in the test/QA plan. As above, detailed reference to SOPs, the calibration portions of the FTP, or other available documents is encouraged. Any needed SOPs will be developed in accordance with *Guidance for Preparing Standard Operating Procedures (SOPs)* (EPA, 2001b).

The testing organization must prepare a test/QA plan and submit it for approval by the APCTVC. The test/QA plan must also be approved by EPA before the test organization can begin ETV testing.

A test/QA plan must contain the 24 elements listed below, the contents of which may stand alone or include references to the FTP or other widely distributed and publicly available sources. Legible hand-notated diagrams from the FTP are acceptable. If specific elements are not included, an explanation for not including them must be provided.

Group A Elements: Project Management

A1 Title and Approval Sheet
A2 Table of Contents
A3 Distribution List
A4 Project/Task Organization
A5 Problem Definition/Background
A6 Project/Task Description
A7 Quality Objectives and Criteria
A8 Special Training/Certifications
A9 Documentation and Records

Group B Elements: Data Generation and Acquisition

B1 Sampling Process Design (Experimental Design)
B2 Sampling Methods
B3 Sample Handling and Custody
B4 Analytical Methods
B5 Quality Control
B6 Instrument/Equipment Testing, Inspection, and Maintenance
B7 Instrument/Equipment Calibration and Frequency
B8 Inspection/Acceptance of Supplies and Consumables

B9 Non-direct Measurements
B10 Data Management

Group C Elements: Assessment and Oversight

C1 Assessments and Response Actions
C2 Reports to Management

Group D Elements: Data Validation and Usability

D1 Data Review, Verification, and Validation
D2 Verification and Validation Methods
D3 Reconciliation with User Requirements

The APCTVC will provide a test/QA plan template that illustrates its expectations.

10.3 Additional Requirements to be Included in the Test/QA Plan

The test/QA plan must include or reference a diagram and description of the extractive gaseous measurement system to be used for the testing and a list of the reference analyzers and measurement ranges to be used for quantifying the concentrations of all gaseous compounds to be measured, including both primary and ancillary pollutants.

The test/QA plan must include or reference a schematic drawing that shows all sample and test locations, including the inlet and outlet to the technology sampling locations. The location of flow disturbances and the upstream and downstream distances from the sampling ports to those flow disturbances must be noted. The number of traverse points that will be sampled must be provided.

The test/QA plan must include or reference the appropriately detailed descriptions of all measuring systems that will be used during the test.

The test/QA plan must explain or reference the specific techniques to be used for monitoring process conditions appropriately for the source being tested. It must also note the techniques that will be used to estimate any other operational parameters.

The test/QA plan must include and document estimates of historical measurement variability that will be used, as discussed in Section 5.1.1, to compute the number of tests required and provide confidence intervals on single-test ETVs.

The test/QA plan must include a list of Data Quality Indicator Goals for individual measurements that conform to those specified in the relevant sections of the FTP and the corresponding acceptance criteria.

11.0 ASSESSMENT AND RESPONSE

Each independent testing organization must conduct internal assessments of its data quality and technical systems and must allow external assessments of these systems by APCTVC and EPA QA personnel. After an assessment, the testing organization will be responsible for developing and implementing corrective actions in response to the assessment's findings.

As appropriate, the APCTVC and/or EPA will conduct assessments to determine the testing organization's compliance with its test/QA plan. The requirement to conduct assessments is specified in EPA's *ETV Quality Management Plan* (EPA, 2002a), and in APCTVC's QMP (APCTVC, 1998). EPA will assess APCTVC's compliance with APCTVC's test/QA plans. APCTVC will assess the compliance of other organizations with their test/QA plans. The assessments will be conducted according to *Guidance on Technical Audits and Related Assessments for Environmental Data Operations* (EPA, 2000) and *Guidance on Assessing Quality Systems* (EPA, 2001c).

11.1 Assessment Types

Quality system audit—Qualitative assessment of a particular quality system to establish whether the prevailing quality management structure, policies, practices, and procedures meet EPA requirements and are adequate for ensuring that the type and quality of measurements needed are obtained.

Technical systems audit—Qualitative on-site audit of the physical setup of the test. The auditors determine the compliance of testing personnel with the test/QA plan.

Performance evaluation audit—Quantitative audit in which measurement data are independently obtained and compared with routinely obtained data to evaluate the accuracy (bias and precision) of a measurement system.

Audit of data quality—Qualitative and quantitative audit in which data and data handling are reviewed and data quality and data usability are assessed.

11.2 Assessment Frequency

Activities performed during verifications that affect the quality of the data will be assessed regularly and the findings reported to management to ensure that the requirements stated in the generic verification protocols and the test/QA plans are being implemented as prescribed.

The types and minimum frequency of assessments for the ETV Program are listed in Part A Section 9.0 of EPA's *ETV Quality Management Plan* (EPA, 2002a). Tests conducted by the APCTVC will have, at a minimum, the following types and numbers of assessments:

- Quality system audit: Self-assessments by the testing organization at least once, and at least one independent assessment of the testing organization.

- Technical systems audits: Self-assessments (qualitative) by the testing organization at least once per test, and at least one independent assessment of the testing organization.
- Performance evaluation audits: Self-assessments (quantitative) by the testing organization on each test, and at least one independent assessment of the testing organization.
- Audits of data quality: Self-assessments (quantitative and qualitative) by the testing laboratory of at least 10 percent of all the ETV data with detailed reports of the audit results to be included in the data packages sent to the APCTVC for review.

The independent assessments of tests conducted by RTI for the APCTVC will be performed by EPA. The independent assessments of other organizations will be performed by APCTVC.

11.3 Response to Assessment

When needed, appropriate corrective actions will be taken and their adequacy verified and documented in response to the findings of the assessments. Data found to have been taken from nonconforming technology will be evaluated to determine its impact on the quality of the required data. The impact and the action taken will be documented. Assessments are conducted according to procedures contained in the APCT QMP. Findings are provided in audit reports. Responses by the testing organization to adverse findings are required within 10 working days of receiving the audit report. Followup by the auditors and documentation of responses are required.

12.0 SAFETY MEASURES

12.1 Safety Responsibilities

The testing organization's project leader is responsible for ensuring compliance with all applicable occupational health and safety requirements. Each individual staff member is expected to follow the requirements and identify personnel who deviate from them and report such action to their supervisor.

12.2 Safety Program

The testing organization must maintain a comprehensive safety program and ensure that all test personnel are familiar with and follow it.

13.0 REFERENCES

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EPA. *Guidance on Assessing Quality Systems (Quality Staff Draft). EPA QA/G-3*. Office of Environmental Information, U.S. Environmental Protection Agency. Washington, DC. August 2001c.

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U.S. Government. Protection of Environment. Title 40, Part 89, Code of Federal Regulations, as of July 1, 2002. Federal Register. Washington, DC. 2002.

APPENDIX A: EXAMPLE VERIFICATION STATEMENT

Appendix A is an example verification statement written for a generic SCR control technology. The technology is assumed to be directed at a highway use engine. It is assumed to be an efficient control device, requiring only a single test by the minimum-number-of-tests calculation. The values are completely hypothetical.

This generic verification statement is intended only to show the form of a verification statement. It will require modification for each technology verified, depending on the details of that technology's design, construction, and operation. The test/QA plan written for each test will include a draft verification statement customized for the technology actually being tested. The text of that specific verification statement will address the significant parameters that apply to the technology tested.

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**SCR FOR MOBILE DIESEL ENGINE**		
APPLICATION:	**CONTROL OF EMISSIONS FROM MOBILE DIESEL ENGINES IN (*HIGHWAY*) (*NONROAD*) USE BY (*TECHNOLOGY TYPE*)**		
TECHNOLOGY NAME:	**TECHNOLOGY NAME**		
COMPANY:	**COMPANY NAME**		
ADDRESS:	**ADDRESS**	**PHONE:**	**(000) 000-0000**
	CITY, STATE ZIP	**FAX:**	**(000) 000-0000**
WEB SITE:	**http://www.company.com**		
E-MAIL:	**some.one@company.com**		

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholder groups that consist of buyers, vendor organizations, permitters, and other interested parties; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The Air Pollution Control Technology Verification Center (APCTVC), one of six centers under the ETV Program, is operated by the RTI, in cooperation with EPA's National Risk Management Research Laboratory. The APCTVC has evaluated the performance of a _____*TYPE*_____

emission control technology for mobile diesel engines, the *TECHNOLOGY* by *COMPANY NAME*.

ETV TEST DESCRIPTION

All tests were performed in accordance with the APCTVC *Generic Verification Protocol for Determination of Emissions Reductions from Selective Catalytic Reduction Control Technologies for Highway, Nonroad, and Stationary Use Diesel Engines* and the specific technology test plan "ETV Test/QA Plan for *TECHNOLOGY NAME*". These documents include requirements for quality management, quality assurance, procedures for product selection, auditing of the test laboratories, and test reporting format.

The mobile diesel engine air pollution control technology was tested at *TESTING ORGANIZATION*. The performance verified was the percentage emission reduction achieved by the technology for particulate matter (PM), nitrogen oxides (NO_x), hydrocarbons (HCs), and carbon monoxide (CO) relative to the performance of the same baseline engine without the technology in place. Operating conditions were documented, and ancillary performance measurements were also made. The basic modules of the test procedure are found in the Federal Test Procedures (FTPs) for highway engines (40CFR, Part 86, Subpart N) and nonroad engines (40CFR, Part 89, Subpart E). For highway use, a single full FTP test was conducted, augmented by additional hot start transient tests as needed to meet the requirements of the generic verification protocol (GVP). For nonroad use, three or more multimode tests were conducted as described in the GVP. A summary description of the ETV test is provided in Table A-1.

Table A-1. Summary of the conditions for ETV test of *TECHNOLOGY NAME* on ENGINE DESCRIPTION.

Test Conducted	**Highway Transient Federal Test Procedure**
Engine Family	*ENGINE MFGR NAME* Series *XXXYYY*, ??? operating hours prior to test
Engine Size	YYY kW (XXX hp)
Technology	ACME Mark II SCR, Model AA1 for Model XXXYYY diesel engines
Technology description	Ammonia injection SCR
Test cycle or mode description	1 FTP cold start cycle, three FTP hot start cycles, and 1 highway steady state Supplemental Emissions Test (SET) cycle
Test fuel description	EPA standard diesel per 40 CFR Part 86.1313-98 (15 ppm S for SCR)
Critical measurements	PM, NOx, HCs, and CO
Ancillary measurements	NH_3 by CTM-038, CO_2, back-pressure at engine exhaust port, exhaust temperature, fuel consumption

VERIFIED TECHNOLOGY DESCRIPTION

This verification statement is applicable to the *TECHNOLOGY NAME* (to include model number and other identifying information as needed). *TECHNOLOGY NAME* is packaged and marketed for particular engine families (for example, Model AA1 is properly sized for the A1A1 engine) or as a unit suitable for use on engines below a particular diesel power rating. The monitoring and notification system functionally tested and used with this product includes *list monitoring and operator notification functions*. The unit whose performance was verified was the Model AA1, which is rated for YYY kW (XXX hp) engines fueled by ultralow-sulfur diesel (ULSD) fuel.

This verification statement describes the performance of *TECHNOLOGY NAME* on the diesel engine identified in Table A-1.

VERIFICATION OF PERFORMANCE

TECHNOLOGY NAME achieved the emissions reduction shown in Table A-2 at the stated conditions. Table A-2 may include ETV results for both the initial operation (degreened) and for the technology following the stated period of aging. For the purposes of determining the status of the technology in regard to EPA's voluntary retrofit program, the prospective user is encouraged to contact EPA-Office of Transportation and Air Quality (OTAQ) or visit the retrofit program Web site at http://www.epa.gov/otaq/retrofit/.

The APCT QA officer has reviewed the test results and quality control data and has concluded that the data quality objectives given in the generic verification protocol and test/QA plan have been attained.

During the ETV tests, EPA or APCTVC quality assurance staff conducted technical assessments at the testing organization. These confirm that the ETV tests were conducted in accordance with testing organization's EPA-approved test/QA plan.

This verification statement verifies the emissions characteristics of *TECHNOLOGY NAME* within the stated range of application. Extrapolation outside that range should be done with caution and an understanding of the scientific principles that control the performance of *TECHNOLOGY NAME*. This verification focused on emissions. Potential technology users may obtain other types of performance information from the manufacturer.

Table A-2. Verified emissions reductions for hypothetical *TECHNOLOGY NAME*

Test Engine: Manufacturer name Model No. AA1	Technology Test		
	Baseline Engine	**Controlled Engine**	**Emissions Reduction, percent**
Fuel			
Critical Measurements of Emissions			
Hot Start PM, g/bkWh (g/bhp-hr)			
Composited PM, g/bkWh (g/bhp-hr)			
Hot Start NO_X, g/bkWh (g/bhp-hr)			
Composited NO_X, g/bkWh (g/bhp-hr)			
Composited HC, g/bkWh (g/bhp-hr)			
Composited CO, g/bkWh (g/bhp-hr)			
Ancillary Measurements			
Engine Power, kW (hp)			
Peak Torque, N-m (lb_f-ft)			
Composited CO_2, g/bkWh (g/bhp-hr)			
Composited NH_3, ppm			
Composited NH_3, g/bkWh (g/bhp-hr)			
Exhaust Flow, L/min (ft^3/min)			
Exhaust Temperature, °C (°F)			
Back-pressure, kPa (in. Hg)			
Fuel Usage, L (gal)			
Reductant usage, L/test			
Technology In/Out Temp., °C (°F)			
Regeneration	brief description		
Maintenance Schedule	brief description		
Comments			

In accordance with the generic verification protocol, this verification statement is valid commencing on *DATE* indefinitely for application of *TECHNOLOGY NAME* within the range of applicability of the statement.

Hugh W. McKinnon, MD MPH Date
Director
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency

Jack R. Farmer Date
Program Director
Air Pollution Control Technology Verification Center
Research Triangle Institute

NOTICE: ETV verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. EPA and RTI make no expressed or implied warranties as to the performance of the technology and do not certify that a technology will always operate as verified. The end user is solely responsible for complying with any and all applicable federal, state, and local requirements. Mention of commercial product names does not imply endorsement.

APPENDIX B: SCR MONITORING/NOTIFICATION SYSTEMS FUNCTIONAL TEST PROCEDURES

A variety of SCR system designs utilizing different reductants, catalyst configurations, injection systems, and strategies are possible. There are also differing methods of monitoring these SCR systems for reductant tank level, reductant leakage, and possible malfunctions, such as loss of air pressure on an air assisted system or an inoperable heater on a urea-based system. These systems affect the operability and safety of SCR systems.

Before testing begins, manufacturers are required to present for approval test procedures to demonstrate the basic functioning of key parts of their SCR monitoring and notification systems. The test procedures should cover the reductant tank level monitoring and notification system, reductant leak detection monitoring and notification system, and other malfunction monitoring and notification systems. It is not necessary to have the entire monitoring and notification system present if functionality can be demonstrated with a portion – a buzzer or warning light may be missing. This modification to the monitoring/notification system would have to be included in the test plan and agreed upon between the manufacturer and EPA ahead of time. This proposal will be evaluated by the APCTVC and the test laboratory and incorporated into the test/QA plan.

The information required to be included in the test report follows:

Product and Test Information

Product Name	Test Number
Product Number	Test Date
Product Version	Test Time

Tank Level Monitoring and Notification System
Parameters Sensed
Information and Codes Stored
Notification Method
Design Criteria for Notification
Test Method Summary (include any alterations to the notification system, such as not including warning lights or audible alarm for testing purposes)
Measured Criteria for Notification

Reductant Leak Detection Monitoring and Notification System
Parameters Sensed
Information and Codes Stored
Notification Method
Design Criteria for Notification
Test Method Summary (include any alterations to the notification system, such as not including warning lights or audible alarm for testing purposes)
Measured Criteria for Notification

Other Malfunction Monitoring and Notification Systems
Malfunction Monitoring and Notification System 1

System Title
Parameters Sensed
Information and Codes Stored
Notification Method
Design Criteria for Notification
Test Method Summary (include any alterations to the notification system, such as not including warning lights or audible alarm for testing purposes)
Measured Criteria for Notification

Malfunction Monitoring and Notification System 2
System Title
Parameters Sensed
Information and Codes Stored
Notification Method
Design Criteria for Notification
Test Method Summary (include any alterations to the notification system, such as not including warning lights or audible alarm for testing purposes)
Measured Criteria for Notification