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December 2004

Test and Quality Assurance Plan

New Condensator, Inc. - The Condensator Diesel Engine Retrofit Crankcase Ventilation System

Prepared by:

Greenhouse Gas Technology Center
Southern Research Institute

Under a Cooperative Agreement With
U.S. Environmental Protection Agency

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A U.S. EPA Sponsored Environmental Technology Verification (ETV) Organization

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This Test and Quality Assurance Plan has been reviewed and approved by the Greenhouse Gas Technology Center Project Manager and Center Director, the U.S. EPA APPCD Project Officer, and the U.S. EPA APPCD Quality Assurance Manager.

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List of Acronyms and Abbreviations

ADQ	audit of data quality
APPCD	Air Pollution Prevention and Control Division
Bhp	brake horsepower
BSFC	brake specific fuel consumption
CFR	Code of Federal Regulations
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
COV	coefficient of variation
CVS	constant volume sampling
DEER	Department of Engine and Emissions Research
DQIG	data quality indicator goals
DQO	data quality objective
EPA-ORD	Environmental Protection Agency Office of Research and Development
ETV	Environmental Technology Verification
FS	full scale
FTP	Federal Test Procedure
GHG Center	Greenhouse Gas Technology Center
GVP	ETV Generic Verification Protocol
NCI	New Condensator, Inc.
NIST	National Institute of Standards and Technology
NO_2	nitrogen dioxide
NO_X	blend of NO, NO_2, and other oxides of nitrogen
PEA	performance evaluation audit
PM	particulate matter
ppmv	parts per million by volume
QA/QC	quality assurance / quality control
QMP	quality management plan
QPP	quality policy and procedures
QSM	quality systems manual
SOF	soluble organic fraction
SOP	standard operating procedure
SwRI	Southwest Research Institute
THC	total non-methane hydrocarbons (as carbon)
TQAP	test and quality assurance plan
TSA	technical systems audit

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1.0 INTRODUCTION

1.1 BACKGROUND

The U.S. Environmental Protection Agency's Office of Research and Development (EPA-ORD) operates the Environmental Technology Verification (ETV) program to facilitate the deployment of innovative technologies through performance verification and information dissemination. The ETV program's goal is to further environmental protection by substantially accelerating the acceptance and use of improved and innovative environmental technologies. Congress funds ETV in response to the belief that there are many viable environmental technologies that are not being used for the lack of credible third-party performance data. The performance data developed under this program will allow technology buyers, financiers, and permitters in the United States and abroad to make more informed decisions regarding environmental technology purchase and use.

The Greenhouse Gas Technology Center (GHG Center) is one of six ETV organizations. EPA's partner verification organization, Southern Research Institute (Southern), manages the GHG Center. The GHG Center conducts verification testing of promising GHG mitigation and monitoring technologies. It develops verification protocols, conducts field tests, collects and interprets field and other data, obtains independent peer-review input, and reports findings. The GHG Center conducts performance evaluations according to externally reviewed verification Test and Quality Assurance Plans (TQAPs) and established protocols for quality assurance (QA).

Volunteer stakeholder groups guide the GHG Center's verification activities. These stakeholders advise on specific technologies most appropriate for testing, help disseminate results, and review TQAPs and technology Verification Reports. National and international environmental policy, technology, and regulatory experts participate in the GHG Center's Executive Stakeholder Group. The group also includes industry trade organizations, environmental technology finance groups, governmental organizations, and other interested parties. Industry-specific stakeholders peer-review key documents prepared by the GHG Center and provide verification testing strategy guidance in those areas related to their expertise.

One sector of significant interest to GHG Center stakeholders is transportation - particularly technologies that result in fuel economy improvements. The Department of Energy reports that in 2001, "other trucks" (all trucks other than light-duty trucks) consuming diesel fuel emitted approximately 72.5 million metric tons of carbon dioxide (CO_2). These emissions increase to 107.5 million metric tons when considering all diesel vehicles in the transportation sector. Small fuel efficiency or emission rate improvements are expected to have a significant beneficial impact on nationwide greenhouse gas emissions.

New Condensator, Inc. (NCI) of Grass Valley, California owns the rights to a technology that is planned for use as a retrofit device for existing light and heavy duty diesel engines. The Condensator technology is applicable to diesel engines that have open crankcase ventilation systems. The Condensator is designed to collect and filter the blow-by exhaust from the crankcase and re-route exhaust vapors back to the engine air intake, essentially converting the engine to a closed crankcase system. NCI claims that enhanced fuel economy, reduced opacity, and 100% containment of the blow-by gases are the benefits of using this technology.

NCI wishes to verify performance of the Condensator technology for reductions in fuel consumption and emissions as a retrofit modification to a heavy-duty open crankcase diesel engine. NCI is a suitable

verification candidate considering its potentially significant beneficial environmental quality impacts and ETV stakeholder interest in verified transportation sector emission reduction technologies.

This test will be conducted under the *Generic Verification Protocol for Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engine* because of the parameters to be measured. The document is an ETV Generic Verification Protocol (GVP) developed by the Air Pollution Control Technology Verification Center. This GVP makes use of the Federal Test Procedure (FTP) as listed in 40 CFR Part 86 for highway engines as a standard test protocol. Performance will be assessed using the GVP test sequence by comparing the fuel consumption and emission rates measured on a heavy-duty test engine before and after installation of the NCI Condensator technology. Verification testing will be directed by the GHG Center. The tests will take place at Southwest Research Institute's (SwRI) Department of Engine and Emissions Research (DEER) in San Antonio, TX. The test program is described in the following sections. Any deviations from the GVP are noted in Section 13 of this TQAP.

This TQAP specifies verification parameters and the rationale for their selection. It contains the verification approach, data quality objectives (DQOs), and Quality Assurance/Quality Control (QA/QC) procedures. It will also guide test implementation, document creation, data analysis, and interpretation.

This TQAP has been peer-reviewed by NCI, SwRI, and the EPA-ETV QA Manager. The EPA-APPCD Project Officer provided final approval of the TQAP. The TQAP meets the requirements of the GHG Center's Quality Management Plan (QMP) once approved and signed by the responsible parties listed on the front of this document. The TQAP is available on GHG Center internet site at www.sri-rtp.com and the ETV program site at www.epa.gov/etv.

The GHG Center will prepare a verification report and verification statement upon field test completion. The same organizations listed above will review the report and statement, followed by EPA-ORD technical review. The GHG Center Director and EPA-ORD Laboratory Director will sign the verification statement when this review is complete and the GHG Center will post the final documents as described above.

1.2 SWRI TESTING QUALIFICATIONS

The GHG Center has selected SwRI to conduct the testing for this verification. The following describes the accreditations and registrations of SwRI relevant to this TQAP.

The SwRI DEER is registered to International Organization for Standardization 9002 "Model for Quality Assurance in Production and Installation." This independently assessed quality system provides the basis for quality procedures that are applied to every project conducted in the DEER. DEER is accredited to ISO/IEC Guide 25 "General Requirements for the Competency of Calibration and Testing Laboratories" and EN 45001, "General Criteria for the Operation of Test Laboratories." The American Association for Laboratory Accreditation Certificate Number 0702-01 accredits DEER to perform evaluations of automotive fluids, fuel emissions, automotive components, engine and power-train performance and durability using stationary engine dynamometer test stands (light-duty, non-road, and heavy-duty) and vehicle dynamometer facilities, and automotive fleets (see http://www.a2la2.net/scopepdf/0702-01.pdf). The certificate accredits DEER to use specific standards and procedures, including dynamometer procedures for hydrocarbons, carbon monoxide, oxides of nitrogen, and particulate matter. DEER has also: (1) achieved Ford Tier 1 status for providing engineering services, (2) received the Ford Q1 Quality Award and the Ford Customer-Driven Quality Award, and (3) maintains its status as a Caterpillar-certified supplier.

SwRI has conducted testing for a previous GHG Center technology verification program. Testing was conducted on a light-duty gasoline-fueled vehicle. SwRI has also conducted the testing for several heavy-duty diesel verification tests for another ETV Center. The EPA has reviewed the TQAP for these tests and the DEER quality system and verified that the information conforms to the specific required elements of the [*EPA Requirements for Quality Assurance Project Plans, EPA QA/R-5]*, the ETV QMP, and the general requirements of the GVP.

1.3 ORGANIZATION OF THIS TQAP

This TQAP addresses ETV technology testing at SwRI under the applicable GVP. It is deliberately organized to parallel the structure of EPA QA/R-5. Since all laboratory data will be generated by SwRI, much of this TQAP also parallels the SwRI *Test/QA Plan for the Verification Testing of Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines (Version 1.0, April 8, 2002; SwRI QPP)* which was developed based on the GVP. The referenced SwRI QPP was developed for ETV testing under the current GVP and is posted on the ETV website. Differences between the SwRI QPP and this TQAP reflect organizational differences and the specific role of the GHG center as the verification organization on this test. This TQAP also contains test-specific details of the NCI Condensator technology, its implementation, verification parameters, schedule, and test design. These details are generally inserted in the appropriate sections of the main text rather than in a test-specific attachment to the existing SwRI QPP.

This TQAP also describes testing under the framework of the GVP and the relevant FTP (from 40 CFR 86 Subpart N for highway engines), and both documents will be cited as applicable by reference where such citation is clear. This TQAP also describes how the FTP will be specifically implemented for this verification.

1.4 REFERENCED SWRI QUALITY DOCUMENTS

Several relevant internal SwRI documents will be incorporated by reference in this TQAP, including the (1) DEER Quality System Manual (QSM), (2) Quality Policy and Procedures (QPPs), and (3) Standard Operating Procedures (SOPs). These internal quality documents, unlike the GVP and FTP references, are considered proprietary to SwRI and are not publicly available. However, they will be made available for review during the on-site assessment of the DEER technical and quality systems, and for test-specific on-site audits by the GHG or EPA QA personnel. Several of the referenced SOPs were previously reviewed by GHG Center staff as part of a previous verification test and found adequate by the GHG Center QA manager as discussed in the TSA report for that test. Certain sections of this document reference specific SwRI quality documents that describe DEER's conformance with specific QPP-required elements. These references do not supersede the applicable GVP and FTP citations, but are included to document the specific implementations of these directions by SwRI staff.

2.0 TEST DESCRIPTION AND TEST OBJECTIVES

2.1 TECHNOLOGY DESCRIPTION

Many on and off-road heavy duty diesel engines have an open crankcase and blow-by tube, especially on older vehicles. On these engines, crankcase blow-by is emitted directly to the atmosphere through the blow-by tube, resulting in emissions of particulate matter (PM), carbon monoxide (CO), hydrocarbons (THC), and other pollutants. NCI's Condensator is designed to capture and filter these emissions. This technology is applicable to light- to heavy-duty trucks, both on- and off-road, and is also available for marine and generator applications. The Condensator is designed to collect and filter the blow-by exhaust from the crankcase and re-route exhaust vapors back to the engine air intake. This removes particulate from the blow-by exhaust and creates a closed crankcase system. NCI claims that enhanced fuel economy, reduced opacity, reduced emissions, and containment of the blow-by gases are the benefits of using this technology.

The NCI Condensator consists of a blow-by manifold, two Condensator containers, and associated tubing to route filtered exhaust gases back to the engine intake. The two Condensator containers are arranged in parallel and hold the collected waste/sludge. Each contains a silica bead separator system that filters the crankcase exhaust. Rubber hoses are used to connect the Condensator to the air intake and blow-by tube. Hose clamps keep the hoses in place. NCI requires the Condensator unit to be installed away from extreme heat such as exhaust manifolds. NCI states that system efficiency typically increases as the connecting hose length decreases. Figure 1-1 illustrates typical Condensator installations.

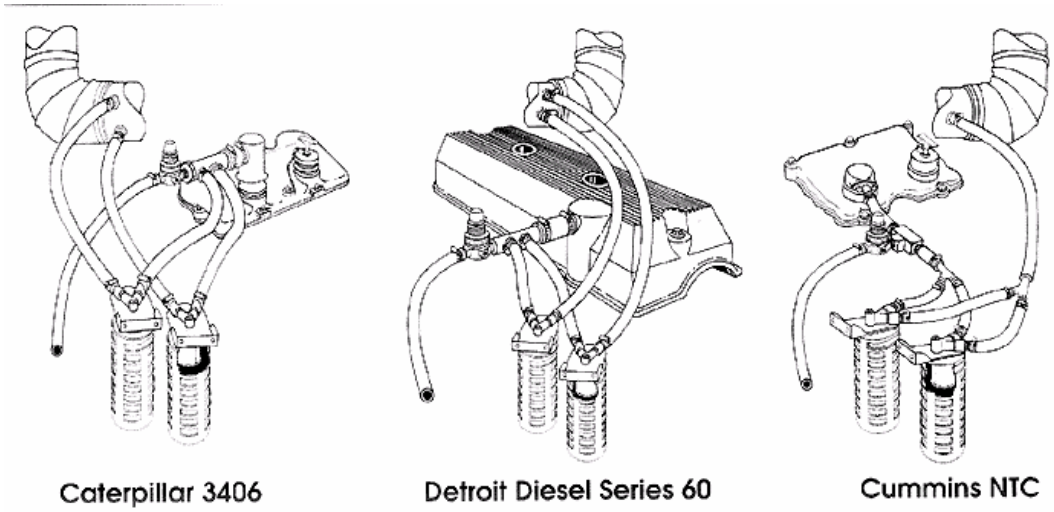

Figure 1-1. NCI Condensator on Typical Heavy Duty Diesel Engines

According to NCI, crankcase exhaust comes in contact with silica bead separators in the Condensator, resulting in a molecular separation process where large, heavier oil molecules condense and collect in the Condensator containers. Water and acid present with the oil will also drop into the containers. Gaseous emissions, including hydrocarbons, continue through the system and are vented back into the engine air intake. Waste oil and condensate collected in the Condensator containers should be emptied during

vehicle oil changes. This is done by unscrewing the container from the head and properly disposing of the waste. The separators are cleaned periodically in a solvent to dislodge and remove any carbon or sludge that may have attached to the silica beads.

By eliminating the blow-by emissions point, the environmental impact of the Condensator is immediate. NCI claims that engine performance and exhaust emissions will further improve after a break-in period of around 1800 miles. The technology was previously tested by Automotive Testing and Development Services, Inc. (ATDS) in California in March-April, 2004 where it was demonstrated to reduce total vehicle diesel emissions by 24% for CO and 20% for PM. Emissions of THC, NO_x, and CO_2 and fuel consumption changed 1% or less (increase or decrease). According to NCI, several other tests have shown fuel economy savings in the range of 15 to 25%. These tests were conducted according to the provisions of 40 CFR 86 and/or California Title 13 for submission to California Air Resources Board (CARB). In addition to this test, previous testing with the U.S. Department of the Navy indicated fuel economy improvements in the range of 4% to 27%.

NCI states that this technology will provide the following benefits:

- Increase fuel efficiency in open crankcase diesel engines;
- Lower emissions in diesel engines, especially PM, CO and hydrocarbons;
- Save operating costs with lower fuel costs and increased vehicle mileage; and
- Be applicable to any diesel engines with open crankcase including light and heavy duty, on and off road, and marine engines.

2.2 TEST DESCRIPTION

2.2.1 Overview

This TQAP describes testing of the Condensator technology under the GVP. The general test sequence described in GVP Sections 5.2.2 and 5.4.2 is applicable to this test. Testing is being completed to verify the performance of the NCI Condensator system in reducing exhaust emissions and improving fuel economy of an open crankcase heavy-duty diesel engine. The exhaust from the engine will be analyzed for emissions of NO_x, PM, THC, CO, CO_2, and CH_4. For the baseline engine, this will include emissions of PM and THC from the crankcase blow-by tube. Additional measurements and calculation procedures will be used to determine fuel economy of the engine over specified test cycles. As a secondary parameter, up to six collected PM samples will be analyzed for soluble organic fraction (SOF) to demonstrate the amount of SOF captured by the Condensator. The testing after installation of the Condensator will be conducted twice including once immediately after installation and preconditioning, and again after a 45 hour break-in period.

The general sequence of test events follows. Detailed descriptions of each test phase are provided in Sections 2.2 through 2.4:

1. Obtain a representative test engine and inspect the engine;
2. Change the engine oil and filter;
3. Map the baseline engine (develop torque curve);
4. Precondition the baseline engine;
5. Soak the baseline engine;

6. Perform baseline engine testing for exhaust emissions, blow-by emission, and fuel consumption;
7. Install the NCI Condensator system;
8. Map the modified engine;
9. Precondition the modified engine;
10. Soak the modified engine;
11. Perform modified engine testing for exhaust emissions and fuel consumption;
12. Perform 45 hour modified engine break-in period;
13. Repeat the modified engine testing for exhaust emissions and fuel consumption;
14. Evaluate the test data for data quality; and
15. Complete additional testing as necessary to achieve data quality objectives.

The verification test generally requires operation of a test engine on an engine dynamometer. The engine dynamometer simulates operating conditions of the engine by applying loads to the engine and measuring the amount of power that the engine can produce against the load. The engine is operated on the dynamometer over a simulated duty cycle that mimics a typical on-road heavy-duty vehicle. This is the "transient" cycle heavy-duty FTP specified in 40 CFR 86.1333.

Exhaust emissions from the engine are collected through a constant volume sampling (CVS) system and then analyzed to determine emission concentrations. An adjustable-speed turbine blower in the CVS dilutes the exhaust with ambient air while the vehicle operates on the dynamometer. This dilution prevents the exhaust moisture from condensing and provides controllable sampling conditions. A sample pump and a control system transfers diluted exhaust to emission analyzers, sample bags, or particulate sampling systems (filters). Samples are collected at constant sampling rates.

For the baseline testing, blow-by emissions will also be quantified including THC and PM. The blow-by emissions testing will be conducted following procedures developed by SwRI (SOP 07-043). These procedures were specifically designed to measure PM and THC emissions from an open crankcase blow-by tube. Total baseline engine PM and THC emissions will be the sum of the PM and THC emissions measured from the engine exhaust and the blow-by tube. After installation of the Condensator, the blow-by exhaust is eliminated.

2.3 TEST ENGINE SELECTION AND SPECIFICATIONS

The diesel engine used in this test program will be a Cummins N-14 370-HP (turbocharged) engine manufactured in 1997. This engine was selected for testing because it represents a large segment of heavy-duty diesel engines currently on the road for which the Condensator technology is intended. The Condensator will also be applicable to other types of heavy duty diesel engines. The test engine is located at the SwRI facility and SwRI has verified that the engine has not been rebuilt or modified, and is operating reasonably within original OEM specifications.

Cummins states that there were over 150,000 N-14 engines on the road in 2003. More than 100,000 additional units were supplied to the military for a variety of logistical and special-purpose equipment applications. The engine has an advanced electric control module (ECM) that provides improved engine controls. The specifications for a Cummins N-14 370 are provided in Table 2-1. The N-14 series of engines includes engines in a 330 – 525 HP range. The specifications provided in Table 2-1 are for a 370-HP engine, but many of these parameters apply to the entire HP range of N-14 by Cummins engines.

Table 2-1. Cummins N-14 370 HP Specifications

Parameter	Value (SI units)	Value (Metric units)
Advertised HP	370 Bhp	276 kW
Peak Torque	1255 lb.·ft	2020 N·m
Governed Speed	1800/2100 rpm	1800/2100 rpm
Clutch Engagement Torque	900 lb.·ft	1220 N·m
Number of Cylinders	6	6
Bore and Stroke	5.5 X 6.0 in	(140 X 152 mm)
Engine Displacement	855 cu. in.	14 L
Compression Ratio	18.5:1	18.5:1
Operating Cycles	4	4
Oil System Capacity*	11.0 U.S. gallons	42 L
Coolant Capacity (engine only)	20 U.S. qts.	21 L
Net Weight with Standard Accessories, Dry	2805 lbs.	1272 kg
Weight per Power	8.01 lbs/HP	4.87 kg/kW

*with combination lube filter

2.4 BASELINE ENGINE PREPARATION

2.4.1 Engine Inspection

A Cummins representative will visually inspect the visible parts of the engine to ensure that:

- the engine is in good operating condition,
- there is not any excessive wear on visible parts,
- there are no damaged or broken parts, and
- there is not any excessive buildup on visible engine parts.

The Cummins representative will document any potential problems noted during the inspection and present these to the GHG Center field team leader. The field team leader will determine whether the test engine is acceptable, needs parts replaced, or should not be used for testing based on the results of the inspection. The field team leader will also document the engine condition. All repairs to the baseline engine will be documented by the Cummins representative and field team leader.

2.4.2 Engine Oil Change

The test engine's oil will be changed prior to baseline testing. Technicians will change the engine oil using the standard manufacturer oil change procedure. This ensures that the engine oil will not impact the performance of the engine from the baseline to modified engine test. A suitable grade of engine oil will be used based on manufacturer specifications.

The technicians performing the engine oil change will document the oil change, including the quantity and type of oil used. Documentation will be signed by the technicians and copies provided to the field

team leader. The engine lubricant will not be changed again as significant wear of the lubricant will not occur during the test period. Therefore, the same engine oil will be used throughout the entire test (baseline and modified engine).

2.5 ENGINE MODIFICATION WITH THE CONDENSATOR TECHNOLOGY

The test engine will be modified by installing the NCI Condensator system after baseline engine testing is complete. A Cummins technician will be on-site to perform all equipment installation and engine mechanical work on the test engine. The GVP requires that NCI provide written descriptions of the procedures for installation and post-installation engine adjustments required for optimum operation [*GVP, Section 2.2.3*]. NCI personnel will be present for oversight and consultation during the installation of the Condensator technology.

Installation of the Condensator is fairly straightforward and does not require major modifications to the engine. The Condensator blow-by manifold is attached to the crankcase blow-by tube using rubber tubing and hose clamps. The manifold directs the crankcase exhaust through the two Condensator vessels arranged in series, and gases leaving the Condensator are directed to the engine air intake using additional rubber tubing. No additional modifications or adjustments to the engine are needed.

NCI will approve the installation and modified engine testing will commence once installation and adjustment is complete.

2.6 ENGINE TESTING PROCEDURES

The baseline engine will be installed on the engine dynamometer after engine preparations are completed, engine installation is completed, and SOPs 07-001 (*Power Validation for Heavy-Duty Diesel Engines*) and 07-002 (*Power Mapping for Heavy-Duty Diesel Engines*) are addressed. The engine test procedure is described in the following sections.

2.6.1 Break-in Period

The baseline engine should go through a break-in period to ensure proper break-in of the new engine oil. Break-in is completed by operating the engine at specified conditions for a specified time period. The cycle operates at various engine conditions, including idle, peak torque, rated speed, and high idles. The actual break-in time for the baseline tests will be documented by SwRI. This allows the engine to stabilize and eliminates any effects of break-in on engine performance. The GVP (Section 5.2.6) specifies a range of 25 -125 hours for equipment de-greening. Since only fresh oil is added to the engine and no other mechanical changes will be performed on the baseline engine, a break-in period of 25 hours is specified here.

NCI claims that engine performance is improved immediately after installation of the Condensator and does not specify any required de-greening period. However, NCI also claims that performance of the engine and Condensator will improve after around 1800 miles (or 45 hours) of operation. Therefore, two sets of tests will be conducted on the modified engine. The first will be conducted with no break-in period. The engine will be preconditioned and soaked (as described in Section 2.6.4), and then immediately tested. Testing will then be repeated on the modified engine after a 45 hour Condensator break-in period. The actual break-in time and operating conditions will be documented by SwRI.

2.6.2 Engine Mapping

Engine mapping is a procedure that is completed to generate a torque curve for the test engine. It is generated by running the engine at full throttle at increasing engine speed from curb idle through the manufacturer's rated speed. The engine torque is measured at each speed. The torque curve is subsequently used to generate data for the transient test cycle for that specific engine. The engine mapping procedure follows the procedure specified at 40 CFR 86 Subpart N, Sections 86.1332 and 86-1333.

Engine mapping will be completed after the break-in procedure is completed for both the baseline and modified engine. The baseline engine map obtained will be compared to the manufacturer-specified engine map. Significant differences identified between the two maps will lead to an investigation of the cause of this discrepancy. Corrective actions will be reviewed once the cause is identified. The required corrective action will be addressed and considered prior to accepting the engine for further testing. The engine may be labeled as unacceptable for the test if fundamental problems with the engine are identified based on the engine map. A new test engine would then be located.

In order to allow a fair comparison of engine performance with the baseline and modified engine, the torque curve developed during the baseline mapping will be used to develop the FTP duty cycle for all testing periods. Mapping results will be reported for both the baseline and modified engines only so that potential users can see changes in engine performance that may have occurred due to the Condensator.

2.6.3 Test Cycle

The test engine is operated on the dynamometer over a transient driving cycle that simulates the operation of a typical on-road heavy-duty vehicle. This test cycle is the heavy-duty FTP specified in 40 CFR 86.1333. It is typically used for emissions testing of heavy-duty on-road engines. The FTP cycle takes into account the operation of a variety of heavy-duty trucks and buses, and includes simulation of traffic on roads and expressways in and around cities. The average speed is about 30 km/h and the equivalent distance traveled is 10.3 km. The cycle lasts 1200 s [dieselnet: http://www.dieselnet.com/standards /cycles/ftp_trans.html].

The test cycle is specified as a normalized cycle. The data points specified in the FTP are the percent of maximum torque and speed over time. The specific transient cycle for the test engine is calculated based on these values and the engine mapping values for test engine torque vs. engine speed. One complete FTP cycle consists of two test segments. The first is a “cold-start test” completed after the engine has been “soaked” (not operating) for a specified time period (overnight). The second period is a “hot-start” test. This is the same cycle as the cold start test, begun 20 minutes after the completion of the cold-start test, while the engine is still “hot”.

The specific FTP cycle used for both the baseline and modified engines will be calculated for this verification test using the baseline engine mapping results even though engine mapping is completed for both the baseline and modified engines.

Testing of each engine configuration will consist of a single cold-start test, followed by the required 20-minute soak period, and a minimum of three hot-start tests. A 20-minute soak period is required between each hot-start test.

2.6.4 Engine Preconditioning

The test engine will be preconditioned after engine mapping is completed. Preconditioning is completed by running the engine through the FTP test cycle that it will be seeing for the actual test procedure. Both the baseline and modified engine will be preconditioned for this test by running the engine through the transient FTP cycle three times. The transient cycles, each 20 minutes long, are run concurrently without any soak period. Once the preconditioning runs are completed, the engine is turned off and allowed to "soak" overnight. The length of the soak period between the end of preconditioning and beginning of test runs will be approximately the same for both the baseline and modified test engine.

2.6.5 Emissions and Fuel Consumption Testing

The emissions and fuel consumption tests will be completed after the overnight soak following the preconditioning runs, and again after the 45 hour break-in period. The test runs will consist of operating the test engine over the specified FTP test cycle for one cold-start test, and a minimum of three hot-start tests for both the baseline and modified engine. Additional hot-start tests may be added depending on the data quality of the initial test runs as well as reaching agreement between all parties and funding agencies involved in the test campaign. Total minimum test duration is two hours and twenty minutes, consisting of one cold-start test, three hot-start tests, and three soak periods, each twenty minutes long.

The brake-specific fuel consumption (BSFC) evaluated during the test is a measure of engine efficiency and is a primary verification parameter for this test series during the FTP transient cycles. BSFC is the ratio of the engine fuel consumption to the engine power output and has units of grams of fuel per kilowatt-hour (g/kWh) or pounds mass of fuel per brake horsepower-hour (lb/Bhp-hr). The calculation of BSFC is shown at 40 CFR 86.1342-90. The equation and supporting parameters are:

$$BSFC = \frac{\frac{1}{7}(M_c) + \frac{6}{7}(M_h)}{\frac{1}{7}(Bhp - hr_c) + \frac{6}{7}(Bhp - hr_h)} \qquad \text{Equation 1}$$

where: BSFC = brake-specific fuel consumption in pounds of fuel per brake horsepower-hour, lbs/Bhp-hr

M_c = mass of fuel used by the engine during the cold start test, lbs

M_h = mass of fuel used by the engine during the hot start test, lbs

$Bhp\text{-}hr_c$ = total brake horsepower-hours (brake horsepower integrated with respect to time) for the cold start test

$Bhp\text{-}hr_h$ = total brake horsepower-hours (brake horsepower integrated with respect to time) for the hot start test

The Bhp-hr values for each test are calculated using the engine torque and speed data measured on the dynamometer. The mass of fuel, M, used during each test is calculated via a carbon balance method using the emission rates and fuel properties determined during testing. These rather complex calculations are specified in 40 CFR 86.1342-90 and not repeated here. Generally, the calculations rely on the measured engine exhaust mass emissions of THC, CO, and CO_2 and the measured test fuel carbon weight fraction, specific gravity, and net heating value. These fuel properties are cited on the fuel certificate of analyses and are determined using the following methods:

- Specific gravity – ASTM D1298
- Carbon weight fraction – ASTM D3343
- Net heating value – ASTM D3348

Exhaust emissions will be analyzed for NO_x, PM, THC, CO, CO_2, and CH_4 during the test period. Blow-by emissions of PM and THC will also be determined during the baseline testing. Engine and dynamometer operating conditions will be recorded. Sampling system, emission analyzer, and test cell operations will also be monitored. At the conclusion of testing, up to six of the collected PM samples (three from the blow-by tube and three from the exhaust) will be analyzed for SOF. This secondary verification parameter will provide an indication of how much of the SOF emissions are captured by the Condensator technology.

Each test run will be followed by evaluation of data quality in accordance with the requirements of Section 3. Achievement of all data quality indicator goals and FTP requirements will allow the field team leader to declare a run valid. A test run where required data quality indicator goals are not met will cause the test run to be invalidated and repeated immediately (if a hot-start).

2.7 ADDITIONAL TEST CONSIDERATIONS

2.7.1 Test Fuel

Testing will use standard diesel test fuel (40 CFR 86.1313-98) with sulfur in the range of 300-500 ppm. The GHG Center will review fuel analyses and verify the fuel to be within specifications before the start of engine testing. The reference for test fuel requirements in the GVP is Section 5.2.10.

2.7.2 Back-Pressure

Baseline engine back-pressure will be set to the value required by the applicable FTP (highway or nonroad) within the test cell. The back-pressure of the retrofit control technology may be greater than the FTP requirement once it has been installed for the ETV test. The ETV test would then be conducted without adding additional back-pressure; if not, the test cell will be adjusted to meet the FTP requirements. Back-pressure of a retrofit control technology may affect the performance of an engine, so the ETV test will measure and report back-pressure with the control device 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 Condensator installed.

2.7.3 Durability

The aged technology test described in the GVP will not be part of this verification test due to time and budgetary constraints [*GVP, Section 5.2.9*]. Durability testing may be completed in a subsequent testing phase if this verification test program is successful. This is mentioned in Section 13 as a deviation from the GVP.

2.8 TEST ORGANIZATION AND RESPONSIBILITIES

The EPA has overall responsibility for the ETV Program for the GHG Center. Southern is EPA's verification partner in this effort. SwRI is the testing organization selected for this test. Management and testing are performed in accordance with procedures and protocols defined by a series of quality management documents. These include (see Section 14.0) in order of precedence:

- EPA Requirements for Quality Assurance Project Plans (EPA QA/R-5);
- EPA's Quality and Management Plan for the overall ETV program (EPA QMP);
- QMP for the GHG Center;
- SwRI's Quality System Manual – 2000 (QSM);
- DEER's Quality System Manual (QSM);
- The GVP for Verification Testing of Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines; and
- This TQAP.

SwRI will conduct field verification and analyze data. Southern will prepare a verification report and statement. The various management and QA responsibilities are divided between EPA, Southern, and SwRI key project personnel as defined below. The lines of authority between key personnel for this project are shown on the project organization chart in Figure 2-1. Project management responsibilities are divided among the EPA, Southern, and SwRI staff as described below.

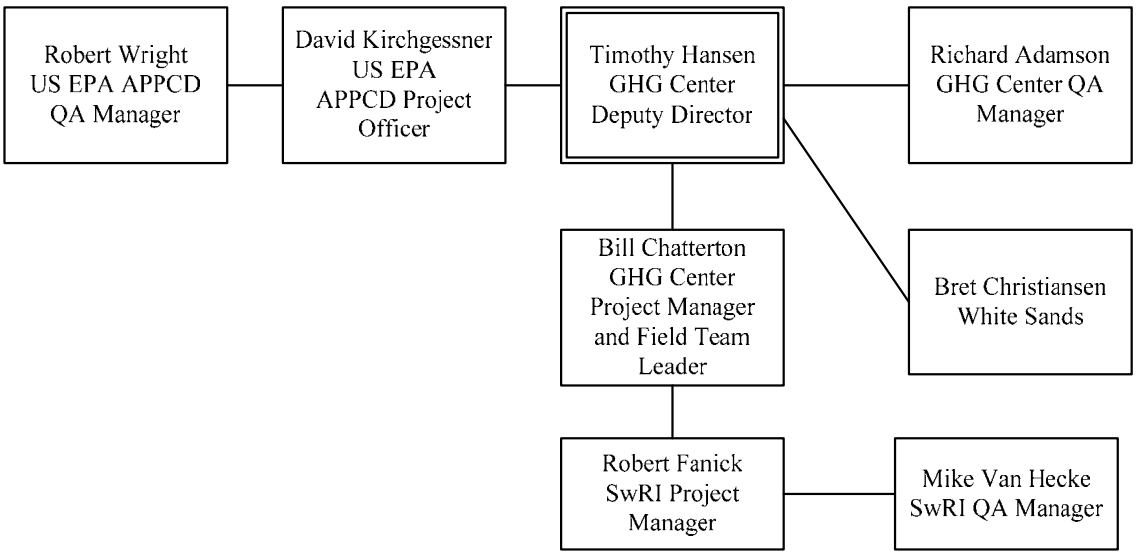

Figure 2-1. Project Organization

2.8.1 EPA

2.8.1.1 Project Management

The EPA Project Manager, David Kirchgessner, has overall EPA responsibility for the GHG Center. He is responsible for obtaining EPA's final approval of project TQAPs and reports.

2.8.1.2 Quality Manager

The EPA Quality Manager for the GHG Center is Robert Wright of EPA's Air Pollution Prevention and Control Division (APPCD). His responsibilities include:

- Communicate quality systems requirements, quality procedures, and quality issues to the EPA Project Manager and the GHG Project Manager;

- Review and approve GHG Center quality systems documents to verify conformance with the quality provisions of the ETV quality systems documents;
- Conduct performance evaluations of verification tests, as appropriate;
- Provide assistance to GHG Center personnel in resolving QA issues;
- Review and approve this TQAP;
- Review and approve the verification report and statement for each technology tested under this TQAP; and

2.8.2 Southern Research Institute

2.8.2.1 GHG Center Deputy Director

Southern's GHG Center has overall planning responsibility and will ensure successful verification test implementation. The GHG Center will:

- coordinate all activities;
- develop, monitor, and manage schedules; and
- ensure the achievement of high-quality independent testing and reporting.

Mr. Timothy Hansen is the GHG Center Deputy Director. He will ensure that staff and resources are sufficient and available to complete this verification. He will review the TQAP to ensure consistency with ETV operating principles. He will oversee GHG Center staff activities and provide management support where needed. Mr. Hansen will sign the verification statement along with the EPA-ORD Laboratory Director.

2.8.2.2 GHG Center Project Manager

Mr. Bill Chatterton will serve as the Project Manager for the GHG Center. His responsibilities include:

- drafting the TQAP and verification report;
- overseeing the field team leader's data collection activities, and
- ensuring data quality objectives (DQOs) are met prior to completion of testing.

The project manager will have full authority to suspend testing should a situation arise that could affect the health or safety of any personnel. He will also have the authority to suspend testing if the DQIGs described in Section 3.0 are not being met. He may resume testing when problems are resolved in both cases. He will be responsible for maintaining communication with NCI, SwRI, EPA, and stakeholders..

2.8.2.3 GHG Center Field Team Leader

Mr. Chatterton will also serve as the Field Team Leader. He will supervise all SwRI testing activities to ensure conformance with the TQAP. Mr. Chatterton will assess test data quality and will have the authority to repeat tests as determined necessary to ensure achievement of data quality goals. He will perform on-site activities required for data quality audits under the direction of the GHG Center QA Manager and perform other QA/QC procedures as described in Section 3.0. He will also communicate with the SwRI Program and Quality Managers to coordinate the internal audit activities of the SwRI Quality Manager with those of the GHG Center. Mr. Chatterton will communicate test results to the deputy director at the completion of each test run. The field team leader and deputy director will then determine if sufficient test runs have been conducted to report statistically valid fuel economy improvements.

2.8.2.4 GHG Center Quality Manager

Southern's QA Manager, Dr. Richard Adamson, is responsible for ensuring that all verification tests are performed in compliance with the QA requirements of the GHG Center QMP, GVPs, and TQAP. He has review this TQAP. He has reviewed the applicable elements of the SwRI Quality System and approved the quality requirements for implementation by SwRI technical and quality staff on this test. He will also review the verification test results and ensure that applicable internal assessments are conducted as described in Section 9.5. He will reconcile the DQOs and MQOs at the conclusion of testing and will conduct or supervise the ADQ. In addition, the QA manager will review the results of the PEA that is administered by the field team leader. Dr. Adamson will report all internal reviews, DQO reconciliation, the ADQ, the PEA, and any corrective action results directly to the GHG Center Deputy Director who will provide copies to the project manager for corrective action as applicable and citation in the final verification report. He will review and approve the final verification report and statement. He is administratively independent from the GHG Center Deputy Director.

2.8.3 SwRI

2.8.3.1 SwRI Program Manager

Mr. Bob Fanick is the SwRI Program Manager for this test program. He will be the primary contact for SwRI and will be responsible for set-up and testing of the vehicle. He will also review the TQAP and report.

2.8.3.2 SwRI Quality Manager

Mr. Mike Van Hecke plays a central role in the introduction, implementation, and consistent application of continuous quality improvement at the DEER. He fulfills the role as quality management representative for SwRI and conducts audits of all pertinent quality standards to ensure compliance. He is administratively independent of the unit generating the data and conducts QA activities as specified in SwRI's internal SOPs. He will conduct these internal QA activities on this test as described in Section 9 and report results to the GHG Center QA Manager. However, these activities do not replace or eliminate the need for the GHG Center internal QA reviews and activities outlined in Section 2.8.2.4 above.

2.8.3.3 Support Personnel

All persons supporting the project will be qualified as prescribed by SwRI QPP 10 (Training and Motivation).

2.8.4 NCI

Mr. James Brock will serve as NCI's primary contact person. Mr. Brock will provide technical support in accurately representing the Condensator technology. Mr. Brock will review the TQAP and report and provide written comments. Mr. Brock will be present during the verification testing to ensure proper installation and operation of the Condensator.

2.9 SCHEDULE AND MILESTONES

The tentative schedule of activities for testing the Condensator technology is as follows:

Verification Test Plan Development	**Dates**
GHG Center Internal Draft Development	September 15, – 30, 2004
NCI Review/Revision	October 4 – 18, 2004
Industry Peer-Review/Revision	October 25 – November 1, 2004
EPA TQAP Review	November 8 – 26, 2004
Final TQAP Revision and EPA Approval	November 26 – December 6, 2004
Final Document Posted	December 30, 2004

Verification Testing and Analysis	**Dates**
Preliminary Teleconference and Project Review	Late December, 2004
Testing	January, 2005 (exact dates to be determined)
Data Validation and Analysis	January, 2005

Verification Report Development	**Dates**
GHG Center Internal Draft Development	January 31 2005
NCI Review and Report Revision	February 1 – 15, 2005
EPA and Industry Peer-Review	February 18 – 28, 2005
Final Report Revision and EPA Approval	March 2005
Final Report Posted	March 31, 2005

2.10 DOCUMENTATION AND RECORDS

Test-specific documentation and records generated by SwRI will be processed as specified in:

- SwRI QPP 03 (Document Preparation and Control);
- SwRI QPP 07 (Testing and Sample Analysis); and
- SwRI QPP 14 (Quality Records).

Copies of results and supporting data will be transferred to the GHG Center and managed according to the GHG Center QMP. See Section 8 for details of test data acquisition and management. SwRI, in accordance with Part A, Sections 5.1 and 5.3 of EPA's QMP, will retain all test-specific documentation and records for seven years after the final payment of the agreement between SwRI and the GHG ETV Center. Southern will retain all verification reports and statements for seven years after final payment of the agreement between Southern and EPA.

3.0 DATA QUALITY OBJECTIVES

3.1 DATA QUALITY OBJECTIVES

DQOs are statements about the planned overall accuracy of the verification parameters. Three documents provide the basis for this subsection: (1) the [*GVP*], (2) the *Test and Quality Assurance Plan—ConocoPhillips Fuel-Efficient High-Performance SAE 75W90 Rear Axle Gear Lubricant* (SRI/USEPA-GHG-TQAP-28), and (3) the *Test and Quality Assurance Plan—Universal Cams, LLC Dynamic Cam Diesel Engine Retrofit System* (SRI/USEPA-GHG-TQAP-31). An abbreviated discussion of DQO development is presented here.

The primary verification parameters for this technology are reduction in BSFC and PM emissions. Improvement in these parameters will be expressed as the mean change, or delta (Δ), between results from the baseline and modified engine tests. Based on tests previously conducted by NCI, decreases of up to 10 to 20 percent are possible for both parameters. Therefore, the DQO for these parameters is to demonstrate a statistically significant delta of 10 percent or greater. This section provides a brief description of the data analysis and statistical procedures used here to demonstrate if this DQO is met. More detailed presentations of the statistical analyses that will be used are presented in the reference materials cited above.

This verification also includes determination of NO_X, CO, and THC, emissions as secondary verification parameters. These emissions tend to be much lower than any applicable standards, and their higher measurement variability (because of low absolute values) lead to large Δ determination errors. Therefore, this verification will not adopt explicit engine emission DQOs analogous to the BSFC and PM DQO. The implicit DQOs will be that all emissions tests will conform to the specified reference methods. Each of the reference methods include numerous QA/QC checks and data quality indicators (DQIs) that, if met, ensure that the tests were properly performed. Section 6.0 summarizes these checks. Although explicit DQOs are not specified for these emission parameters, the analysis described in Section 3.1.1 for determination of statistical significance in changes in BSFC will also be used to evaluate if changes in emissions are significant.

3.1.1 Determination of Statistical Significance

The mean BSFC and PM deltas cannot be deemed statistically significant if they are equal to or smaller than the 95 percent confidence intervals for each parameter. For each parameter, the confidence interval (*e*) is a function of the sample standard deviation (s_{n-1}) and the number of test runs conducted during the test campaign. The coefficient of variation (COV), or the sample standard deviation normalized against the sample mean (for each test condition), combined with the number of test runs will therefore serve as the DQI that links the width of the confidence interval with the DQO. The mean delta for BSFC and PM emissions must be greater than *e*. If it is not, the 95 percent confidence interval is wider than the change itself, and it cannot be deemed statistically significant.

Data collected during several similar ETV verifications show that, when the test methods are properly applied, COVs of 0.7 and 2.2 percent is achievable for BSFC and PM emissions, respectively. The data evaluated to develop these COVs includes nine test series for similar diesel engine retrofit technology engine dynamometer tests. Each test series consisted of three test runs (n=3). By conducting at least three baseline and modified engine test runs and achieving the 0.7 and 2.2 percent COVs, this verification

will be able to demonstrate statistically significant BSFC and PM deltas of 2 and 5 percent, respectively. If changes in these parameters are statistically significant, the GHG Center will calculate the difference's confidence interval. After the 3rd test run, and after each following run (up to the 6th), analysts will calculate a test statistic, t_{test}, and compare it with the Student's T distribution value with (n_1 + n_2 - 2) degrees of freedom as follows:

$$t_{test} = \frac{(\overline{X}_1 - \overline{X}_2) - (\mu_1 - \mu_2)}{\sqrt{s_p^{\,2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \qquad \text{Equation 2}$$

$$s_p^2 = \frac{(n_1 - 1)s_1^{\,2} + (n_2 - 1)s_2^{\,2}}{n_1 + n_2 - 2} \qquad \text{Equation 3}$$

Where:

X_1	=	mean BSFC or PM with baseline engine
X_2	=	mean BSFC or PM with Condensator
$\mu_1 - \mu_2$	=	zero (H_o hypothesizes that there is no difference between the population means)
n_1	=	number of repeated test runs with baseline engine
n_2	=	number of repeated test runs with Condensator
s_1^2	=	sample standard deviation with baseline engine, squared
s_2^2	=	sample standard deviation with Condensator, squared
s_p^2	=	pooled standard deviation, squared

Selected T-distribution values at a 95-percent confidence coefficient ($t_{0.025,\ DF}$) appear in the following table.

Table 3-1. Selected T-distribution Values

n_1	n_2	Degrees of Freedom, DF (n_1+n_2-2)	$t_{0.025,\ DF}$
3	3	4	2.776
4	4	6	2.447
5	5	8	2.306
6	6	10	2.228

If $t_{test} > t_{0.025,DF,}$ then it is concluded that the data shows a statistically significant difference in the verification parameter. Otherwise, it will be concluded that a significant change did not occur. If significant, the differences and their confidence intervals will be reported.

Use of equations 2 and 3 requires the assumption that the baseline and modified engine test run results have similar variance. The ratio of the sample variances (sample standard deviation squared) between the two test series is a measure of this similarity. Analysts will calculate an F_{test} statistic according to Equation 4 and compare the results to the values in Table 3-1 to determine the degree of similarity between the sample variances.

$$F_{test} = \frac{s^2_{\max}}{s^2_{\min}} \qquad \text{Equation 4}$$

Where:

F_{test} = F-test statistic
s^2_{max} = larger of the sample standard deviations, squared
s^2_{min} = smaller of the sample standard deviations, squared

Table 3-2 presents selected $F_{0.05}$ distribution values for the expected number of test runs and the acceptable uncertainty (α; 0.05).

Table 3-2. Selected $F_{0.05}$ Distribution Values

	s^2_{max} number of runs	**3**	**4**	**5**	**6**
s^2_{min} number of runs	**Degrees of Freedom**	**2**	**3**	**4**	**5**
3	**2**	19.00	19.16	19.25	19.30
4	**3**	9.55	9.28	9.12	9.01
5	**4**	6.94	6.59	6.39	6.26
6	**5**	5.79	5.41	5.19	5.05

If the F-test statistic is less than the corresponding value in Table 3-2, then analysts will conclude that the sample variances are substantially the same and the statistical significance evaluation and confidence interval calculations are valid approaches. If a statistically significant difference in either parameter is observed, the 95-percent confidence interval will be calculated. The half width (e) of the 95 percent confidence interval is:

$$e = t_{.025,DF}\sqrt{s_p^2\left(\frac{1}{n_1}+\frac{1}{n_2}\right)} \qquad \text{Equation 5}$$

Reported results for improvement in BSFC and PM emissions will include the 95 percent confidence interval, if the results are statistically significant.

4.0 SAMPLING AND ANALYTICAL PROCEDURES

The sampling system is comprised primarily of the exhaust sampling system to which continuous measurement devices and particulate filters are attached.

4.1 EXHAUST GAS SAMPLING SYSTEM

The exhaust gas sampling system conforms to 40 CFR 86.1310 and 89.308, respectively. The system that will be used at SwRI is depicted in Figure 4-1.

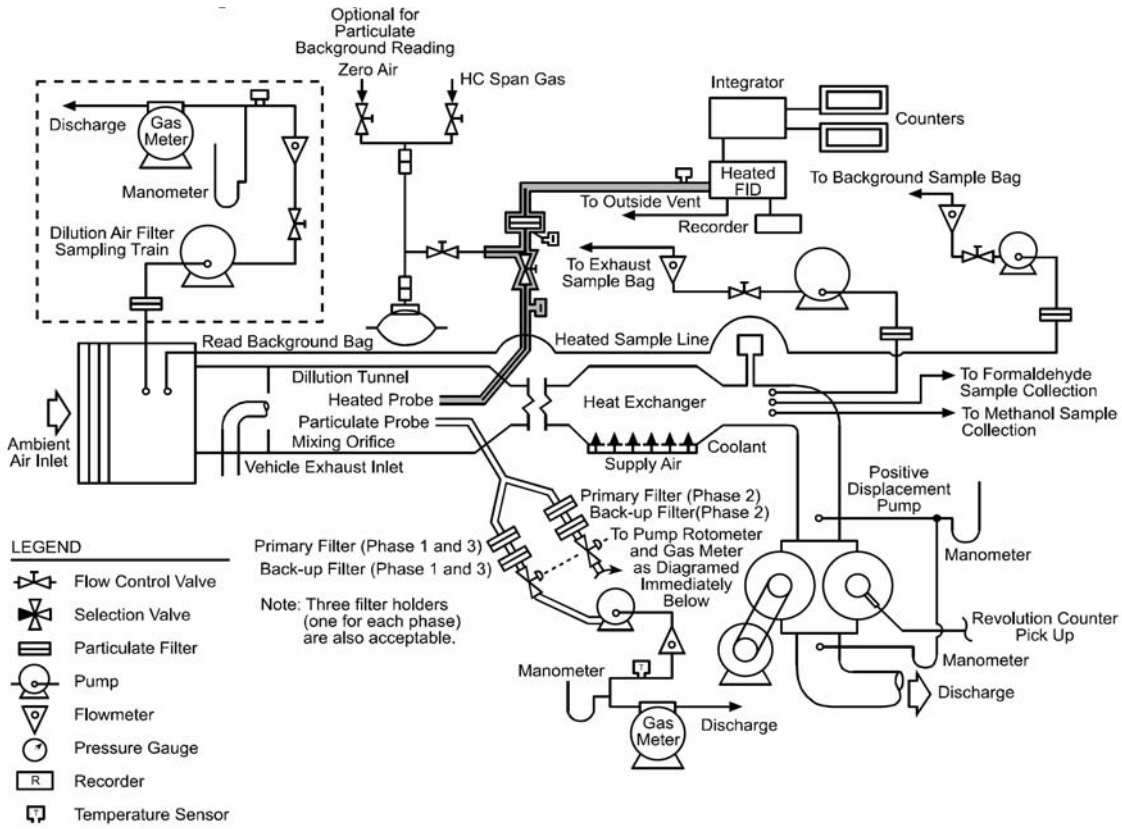

Figure 4-1. SwRI Gaseous and Particulate Emissions Sampling System (PDP-CVS)

The exhaust gas measurement system conforms to 40 CFR 86.1310 and 40 CFR 89.309. Table 4-2 lists the major equipment to be used during the test campaign, expected values, and instrument spans. Typical manufacturers and model numbers are listed for reference only.

Table 4-2. Exhaust Gas Measurement System Specifications

Parameter or Subsystem	Expected Operating Range	Manufacturer, Model / Operating Principle	Span	Measurement Frequency
Dynamometer speed	0 - 2100 RPM	Varies with test cell	Varies with test cell up to 6000 RPM	10 Hz (10/s)
Dynamometer load	0 - 368 hp, 0 - 1350 lb.ft	Varies with test cell	Varies; up to 600 hp, 2600 lb.ft	10 Hz (10/s)
CVS pressure	950 - 1050 millibar	SwRI-built constant volume sampler	0 - 1500 millibar	10 Hz (10/s)
CVS temperature	0 to 191 ^{o}C		0 - 200 ^{o}C	
CVS volumetric flow rate	2000 ft^3 / min (nominal)		1800-2200 ft^3 / min; Varies with test cell	
CO	0 - 300 ppmv	Horiba OPE-135 / NDIR	0 – 1000 ppmv	1 analysis per bag, 2 bags (1 dilute exhaust, 1 ambient air) per each cold-start. Similar set of 2 bags for each hot-start
CO_2	0 - 10000 ppmv	Horiba OPE-135 / NDIR	0 - 10000 ppmv	
CH_4	0 - 10 ppmv 0-100 ppm	GC/FID	10 ppmv 100 ppmv	
NO_X	0 - 300 ppmv	Rosemount 955 / Chemiluminescence	0 - 300 ppmv	10 Hz (10/s) (Note: online gas analysis through sampling probe)
THC	0 - 100 ppmv	Rosemount 402 / HFID	0 - 100 ppmv	
PM	0 - 5 mg	Gravimetric	0 - 1000 mg	1 per each cold- and hot-start

4.2 CRANKCASE BLOW-BY EXHAUST SAMPLING

Since no EPA standard method is available to measure blow-by PM and THC emissions, SwRI developed SOP 07-043 based on a modification of the standard method used for exhaust measurements. For PM emissions, the sampling system consists of a vacuum breaker, a filter holder, and a pump. The vacuum breaker maintains the blow-by exit pressure near ambient pressure for different engine speeds and loads while blow-by sampling is performed. This is done to prevent the sampling system from causing engine backpressure changes, affecting engine performance. The pressure control is done by allowing excess ambient air to be entrained with the blow-by flow during sampling. The pump draws the blow-by flow and ambient excess air through a filter holder to PM collection. For THC emissions, a heated sample line will be attached to the blow-by exhaust and gases will be directed to the THC analyzer for quantification. Instrument specifications and DQIGs for the blow-by sampling are the same as those for the exhaust gas sampling.

4.3 FILTER WEIGHING

Particulate filters are stored, conditioned, and weighed in a dedicated facility which conforms to 40 CFR 86.1312. The chamber in which the particulate filters are conditioned and weighed conforms to 40 CFR 86.112 without deviation. After the filter weighing is completed, up to three samples from the blow-by tube and three from the exhaust will be randomly selected for determination of SOF. SwRI follows an in-house SOP for determination of SOF where samples are extracted with toluene/ethanol, and analyzed for organic compounds using gas chromatography.

4.4 GASEOUS ANALYZERS

Gaseous analyzers conform to §86.309, §86.1311, and §89, Subpart D, App B, Figure 1 without deviation. Their operation is specified in SwRI SOP# 07-009, which conforms to required elements B4 (Analytical Methods), B5 (Quality Control), and B6 (Instrument/Equipment Testing, Inspection, and Maintenance) of EPA QA/R-5.

5.0 SAMPLE HANDLING AND CUSTODY

Only particulate matter (PM) filter measurements and bag samples involve manual handling, since gaseous emission measurements are made and recorded by the computer-controlled data system associated with the continuous sampling system.

The PM filters are prepared and processed according to SwRI SOP# 07-020 which specifies a method of conditioning and weighing filters used to collect particulate samples during exhaust emission testing. This SwRI SOP conforms to required element B3 (Sample Handling and Custody) of EPA QA/R-5.

Samples are handled according to SwRI SOP 07-023. This SOP conforms to required element B3 (Sample Handling and Custody) of EPA QA/R-5.

6.0 DATA QUALITY INDICATOR GOALS AND QA/QC CHECKS

Test measurements that contribute to a verification parameter's determination have specific data quality indicator goals (DQIGs) that, if met, imply achievement of the parameter's DQOs. For this test, completion of the QA/QC checks and achievement of the DQIGs ensures that the specified test methods have been completed in accordance with the TQAP and CFR test method requirements. Based on historical data, when testing is properly completed, the specified DQOs should be achievable.

Tables 6-1 through 6-5 list the individual analyzer and system DQIGs in terms of accuracy. A variety of calibrations, QA/QC checks, and other procedures ensure the achievement of each DQIG. The table summarizes those QA/QC checks for each of the major test systems.

Table 6-1. CVS System Data Quality Indicators and QA/QC Checks

Parameter	Data Quality Indicators Goals			QA/QC Checks		
	Accuracy	**How Verified**	**Frequency**	**Description**	**Frequency**	**Allowable Result**
Pressure	± 2.0 % of reading	Calibration of sensors with NIST-traceable standard	At initial installation, annually, or after major repairs	Inspect calibration certificates	Prior to test	Current calibration meeting DQI goal
Temperature	± 2.0 % of reading	Calibration of sensors with NIST-traceable standard		Inspect calibration certificates	Prior to test	Current calibration meeting DQI goal
Volumetric flow rate	± 0.5 % of reading	CVS and propane critical orifice calibration		Inspect calibration data	Prior to test	Current calibration meeting DQI goal
				Propane composition verification via analysis with FID	Prior to placing new propane tank in service	< 0.35 % difference from previously used and verified tank
				Propane injection check	Weekly	Difference between injected and recovered propane ≤ ± 2.0 %
				Sample bag leak check	Before each test run	Maintain 10” Hg for 10 seconds
				Flow rate verification	Before each test run	≤ ± 5 cfm of nominal test point
				Dilution air temperature	During each test run	Between 20 and 30 ^{o}C

Table 6-2. Instrumental Analyzers Data Quality Indicators and QA/QC Checks

Parameter	Data Quality Indicators Goals			QA/QC Checks		
	Accuracy	How Verified	Frequency	Description	Frequency	Allowable Result
CO CO_2 NO_x THC	± 1.0 % FS or ± 2.0 % for each calibration gas	11-point calibration (including zero) with gas divider; protocol calibration gases	Monthly	Review and verify analyzer calibration	Once during test and upon completion of new calibration	Current calibration meeting DQI goal
				Gas divider linearity verification	monthly	All points within ± 2.0 % of linear fit; FS within ± 0.5 % of known value
				Calibration gas certification or naming	Prior to service	Average concentration of three readings must be within ± 1 % for calibration gas and NIST-traceable reference material
				Zero gas verification	Prior to service	HC < 1 ppmv CO < 1 ppmv CO_2 < 400 ppmv NO_X < 0.1 ppmv O_2 between 18 and 21 %
				Analyzer zero and span	Before and after each test run	All values within ± 2.0 % of point of ± 1.0 % of FS; zero point within ± 0.2 % of FS
				Analyzer drift	For each bag analysis	Post-test zero or span drift shall not exceed ± 2.0 % FS
CO_2 only				Wet CO_2 interference check	Monthly	CO (0 to 300 ppmv) interference ≤ 3 ppmv; CO (> 300 ppmv) interference ≤ 1 % FS
NO_X only				CO_2 Quench Check	Annually	NO_x quench ≤ 3.0 %
				Converter Efficiency Check	Monthly	Converter Efficiency >90%

Table 6-3. Particulate Matter Analysis Data Quality Indicators and QA/QC Checks

Data Quality Indicators Goals			QA/QC Checks		
Accuracy	**How Verified**	**Frequency**	**Description**	**Frequency**	**Allowable Result**
± 1.0 µg	NIST-traceable scale calibration, weighing room controls, filter weight control	Daily	NIST-traceable calibration weight cross-check	Daily	Weight change <1.0 µg
			Weight room temperature	Daily	Between 19 and 25 ^{o}C
			Weight room relative humidity	Daily	Between 35 and 53% RH
			Reference filter weight change	Daily	Weight change <20 µg

Table 6-4. Supplementary Instruments and Additional QA/QC Checks

Description	Frequency	Allowable Result
Test cell Wet/dry bulb thermometer calibration	Monthly	Within ± 1.0 ^{o}F NIST-traceable standard
Test cell Barometer calibration	Weekly	Within ± 0.1" Hg of NIST-traceable standard
Test cell temperature	Each test run	Between 68 and 86 ^{o}F
Test fuel analysis	Prior to testing	Conforms to 40 CFR §86.1313 specifications (See Appendix A-2)

Table 6-5. Dynamometer Data Quality Indicators and QA/QC Checks

	Data Quality Indicators Goals			QA/QC Checks		
Parameter	**Accuracy**	**How Verified**	**Frequency**	**Description**	**Frequency**	**Allowable Result**
Speed	± 2.0 %	60-tooth wheel combined with frequency counter	At initial installation, annually, or after major repairs	Inspect calibration certificate	Prior to test	Current calibration meeting DQI goal
Load (Torque Sensor)	±0.5%	NIST-traceable weights and torque arm	Weekly	Inspect calibration certificate	Prior to test and after new calibration	Current calibration meeting DQI goal
				Torque trace acceptance test	Each test run	± 2.5 lb.ft for values ≤ 550 lb.ft, ± 5.0 lb.ft for values ≤ 1050 lb.ft, ± 10 lb.ft for values ≤ 1550 lb.ft

7.0 INSTRUMENT CALIBRATION AND FREQUENCY

The calibration schedule for major instruments is included with other QC activities in Table 6-1 above. 40 CFR 86.1316-86.1326 completely specifies the methods, frequency, and requirements of these calibrations. The general reference is *QPP 05 - Measurement and Test Equipment*. Records of all calibration activities are retained at SwRI and will be inspected by the GHG Field Team Leader and/or QA Manager.

8.0 DATA ACQUISITION AND MANAGEMENT

This section describes the generation and processing of test data at SwRI and the flow and disposition of these data from origin to the GHG Center reporting and archiving. Data acquisition and data management at SwRI are performed according to *QPP 08 - Data Processing and Reduction*, which conforms to required element B10 (Data Management) of EPA QA/R-5. The planned data streams, with responsibilities of the project manager and QA Manager, are depicted in Figure 8-1. The project manager is operationally responsible for all aspects of a test. The QA Manager is operationally responsible for all data quality aspects of a test with primary, but not exclusive, focus on the areas indicated in the figure. Qualitative data regarding the technology to be tested, per 40 CFR 86.1344 and 89.405, are manually recorded on the data sheets specified in SwRI #SOP 07-003. Operating and emissions data are captured by the data system described schematically in Figure 8-1.

SwRI will submit copies of initial raw and intermediate data at the end of each test sequence (setup, baseline, control) and at test completion. These data include:

- documents describing the engine, inspection, and setup activities;
- tracking forms for daily test activities and QC check results;
- external documents such as test fuel lot analyses and NIST-traceable calibration gas certificates;
- test cell data system printouts showing run summary instrument results for test cell system (dyno, CVS, direct and bag cart analysis instruments, etc.); and
- QC check summary printouts (zero, span drift, etc.).

SwRI will prepare and submit a letter report in printed and electronic (Microsoft Word) format to the GHG Center after completion of the field activities. The report will describe the test conditions, document all QA/QC procedures, summarize intermediate data, and present the verification test results. The SwRI QAO will also submit a QA report documenting the internal data assessment activities of the test as described in Section 9 below.

The GHG Center Project Manager will incorporate the SwRI material into the final verification report and statement and submit for review according to the GHG Center QMP and ETV Program guidance documents. The GHG Center QA Manager will incorporate the SwRI QA material into the GHG Center's internal assessment documentation for the test, along with assessment activities of the Center. These will include the supplemental TSA, performance audit, and ADQ described in Section 14.

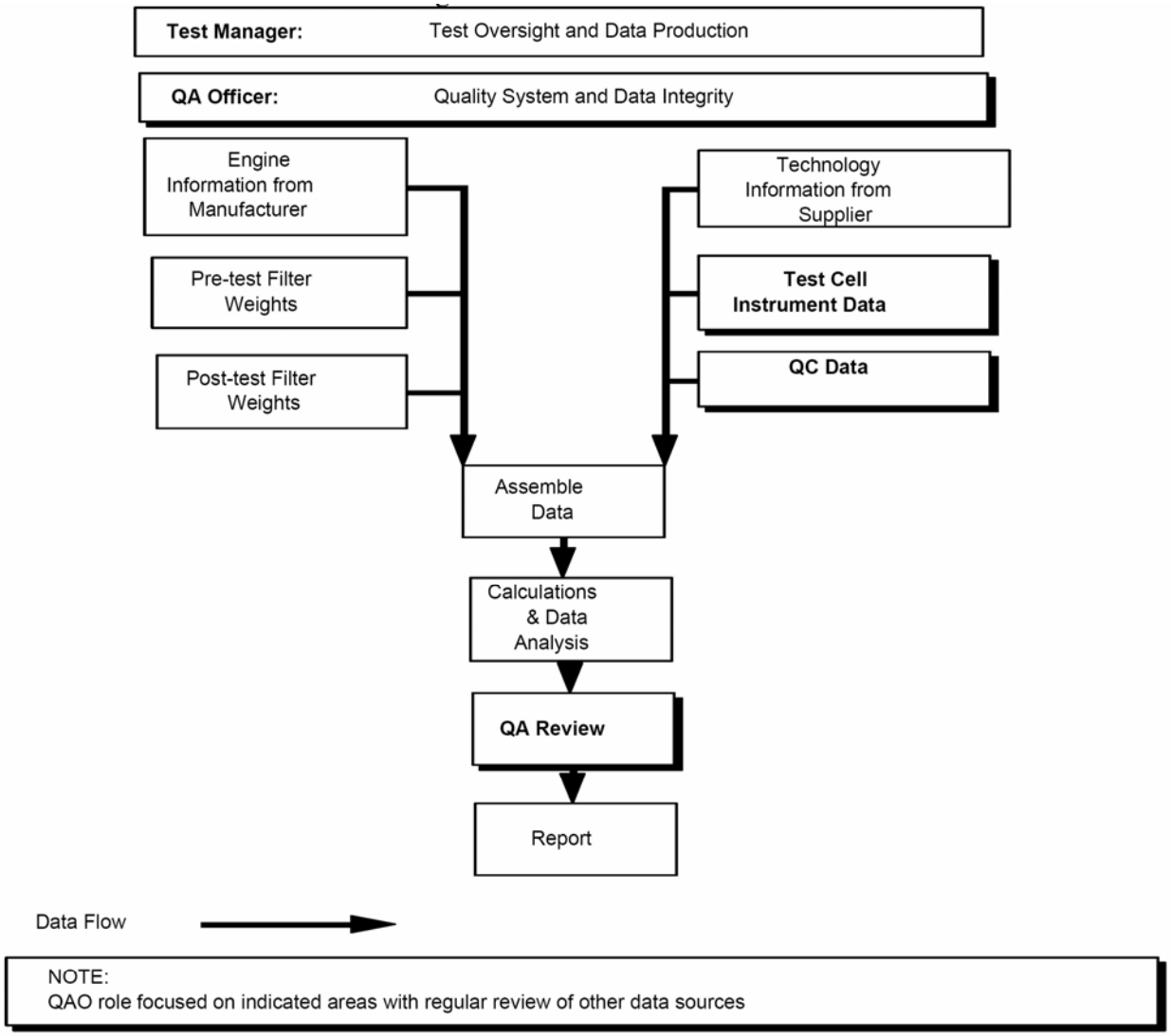

Figure 8-1. ETV Data Management System

9.0 INTERNAL AND EXTERNAL AUDITS

Several assessments are specified for this verification in accordance with the GHG Center QMP and the ETV Program QMP.

9.1 TECHNICAL SYSTEMS AUDIT

The GHG Center staff has previously conducted a quality and technical systems audits (TSA) of the SwRI DEER on an earlier related ETV test involving fuel economy and emissions performance on a light-duty vehicles. That TSA addressed major test components including documentation and adherence to standard procedures for testing, instrument calibration and QC checks, data processing, audits, and reporting. It also included review of some of the documentation of elements of the SwRI/DEER quality system. In view of the positive findings of that TSA and the similarity between the previous verification and the upcoming test, a second TSA on this technology class is not proposed for the upcoming test.

A tracking checklist of calibrations and QC activities was used as part of the TSA on the previous project. A version of that checklist will be adapted to the experimental details of the upcoming test. The field team leader will verify during the test that the equipment, SOPs, and calibrations are as described in this TQAP. The field team leader will complete the items on this checklist during his observation of the test and return the form to the GHG Center QA manager as part of the QC documentation of the test. He will incorporate this material into the ADQ described below.

9.2 PERFORMANCE EVALUATION AUDITS

The GHG Center specifies internal Performance Evaluation Audits (PEAs), as applicable, on critical measurements of every verification test. The Center will use the SwRI quality infrastructure for an internal PEA for this test. SwRI maintains a set of NIST-certified gas standard mixtures in the concentration ranges applicable to these measurements. The monthly calibration procedure requires that the DEER challenge the analytical instruments with these standards as a performance check independent of the calibration gas standards. The GHG Center will use this internal check in lieu of a blind PEA. The standard mixture challenge from that time will be used as a PEA if a monthly analyzer calibration under SOP 6-012 has been performed within a week of testing on the test cell used for this study. A separate challenge, according to the applicable portion of the SOP, will otherwise be conducted during the period of the test.

9.3 AUDIT OF DATA QUALITY

The GHG Center QA Manager will oversee an audit of data quality (ADQ) of at least 10% of all of the verification data in accordance with Table 9-1 of the ETV QMP. The ADQ will be conducted in accordance with EPA's [*Guidance on Technical Audits and Related Assessments for Environmental Data Operations*]. The ADQ will include (1) verification of input data and outputs reported by test cell instrumentation, (2) checks of intermediate calculations, and (3) a review of study statistics. The ADQ will also draw conclusions about the quality of the data from the project and their fitness for their intended use. Effort on this audit will be assigned as follows. The SwRI QAO, in this case, will conduct an internal ADQ of results generated by SwRI covering the areas described above and submit the audit report to the GHG Center QA Manager. The GHG Center QA Manager will review and incorporate this into an overall ADQ report, including documentation of subcontractor oversight and review of the final processing and reporting of the results.

9.4 EXTERNAL ASSESSMENTS

SwRI and GHG Center staff will cooperate with any external assessments by EPA. EPA personnel may conduct optional assessments (TSA, PEA, or ADQ) during this or any subsequent test. The external assessments will be conducted as described in EPA QA/G-7.

9.5 INTERNAL ASSESSMENTS

Internal assessment reports will be reviewed by the SwRI QAO and GHG Center QA Manager and they will respond as noted in Section 11. The written report of the ADQ will be reviewed by the GHG Center QA Manager and incorporated into or submitted as separate addenda to the verification report.

10.0 CORRECTIVE ACTION

A corrective action must occur when the result of an audit or quality control measurement is shown to be unsatisfactory as defined by the DQOs or by the measurement objectives for each task. The corrective action process involves the GHG Center project and QA staff as well as subcontractor personnel. A written corrective action report is required on major corrective actions that deviate from the TQAP. Corrective action is performed at SwRI according to *QPP 11 - Nonconformance and Corrective Action*, which conforms to required elements B5 (Quality Control) and C1 (Assessments and Response Actions) of EPA QA/R-5. Situations requiring corrective action will be communicated to the GHG Center field team leader who will, under direction of the GHG Center project manager, assess the incident and take and document appropriate action on behalf of the center. The project manager is responsible for and is authorized to halt work if it is determined that a serious problem exists.

11.0 DATA REDUCTION, REVIEW, VALIDATION, AND REPORTING

The field team leader's primary on-site function will be to monitor SwRI's activities. He will be able to review, verify, and validate certain data (test cell file data, QA/QC check results) during testing. The GHG Center project manager will incorporate the SwRI material into the final verification report and statement and submit this information for review according to the GHG Center QMP and ETV program guidance documents. The GHG Center QA Manager will incorporate the SwRI QA material into the GHG Center's internal assessment documentation for the test along with assessment activities of the Center. These will include the performance audit and ADQ described in Section 9.0.

12.0 REPORTING OF DATA QUALITY INDICATORS

The SwRI staff will collect and tabulate the DQIG values specified in Table 6-1 as part of the data processing steps described above. These will be reviewed both internally and by the GHG Center project manager and QA Manager in the preparation of their verification report and assessment reports. These reports, as specified in the GHG Center QMP, are submitted to both the EPA project officer and QA Manager.

13.0 DEVIATIONS FROM GVP

The technical aspects of this TQAP were constructed to be consistent with the technical requirements and philosophy of the GVP. The only planned deviations from the GVP are the omission of the durability test with an aged technology, and the omission of the additional GVP test runs at maximum power and torque. No other deviations from the GVP or this document are anticipated. If any such deviations are identified in the course of implementing this test, SwRI staff will consult with GHG Center staff as soon as possible to resolve the issues. Section 2.7 of EPA/QA R-5 states that the EPA will be notified of any significant deviations and the QAO will revise this document and submit it to EPA for review and approval.

14.0 REFERENCED QUALITY DOCUMENTS

14.1 EPA-ETV

EPA QA/R-5	EPA Requirements for Quality Assurance Project Plans, EPA QA/R-5, Office of Environmental Information, U.S. Environmental Protection Agency, EPA/240/B-01/003, March 2001.
EPA ETV QMP	Environmental Technology Verification Program Quality and Management Plan for the Pilot Period (1995-2000), National Risk Management Research Laboratory, National Exposure Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, EPA/600/R-98/064, May 1998 (or current version).
EPA QA/G-5	Guidance on Quality Assurance Project Plans, EPA QA/G-5, Office of Environmental Information, U.S. Environmental Protection Agency, EPA/600/R-98/018, February 1998.
EPA QA/G-7	Guidance on Technical Audits and Related Assessments, EPA QA/G-7, Office of Environmental Information, U.S. Environmental Protection Agency, EPA/600/R-99/080, January 2000.
GVP	Generic Verification Protocol for Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines (Draft), EPA Cooperative Agreement No. CR826152-01-3, January 2002.

14.2 GHGTC

GHGTC QMP	Greenhouse Gas Technology Center Quality Management Plan, Version 1.4, March, 2003.
SRI/USEPA-GHG-QAP-28	Test and Quality Assurance Plan—ConocoPhillips Fuel-Efficient High-Performance SAE 75W90 Rear Axle Gear Lubricant, SRI/USEPA-GHG-QAP-28, March 2003.

14.3 SOUTHWEST RESEARCH INSTITUTE

SwRI QAPP	Test/QA Plan for the Verification Testing of Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines (Version 1.0 April 8, 2002).

Quality Policy and Procedures (QPPs)

QSM	Quality System Manual – 2000, April 2001
QPP-03	Document Preparation and Control
QPP-05	Measurement and Test Equipment
QPP-07	Testing and Sample Analysis
QPP-07-003	Transient Test for Heavy-Duty Diesel Engines
QPP-08	Data Processing and Reduction
QPP-09	Analysis and Reporting
QPP-10	Training and Motivation
QPP-11	Nonconformance and Corrective Actions
QPP-12	Internal Audits
QPP-14	Quality Records

Standard Operating Procedures (SOPs)

SOP-06-003	Linearity Verification of Gas Dividers
SOP-06-002	NO_x Converter Efficiency Determination
SOP-06-012	Monthly Calibration of Analyzers for Continuous Dilute Gaseous Exhaust
SOP-06-016	Wet CO_2 Interference Check for CO Analyzers
SOP-06-021	FID Response for Methane
SOP-06-025	NO_x Analyzer and System Response Checks
SOP-06-041	NOx Analyzer CO_2 Quench Check
SOP-06-044	Hydrocarbon Analyzer Optimization
SOP-07-001	Power Validation for Heavy-Duty Diesel Engines
SOP-07-002	Power Mapping for Heavy-Duty Diesel Engines
SOP-07-009	Emissions Testing During Heavy-Duty Diesel Engine Transient Cycle
SOP-07-020	Particulate Filter Conditioning and Weighing
SOP-07-023	Operation of Bag Cart
SOP-12-001	Quality Audits
SOP-07-043	Blow-by Emissions Measurement of Heavy Duty Diesel Engines

Appendix A

Appendix A-1. Test Results Summary and DQO Checks

- Complete after each hot start test run is complete.
- After the third hot start test (and any additional tests), calculate the mean, sample standard deviation, and coefficient of variation (COV) for each parameter. COV is the sample standard deviation divided by the mean, as a percentage.
- Verify that the Data Quality Objectives (DQOs) are met for each parameter.
- Signature:_____

Table A-1a: Baseline Test Results & DQO Check

Parameter	Hot Start Run Number	Reported Value, g/Bhp-hr*	Mean, g/BHP-hr	s_{n-1}, g/Bhp-hr	Calculated COV, %	DQO COV, %,
BSFC	1					
	2					
	3					0.7
CO_2	1					
	2					
	3					0.8
PM	1					
	2					
	3					2.2
NO_X	1					
	2					
	3					1.2

*The value is the weighted value of the single cold start FTP test with the hot start FTP test for each run. See the TQAP for detailed calculations.

Table A-1b: Candidate Test Results & DQO Check

Parameter	Hot Start Run Number	Reported Value, g/Bhp-hr*	Mean g/BHP-hr	s_{n-1}, g/Bhp-hr	Calculated COV, %	DQO COV, %,
BSFC	1					
	2					
	3					0.7
CO_2	1					
	2					
	3					0.8
PM	1					
	2					
	3					2.2
NO_X	1					
	2					
	3					1.2

Appendix A-2. Test Fuel Verification

- Obtain a copy of the test fuel lot analysis.
- Review all analysis results and test method documentation.
- Properties and test methods must conform to the specifications given in the following table.

Audit Date: _____ Signature: _____

Fuel Lot ID: _____ Date Received: _____

Table A-2. Test Fuel Specifications

Description	ASTM Test Method No.	Specified Value	Analysis Value	Mfg. Certified Value	Meets Spec.?
Cetane Number	D613	40 - 50			
Cetane Index	D976	40 - 50			
Distillation Range: IBP 10 % point 50 % point 90 % point Endpoint	 D 86	 340 - 400 ^{o}F 400 - 460 ^{o}F 470 - 540 ^{o}F 560 - 630 ^{o}F 610 - 690 ^{o}F			
Sulfur	D 2622	0.03 - 0.05 %			
Viscosity	D 445	2.0 - 3.2			
Flashpoint	D 93	130 ^{o}F min.			
Hydrocarbons: Olefins Aromatics	 D 1319 D 5186	 Balance 27 %			
Specific Gravity	D 287	32-37 ^{o}API			

Notes: _____

_____

_____

_____

_____

_____

_____

Appendix A-3
QA/QC Checks

Signature: _____

Table A3-1: QA/QC Checks						
QA/QC Check Description	**Frequency**	**Allowable Result**	**Date Check Completed (SwRI)**	**Date Audit Completed (GHG Center)**	**OK?**	**Audit Data Source**
Dynamometer						
Dynamometer Calibration Certificates Review	Prior to test	Sensor accuracies (speed and load) meet Table 6-1 specifications				
Torque trace acceptance test	Each test run	± 2.5 lb.ft for values ≤ 550 lb.ft, ± 5.0 lb.ft for values ≤ 1050 lb.ft, ± 10 lb.ft for values ≤ 1550 lb.ft				
CVS System						
CVS System Calibration Certificates Review	Prior to test	Sensor accuracies (P, T, Q) meet Table 6-1 specifications				
Propane tank composition verification	Prior to placing new propane tank in service	< 0.35 % difference from previously used and verified tank				
Propane injection check	Weekly	Difference between injected and recovered propane ≤ ± 2.0 %				
Sample bag leak check	Before each test run	Maintain 10” Hg for 10 seconds				
Flow rate verification	Before each test run	≤ ± 5 cfm of nominal test point				
Dilution air temperature verification	During each test run	Between 20 and 30 ^{o}C				
Emission Analyzers						
Analyzer calibrations review	Once during test and upon completion of new calibration	All values within ± 2.0 % of point of ± 1.0 % of FS;				
Gas divider linearity verification	monthly	All points within ± 2.0 % of linear fit; FS within ± 0.5 % of known value				

Table A3-1: QA/QC Checks						
QA/QC Check Description	**Frequency**	**Allowable Result**	**Date Check Completed (SwRI)**	**Date Audit Completed (GHG Center)**	**OK?**	**Audit Data Source**
Calibration gas certification or naming	Prior to service	Average concentration of three readings must be within ± 1 % for calibration gas and NIST-traceable reference material				
Zero gas verification	Prior to service	HC < 1 ppmv CO < 1 ppmv CO_2 < 400 ppmv NO_X < 0.1 ppmv O_2 between 18 and 21 %				
Analyzer zero and span	Before and after each test run	All values within ± 2.0 % of point of ± 1.0 % of FS; zero point within ± 0.2 % of FS				
Analyzer drift	For each bag analysis	Post-test zero or span drift shall not exceed ± 2.0 % FS				
Wet CO_2 interference check	Monthly	CO (0 to 300 ppmv) interference ≤ 3 ppmv; CO (> 300 ppmv) interference ≤ 1 % FS				
CO_2 Quench Check	Annually	NO_x quench ≤ 3.0 %				
Converter Efficiency Check	Monthly	Converter Efficiency >90 %				
Particulate Measurement						
NIST-traceable calibration weight cross-check	Daily	Weight change < 10 µg				
Weight room temperature	Daily	Between 19 and 25 ^{o}C				
Weight room relative humidity	Daily	Between 35 and 53 % RH				
Reference filter weight change	Daily	Weight change < 20 µg				
Ambient Monitoring						
Test cell Wet/dry bulb thermometer calibration	Monthly	± 1.0 ^{o}F NIST-traceable standard				

Table A3-1: QA/QC Checks						
QA/QC Check Description	**Frequency**	**Allowable Result**	**Date Check Completed (SwRI)**	**Date Audit Completed (GHG Center)**	**OK?**	**Audit Data Source**
Test cell Barometer calibration	Weekly	Within ± 0.1” Hg of NIST-traceable standard				
Test cell temperature	Each test run	Between 68 and 86 ^{o}F				

Appendix A-4. Corrective Action Report

Verification Title:_____

Verification Description:_____

Description of Problem:_____
_____
_____
_____
_____
_____

Originator:_____ Date:_____

Investigation and Results:_____
_____
_____
_____
_____
_____

Investigator:_____ Date:_____

Corrective Action Taken:_____
_____
_____
_____
_____
_____

Originator:_____ Date:_____
Approver:_____ Date:_____

Carbon copy: GHG Center Project Manager, GHG Center Director, SRI QA Manager, APPCD Project Officer