SRI/USEPA-GHG-QAP-31
June 2004

Test and Quality Assurance Plan

Universal Cams, LLC
Dynamic Cam™
Diesel Engine Retrofit System

Prepared by:

Greenhouse Gas Technology Center
Southern Research Institute

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

EPA REVIEW NOTICE

This report has been peer and administratively reviewed by the U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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Greenhouse Gas Technology Center

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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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 Test Plans 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.

Universal Cams, LLC (UC) of Stuart, Florida, has developed a technology that is planned for use as a retrofit device for existing diesel, gasoline, and other engines. This technology can also be installed in new engines during production. The Dynamic Cam™ technology includes a cam-shaft, camshaft sprocket gear, and fuel injectors which are installed as one-time replacements of an OEM camshaft, camshaft sprocket, and fuel injectors. UC states that the technology will produce significant reductions in fuel consumption and emissions and will also produce improvements in engine horsepower and torque. UC wishes to verify performance of its Dynamic Cam™ technology for reductions in fuel consumption and emissions as a retrofit modification to a heavy-duty highway diesel engine. UC 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. This document is an ETV Generic Verification Protocol (GVP) developed by the Air Pollution Control Technology Verification Center (APCTVC). 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 UC Dynamic Cam™ 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 prepared by the GHG Center has been peer-reviewed by the technology developers (Universal Cams), 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 (VR) and Verification Statement (VS) upon field test completion. The same organizations listed above will review the report, followed by EPA-ORD technical review. The GHG Center Director and EPA-ORD Laboratory Director will sign the VS 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 (ISO) 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 (A2LA) 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, nonroad, 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 one 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]*, the ETV QMP, and the general requirements of the GVP.

1.3 ORGANIZATION OF THIS PLAN

This plan 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 plan 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. This should aid SwRI project personnel as well as the reviewer familiar with verification testing under the referenced documents. 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 plan reflect organizational differences and the specific role of the GHG center as the verification organization on this test. This plan also contains test-specific details of the UC Dynamic Cam™ 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 plan also describes testing under the framework of the GVP and the relevant Federal Test Procedures (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 plan 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. The following 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

The camshaft in an internal combustion engine is composed of lobes (called cams) and the shaft upon which the cams are mounted. It is tied to the engine's crankshaft by a chain, gears, or a belt. The camshaft lobes push against the valves in the engine as the camshaft rotates. The valves let the air/fuel mixture into the engine and allow the exhaust out of the engine. The camshaft and its lobes control the opening and closing of the valves in the cylinder heads -- when they open; when they close; how fast they open; how fast they close; and how high (lift) they open. Most engines have one camshaft. However, some engines have two camshafts or more. Springs on the valves return them to their closed position. There is a direct relationship between the shape of the lobes and the way the engine performs at different speed ranges.

The Universal Cams technology consists of three modified components of an internal combustion engine: (1) the camshaft, (2) cam sprocket, and (3) fuel injectors. These three proprietary products are referred to as the "Dynamic Cam™" technology. They are a suite of products complementing each other that UC claims can apply to all internal combustion engines using camshafts. UC also claims that every engine modified with this technology requires less fuel and more air, thereby reducing emissions and improving fuel economy.

The UC technology can be installed in either new engines (during production) or in used or rebuilt engines (in retrofit applications). UC states that the installation of this technology is identical to the installation process for any OEM camshaft, sprocket, and fuel injection system. No special installation procedures are required.

The three components of the UC Dynamic Cam™ technology to be verified are:

(1) Sprockey™ - This is an overhead camshaft sprocket or cam gear replacement. It is designed to be a replacement sprocket for the OEM camshaft sprocket or cam gear on all kinds of engines. UC claims that the modified sprocket changes the camshaft configuration, thereby improving the effectiveness of the camshaft. Sprockey™ can be installed by any competent mechanic using normal OEM installation procedures. The design was originally intended for heavy-duty diesel engines, but can also be applied to other types of engines. UC currently considers the Sprockey™ degree modifications and algorithmic differences proprietary.

(2) DynaCam™ - This is a camshaft replacement with new lobe configuration. Camshafts can be enhanced by modifying their lobe shape and configuration. The UC design was originally intended for heavy-duty diesel engines. UC can replace any camshaft arrangement – single overhead, double overhead, etc. The DynaCam™ differs from typical camshaft and lobe configurations by modifying the position, or degree, and shape of the camshaft lobes. UC states that the design creates a more efficient lobe shape for opening and closing valves. Lobe shapes will vary between engines and the position of the lobes is critical. UC considers the lobe positions and shapes proprietary at this time. Additional details will be disclosed after completion of successful verification testing.

(3) Leanjector™ - This is a fuel injector (reduced-fuel flow) replacement. Many engine manufacturers have adopted a "starve-the-engine" approach to meet emission reduction standards. This approach severely limits the amount of air that can be mixed with fuel in the combustion chamber. Universal Cams has observed that modifying an engine with just the Sprockey™ device alone or the Sprockey™ and DynaCam™ devices together makes the engine run leaner. The modified engines run with the same

amount of air (or more), but with far less fuel. The computer-controlled fuel injectors will adjust to providing less fuel but the reduced fuel flow can be made much more effective by installing the Leanjector™ injectors.

UC states that this technology will provide the following benefits:

- Increase fuel efficiency in both diesel and gasoline engines;
- Lower emissions in both diesel and gasoline engines, especially PM and NO_x;
- Significantly increase horsepower and torque in all engines;
- Save operating costs with lower fuel costs and increased vehicle mileage;
- Be applicable to compression ignition (diesel) and spark-ignition (gasoline) and four- and two-stroke engines;
- Be applicable to diesel, gasoline, natural gas, alternative fuels, bio-fuels, blended bio-fuels, hydrogen, and multi-fuel engines; and
- Retrofit into any existing internal combustion engine that uses camshafts - including automobiles, light and heavy trucks, buses, heavy construction equipment, tractors and combines, locomotives, yachts, ships, generators, and compressors.

UC claims that normal OEM installation procedures are used for installation of the Dynamic Cam™ technology. Cummins camshaft installation procedures are included in Appendix B of this TP. A local Cummins technician will be responsible for removal of the existing camshaft, cam sprocket, fuel injectors (and ancillary equipment) and subsequent installation of the Dynamic Cam™ technology.

2.2 TEST DESCRIPTION

2.2.1 Overview

This TQAP describes testing of the Universal Cams Dynamic Cam™ 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 Universal Cams Dynamic Cam™ system in reducing exhaust emissions and improving fuel economy of a 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. Additional measurements and calculation procedures will be used to determine fuel economy of the engine over a specified test cycle.

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. Install new OEM fuel injectors;
3. Change the engine oil and filter;
4. Break-in the fuel injectors and lubricant;
5. Map the baseline engine (develop torque curve);
6. Precondition the baseline engine ;
7. Soak the baseline engine;
8. Perform baseline engine testing for emissions and fuel consumption;
9. Install the Universal Cams Dynamic Cam™ system;
10. Break-in the UC system;
11. Map the modified engine;
12. Precondition the modified engine;
13. Soak the modified engine;

14. Perform modified engine testing for emissions and fuel consumption;
15. Evaluate the test data for data quality; and
16. 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 routed through a constant volume sampling (CVS) system to determine emission concentrations. An adjustable-speed turbine blower 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.

2.3 TEST ENGINE SELECTION AND SPECIFICATIONS

UC was responsible for selecting a representative test engine for the current verification based on their intended market. The diesel engine used in this test program will be a Cummins N-14 350-HP (turbocharged) engine manufactured in 1997. The Cummins N-14 series engine was manufactured from 1988 to 2002. This engine was selected for testing because it represents a large segment of heavy-duty diesel engines currently on the road for which the UC technology is intended. UC is responsible for locating and procuring the test engine and delivering it to the SwRI DEER. UC is also responsible for verifying that the engine has not been rebuilt or modified, and is operating reasonably within original OEM specifications. UC will provide documentation (such as operating and maintenance records) verifying the original certification, purchase, use, and history of this engine.

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-14 350 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 350-HP engine, but many of these parameters apply to the entire HP range of N-14 by Cummins engines. Parameters that may vary from engine to engine with varying horsepower are horsepower, peak torque, compression ratio, weight-to-power ratio, and, in some cases, governed speed.

Table 2-2 lists maximum performance data for Cummins N-14 350-HP engine operating parameters.

Table 2-1. Cummins N-14 350 HP Specifications

Parameter	Value (SI units)	Value (Metric units)
Advertised HP	350 bhp	261 kW
Peak Torque	1400 lb.·ft	1898 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

Table 2-2. Cummins N-14 350 Hp Maximum Rated Performance Data

Parameter	Governed Speed	Peak Power	Peak Torque
Engine speed, *RPM*	2100	1600	1200
Output, *BHP (kW)*	350 (261)	368 (274)	308 (230)
Torque, *lb·ft (N·m)*	875 (1187)	1208 (1638)	1350 (1831)
Inlet air flow, *CFM (litre/sec)*	1212 (572)	983 (464)	678 (320)
Charge air flow, *lb/min (kg/min)*	84 (38)	68 (31)	48 (22)
Exhaust gas flow, *CFM (litre/sec)*	2254 (1064)	2067 (975)	1642 (775)
Exhaust gas temperature, *°F (°C)*	606 (319)	727 (386)	846 (452)
Engine coolant heat rejection, *BTU/min (kW)*	6100 (107)	6100 (107)	5600 (99)
Radiator coolant flow, *U.S. gpm (litre/min)*	98 (371)	75 (284)	56 (212)
Turbo compressor outlet pressure, *in hg (mm hg)*	50 (1274)	46 (1170)	34 (867)
Turbo compressor outlet temperature, *°F (°C)*	319 (159)	308 (153)	257 (125)
Nominal fuel consumption, *lb/hr (kg/hr)*	121.2 (55.0)	117 (53.3)	98 (44.4)
Maximum fuel flow to pump, *lb/hr (kg/hr)*	550 (249)	450 (204)	350 (159)
Brake mean effective pressure, *PSI (kPa)*	154 (1064)	213 (1469)	238 (1639)

2.4 BASELINE ENGINE PREPARATION

2.4.1 Fuel-Injector Replacement

The engine will have new OEM replacement fuel injectors installed prior to beginning the testing of the baseline engine. Fuel injectors will be replaced to ensure that the baseline injectors are operating properly for comparison to the modified engine (which includes new Leanjector™ fuel injectors). The injectors will be replaced using procedures specified in the engine maintenance manual. All equipment installation and engine mechanical work on the Cummins engine will be performed by a local Cummins representative (Cummins Southern Plains). The technician will document all work completed, parts replaced, specific part numbers, and modifications to the engine.

2.4.2 Engine Inspection

The Cummins representative will visually inspect the visible parts of the engine during installation of the baseline OEM fuel injectors 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.

2.4.3 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 UC TECHNOLOGY

The test engine will be modified by installing the Universal Cams Dynamic Cam™ system after baseline engine testing is complete. A local Cummins representative (Cummins Southern Plains) will perform all equipment installation and engine mechanical work on the Cummins engine.

The GVP requires that UC provide written descriptions of the procedures for installation and post-installation engine adjustments required for optimum operation [*GVP, Section 2.2.3*]. UC states that the Cummins technician will be present and will be directed by UC regarding the installation of modified parts and subsequent tuning of the engine. UC personnel will be present for oversight and consultation during the installation of the Dynamic Cam™ technology. UC considers any other tuning steps proprietary. The Cummins representative will be required to sign a nondisclosure agreement with UC prior to commencing work on this engine.

The ETV verification process typically presents information necessary for anyone to duplicate the testing process. This UC TQAP indicates that some aspects of post-installation engine adjustment are considered proprietary by UC and will not be presented in this TQAP. The GHG Center cautions that users will not have access to certain technology tuning procedures unless provided by UC or their designated installers. Therefore, the user may not be able to duplicate the test procedures and results presented in the VR.

The Cummins technician, specifically certified by Cummins to work on N-14 engines, will remove the existing camshaft, cam sprocket, and fuel injectors (and any other auxiliary parts associated with this equipment). These will be replaced with the UC Dynamic Cam™ technology, consisting of camshaft (DynaCam™), cam sprocket (Sprockey™), and fuel injectors (Leanjector™) as well as any auxiliary parts. The technician will complete the installation based on:

- the Cummins Shop Manual for Camshafts (001-008 - included in Appendix B of this TQAP),
- Cummins Bulletin No. 3666142, Troubleshooting and Repair Manual, and
- any other Cummins written instructions for removal of this equipment and work with any other part of the N-14 engine during this process.

UC representatives will not physically touch the engine or Dynamic Cam™ technology unless assistance is requested by Cummins. Any “hands-on” interaction by UC will be documented by the field team leader and reported in the VR. Any alterations in the installation procedure will also be documented and reported in the VR.

UC will need to adjust the fuel/air mixture to optimize the effect of the Dynamic Cam™ operation after installation. These procedures are currently considered proprietary by UC. These procedures will be revealed after testing has been completed. The Cummins technician will follow the verbal instructions from UC for engine adjustment. The GHG Center will document all adjustments made to the engine after installation of the UC Dynamic Cam™ system. Such adjustments will be reported in the VR. UC 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 and modified engine must go through a break-in period to ensure proper break-in of new parts and the engine oil. 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.

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.

2.6.1.1 Baseline Engine Break-in

The baseline engine will undergo break-in for the new engine lubricant and the new baseline fuel injectors. This verification test will have the baseline engine operate under the Cummins break-in cycle for a period of 25 hours. This will ensure that the engine oil and fuel injectors are broken in. The actual break-in time, operating conditions, and test cycle will be documented by SwRI.

2.6.1.2 Modified Engine Break-in

The modified engine will undergo break-in for the UC Dynamic Cam™ system. UC does not specify any required break-in period, but this period will be used to ensure that the technology is functioning properly and has been operated for the same amount of time as the new baseline engine parts prior to testing. Therefore, for this verification test, the modified engine will also be operated under the conditions of the Cummins break-in cycle for a period of 25 hours. The actual break-in time, operating conditions, and test cycle 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 engines. 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.

Mapping results will be reported for both the baseline and modified test engine. Results will be compared to evaluate changes in engine performance as a result of the installation of the Dynamic Cam™ technology.

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. The prep period is completed after this one-hour period. The preconditioning runs are completed and then 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. 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:

$$BSFC = \frac{1/7(M_c) + 6/7\,(M_h)}{1/7(BHP\text{-}hr_c) + 6/7\,(BHP\text{-}hr_h)} \qquad \text{Eqn. 1}$$

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 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 calculations are specified in 40 CFR 86.1342-90.

Exhaust emissions will be analyzed for NO_x, PM, THC, CO, CO_2, and CH_4 during the test period. Engine and dynamometer operating conditions will be recorded. Sampling system, emission analyzer, and test cell operations will also be monitored.

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).

2.6.6 Evaluation of Maximum Fuel Consumption

In addition to the FTP cycle fuel consumption, the GVP also specifies measurement of fuel consumption at maximum power (rated conditions) and at peak torque at intermediate speed [GVP, Section 5.2.12]. These measurements will be made for both the baseline and modified engine after completion of the FTP cycle tests. Fuel consumption will be measured for three five-minute steady-state tests with the engine operating at the specified conditions, based on the engine map. The tests will alternate between the two conditions. Fuel consumption of the engine will be monitored at maximum power at rated speed for five minutes, then peak torque (at intermediate speed) for five minutes, and this cycle is repeated two more times. The carbon balance or direct-fuel measurement calculation of modal BSFC may be used (see 40 CFR 86 Subpart N for both calculations), depending on available equipment. The maximum fuel consumption will be reported as the mean and standard deviation of the three runs.

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 de-greened control technology 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 19), 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 Generic Verification Protocol (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 (VR) and Verification Statement (VS). The various management and quality assurance (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.

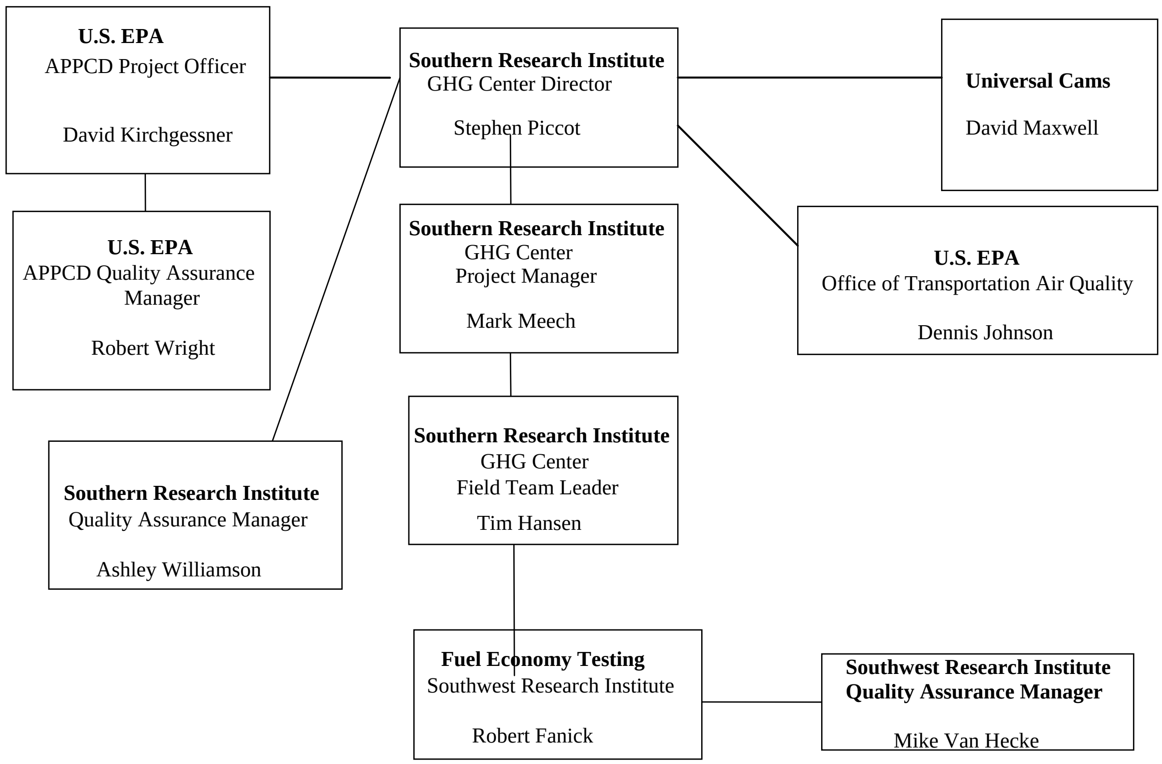

Figure 2-1. Project Organization

Project management responsibilities are divided among the EPA, Southern, and SwRI staff as described below.

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 (PEs) of verification tests, as appropriate;
- Provide assistance to GHG Center personnel in resolving QA issues;
- Review and approve this TQAP;
- Review and approve the VR and VS for each technology tested under this TQAP; and

2.8.2 Southern Research Institute

2.8.2.1 GHG Center 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. Stephen Piccot is the GHG Center 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. Piccot will sign the VS along with the EPA-ORD Laboratory Director.

2.8.2.2 GHG Center Project Manager

Mr. Mark Meech will serve as the Project Manager for the GHG Center. His responsibilities include:

- drafting the TQAP and VR;
- 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 UC, SwRI, EPA, and stakeholders.

2.8.2.3 GHG Center Field Team Leader

Mr. Tim Hansen will serve as the Field Team Leader and will supervise all SwRI activities to ensure conformance with the TQAP. Mr. Hansen 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. Hansen will communicate test results to the project manager at the completion of each test run. The field team leader and project manager 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. Ashley Williamson, 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 will review this TQAP. He has reviewed the applicable elements of the SwRI Quality System and approved quality requirements for implementation by SwRI technical and quality staff on the coming test. He will also review the verification test results and ensure that applicable internal assessments are conducted as described in Section 9.5. Dr. Williamson will report all internal audit and corrective action results directly to the GHG Center 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 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 VR.

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. He will conduct an internal PEA and ADQ of SwRI data collection activities on this test as described in Section 9 and report results to the GHG Center QA Manager.

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 Universal Cams

Mr. David Maxwell will serve as Universal Cams' primary contact person. Mr. Maxwell will provide technical support in accurately representing the UC technology. Mr. Maxwell will review the TQAP and VR and provide written comments. Mr. Maxwell may be present during the verification testing. UC will be responsible for procuring the engine and sending it to SwRI. UC will be responsible for contacting and directing the local Cummins technician.

2.8.5 EPA-OTAQ

Mr. Dennis Johnson will be the Project Engineer for EPA's OTAQ. He was provided a copy of the TQAP for consistency review with OTAQ requirements and test protocols.

2.9 SCHEDULE AND MILESTONES

An independent quality system and technical system assessment will be performed following submittal of the TQAP.

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

Verification Test Plan Development	**Dates**
GHG Center Internal Draft Development	October 15, 2003 – January 16, 2004
UC Review/Revision	January 16 – February 13, 2004
Industry Peer-Review/Revision	February 20 - March 5, 2004
EPA Plan Review	March 9 – April 5, 2004
Final Plan Revision and EPA Approval	April 6 – April 19, 2004
Final Document Posted	April 28, 2004

Verification Testing and Analysis	**Dates**
Preliminary Meeting and review at SwRI	May 24, 2004
Testing	May 25 – June 4, 2004
Data Validation and Analysis	June 7 – June 18, 2004

Verification Report Development	**Dates**
GHG Center Internal Draft Development	June 21– July 23, 2004
UC Review and Report Revision	July 26– August 6, 2004
EPA and Industry Peer-Review	August 2-August 11 2004
Final Report Revision and EPA Approval	August 23 – September 10, 2004
Final Report Posted	September 24, 2004

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 CRITICAL MEASUREMENTS

Critical measurements are for the exhaust gas concentrations of CO_2, NO_x, PM, HC, and CO [*GVP, Section 2.3*]. CO_2 is listed as a required secondary measurement under the GVP. However, CO_2 emissions and the related quantity BSFC are primary measurements for this and other GHG Center verifications because of the economic and GHG implications of improved fuel economy.

3.2 DATA QUALITY OBJECTIVES

DQOs are statements about the planned overall accuracy of the BSFC improvements and pollutant reductions. Two documents provide the basis for this subsection: (1) the [*GVP*] and (2) the *Test and Quality Assurance Plan—ConocoPhillips Fuel-Efficient High-Performance SAE 75W90 Rear Axle Gear Lubricant* published by the GHG Center ("Lubricant TP"). The references contain more detailed discussion than can be provided here.

3.2.1 Minimum Number of Test Runs

More test runs generally provide a more precise characterization. The first DQO development step involves determining the minimum number of test runs that will achieve the required data quality.

The BSFC improvement, for example, is the difference between the baseline engine and the same engine with the UC modifications in place. The difference is also known as "delta" (or Δ). The estimate for the minimum number of test runs required to show a statistically significant Δ depends on:

- the expected mean BSFC value for each test condition,
- the absolute value of Δ, and the resulting relative value expressed as a percentage,
- allowable statistical uncertainty, and
- the test data's relative standard deviation, expressed as a percentage (also known as the coefficient of variation, or COV).

The following equation for the minimum number of test runs is derived from the GVP (Appendix B, Equation B-1):

$$n \approx \left(Z_\alpha + Z_\beta\right)^2 \frac{\left[COV_1^2 + \left(1 - \delta/100\right)^2 * COV_2^2\right]}{\delta^2} \qquad \text{Eqn. 2}$$

where:

n = number of test runs, rounded up to the next integer
Z_α = 1.645, or normal distribution value for upper-tail probability when 1-α is 0.95
Z_β = 1.282, or normal distribution value for upper-tail probability when 1-β is 0.90
COV_1 = coefficient of variation (sample standard deviation divided by the mean, expressed as a percentage) of the baseline engine BSFC
COV_2 = coefficient of variation of the modified engine BSFC
δ = relative BSFC change between the as-received engine and the modified engine, expressed as $\frac{\Delta}{BSFC_{baseline}} * 100$

Table 3-1 shows the estimated number of test runs for each verification parameter. An estimated 20% improvement in BSFC provided by UC is the source for the assumption of a 20-percent improvement for each verification parameter identified in the table. Previous engine dynamometer tests of baseline and modified 275-hp Cummins and 400-hp Detroit diesel engines conducted by SwRI form the basis for the Table 3-1 entries. SwRI performed the engine dynamometer tests as part of past ETV verifications of diesel retrofit technologies. A total of nine test series was considered for the BSFC COV estimates and six for each of the pollutant COV estimates. Each test series consisted of three test runs. The engines, test equipment, and test conditions are expected to be similar to those experienced in this verification. Note that the GVP adopts n = 3 as the minimum number of test runs, even though the table shows that the equation yields n < 1 for most parameters.

Table 3-1. GVP Test Run Estimate[a]

Parameter	Value A[b], lb/Bhp-hr	$s_{n-1,A}$, $S_{n-1,B}$[c] lb/Bhp-hr	COV_A, %	Value B[b] lb/Bhp-hr	COV_B, %	$n_{Eqn. 2}$	$n_{rounded}$
BSFC	0.412	0.005	0.7	0.330	0.9	0.02	3
CO_2	592	7.000	0.8	473	1.0	0.03	3
PM	0.072	0.002	2.2	0.058	2.8	0.21	3
NO_X	3.970	0.060	1.2	3.176	1.4	0.06	3
THC	0.174	0.035	7.3	0.139	9.1	2.52	3[d]
CO	1.020	0.060	2.5	0.816	3.1	0.26	3[d]

[a]Assumes 20-percent improvement for each parameter
[b]Value A is the mean for the as-received engine; Value B is the mean for the UC-modified engine.
[c]s_{n-1} is sample standard deviation. The table assumes the same absolute sample standard deviation for the as-received and UC-modified engine.
[d]THC and CO are not a primary focus of this verification.

The primary verification parameters are BSFC (as derived from CO_2), NO_X, and PM. The tests will include THC and CO, but no DQOs will apply because they are not the primary focus of this verification. 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.

3.2.2 Confidence Intervals and DQOs

Fuel consumption improvement or pollutant reductions will be expressed as the mean Δ between the baseline and modified engine combined with an accuracy statement. The accuracy statement will be the 95-percent confidence interval, expressed in relative terms. An example would be "BSFC mean Δ was 20 ± 2.9 percent." The confidence interval depends on the sample standard deviation (s_{n-1}) for each parameter as found during the tests. The mean Δ for each parameter must be greater than s_{n-1} [Lubricant TP, Section 2.3]. If it is not, the 95-percent confidence interval is wider than the change itself, and it cannot be deemed statistically significant [Lubricant TP, Section 2.2, 2.4].

This implies that s_{n-1} could serve as each parameter's DQO because it is directly related to the determinations' overall accuracy. More generally, the COV (a normalized expression of s_{n-1}) will be the DQO. The COVs for the historical SwRI data set for similar diesel engine retrofit technology engine dynamometer tests provide the DQO goals for this test. Based on this historical data and testing similarities, the DQOs, stated as COVs, should be achievable for the UC test if the test personnel adhere to the test procedures and methods specified in this TQAP. Table 3-2 summarizes each DQO. It also shows the smallest quantifiable mean Δ based on the COV for the historical data set, for which the UC test should be similar.

Table 3-2. Data Quality Objectives					
Parameter	**Expected Baseline Value, lb/Bhp-hr**	**s_{n-1}, g/Bhp-hr**	**COV, %, DQO**	**95%-Confidence Interval (Smallest Quantifiable Mean Δ), lb/Bhp-hr**	**Smallest Quantifiable Mean Δ, % (relative to baseline)**
BSFC	0.412	0.003	**0.7**	± 0.007	± 1.6
CO_2	592	4.961	**0.8**	± 11.2	± 1.9
PM	0.072	0.002	**2.2**	± 0.004	± 5.0
NO_X	3.970	0.046	**1.2**	± 0.104	± 2.7

As an example, the BSFC shown in Table 3-2 indicates that the baseline engine is expected to use about 0.412 lb/Bhp-hr of fuel, based on historical data. Testers can expect the sample standard deviation for the baseline BSFC to be ± 0.003 lb/Bhp-hr, or a 0.7 percent COV. Completion of three test runs yielding this or a lower COV would meet the specified DQO for BSFC. The 95% confidence interval corresponding to the standard deviation and COV for the baseline BSFC data set is ± 0.007 lb/Bhp-hr. To be statistically significant, the mean Δ must be greater than the 95% confidence interval of either the baseline or candidate data sets (assumed to be indentical in this case). Therefore, the smallest statistically significant quantifiable mean Δ is equivalent to the 95% confidence interval. This is ± 1.6 percent of the expected baseline BSFC value.

3.2.3 Additional DQO Information

SwRI's historical data are based on twenty test runs. This test campaign will use three and it is possible that the observed COVs may be greater than the DQO goals listed in Table 3-2. This situation would result in the field team leader, GHG Center project manager, UC personnel, and other funding agencies possibly opting to conduct more test runs to better characterize the COVs and the technology performance.

It is also possible that the mean Δ for any parameter could be less than the standard deviation for either data set, even though the tests meet the DQOs for the associated COVs. The report will, therefore, note that the mean Δ is not 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.

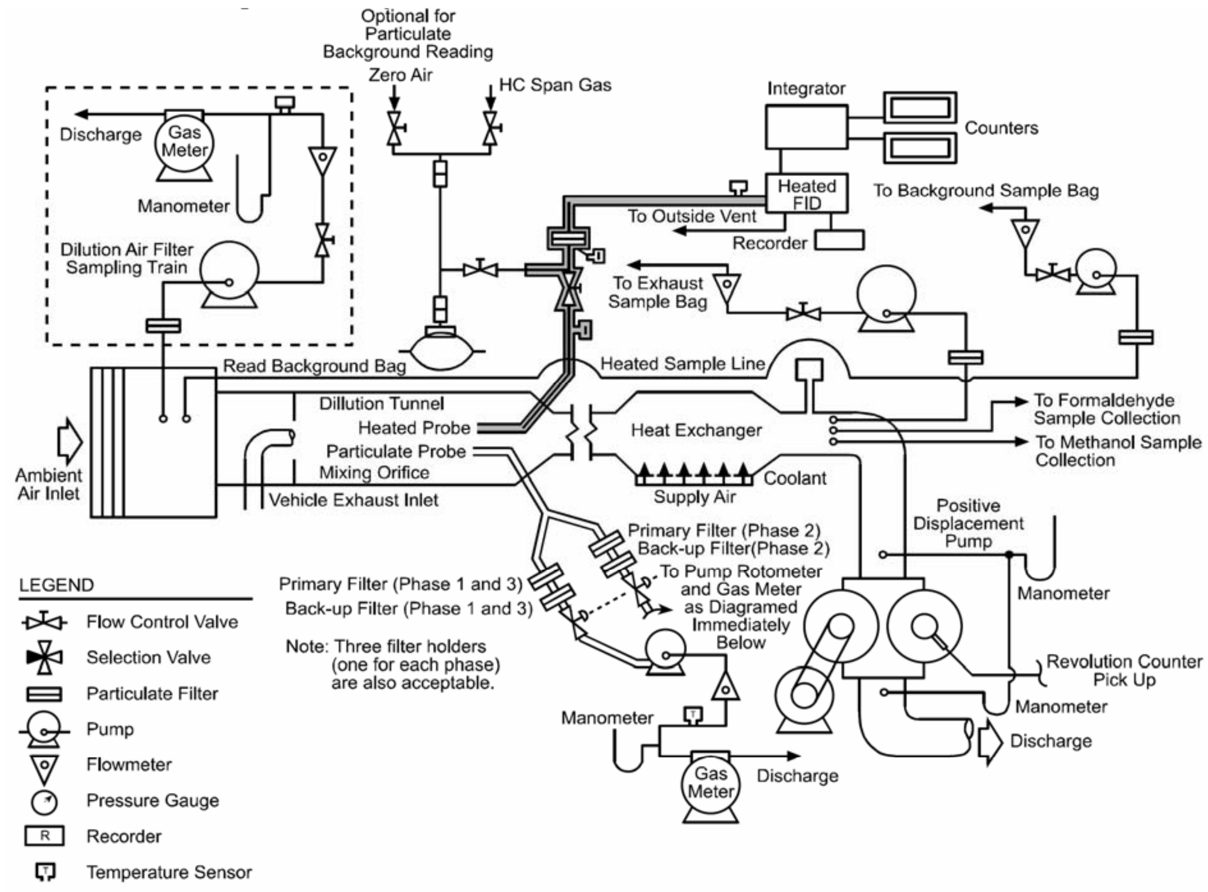

Figure 4-1. Gaseous and Particular Emissions Sampling System (PDP-CVS) [SwRI]

4.2 EXHAUST GAS MEASUREMENT SYSTEM SPECIFICATIONS

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 - 100 ppmv 100 ppm	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

4.3 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.

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 DQI goals 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.

Table 6-1 lists 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. Data Quality Indicator Goals and QA/QC Checks

System or Parameter		Data Quality Indicator Goal			QA/QC Check		
		Accuracy	**How Verified**	**Frequency**	**Description**	**Frequency**	**Allowable Result**
Dynamometer	Speed	± 2.0 %	60-tooth wheel combined with frequency counter	At initial installation 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
CVS System	Pressure	± 2.0 % of reading	Calibration of sensors with NIST-traceable standard	At initial installation 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	At initial installation or after major repairs	Inspect calibration certificates	Prior to test	Current calibration meeting DQI goal
	Volumetric flow rate	± 0.5 % of reading	CVS and propane critical orifice calibration	At initial installation or after major repairs	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

TABLE 6-1. Data Quality Indicator Goals and QA/QC Checks							
System or Parameter		Data Quality Indicator Goal			QA/QC Check		
		Accuracy	How Verified	Frequency	Description	Frequency	Allowable Result
					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 °C
Instrumental Analyzers	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

TABLE 6-1. Data Quality Indicator Goals and QA/QC Checks

System or Parameter	Data Quality Indicator Goal			QA/QC Check		
	Accuracy	How Verified	Frequency	Description	Frequency	Allowable Result
				CO Analyzer Only		
				Wet CO_2 interference check	Monthly	CO (0 to 300 ppmv) interference ≤ 3 ppmv; CO (> 300 ppmv) interference ≤ 1 % FS
				NO_x Analyzer Only		
				CO_2 Quench Check	Annually	NO_x quench ≤ 3.0 %
				Converter Efficiency Check	Monthly	Converter Efficiency >90%
Particulate Matter Analysis	± 1.0 µg	NIST-traceable scale calibration, weighing room controls, filter weight control	Daily	NIST-traceable calibration weight cross-check	Daily	Weight change <10 µg
				Weight room temperature	Daily	Between 19 and 25 °C
				Weight room relative humidity	Daily	Between 35 and 53% RH
				Reference filter weight change	Daily	Weight change <20 µg
Supplementary instruments and additional QA/QC checks				Test cell Wet/dry bulb thermometer calibration	Monthly	Within ± 1.0 °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 °F
				Test fuel analysis	Prior to testing	Conforms to 40 CFR §86.1313 specifications (See Appendix A-2)

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. Specific instruments and the applicable SOPs for implementation are described below. 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 VR and VS 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.

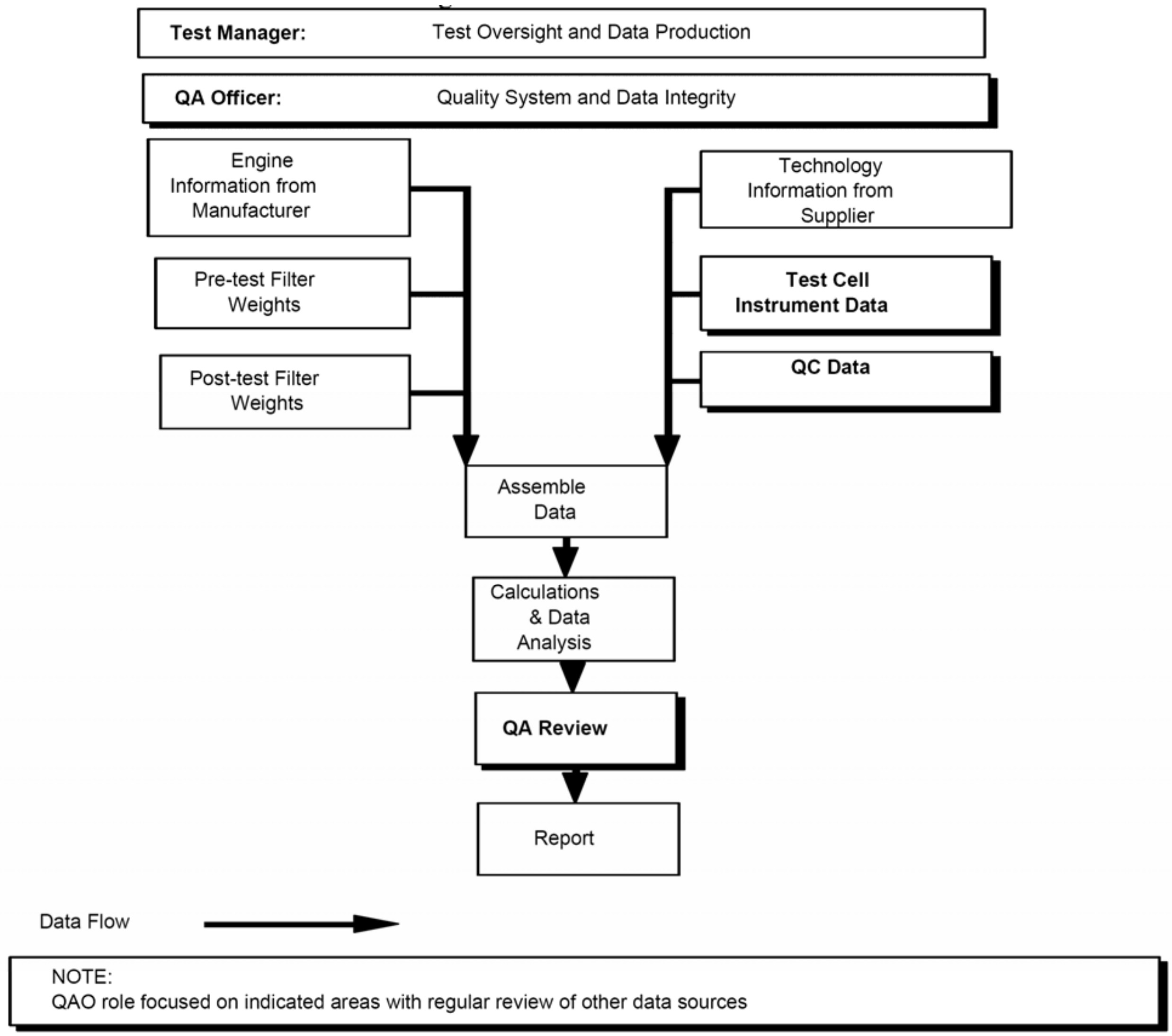

Figure 8-1. ETV Data Management System

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 percent 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 VR.

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 request (CAR) 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 VR and VS 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 VR 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 plan were constructed to be consistent with the technical requirements and philosophy of the GVP. The only planned deviation from the GVP is the omission of the durability test with an aged technology. No other deviations from the GVP or this document are anticipated. Should this phase of testing be successful, a second phase of testing is planned that will address durability testing. 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

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				
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				

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**
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 °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 °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 °F				

Appendix A-4
Evaluation of Maximum Fuel Consumption

- Measure fuel consumption at maximum power (rated conditions) and at peak torque at intermediate speed.
- Complete for both the baseline and modified engine after completion of the FTP cycle tests.
- Measure fuel consumption during each of three five-minute steady-state tests with the engine operating at the specified conditions, based on the engine map.
- Alternate between the two conditions during the testing. Monitor fuel consumption at maximum power at rated speed for five minutes, then peak torque at intermediate speed for five minutes.
- Use carbon balance or direct-fuel measurements for calculation of modal BSFC (see 40 CFR 86 Subpart N for both calculations), depending on available equipment.

Signature:____

Date:____

☐ Baseline engine

☐ Modified engine

Date	Test ID No.	Operating Conditions[a]	Brake Specific Fuel Consumption (BSFC) (g/BHP-hr)
	1a	MP	
	1b	PT	
	2a	MP	
	2b	PT	
	3a	MP	
	3c	PT	
	Mean	MP	
	Std. Deviation	MP	
	Mean	PT	
	Std. Deviation	PT	

[a] Indicate maximum power (MP) or peak torque (PT)

NOTES:

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Appendix A-5. Corrective Action Report

Verification Title:____

Verification Description:____

Description of Problem:____

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Originator:______________________ Date:____________

Investigation and Results:____

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Investigator:______________________ Date:____________

Corrective Action Taken:____

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Originator:______________________ Date:____________
Approver:______________________ Date:____________

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

Appendix B