SRI/USEPA-GHG-QAP-28
March 2003

Test and Quality Assurance Plan

ConocoPhillips
Fuel-Efficient High-Performance SAE 75W90 Rear Axle Gear Lubricant

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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Rear Axle Gear Lubricant

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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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Test Plan Final: March 2003

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List of Acronyms and Abbreviations

APPCD	Air Pollution Prevention and Control Division
^{o}C	degrees Centigrade
CFR	Code of Federal Regulations
CFO	critical flow orifice
CFV	critical flow venturi
CO	carbon monoxide
CO_2	carbon dioxide
COV	coefficient of variation
cP	Centipoise
cSt	Centistoke
CVS	constant volume sampling
CWF	carbon weight fraction
DDS	Durability Driving Schedule
DQI	data quality indicator
DQO	data quality objective
EPA-ORD	Environmental Protection Agency Office of Research and Development
ETV	Environmental Technology Verification
^{o}F	degrees Fahrenheit
FEHP	ConocoPhillips Fuel-Efficient High-Performance SAE 75W90 rear-axle gear lubricant
FTP	Federal Test Procedure
FRL	Ford Research Laboratory
g/mi	grams per mile
GHG	greenhouse gas
HFET	Highway Fuel Economy Test
Hz	Herz
ISO	International Organization for Standardization
Kg/L	kilograms per liter
lbf	pounds force
LHV	lower (or net) heating value
MAD	mileage accumulation dynamometer
mpg	miles per gallon
NIST	National Institute of Standards and Technology
NO	nitric oxide
NO_2	nitrogen dioxide
NO_X	blend of NO, NO_2, and other oxides of nitrogen
PEA	performance evaluation audit
QA	quality assurance
QA/QC	quality assurance / quality control
QMP	Quality Management Plan
SAE	Society of Automotive Engineers
SAO	smooth approach orifice
SG	specific gravity
SOP	standard operating procedure
SRI	Southern Research Institute
SRM	standard reference material

List of Acronyms and Abbreviations
(continued)

SUV	sport utility vehicle
SwRI	Southwest Research Institute
SwRI DER	Southwest Research Institute Department of Emissions Research
THC	total hydrocarbons (as carbon)
UDDS	Urban Dynamometer Driving Schedule
VETS	Vehicle Emissions Testing System
VEZ	vehicle emission zero (gas)
U.S. EPA	United States Environmental Protection Agency

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. With performance data developed under this program, technology buyers, financiers, and permitters in the United States and abroad will be better equipped to make 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 (SRI), 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 (Test Plan) 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 1999, automobiles and light trucks consumed approximately 192.8 x 10^6 and 139.8 x 10^6 gallons per day of gasoline and diesel fuel, respectively. Combustion products from these fuels represented approximately 169.7 million metric tons of carbon dioxide (CO_2) for automobiles and 123.0 million metric tons for light trucks. Automobiles and light trucks are responsible for approximately 34.2 and 24.8 percent of total CO_2 emissions in the U.S., respectively. Small fuel efficiency or emission rate improvements are expected to have a significant beneficial impact on nationwide greenhouse gas emissions.

ConocoPhillips has developed the Fuel-Efficient High-Performance SAE 75W90 Rear-Axle Gear Lubricant (FEHP) and has requested that the GHG Center independently verify its performance. ConocoPhillips developed FEHP in partnership with an axle manufacturer (Visteon Corporation) and an additive supplier (Ethyl Petroleum Additives, Ltd.), and markets it as a fuel-efficient high- performance multi-grade gear lubricant for light duty trucks, automobiles, and sport utility vehicles (SUVs). The development process included durability tests on 43 vehicles operating over a total of 2.8 million fleet miles. The developers report incremental (0.1 to 0.2 miles per gallon [mpg]) fuel economy improvements with FEHP as compared to standard lubricants.

FEHP is a suitable verification candidate considering its potentially significant beneficial environmental quality impacts and ETV stakeholder interest in verified transportation sector emission reduction technologies. The GHG Center plans to verify the fuel economy performance attributable to FEHP in a Ford Motor Company (Ford) Lincoln-brand SUV. Verification tests will take place at Southwest Research Institute's Department of Emissions Research (SwRI DER) in San Antonio, TX, and will consist of repeated fuel economy tests as described below.

This Test Plan specifies FEHP lubricant performance 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, and will guide test implementation, document creation, data analysis, and interpretation.

The technology developers, technology user (Ford), SwRI, and the EPA QA team have reviewed this Test Plan. Once approved, as evidenced by the signature sheet at the front of this document, it will meet the requirements of the GHG Center's Quality Management Plan (QMP) and thereby satisfy the ETV QMP requirements. The GHG Center will post the final Test Plan on their Internet site at www.sri-rtp.com and the ETV program site at www.epa.gov/etv.

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

The following subsection (1.2) describes the FEHP technology and the performance verification parameters to be quantified. Subsection 1.3 discusses the GHG Center's procedure for selecting the independent lab that will perform the fuel economy tests. Section 1.0 concludes with a discussion of key organizations participating in this verification, their roles, and the verification test schedule. Section 2.0 describes the technical approach for verifying each parameter, including sampling and analytical procedures. Section 3.0 identifies the data quality assessment criteria for critical measurements, states the accuracy, precision, and completeness goals for each measurement, and outlines QA/QC procedures. Section 4.0 discusses data acquisition, validation, reporting, and auditing procedures.

1.2. FEHP DESCRIPTION

ConocoPhillips and Visteon state that FEHP provides excellent fuel economy, extreme pressure lubrication and antiwear protection under severe service. The product developers performed extensive bench, dynamometer, and vehicle tests. They used proprietary axle efficiency and spin-loss tests to evaluate frictional losses and to optimize axle efficiency while maintaining low temperatures. ConocoPhillips' controlled test results found FEHP lubricant properties to be better than synthetic reference fluids under most conditions. Subsequent EPA fuel economy testing by the Ford Research Laboratory (FRL) confirmed this by showing a 1.5 percent increase in fuel economy over the reference oil normally installed in light truck rear axles.

According to ConocoPhillips, the FEHP offers the following benefits:

- improved axle efficiency,
- reduced temperature under severe towing,
- reduced spin losses,
- improved thermal and oxidative stability.

Projects to certify the FEHP for use in limited slip differentials have been completed successfully, and the FEHP is in current production.

ConocoPhillips states that the FEHP's unique fluid properties include high lubricant film strength under heavy loads and high temperatures. This is said to provide excellent component surface protection. At low temperatures, the FEHP minimizes frictional drag with a viscosity of 90,000 cP at –40 °C. Table 1-1 summarizes typical FEHP physical properties.

Table 1-1. FEHP Fluid Properties

Specified Test	Specified Method	Minimum Value Allowed	Maximum Value Allowed	Typical Values
Kinematic Viscosity at 100 °C, cSt	ASTM D445	17	18.5	17.65
Kinematic Viscosity at 40 °C, cSt	ASTM D445	--	--	108.7
Viscosity Index	ASTM D2270	172	--	179.5
Pour Point, °C	ASTM D97	--	-42	-48
Sulfur, %	ASTM D1552	1.23	2.21	1.8
Phosphorus, %	ASTM D4951	0.07	0.123	0.09
Nitrogen, %	ASTM D4629	0.083	0.263	0.14
Boron, %	ASTM D4951	0.006	0.19	0.012
Moisture, %	Karl Fischer Titration, ASTM D6304	--	0.10	0.04
Flash Point, °C	ASTM D92	150	--	193
Density @ 60 °F, Kg/L	ASTM D4052	--	--	0.866
Copper corrosion	ASTM D130	--	2b	1b

1.3. PERFORMANCE VERIFICATION PARAMETERS

The GHG Center will verify the fuel economy change (Δ or "delta") due to FEHP use. Δ will be the primary performance parameter as quantified by the following equation:

$$\Delta = \textit{Mean Fuel Economy}_{FEHP} - \textit{Mean Fuel Economy}_{Ref.Oil} \qquad \text{(Eqn. 1)}$$

Where:
Δ = fuel economy change, mpg
Mean Fuel Economy $_{\text{FEHP}}$ = average fuel economy with FEHP lubricant, mpg
Mean Fuel Economy $_{\text{Ref.Oil}}$ = average fuel economy with reference lubricant, mpg

The verification will consist of a series of fuel economy tests on one 2003 model year Lincoln Navigator SUV. The general test sequence will be:

- Installation and break-in of fresh standard factory-specified SAE 75W-140 rear-axle lubricant (the "reference oil") and engine lubricant for 1000 miles;
- Reference oil fuel economy tests;
- Removal of the reference oil; rear axle cleaning and preparation for the FEHP;
- Installation and break-in of fresh FEHP and engine lubricant for 1000 miles;
- Fuel economy tests with FEHP.

Subtraction of the average reference oil test results from the average FEHP test results will yield the fuel economy change attributable to FEHP as shown in Eqn. 1.

The test vehicle will have from 10,000 to 25,000 miles on its odometer at the beginning of the test campaign. At this mileage, the vehicle can be expected to operate normally with minimal aging effects. Testers will ensure that the vehicle's engine lubricant is fresh at the beginning of each series of rear-axle lubricant tests. This is because the 1000 mile break-in period for the rear-axle lubricant represents a significant fraction of the engine lubricant's 3500 to 7000 - mile life.

Each fuel economy test run will conform to the widely accepted Federal Test Procedure (FTP) and Highway Fuel Economy Test (HFET) for highway vehicles. Code of Federal Regulations (CFR) Title 40 Part 86, "Control of Emissions from New and In-Use Highway Vehicles and Engines" (1), § 86.115, and Part 600, "Fuel Economy of Motor Vehicles" (2), § 600.109, are the FTP and HFET source documents.

Test personnel will operate the test vehicle on a chassis dynamometer according to the load profiles specified in the FTP and HFET. The GHG Center will use the composite fuel economy, determined by harmonically averaging the city and highway fuel economy values (weighted 0.55 and 0.45, respectively), to determine fuel economy change.

The expected fuel economy change will be small, but consistent. Several repeated test runs under each lubricant condition will be necessary to support a credible and statistically valid fuel economy change determination. Section 2.0 presents detailed discussion of the number of test runs required and brief descriptions of measurement and analysis methods.

The vehicle tests will also quantify pollutant and greenhouse gas emissions (CO, CO_2, NO_X, and THC) Although these parameters are not part of the primary verification, they are of interest to the GHG stakeholder community. The marginal cost of their measurement and reporting, in conjunction with the fuel economy test runs, is minimal. The verification Test Report will include these results for information only.

1.4. LABORATORY SELECTION

In order to discern a difference in fuel economy that is less than 0.2 mpg, run-to-run variability within each test condition (i.e. reference oil or FEHP) must be very low. Differences may not be discernable without adherence to strict laboratory and test procedures. As will be discussed in Section 2.0, this means that the standard deviation (or coefficient of variation) of each test run series must also be very low. The GHG Center examined three testing laboratories' qualifications to assess each lab's ability to produce high precision test data. Table 1-2 summarizes their characteristics.

Table 1-2. Laboratory Selection Criteria

	Southwest Research Institute	**Ford Research Laboratory**	**Environmental Solutions Worldwide, Inc.**
Has experience conducting fuel economy tests under EPA city and highway driving cycles	Yes	Yes	Yes
Maintains test facility and equipment which comply with 40 CFR Part 86 specifications (e.g., chassis dynamometer capable of reproducing road load and vehicle inertia weight, constant volume sampling system, and various analyzers for exhaust emission measurements)	Yes	Yes	Yes
Has conducted fuel economy tests which required detection of small improvements	Yes – engine lubrication oil	Yes – ConocoPhillips FEHP axle lubricant	No
Typical fuel economy improvements measured (mpg)	0.55 ± 0.18 [a]	0.29 ± 0.08[a]	Not Available
Has developed test procedures to reduce variability in fuel economy determinations	Yes	Yes	No
Typical fuel economy test repeatability results; Standard deviation of triplicate test runs (mpg)	0.02 to 0.18	0.03 to 0.09	0.15 to 0.30
Is independent from the technology vendor	Yes	No[b]	Yes
Approximate cost for conducting 6 to 10 test runs	25 K – 35 K	10 K – 15 K	20 K – 30 K

[a] Represents 90 % confidence interval of three repeat test runs.
[b] Although Ford does not have a financial interest in the FEHP, most new Ford Expedition and Lincoln Navigator SUVs use FEHP. Ford is the FEHP's primary customer, and plans to use the axle lubricant on other SUVs and light duty trucks.

GHG Center personnel evaluated each laboratory's qualifications based on their fuel economy measurement experience under EPA city and highway driving cycles, a demonstrated capability to achieve the required standard deviations, and documented test records which show small improvements in fuel economy. The selection criteria also included whether or not the laboratory equipment complied with 40 CFR 86 requirements and whether the laboratory is independent from ConocoPhillips and its partners. Estimated fuel economy test costs were also a factor.

Table 1-2 shows that all three laboratories are familiar with the federal fuel economy test procedures, and maintain the necessary 40 CFR 86 - compliant measurement equipment. Through careful attention to detail and precise test procedure implementation, SwRI and FRL have demonstrated the capability to measure small fuel economy improvements. Both laboratories have developed internal test procedures with proven reductions in fuel economy determination variability.

Section 2.1 discusses why, for a vehicle which gets about 16 mpg, the standard deviations for replicate fuel economy tests must be on the order of ± 0.05 to ± 0.16 mpg, depending on the number of test runs. SwRI's standard deviations for repeated test runs range between 0.02 and 0.18 mpg. FRL's range was tighter (0.03 and 0.09 mpg). The reader should note that three test runs each conducted at 12 different test conditions are the source data for the SwRI standard deviations. FRL's data are based on three test runs, each conducted at 2 different test conditions. The GHG Center expects that with more test data, Ford's standard deviations would be similar to SwRI's. In either case, both laboratories can measure fuel economy changes that are within the expected range.

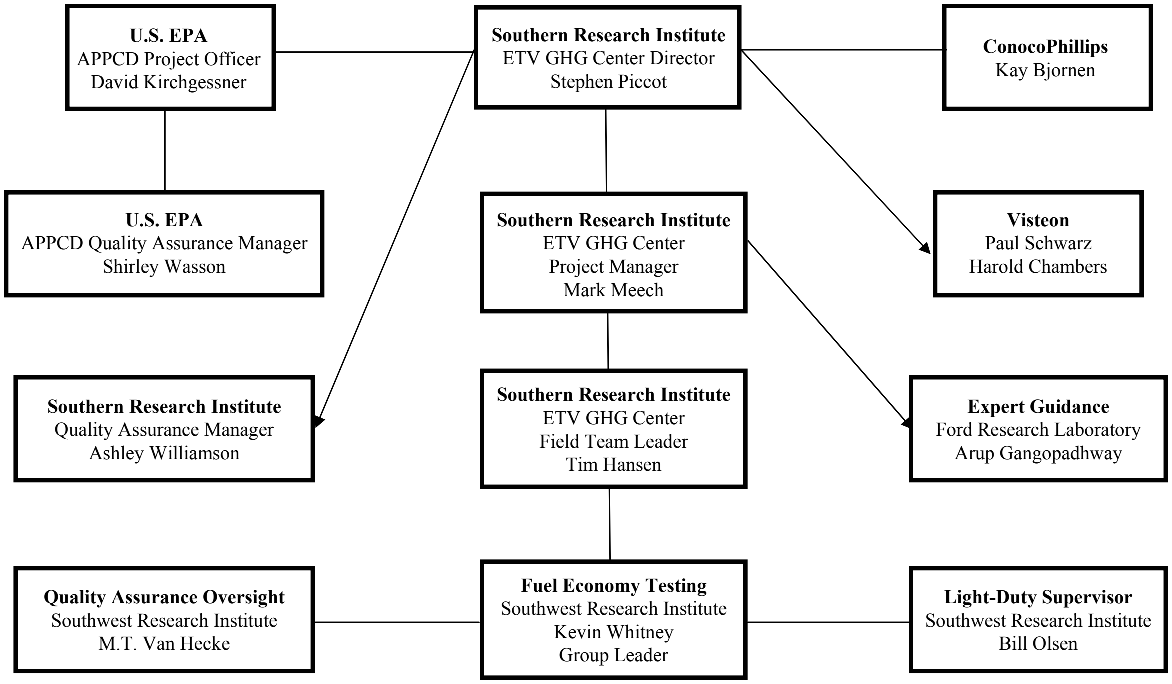
Although FRL does not have a direct financial interest in FEHP, Ford does use the product in their SUVs. It could be construed as a potential conflict of interest for FRL to perform the tests. The GHG Center has, therefore, selected SwRI because of their independence from the vendor and its affiliations. Ford has agreed to provide technical advice on the verification test development, execution, and data analysis because FRL experts have executed fuel economy comparison tests similar to those planned here, and because of their direct experience with the FEHP lubricant,

SwRI DER maintains an International Organization for Standardization (ISO) 9002 "Model for Quality Assurance in Production and Installation" certification and ISO 17025 "General Requirements for the Competency of Calibration and Testing Laboratories" accreditations. Under the terms of these independently assessed quality systems, SwRI evaluates automotive fluids, fuels, emissions, automotive components, engine/power-train performance, and equipment durability for regulatory agencies, automobile manufacturers, and other clients. Their plant facilities include a wide variety of stationary engine dynamometer test stands (light-duty, non-road, and heavy-duty), vehicle dynamometer facilities, and associated state-of-the-art emissions test equipment. SwRI DER has also achieved Ford Tier 1 status for providing engineering services, and has received Ford Q1 Quality Award and the Ford Customer-Driven Quality Award. SwRI was a contributor to the EPA FTP and HFET test development as well. Consequently, the GHG Center has concluded that SwRI is qualified to perform the fuel economy testing described in this Test Plan.

1.5. ORGANIZATION

Figure 1-1 presents the project organization chart. The following paragraphs discuss test participants' functions, responsibilities, and lines of communications.

Figure 1-1. Project Organization



SRI's GHG Center has overall planning responsibility and will ensure successful verification test implementation. The GHG Center will coordinate all participants' 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 Test Plan and Report 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 Verification Statement along with the EPA-ORD Laboratory Director.

The GHG Center's Mr. Mark Meech will have overall responsibility as the Project Manager. His responsibilities include drafting the Verification Test Plan and Verification Test Report, overseeing the Field Team Leader's data collection activities, and ensuring DQOs are met prior to completion of testing. Should a situation arise that could affect the health or safety of any personnel, Mr. Meech will have full authority to suspend testing. He will also have the authority to suspend testing if the data quality indicator goals described in Section 3.0 are not being met. In both cases, he may resume testing when problems are resolved. Mr. Meech will be responsible for maintaining communication with ConocoPhillips, Visteon, SwRI, EPA, and stakeholders.

Mr. Tim Hansen will serve as the Field Team Leader and will supervise all SwRI activities to ensure conformance with the Test Plan. 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 conduct on-site data quality audits and perform other QA/QC procedures as described in Section 3.0. At the completion of each test run, Mr. Hansen will communicate test results to the Project Manager. The Field Team Leader and Project Manager will then determine if sufficient test runs have been conducted to report statistically valid fuel economy improvements.

SRI's QA Manager, Dr. Ashley Williamson, will review this Test Plan. He will also review the verification test results and conduct an Audit of Data Quality (ADQ), described in Section 4.4.4. 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 citation in the final Report.

Ms. Kay Bjornen will serve as ConocoPhillips' primary contact person. Ms. Bjornen will provide technical support in accurately representing the FEHP technology. Ms. Bjornen will review the Test Plan and Test Report, and provide written comments. Ms. Bjornen may be present during the verification testing, and will ensure availability of an adequate quantity of FEHP.

Mr. Arup Gangopadhyay will be the primary FRL contact and will review the Test Plan and Report. Mr. Gangopadhyay or his representative will provide vehicle test procedure technical support and may be present during the verification tests.

Mr. Paul Schwarz will be the primary contact for Visteon Corporation Driveline Systems and will review the Test Plan and Test Report. Mr. Schwarz or his representative will provide axle technical support and may be present during the verification tests.

EPA-ORD will provide oversight and QA support for this verification. The Air Pollution Prevention and Control Division (APPCD) Project Officer, Dr. David Kirchgessner, is responsible for obtaining final Test Plan and Report approvals. The APPCD QA Manager will review and approve the Test Plan and the Report to ensure they meet the GHG Center QMP requirements and represent sound scientific practices.

1.6. SCHEDULE

The tentative schedule of activities for the FEHP lubricant verification testing is:

Verification Test Plan Development Milestone	**Dates**
GHG Center Internal Draft Development	October 15 – January 21, 2002
ConocoPhillips Review	January 22 - January 31, 2002
Industry Peer-Review and Plan Revision	February 3 - February 21, 2003
EPA Plan Review	February 24 - March 7, 2003
Final Plan Revision and EPA Approval	March 10 - March 21, 2003
Final Test Plan Posted	March 24, 2003

Verification Testing and Analysis Milestone	**Dates**
Preliminary Meeting and Review at SwRI	Week of March 17, 2003
Testing	April 2 - April 18, 2003
Data Validation and Analysis	April 21 – April 25, 2003

Verification Report Development Milestone	**Dates**
GHG Center Internal Draft Development	April 28 - May 9, 2003
ConocoPhillips Review and Report Revision	May 12 - May 23, 2003
EPA and Industry Peer-Review	May 27 – June 13, 2003
Final Report Revision and EPA Approval	June 16 - June 27
Final Report Posted	June 30, 2003

2.0 VERIFICATION APPROACH

2.1. INTRODUCTION

Determination of small fuel economy changes is a multi-step process. First, assuming that appropriate test methods have been conducted, the difference (delta, symbolized by Δ) between the reference oil and FEHP mpg data must be statistically significant. Second, analysts must calculate a confidence interval on the difference. Third, that confidence interval must be refined as much as possible. For example, it may be statistically valid to state that the fuel economy changed by "0.2 mpg, with a confidence interval of ± 0.19 mpg", but more test runs may allow statement of a tighter confidence interval such as "0.2 mpg, ± 0.09 mpg."

The complexity and expense of vehicle fuel economy testing shapes the overall verification approach. The testing strategy must employ well-defined test methods which can measure very small mpg differences. The methods must be precise and accurate, yet reasonably economical. This means that run-to-run variability must be reduced as much as possible. The degree of precision towards which to strive, however, must strike a balance between practical testing realities and the increased expense of specially designed test procedures and super-accurate instruments.

In general, for a given test method, procedure, and instrument suite, more test runs will tend to reduce random sampling error effects. With more test runs, the overall reported uncertainty will more closely approach the method's known accuracy. The number of test runs must, again, strike a balance between desires for precision and available budgets.

Mechanical conditions also impose constraints on the test campaign design. As was discussed in Section 1.3, SwRI will first install fresh lubricant in the engine and reference oil in the vehicle's rear axle. A mileage accumulation dynamometer (MAD) will then break the lubricant in over approximately 1000 miles of normal vehicle operation. SwRI will perform the reference oil fuel economy test runs, remove the reference oil (and engine lube), and install FEHP and fresh engine lubricant. The engine lubricant will be the same brand, viscosity, and grade as that used during the first test run series. After a second 1000 mile break-in period, FEHP fuel economy test runs will commence. This means that all reference oil test runs will be completed prior to the commencement of FEHP test runs. Consequently, the GHG Center must specify a sufficient number of test runs with the reference oil without knowing in advance how many FEHP test runs may be required.

The following subsections discuss these concepts in detail and provide a basis for selecting the number of test runs to be conducted. This section concludes with a discussion of the test sequence, laboratory equipment, and the analytical approach.

2.2. FUEL ECONOMY CHANGE STATISTICAL SIGNIFICANCE

Fuel economy change (Eqn. 1), will be the difference between the reference oil and FEHP mean mpg results. Each mean value is the result of a limited number of test runs. Statistical theory (3, 4) shows that the variability between test runs determines how accurately the mean characterizes all possible fuel economy values within a lubricant type (i.e. reference oil or FEHP). If each individual test run result is very close to the mean value, or if variability is small, the mean can be sharply characterized. The difference between two such means would also be sharply characterized, and small differences would be statistically significant.

Large run-to-run variabilities can, however, exist. In these cases, the mean "spreads out" over a larger range of possible values. For example, it could be not statistically significant to report a "0.2 mpg" fuel economy change if the reference oil mpg was 16.12 ± 0.2 mpg while the FEHP mpg was 16.32 ± 0.2 mpg. The difference between two such means may not be statistically significant if the reference oil mean falls within the FEHP confidence interval (stated here as " ± 0.2 mpg").

The GHG Center will therefore evaluate the statistical significance of the difference between the reference oil and FEHP by the following hypothesis test:

$$H_o: \quad |\mu_1 - \mu_2| = 0$$

$$H_1: \quad |\mu_1 - \mu_2| > 0$$

Where:

H_o = Hypothesis that there is no statistically significant difference in fuel economy
H_1 = Hypothesis that there is a statistically significant difference in fuel economy
μ_1 = Mean fuel economy for the population of vehicles treated with FEHP
μ_2 = Mean fuel economy for the population of vehicles treated with reference oil

Rejection of H_o allows the reader to conclude that the fuel economy difference is significant and that it is useful to calculate the difference's confidence interval. However, if the test is unable to reject H_o, the conclusion will be that the FEHP lubricant does not show a significant fuel economy change. Note that this is a "two-tailed" hypothesis test which means that the fuel economy change could be either an increase or a decrease.

Analysts will test the hypothesis by first calculating a test statistic, t_{test}, and then comparing it with the Student's T distribution value with $(n_1 + n_2 - 2)$ degrees of freedom as follows (3):

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

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

Where:

X_1 = Mean fuel economy with FEHP lubricant
X_2 = Mean fuel economy with reference oil
$\mu_1 - \mu_2$ = Zero (H_o hypothesizes that there is no difference between the population means)
n_1 = Number of repeated test runs with FEHP lubricant
n_2 = Number of repeated test runs with reference oil
s_1^2 = Sample standard deviation with FEHP lubricant, squared
s_2^2 = Sample standard deviation with reference oil, squared
s_p^2 = Pooled standard deviation, squared

Selected T-distribution values at a 95-percent confidence coefficient appear in the following table (3).

Table 2-1. 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
7	7	12	2.179
8	8	14	2.145
9	9	16	2.120

The decision rule for the hypothesis test is:

> *Do not reject* H_o *if* $t_{test} \leq t_{0.025,DF}$. *Conclude that the data cannot show a statistically significant difference. The report will show that there is no statistically significant fuel economy difference between FEHP vs. the reference oil.*
>
> *otherwise,*
>
> *Reject* H_o *if* $t_{test} > t_{0.025,DF}$. *Conclude that a significant fuel economy difference exists between the FEHP vs. reference oil. The report will show the difference and its confidence interval.*

This concept is best understood with an example. SwRI provided fuel economy data from a series of 12 different engine lubrication oil tests. They conducted 3 test runs each (36 total) and reported mean mpg and sample standard deviation for each lube oil condition. Means were around 16.12 mpg, fuel economy changes were approximately 0.29 mpg (or 1.8 percent of the mean value), and sample standard deviations ranged between 0.02 and 0.18 mpg, or approximately 0.12 to 1.12 percent of the mean values. The sample standard deviation divided by the mean and multiplied by 100 (the 0.12 to 1.12 percent cited here) is also known as the coefficient of variation (COV). It is helpful to consider the COV as a "normalized" standard deviation.

Based on the SwRI data set, 99 percent of all sample standard deviations will fall between 0.054 and 0.129 mpg. If we assume that the verification test results happen to show the higher standard deviation, the following table summarizes the t-test results for increasing numbers of test runs.

Table 2-2. Sample Data T-test Results Summary

Ref. oil mean fuel economy, mpg	16.12						
FEHP mean fuel economy, mpg	16.41						
Ref. oil Std. Dev., mpg	0.129						
FEHP Std. Dev., mpg	0.129						
Test runs, each	3	4	5	6	7	8	9
s_p^2	0.0166						
$t_{0.025,\ DF}$	2.776	2.447	2.306	2.228	2.179	2.145	2.120
t_{test}	2.753	3.179	3.554	3.894	4.206	4.496	4.769
Significant difference?	No	Yes	Yes	Yes	Yes	Yes	Yes

(reject H_o?)								

Table 2-2 shows that with three test runs each, the difference between the reference oil and FEHP mpg is not statistically significant. The difference between the two is significant for 4 or more test runs each, and the resulting change in fuel economy is meaningful.

The assumption that the reference oil and FEHP test run results have similar variability is fundamental to this process. The ratio of the sample variances (sample standard deviation squared) between the two lubricants is a measure of this similarity and falls somewhere on an F distribution (4).

Analysts will calculate an F_{test} statistic according to Eqn. 4 and compare the results to the values in Table 2-3 to determine the degree of similarity between the sample variances according to Eqn. 4.

$$F_{test} = \frac{s^2_{\max}}{s^2_{\min}}$$ Eqn. 4

Where:

F_{test} = F-test statistic
s^2_{max} = Larger of the reference oil or FEHP sample standard deviations, squared
s^2_{min} = Smaller of the reference oil or FEHP sample standard deviations, squared

The number of test runs for each lubricant and the acceptable uncertainty (α; 0.05 for this verification) determine the shape of the F distribution. Table 2-3 (3) presents selected $F_{0.05}$ distribution values for the expected number of test runs.

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

	s^2_{max} number of runs	**4**	**5**	**6**	**7**
s^2_{min} number of runs	**Degrees of Freedom**	**3**	**4**	**5**	**6**
4	**3**	9.28	9.12	9.01	8.94
5	**4**	6.59	6.39	6.26	6.16
6	**5**	5.41	5.19	5.05	4.95
7	**6**	4.76	4.53	4.39	4.28

If the F-test statistic is less than the corresponding value in Table 2-3, then analysts will conclude that the sample variances are substantially the same and the hypothesis test for statistical significance and confidence interval calculations are valid approaches. If the F-test statistic is equal to or greater than the Table 2-3 value, analysts will conclude that the sample variances are not the same and will consequently modify the confidence interval calculation (Section 2.2) according to Satterthwaite's approximation (4). Satterthwaite's approximation describes how to use a modified Student's T-distribution value in the confidence interval calculation for samples with unequal variances. This is unlikely based on the SwRI data set considered here. The Verification Report will discuss Satterthwaite's approximation if the actual test data indicate that it must be applied.

2.3. FUEL ECONOMY CHANGE CONFIDENCE INTERVAL

If hypothesis H_o can be rejected, it becomes meaningful to calculate the confidence interval. The test results will provide an estimate of the fuel economy change based on a limited sample. Ninety-five percent of the time, the true fuel economy change will be within a certain range of values centered on the test results. This range is known as the 95-percent confidence interval. A narrow confidence interval implies that the fuel economy change is sharply characterized. Conversely, a large confidence interval implies that the data spread across a wide range and the resulting mean fuel economy change could have limited utility.

The half width (e) of the 95 percent confidence interval is (3):

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

SwRI and the GHG Center will calculate and state the mean fuel economy change as:

$$\Delta\ \textit{Fuel Economy (Equation 1)} \pm e\ \textit{(Equation 5)}$$

For example “fuel economy changed by 0.29 ± 0.22 mpg.”

2.4. REFINEMENT OF FUEL ECONOMY CHANGE CONFIDENCE INTERVAL AND NUMBER OF REQUIRED TEST RUNS

As the number of test runs increase, the resulting confidence interval decreases. The following table continues the example given in Table 2-2 by showing the 95-percent confidence intervals in absolute units and as proportions (percent) of the mean fuel economy change.

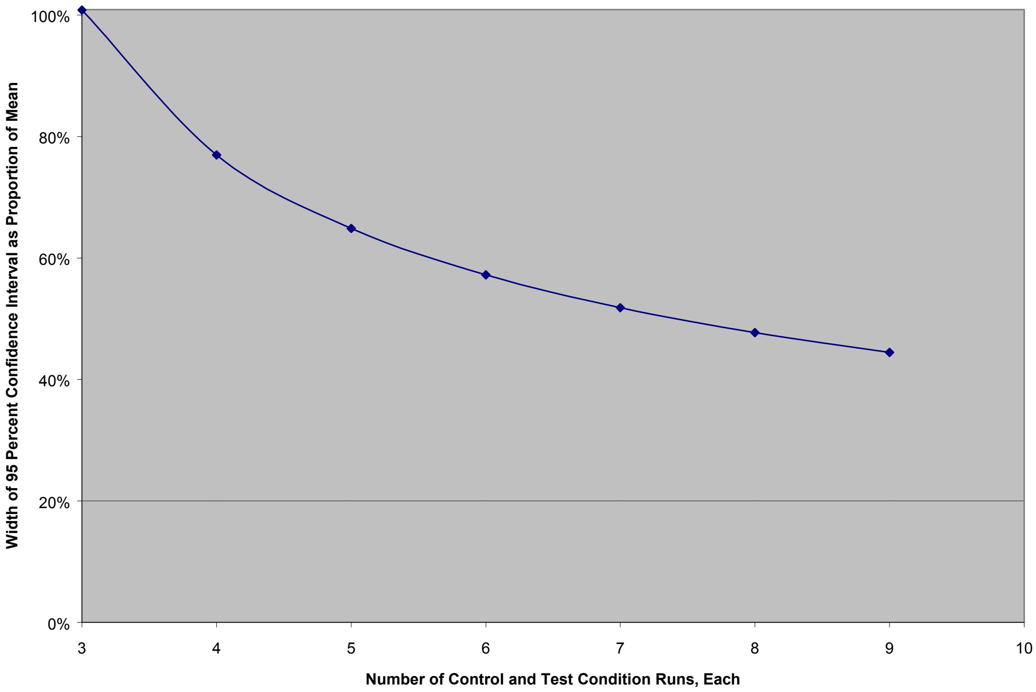
Table 2-4. Sample Data Confidence Intervals

Mean fuel economy change, Δ, mpg	0.29						
Test runs, each	3	4	5	6	7	8	9
s_p^2	0.0166						
$t_{0.025,\ DF}$	2.776	2.447	2.306	2.228	2.179	2.145	2.120
95 % confidence interval, mpg	± 0.29	± 0.22	± 0.19	± 0.17	± 0.15	± 0.14	± 0.13
Confidence interval as percent of mean fuel economy change	± 100.8	± 77.0	± 64.9	± 57.2	± 51.8	± 47.7	± 44.5

This table also provides a different way of understanding why three test runs each do not yield statistically significant results. The confidence interval is slightly larger than the mean fuel economy change itself.

The confidence interval width shrinks quickly between 4 and 7 test runs, but more slowly thereafter. Figure 2-1 is a graph of the relationship.

Figure 2-1. Confidence Interval Decrease Due to Increased Number of Test Runs



The GHG Center plans to conduct all reference oil test runs prior to installing and breaking in the FEHP for the most cost-effective verification. For example, Table 2-3 shows that if testers were to conduct 4 reference oil and then 4 FEHP test runs, the confidence interval is nearly 80 percent of the mean. At that point, no more reference oil test runs could occur. Nine FEHP runs (for a total of 13 test runs) would be needed to reduce the confidence interval to slightly less than 60 percent of the mean. Conversely, 7 test runs each (or a total of 14 test runs; only one more than the previous example) would produce a confidence interval that is 51.8 percent of the mean.

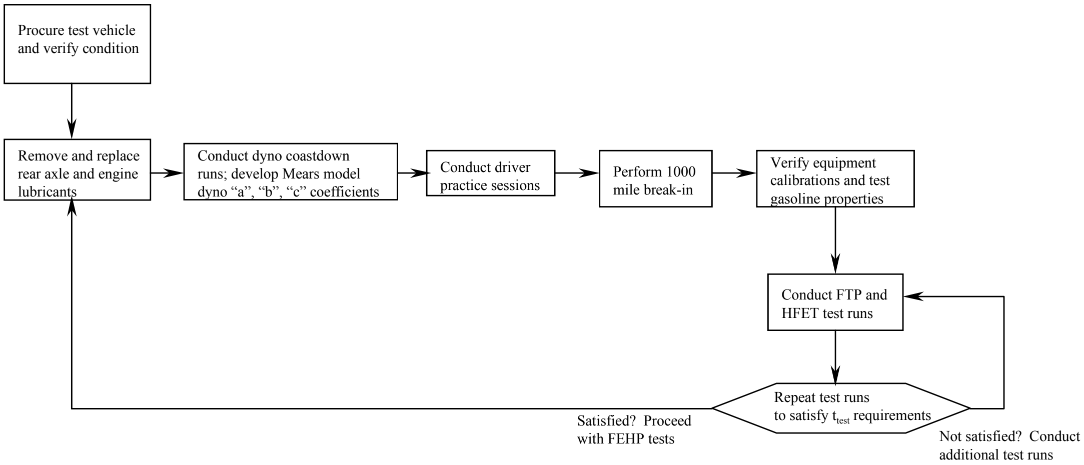
Seven test runs each therefore represents the best compromise between many test runs at great expense or confidence intervals which would be nearly as large as the mean fuel economy change itself. For this reason, the GHG Center will conduct up to 7 reference oil test runs. The Project Manager may authorize between 4 and 6 reference oil test runs if the COV is significantly less than 1.12 percent. He will document this authorization with a corrective action (see Section 4.1.7).

After the first 4 FEHP test runs are complete, the field team leader will evaluate the statistical significance and confidence interval as described above. He will then compare the confidence interval with the DQO criteria in Section 3.0 and decide whether to conduct the next FEHP test run. This process will repeat up to a maximum total of 14 reference oil and FEHP test runs.

2.5. LABORATORY TEST SEQUENCE OVERVIEW AND STEP-BY-STEP TEST PROCEDURES

Figure 2-2 shows a generalized test activity schematic.

Figure 2-2. Test Activities



Testing will begin with procurement of a suitable test vehicle which is representative of the population of interest. For this verification, the vehicle will be a Lincoln Navigator SUV with between 10,000 and 25,000 miles on the odometer. The rear axle must incorporate a standard, non-limited-slip differential. Test personnel will verify the vehicle's proper operation, note the engine and axle types, check tire pressures, and prepare it and the chassis dynamometer for testing. Appendix B-1 contains a sample vehicle receipt form.

After reference oil (and subsequent FEHP) installation and the 1000-mile break-in, a technician will operate the vehicle through a specified driving schedule while the dynamometer simulates road friction, inertia, and other loads. A constant volume sampling (CVS) system will convey the vehicle exhaust through calibrated dilution equipment and inject a series of aliquots of the diluted gas into Tedlar bags. The dilution process prevents potential moisture condensation. A suite of instrumental analyzers will measure the aliquots' pollutant and greenhouse gas (GHG) concentrations. Analysts will then derive fuel economy from the known amount of carbon in the fuel, correlated with the measured amount of carbon in the exhaust gas and the distance traveled on the dynamometer.

Once the vehicle arrives at SwRI, technicians will prepare it for testing and change the rear axle and engine lubricants. The engine oil change will be concurrent with each rear axle lubricant change to ensure that any potential changes in engine oil characteristics don't skew the axle lube results. Test operators and the Field Team Leader will ensure use of the same engine lubricant brand, viscosity, and grade throughout the test campaign. This technique will ensure that the engine lubricant will be in the same state at the start of each axle lube test series. The engine lubricant change will conform to practices recommended in the vehicle owner's manual.

The technician will perform the rear-axle lubricant change according to the procedure in Appendix A-3, taking care to remove as much residue as possible before installing the reference oil. The reference oil will be SAE 75W-140 gear oil, the standard lubricant recommended by the rear axle's manufacturer.

GHG Center personnel will observe the rear-axle lubricant-change procedure at least once during the test campaign.

Once the lubricant drain, flush, and fill sequence is complete, SwRI will set up the chassis dynamometer. All test runs will take place on the same dynamometer (SwRI No. 7). SwRI will conduct triplicate 65- to 15-mph coastdowns on each axle with the reference oil installed in the rear axle and use the results as input to the Mears Model according to EPA-recognized least square methods (5, 6). The Mears Model calculates a three-parameter road load force equation for dynamometer fuel economy tests. This model incorporates frictional coastdown data from drive and non-drive axles with windage and aerodynamic resistance projections to yield the dyno "a", "b", and "c" coefficients.

SwRI will repeat this process with FEHP installed in the rear axle and new engine oil prior to the FEHP test run series.

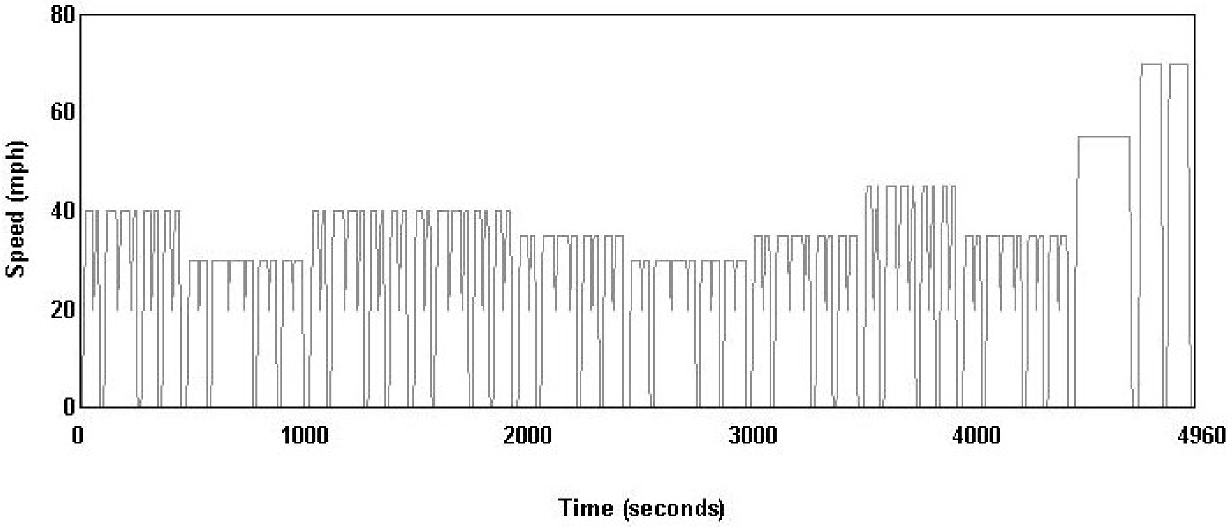
SwRI will develop a customized log form to track these activities. Appendix B-2 shows the form for a similar test campaign.

When technicians have set up the chassis dynamometer and mounted the vehicle on it, the driver assigned to this test campaign will familiarize himself with the vehicle's operation by conducting multiple FTP and HFET dynamometer test sequences as shown in Figures 2-6 and 2-7 below. This "practice" stage will continue until the driver is comfortable with operating the vehicle and can repeatably follow the dynamometer driving trace according to 40 CFR § 86.115 specifications. The same individual will operate the vehicle during all test runs.

SwRI will then break in the reference oil (and the engine lubricant) to ensure stability during testing. Technicians will mount the vehicle on an eddy current-type mileage accumulation dynamometer (MAD) with 24-hour capabilities and run the vehicle for 1000 miles. The MAD system incorporates a computer-based control system which operates the vehicle. The control system maintains vehicle load and speed with a throttle actuator and electric motor. A large blower provides airflow across the vehicle which is proportional to vehicle speed.

The dynamometer will operate the vehicle over the Durability Driving Schedule (DDS) specified in 40 CFR § 86, Appendix IV. This test cycle is 4,960 seconds long at 29.5 mph average speed and includes eleven 3.7-mile "laps" at various speeds. Figure 2-3 is a DDS schematic. Mileage accumulation will require approximately two days.

Figure 2-3. Durability Driving Schedule for Mileage Accumulation



Technicians will then drain and flush the fuel system and fill it with a test gasoline which meets specifications in 40 CFR § 600.107, 40 CFR §86.113-04 and §86.113-94. The Field Team Leader will review the test fuel analysis to ensure that the methods and results conform to the specifications given in Section 3.5.1. Appendix A-2 contains the log form.

Prior to testing, SwRI and the Field Team Leader will verify that all equipment calibrations are current according to the schedules in 40 CFR § 86.116. Table 2-4 summarizes the relevant calibrations, Title 40 CFR citations, and their frequencies. The Field Team Leader will independently check the CO_2 analyzer calibration by subjecting it to a cylinder audit gas with the expected CO_2 concentration in pure nitrogen. Section 3.0 discusses calibrations and QA/QC checks in more detail.

Table 2-5. Equipment Calibrations Summary

Equipment Description	Title 40 CFR Procedure	Calibration Frequency
CO analyzer	§ 86.121	Monthly
CO_2 analyzer	§ 86.122	Monthly
HC analyzer	§ 86.124	Monthly
NO_X analyzer	§ 86.123	Monthly
Chassis dynamometer	§ 86.118	Daily
CVS system	§ 86.119	Weekly

Following test site calibration verifications and driver practice sessions, the GHG Center will authorize initiation of the fuel economy test protocol. The reference oil (followed by the FEHP) tests will consist of consecutive, replicate FTP and HFET fuel economy test runs conducted on the chassis dynamometer.

The Field Team Leader will review the results immediately following each test run. Appendix B-4 provides a sample test run output for comparison. Based on the results, he will determine the number of reference oil (and subsequent FEHP) test runs in accordance with Sections 2.2 through 2.4.

At the conclusion of the reference oil test runs, SwRI technicians will drain and replace the rear-axle reference oil with FEHP according to the procedure in Appendix A-3. Test operators will also change the engine lubricant and repeat the dynamometer setup, practice sessions, lubricant break-in and testing procedures described above.

2.6. TEST EQUIPMENT AND INSTRUMENT DESCRIPTION

This verification's test equipment falls into four major groups:

- Chassis dynamometer
- CVS system
- Emissions analyzers
- Ambient monitoring and control equipment

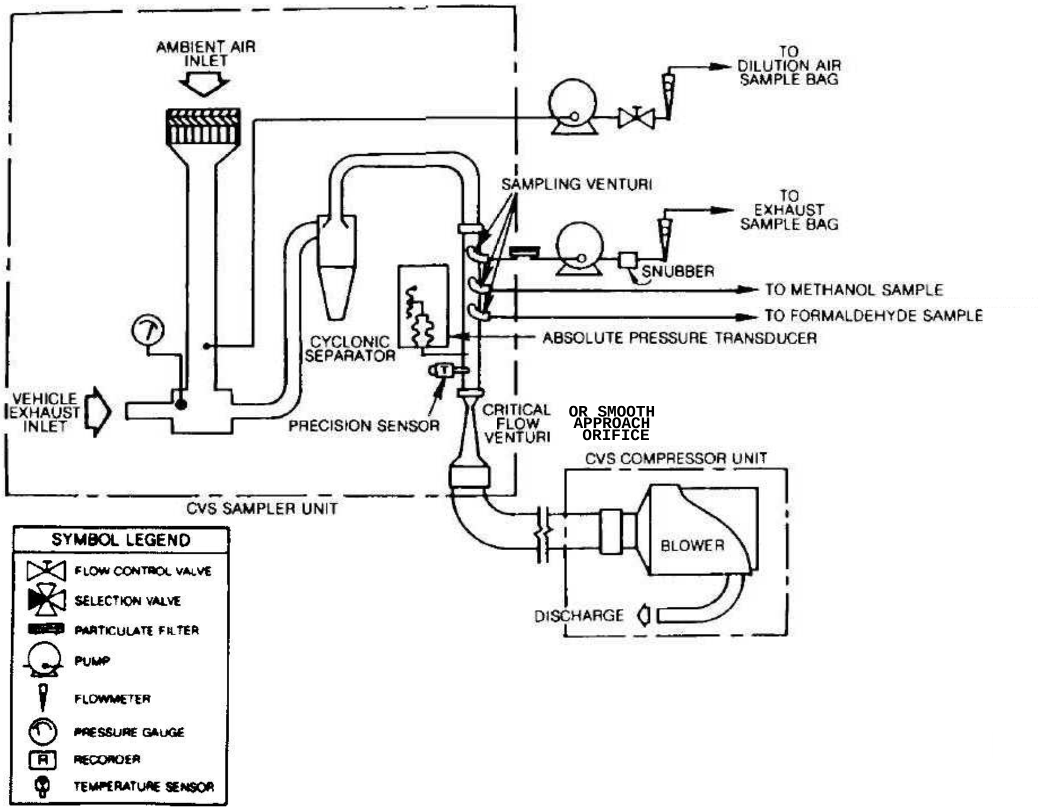
This subsection briefly describes the test equipment, while Sections 3.2 through 3.5 summarize the relevant specifications, calibrations, and QA/QC checks.

This verification will use SwRI's Chassis Dynamometer #7 and its associated sampling and analysis system for light-duty gasoline vehicles. The chassis dynamometer is a 48-inch single-roll electric dynamometer manufactured by Horiba Instruments. This chassis dynamometer utilizes a feed-forward control system for inertia and road load simulation. The dyno electrically simulates vehicle tire/road interface forces, including parasitic and aerodynamic drag. The vehicle experiences the same speed, acceleration/deceleration, and distance traveled as it would on the road.

The dynamometer control unit commands a power converter which delivers regulated alternating current to an electric motor connected to the dyno roll. This electric motor exchanges power with the roll (and the vehicle). Based on feedback from roll torque measurement and velocity sensors, the power exchange motor acts as both a power source and absorber to control the forces exerted on the test vehicle's tires. A preprogrammed road load curve is the basis for the required force during each second of the driving schedule. For light-duty trucks, observed road load and simulated inertia errors are less than ± 0.3 percent.

A Horiba Variable-Flow CVS will sample exhaust emissions. Figure 2-4 is a CVS system schematic (1).

Figure 2-4. CVS System Schematic



Test technicians first connect the vehicle exhaust pipe to the CVS inlet. While the vehicle operates on the dynamometer, an adjustable-speed turbine blower dilutes the exhaust with ambient air. This dilution prevents the exhaust moisture from condensing and provides controllable sampling conditions. A sample pump and a control system transfers diluted exhaust aliquots to several different Tedlar bags during specific phases of each FTP and HFET test run. A regulating needle valve maintains a constant sample flow rate into the bags.

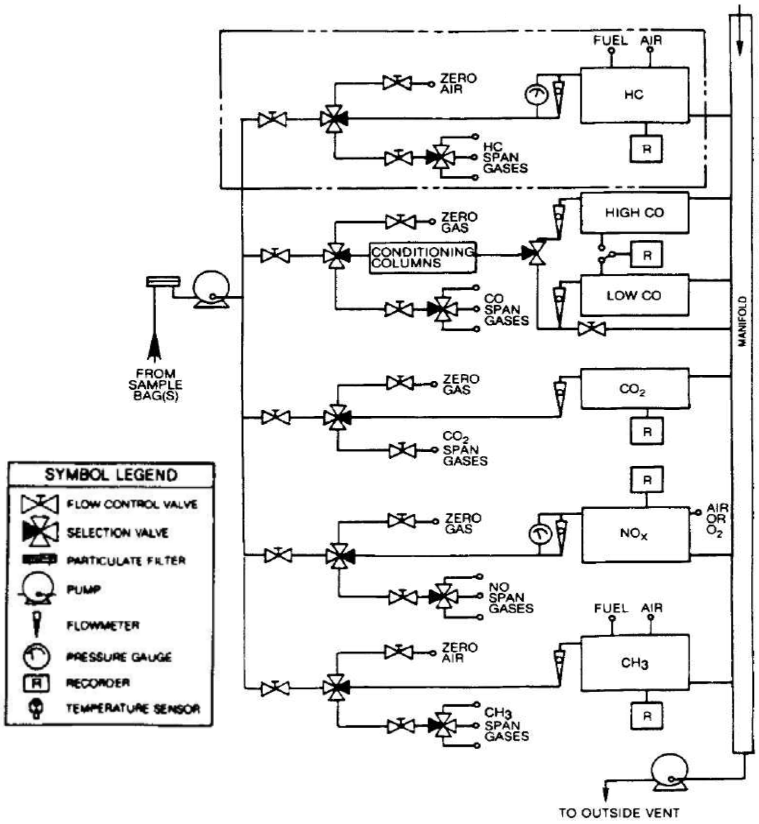
The balance of the dilute exhaust passes through a Horiba "smooth-approach orifice" (SAO) which measures the flow rate. SwRI uses the SAO in lieu of the critical flow-venturi (CFV) specified in the

CFR because its accuracy specifications meet or exceed CFR requirements. Also, the SAO undergoes direct National Institute of Standards and Technology (NIST) traceable calibration. CFVs require calibration by laminar flow elements which are, in their turn, subject to NIST calibration. This means that the CFV calibration is one step removed from direct NIST traceability as compared to the SAO. According to Horiba, EPA has approved the SAO under provisions of 40 CFR § 86.109-94 (a) (6), "Other Systems," because it yields equivalent or superior results.

To ensure that the sample represents the entire volume, the bag sampling rate must remain proportional to the total dilute exhaust volume flow rate throughout each test run. The CVS uses the SAO sensors to concurrently measure the total dilute exhaust volume from which the samples are extracted. SAO throat pressure and temperature measurements, correlated with the SAO's NIST-traceable calibration, allow accurate dilute exhaust volume determinations. This determination generates a feedback signal which adjusts the turbine blower speed. The continuous adjustment allows the blower to maintain constant volumetric flow through the CVS system. The CVS both measures the dilute exhaust volumetric flow and controls the sample dilution ratio to within ± 0.5 percent.

A Horiba analytical bench equipped with 200-Series instrumental analyzers will determine CO, CO_2, HC, and NO_X concentrations in the dilute exhaust. Each analyzer is accurate to ± 2 percent. Sample pumps transfer the dilute exhaust from the sample bags to each analyzer as commanded by the control system. Figure 2-5 is a generalized schematic of the instrumental analyzer system (1).

Figure 2-5. Instrumental Analyzer System



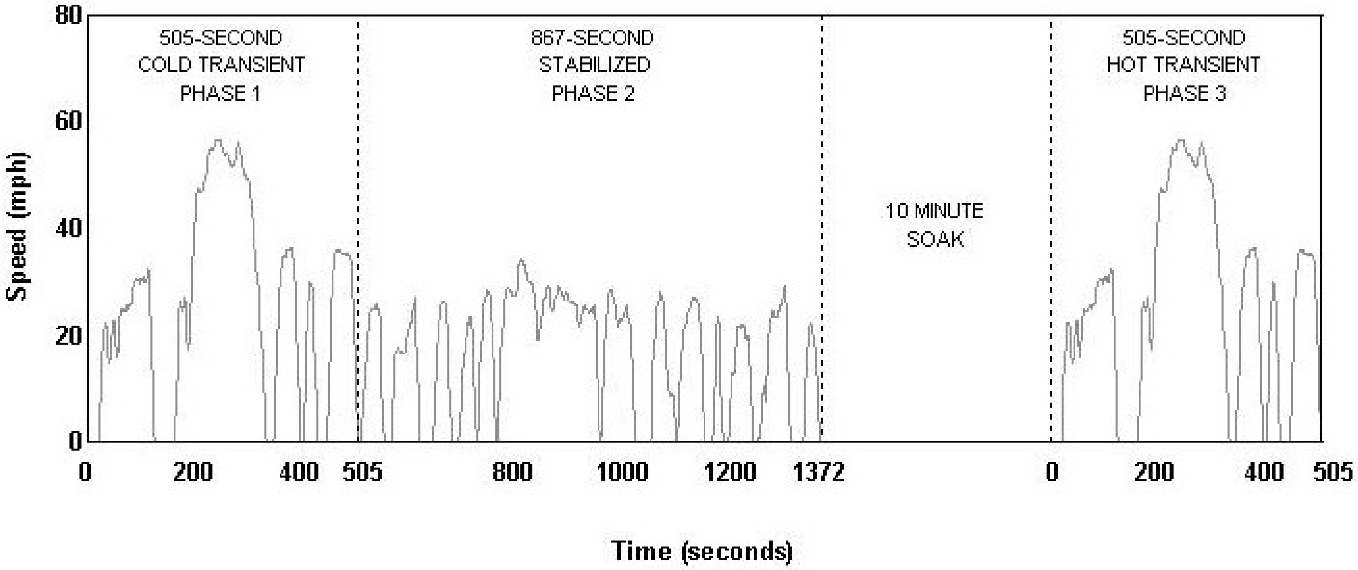
A Horiba VETS-9200 vehicle emissions test system (VETS) will automatically control the chassis dyno, CVS, and analytical bench. The VETS will collect data from the test equipment, calculate and report test results, and will facilitate system calibrations and quality control checks. The VETS also records raw sensor outputs, applies the appropriate engineering conversion and averaging algorithms, and flags data which are outside the permitted values.

Other ancillary equipment includes test site support gear, ambient temperature, humidity, and pressure sensors. SwRI maintains the test cell at 74 ± 2 ^{o}F with target humidity control of 70 ± 10 grains of water per pound of dry air. Technicians measure dry and wet bulb temperatures with an Industrial Instruments and Supplies “Psychro-dyne.” Accuracy is ± 0.5 ^{o}F, as verified with a NIST-traceable calibration thermometer. Barometric pressure is uncontrolled. SwRI calibrates the barometric pressure sensor weekly to ± 0.01 “ Hg with a NIST-traceable barometer. These specifications meet or exceed the CFR requirements.

2.7. ANALYTICAL APPROACH AND RELEVANT CALCULATIONS

During each fuel economy test run, the vehicle will operate over specified cycles which represent city and highway driving conditions. The chassis dynamometer will simulate road, aerodynamic, and vehicle inertial loads during acceleration, deceleration, and at varied velocities. 40 CFR § 86.115 specifies the city, or urban dynamometer driving schedule (UDDS, also known as the FTP), portion of the test run. The UDDS simulates an 11-mile trip in an urban area. It includes stop-and-go driving, multiple vehicle starts, and a short freeway driving segment. Average speed is about 20 miles per hour. Figure 2-6 depicts the cycle.

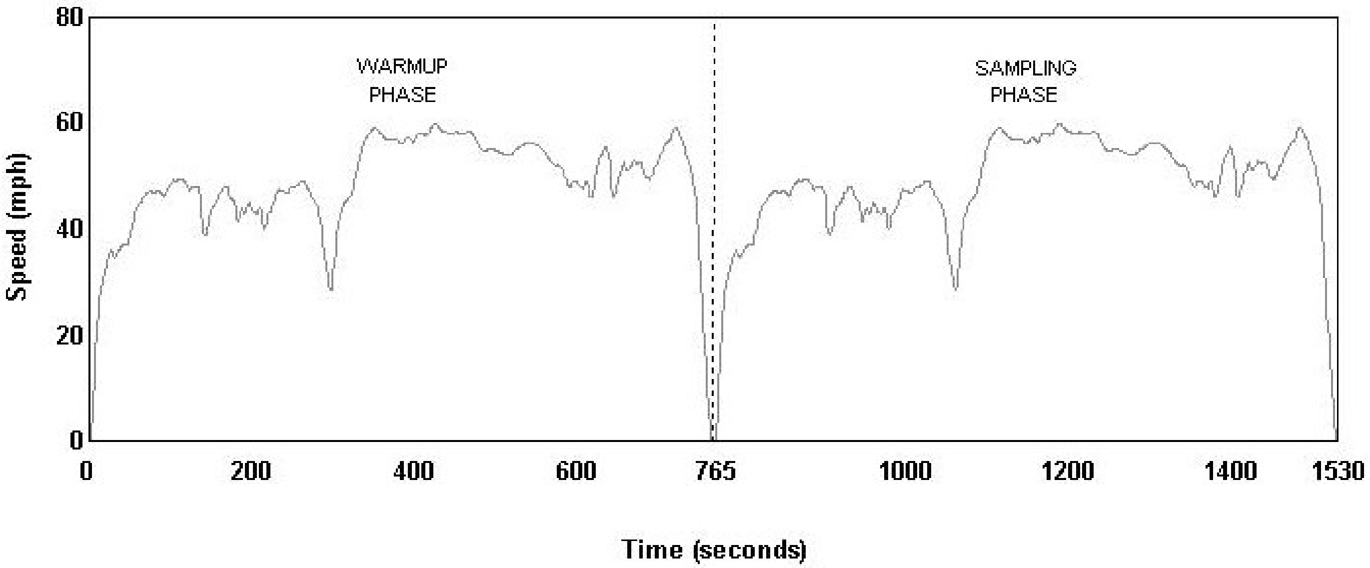
Figure 2-6. Urban Dynamometer Driving Schedule



Technicians will roll the vehicle onto the dynamometer after it has been parked overnight. This ensures a "cold" start.

The highway portion of the test will commence immediately following the end of the UDDS. It utilizes the Highway Fuel Economy Driving Schedule specified in 40 CFR Part 600 Appendix I. This dynamometer run employs a "hot" vehicle start and represents a 10-mile trip with an average speed of 48 mph with little idling and no stops. Figure 2-7 is a cycle schematic.

Figure 2-7. Highway Fuel Economy Driving Schedule



The fuel economy determination stems from the carbon in the emissions measured during the two driving cycles correlated with the known amount of carbon in the fuel and the distance driven on the dynamometer. This determination method, as specified in the CFR, is known as the "carbon balance" method. Carbon mass in the fuel per unit volume divided by carbon mass in the emissions yields the fuel economy in mpg. Dimensional analysis is as follows:

$$\frac{mi}{gal}(or\ mpg) = \frac{g_{carbon,fuel}/gal}{g_{carbon,emissions}/mi} \qquad \text{Eqn. 6}$$

The calculation relies on measured CO, CO_2, and HC mass emission rates (in grams per mile or g/mi), the measured test fuel carbon weight fraction, fuel specific gravity, and net heating value. SwRI will determine those fuel properties by the following test methods:

- Specific gravity -- ASTM D 1298
- Carbon weight fraction -- ASTM D 3343
- Net heating value (Btu/lb) -- ASTM D 3348

From 40 CFR § 600.113 (e), the FTP or HFET fuel economy will be:

$$mpg = \frac{\left(5174 * 10^4\right) * CWF * SG}{\left[CWF * HC + (0.429 * CO) + (0.273 * CO_2)\right] * \left[0.6 * SG * LHV + 5471\right]} \qquad \text{Eqn. 7}$$

Where:

mpg = Miles per gallon
CWF = Carbon weight fraction in the fuel
SG = Fuel specific gravity
HC = Hydrocarbon emission rate, g/mi
CO = Carbon monoxide emission rate, g/mi
CO_2 = Carbon dioxide emission rate, g/mi
LHV = Fuel lower (or net) heating value, Btu/lb

The composite fuel economy depends on the FTP and HFET results as follows:

$$mpg_{composite} = \frac{1}{\frac{0.55}{mpg_{FTP}} + \frac{0.45}{mpg_{HFET}}} \qquad \text{Eqn. 8}$$

Where:

$mpg_{composite}$ = Composite fuel economy, mpg
mpg_{FTP} = FTP results, mpg
mpg_{HFET} = HFET results, mpg

The overall average fuel economy (to be used as input to Equation 1) for either the reference oil or the FEHP will be:

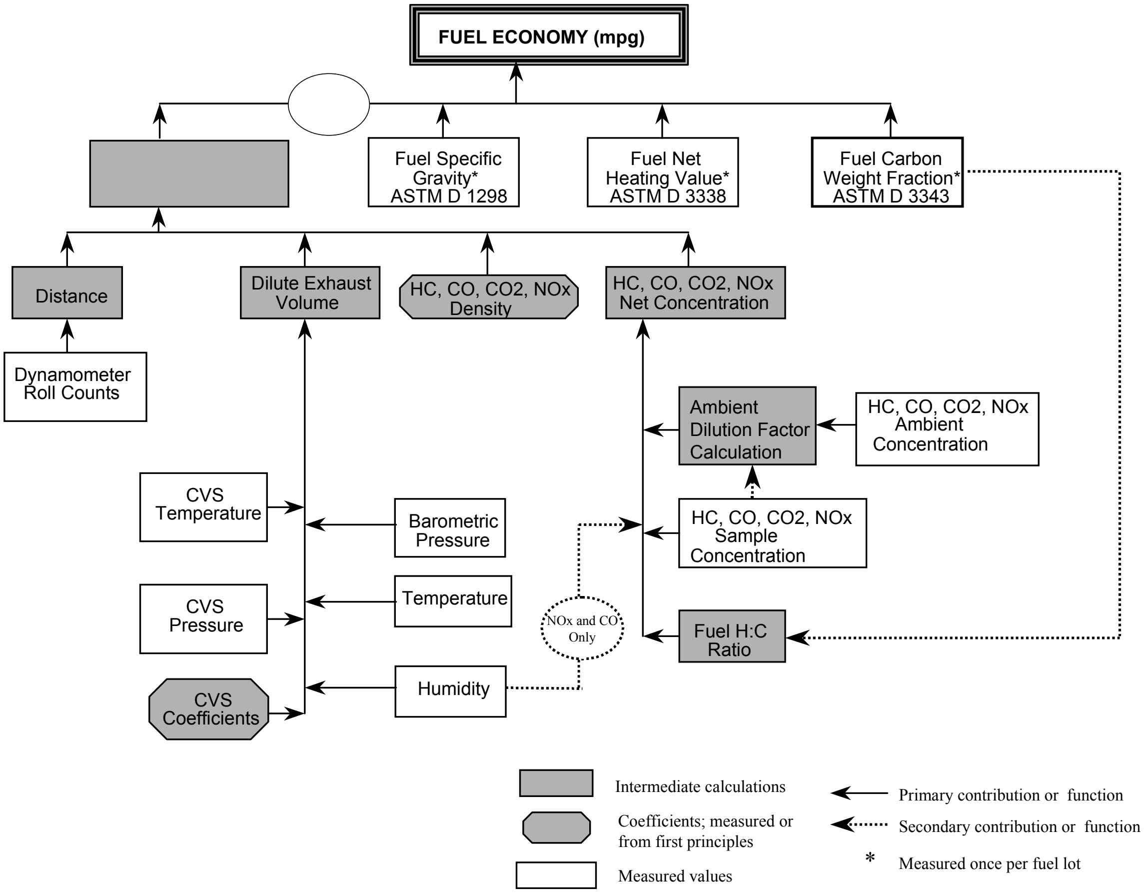
$$Mean\ Fuel\ Economy = \sum_{1}^{n} \frac{mpg_{composite}}{n} \qquad \text{Eqn. 9}$$

Where:

Mean Fuel Economy = Average of all valid reference oil or FEHP test runs, mpg
n = Number of test runs

Referring to Equation 7, the exhaust emission rates in g/mi are the result of the dilute exhaust bag sample instrumental analyses correlated with the CVS dilute exhaust volume, miles traveled on the dynamometer, ambient barometric pressure, ambient pollutant concentrations, etc. 40 CFR § 86.144 contains the detailed calculations. They need not be repeated here. The following figure, however, illustrates how the measurements contribute to the train of calculations. Each of the measured values shown in Figure 2-8 have associated instrument specifications and QA/QC checks which Section 3.0 discusses in greater detail.

Figure 2-8. Fuel Economy Calculation Conceptual Flow



To interpret Figure 2-8, consider humidity as an example. Humidity measurements, combined with the CVS operating coefficients, CVS temperature, CVS pressure, ambient temperature, and ambient barometric pressure, contribute to the dilute exhaust sample volume determination. Humidity measurements also contribute to NO_X and CO net concentration correction factors. The dilute exhaust sample volume, in turn, contributes to the mass emission rate calculation for each pollutant and GHG gas. The VETS system integrates the measured CO, CO_2, and HC mass emission rates into Equation 6 to determine the fuel economy for each dynamometer test phase, and then employs Equation 7 to calculate the test run's composite fuel economy.

SwRI will also determine fuel economy by separate volumetric and gravimetric methods as a cross-check against the carbon balance method. The volumetric method correlates the volume of gasoline consumed during a test run with the dynamometer distance traveled to yield mpg. The gravimetric method correlates the weight of gasoline consumed, its specific gravity, and the dynamometer distance traveled to yield mpg. Section 3.6 discusses this QA/QC check in more detail.

2.8. POLLUTANT AND GHG EMISSIONS

Section 1.3 indicated that the vehicle tests will also quantify pollutant and greenhouse gas emissions (CO, CO_2, NO_X, and THC). Although these parameters are not part of the primary verification, they are of interest to the GHG stakeholder community.

Section 2.7 showed the relationship of pollutant and greenhouse gas emissions measurements with the fuel economy determination. Pollutant and GHG emissions in g/mi are an intermediate determination. The instrument description in Section 2.5, therefore, applies to these measurements as well. Although NO_X values do not contribute to the mpg results, the NO_X instrumentation and measurement techniques are integrated with the other analyses so the marginal cost of reporting NO_X emissions is negligible. Section 3.0 summarizes the relevant instrument specifications and QA/QC checks.

3.0 DATA QUALITY

3.1. BACKGROUND

The GHG Center selects methodologies and instruments for all verifications to ensure a stated level of data quality in the final results. The GHG Center specifies DQOs for each verification parameter before testing as a statement of data quality. Each test measurement that contributes to a verification parameter determination has specific data quality indicators (DQIs) which, if met, ensure achievement of that parameter's DQO.

This verification's DQO will be the fuel economy change's desired confidence level. Section 2.3 discussed the achievable confidence intervals based on SwRI's sample data. For this verification, the DQO statement is as follows:

> *The 95-percent confidence interval of the fuel economy change (Δ) will be less than 60 percent of the mean Δ for Δ values as low as 0.2 mpg. At 0.29 mpg mean Δ, for example, the confidence interval will be less than ± 0.17 mpg (or 60 percent) of the reported mean. For mean values of Δ less than 0.2 mpg, the confidence interval will be less than or equal to ± 0.12 mpg.*

Recalling that the expected fuel economy change will be small, this DQO represents the most economically feasible DQO goal for the expected Δ range. While this DQO is adequate to demonstrate the significance of fuel economy changes expected by ConocoPhillips, statistical significance of fuel economy changes less than 0.12 mpg may not be demonstrable under this Test Plan.

To achieve the DQO, the test site, sampling and analytical methodologies, and test procedures will all adhere to Title 40 CFR Part 86, (1) and Part 600 (2) requirements. If all testing meets the CFR specifications and the mean fuel economy change confidence interval is within the range stated above, then the observed fuel economy change will be real and the DQO will be achieved.

Each CFR testing, sampling, and analytical method will produce results which contribute to the overall fuel economy change determination. If each contributing measurement conforms to the applicable method specifications, then the GHG Center will conclude that the data and the resulting confidence interval calculation are valid.

The CFR methods associate specific accuracy determinations, QA/QC, or analytical procedures with each contributing measurement. These quantitative or qualitative protocols will constitute this verification's DQI goals. The GHG Center will compare the achieved DQIs - most often stated in terms of measurement accuracy, precision, repeatability, completeness, etc. - with the DQI goals outlined below. Achievement of the DQI goals will imply that the contributing measurement conforms to the applicable method specifications and its use in calculating the achieved DQO is valid.

SwRI employs standard operating procedures (SOPs) which incorporate each test method's DQIs. Section 5.0 lists the applicable SOPs and their most recent revision date. SwRI maintains each SOP in accordance with ISO 9002 requirements. In general, ISO 9002 specifies that an independent, ISO-certified auditor periodically reviews SwRI's practices and procedures. The audits include review of instrument calibration records, laboratory operations and conformance with the applicable SOP, NIST (or other standards organization) traceability of calibration materials and sensors, availability of SOPs to operators, etc. During the test campaign, the GHG Center will review SwRI's ISO certification and the associated SOPs to ensure that they are current.

In addition to conforming with the overall governance implied by the ISO 9002 certification, SwRI and the GHG Center will conduct factory calibrations, sensor function, and QA/QC checks on the equipment used for this verification. These will document achievement of the DQI goals. The following subsections describe the dynamometer, constant volume sampling (CVS) system, emissions and ambient instrument specifications, associated DQI goals, and QA/QC checks.

DQO achievement is directly linked to the listed DQI goals and QA/QC checks. If the DQIs are met, the instruments and measurements will achieve the listed accuracies. If each of the listed accuracies is achieved, the DQO will be achieved in turn.

3.2. DYNAMOMETER SPECIFICATIONS, CALIBRATIONS, AND QA/QC CHECKS

Table 3-1 summarizes the dynamometer's specifications.

Table 3-1. Chassis Dynamometer Specifications and DQI Goals

					Data Quality Indicator Goals	
Measurement Variable	**Operating Range Expected in Field**	**Instrument Type / Manufacturer**	**Instrument Range**	**Measurement Frequency**	**Accuracy**	**How Verified / Determined**
Speed	0 to 60 mph	Horiba LDV-48-86-125HP-AC Light-Duty Chassis Dynamometer	0 to 120 mph	10 Hz (10/sec)	± 0.02 % FS	Sensors calibrated and verified during original installation.
Load	0 to 500 lbf		0 to 1,750 lbf		± 0.1 % FS	

SwRI and the manufacturer verified the speed and torque sensor accuracies during initial installation and startup. The QA/QC checks outlined in Table 3-2 are daily operational checks which confirm that the dynamometer is functioning properly. If the daily QA/QC checks conform to these specifications, then it is reasonable to conclude that the dynamometer measurements achieve the specified accuracy. Re-verification or recalibration of the speed and load sensors occurs only when the daily QA/QC checks suffer consistent and repeatable failures. In that event, recalibrations serve as diagnostic troubleshooting tools.

Table 3-2. Chassis Dynamometer QA/QC Checks

QA/QC Check	When Performed/Frequency	Expected or Allowable Result	Response to Check Failure or Out of Control Condition
Road load horsepower calibration	Before initiating test program	Triplicate coastdown checks within ± 1.5 lbf of target	Repeat road load horsepower calibration
Dyno calibration certificate inspection	Once during the test campaign	Sensor accuracies conform to Table 3-1 specifications	Recalibrate or verify dyno sensor performance
Parasitic friction verification	Daily prior to testing	± 2 lbf from existing settings	accept new parasitic loss curve
Dyno warmup verification	Before each test run	≥ 15 minutes of operation; at least 50 mph within 2 hours of the start of testing	Warmup dyno prior to testing
Roadload and inertia simulation check	End of each test run	± 0.3 % average over the entire driving sequence	Identify cause of any problem and correct; repeat test
Valid driver's trace	End of each test run	No deviation from tolerances given in 40 CFR § 86.115	Repeat test

The Field Team Leader will monitor SwRI's QA/QC check performance. The appropriate log form appears in Appendix A4-1.

Immediately prior to each test run, operators will verify that the dynamometer is warmed up. This is an automated check built into the dyno's control computer. If it has not been operated within 2 hours of the test run start, the operator will run it at 50 mph for at least 15 minutes.

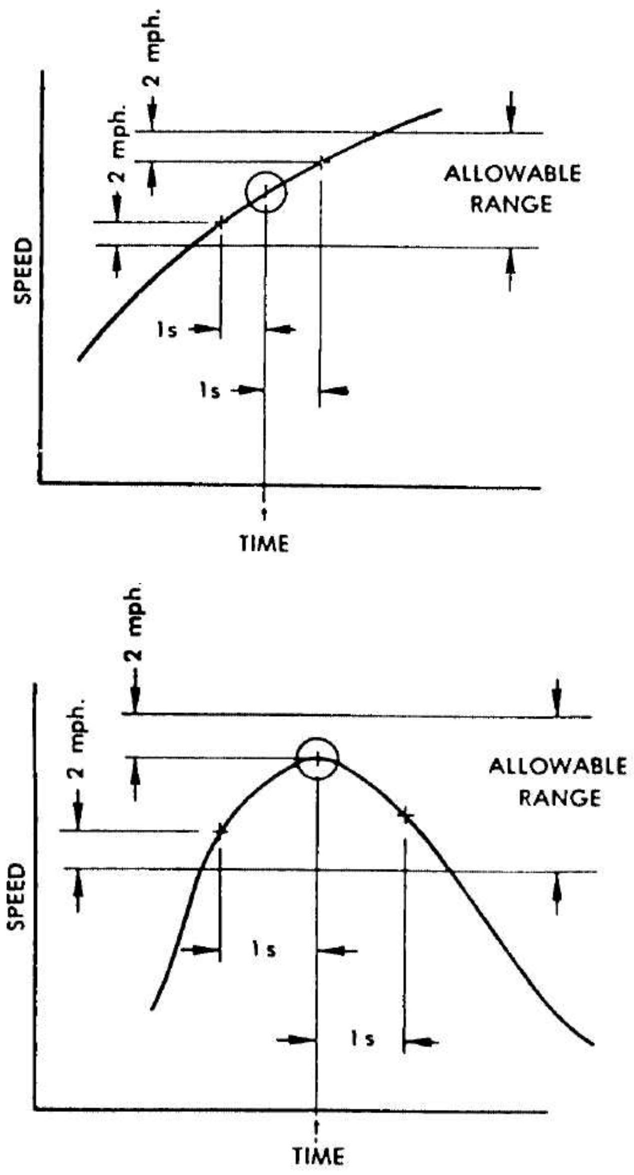
The road load horsepower calibration will occur before the first test run. This calibration's purpose is to determine dynamometer settings based on actual road load data. As discussed in Section 2.4, SwRI will conduct an iterative vehicle coastdown process to establish the dyno settings which best simulate the vehicle's road load data. When calibrated, the dyno must impose forces on the vehicle that are within ± 1.5 lbf of the actual road load forces over three separate coastdown runs.

Test operators will perform a dynamometer parasitic friction verification daily before testing. Roll friction measurements at several speeds serve as input to generate a third-order parasitic loss curve. The operator compares the daily curve to the dyno's reference curve. All forces must be within ± 2 lbf at every point on the curves.

Following each test run, the dyno control computer will print a test summary sheet. This printout will contain the average positive and negative simulation errors recorded during testing. These errors should be no more than ± 0.3 percent average over the entire driving sequence.

The test summary report also validates the drivers' ability to follow the trace according to CFR provisions. Title 40 CFR § 86.115 specifies the tolerances within which the driver must conform to the required dynamometer speed. In general, for a given time t, the speed must be within 2 mph of that required for t minus one second or t plus one second. Figure 3-1 illustrates the concept (1). The upper half is typical of dynamometer traces with a steadily increasing or decreasing speed. The lower half is typical for those portions of the trace which include a maximum or minimum value.

Figure 3-1. Driver's Trace Allowable Range



If the driver's trace exceeds the tolerances, the test summary report will flag the starting time, ending time, and duration. If this occurs, the Field Team Leader will declare the run void and SwRI will repeat it.

As an additional QA/QC check, the Field Team Leader will inspect the most recent dynamometer speed and load sensor installation calibrations.

3.3. CVS SAMPLING SYSTEM SPECIFICATIONS, CALIBRATIONS, AND QA/QC CHECKS

Table 3-3 summarizes the Horiba CVS system specifications.

Table 3-3. CVS Specifications and DQI Goals

					Data Quality Indicator Goals		
Measurement Variable	**Operating Range Expected in Field**	**Instrument Description**	**Range**	**Measurement Frequency**	**Accuracy**	**Completeness**	**How Verified / Determined**
Pressure	950 to 1050 millibar	Horiba Variable-Flow Constant Volume Sampler	0 to 1500 millibar	10/sec	± 2 % reading	100 %	Sensors calibrated and verified during installation.
Temperature	20 to 45 °C		0 to 100 °C		± 2 % reading		
Volumetric Flow Rate	350 to 500 ft^3/min		0 to 700 ft^3/min		± 0.5 % reading		

Similar to the chassis dynamometer, SwRI and Horiba verified the CVS sensor accuracies during initial installation and startup. The QA/QC checks outlined in Table 3-4 are daily operational checks which confirm proper CVS function. If the daily QA/QC checks conform to specifications, then it is reasonable to conclude that the CVS measurement variables achieve the specified accuracy. CVS sensor re-verification or recalibration occurs only during troubleshooting of consistent and repeatable failure of the daily QA/QC checks. As an additional QA/QC check, the Field Team Leader will inspect the most recent CVS sensor calibrations.

Table 3-4 summarizes the CVS QA/QC checks.

Table 3-4. CVS System QA/QC Checks

QA/QC Check	When Performed/Frequency	Expected or Allowable Result	Response to Check Failure or Out of Control Condition
New propane tank composition verification	Prior to placing new propane tank in service	< 0.35 % difference in reading from previously verified tank	Reject new propane tank; obtain and verify another
CVS and propane critical flow orifice calibration certificate inspection	Once during the test campaign	Sensor accuracies conform to Table 3-3 specifications	Recalibrate or verify CVS sensor performance
Propane injection check	Weekly	difference between injected and recovered propane ≤ ± 2.0 %.	Identify cause of any problem and correct; if no problems are identified, recalibrate CVS
Flow rate verification	Before each test run	± 5 cfm of appropriate nominal set point	Set proper flow rate
Sample bag leak check	Before each test run	Maintain 10 “ Hg vacuum for 10 seconds	Identify cause of any problem and correct; replace bag if necessary

The Field Team Leader will monitor SwRI's QA/QC check performance. Appendix A4-2 presents the appropriate log form.

Test operators will compare each new propane cylinder with an approved in-use cylinder before releasing the new cylinder for CVS calibrations. They will separately inject propane from each cylinder into a verified CVS system with a CFO and analyze the amount recovered as described above. The difference between the average of three readings from each of the two cylinders must be < 0.35 percent.

SwRI will verify CVS calibration and proper function weekly with a propane injection test that conforms to 40 CFR § 86.119 specifications. Technicians will inject a known quantity of propane into the CVS system over a specified time period. A NIST-traceable critical-flow orifice (CFO) will control the propane flow. A calibrated THC analyzer will measure the total hydrocarbon concentration, as diluted and injected into a sample bag. The propane mass recovered and reported by the CVS (and VETS) must be within ± 2.0 percent of the mass injected. This procedure will also verify the CVS flow rate because it and the sample dilution ratio are part of the propane mass recovery calculation.

SwRI will check the sample bags for leaks daily. The test operator will evacuate each bag to a vacuum of at least 10 " Hg. Each bag must maintain the achieved vacuum for at least 10 seconds. The technician will discard and replace bags which do not meet the specification.

Prior to starting each test run, the operator will visually confirm the indicated CVS flow rate to ensure that the system is operating at the desired set point.

3.4. EMISSIONS ANALYZER SPECIFICATIONS, CALIBRATIONS, AND QA/QC CHECKS

Table 3-5 lists the emissions analyzers to be used during the test campaign, the expected values, and associated DQI goals.

Table 3-5. Emissions Analyzer Specifications and DQI Goals

					Data Quality Indicator Goals		
Measurement Variable	**Expected Operating Range**	**Instrument Mfg., Model / Type**	**Instrument Range**	**Measurement Frequency**	**Accuracy[a]**	**How Verified / Determined**	**Completeness**
Low CO	0 - 200 ppm	Horiba AIA-210 / NDIR	0 - 200 ppm	1 analysis per bag, 8 bags (4 dilute exhaust, 4 ambient air) per run. 45 second purge period, then 10-second analysis period per bag. Analyzer output to VETS @ 10/sec	± 1.0 % FS or ± 2.0 % of the calibration point	Gas divider with protocol calibration gases at 11 points evenly spaced throughout span (including zero)	100 %
CO	0 - 1000 ppm	Horiba AIA-220 / NDIR	0 - 3000 ppm				
CO_2	0 - 2.0 % (vol)	Horiba AIA-220 / NDIR	0 - 16 % (vol)				
NO_X	0 - 100 ppm	Horiba CLA-220 / Chemiluminescence	0 - 300 ppm				
THC	0 - 250 ppm (carbon)	Horiba FIA-220 / HFID	0 - 1000 ppm (carbon)				

[a] The most stringent accuracy specification applies for each calibration point.

SwRI will verify each analyzer's performance through a series of zero and calibration gas challenges. Each zero and calibration gas must conform to certain specifications and/or be NIST-traceable. Table 3-6 summarizes the applicable QA/QC checks. If all calibration gases and QA/QC checks meet their specifications, then SwRI and the GHG Center will infer that the emissions analyzers meet Table 3-5 accuracy specifications.

Table 3-6. Emissions Analyzer QA/QC Checks

QA/QC Check	When Performed/Frequency	Expected or Allowable Result	Response to Check Failure or Out of Control Condition
NIST-traceable calibration gas verifications	Prior to being put into service	Average of three readings must be within ± 1% of verified NIST SRM concentration	Identify cause of any problem and correct; discard bottle and replace if necessary
Zero-gas verification	Prior to being put into service	HC < 1 ppmC CO < 1 ppm CO_2 < 400 ppm NO_x < 0.1 ppm O_2 between 18 and 21%	Discard bottle and replace
Gas divider linearity verification	Monthly	All points within ± 2% of linear fit FS within ± 0.5% of known value	Identify cause of any problem and correct; replace gas divider if necessary
Analyzer calibrations	Monthly	All values within ± 2% of point or ± 1% of FS; Zero point within ± 0.2% of FS	Identify cause of any problem and correct; recalibrate analyzer
Wet CO_2 interference check	Monthly	CO 0 to 300 ppm, interference ≤ 3 ppm CO > 300 ppm, interference ≤ 1% FS	
NO_X analyzer interference check	Monthly	CO_2 interference ≤ 3 %	
NO_X analyzer converter efficiency check	Monthly	NO_x converter efficiency > 95%	
CO and CO_2 PEAs	Once during testing	± 2 % of analyzer span	Modify or repair sampling system
Calibration gas certificate inspection	Once during testing	Certificates must be current; concentrations consistent with cylinder tags	Obtain gases with current certificates
Bag cart operation	Prior to analyzing each bag	Post-test zero or span drift shall not exceed ±2% full-scale	Zero and span the affected analyzer again and read the BACKGROUND and SAMPLE bags again.

SwRI will verify all new Standard Reference Material (SRM) or other NIST-traceable reference gas concentrations with an emissions analyzer that has been calibrated within the last 30 days. The operator will first zero the analyzer with a certified zero grade gas and then span it with a NIST SRM (or equivalent) three times to ensure stability and minimal analyzer drift.

The operator will then introduce the new reference gas into the analyzer and record the concentration, followed by reintroduction of the NIST SRM to ensure that the analyzer span point does not drift more than ± 0.1 meter divisions. The operator will repeat these last two steps until three consistent values are obtained. The mean of these three determinations must be within one percent of its NIST SRM concentration. SwRI will then consider the reference gas as suitable for emissions analyzer calibrations.

SwRI will verify each new working zero air (or N_2) cylinder's impurities to ensure that it is suitable for emissions analyzer zero checks. Comparisons between a certified Vehicle Emission Zero (VEZ) Gas (or equivalent) and the candidate zero gas will serve this purpose. SwRI will employ an emissions cart (or suite of instruments) that has been calibrated within the last 30 days for this procedure. The operator will zero the analyzers with certified VEZ gas and span them with NIST-traceable reference gases to ensure stability and minimal analyzer drift. The operator will then introduce the candidate cylinder's zero gas to the sample train and record the HC, CO, CO_2, and NO_x values. The results must fall within the ranges given in Table 3-6 for the zero gas to be deemed suitable for instrumental analyzer calibrations.

Prior to the monthly exhaust emission analyzer calibrations, SwRI will verify the calibration gas divider linearity with an HC analyzer known to have a linear response and an HC span gas. The operator will first zero and then span the instrument such that the span occupies 100 meter or chart divisions. The operator will operate the divider in each of its settings in descending order and compare the observed results with a linear scale. The difference between the commanded and observed concentrations must be within ± 2.0 percent of the commanded concentration. Also, this difference must be less than ± 0.5 percent of the span value.

NIST-traceable calibration gases, in conjunction with a verified gas divider and zero gas, will create individual gas concentrations with which to challenge each instrumental analyzer. The gas divider will generate 11 concentrations in 10 percent increments from 0 to 100 percent of each analyzer's span (the CFR requires 7 points). Analyzer response at each point must be within ± 2.0 percent of the concentration or ± 1.0 percent of span, whichever is more stringent. Zero gas response must be within ± 0.2 percent of span (the CFR requires ± 0.3 percent). If any point is outside these limits, operators will generate a new calibration curve.

The CO analyzer wet CO_2 interference check will occur in conjunction with the monthly calibration. This procedure determines the analyzer's response to water vapor and CO_2. The operator will turn the analyzer on, allow it to stabilize, and challenge it with 14-percent CO_2 in N_2 bubbled through water. Analyzer response to the interference gas must be ≤ 3 ppm for spans below 300 ppm; response must be $\leq$ 1.0 percent of span for higher ranges.

The NO_X analyzer CO_2 interference (quench) check will occur in conjunction with the monthly calibration. CO_2 can quench the analyzer's NO response. A verified gas divider will dilute NIST-traceable CO_2 (concentration of 80 to 100 percent of the maximum range expected during testing) by 50 percent with NIST-traceable NO. The operator will calculate the expected dilute NO concentration and record the analyzer's actual response to this challenge. The difference between the calculated NO and measured NO concentrations must be ≤ 3.0 percent.

NO_X analyzer converter efficiency checks will occur monthly. This procedure will use a NO_X generator which dilutes NIST-traceable NO with air. An ozone generator then converts a quantitative portion of the air's oxygen to O_3 which, in turn, converts the same proportion of NO to NO_2. This will create a NO_X blend (NO plus NO_2) of known concentration. The difference between the analyzer's NO response and NO_X response will be the measure of the NO_X to NO converter efficiency. SwRI will require that the NO_X converter efficiency be > 95 percent (the CFR requires 90 percent).

As an independent performance evaluation audit (PEA), the Field Team Leader will introduce NIST-traceable CO and CO_2 in N_2 to the analyzer sampling system at the sample bag inlet manifold (see Figure 2-4). The CO_2 concentrations will approximate that expected during testing. CO and CO_2 analyzer responses must be within ± 2 percent of span.

The Field Team Leader will review certificates for all calibration and zero gases used during the test campaign. All certificates must be current and the cylinder tag concentrations must match those on the applicable certificate. He will also monitor SwRI's QA/QC check performance. Appendix A4-3 contains the required log form.

3.5. AMBIENT INSTRUMENT SPECIFICATIONS, CALIBRATIONS, AND QA/QC CHECKS

Required meteorological parameters include ambient air temperature, absolute and relative humidity, and barometric station pressure. These values enter into a variety of corrections and calculations. SwRI will acquire these data with the instruments listed in Table 3-7.

Table 3-7. Ambient Instrument Specifications and DQI Goals

					Data Quality Indicator Goals		
Measurement Variable	**Expected Operating Range**	**Manufacturer**	**Instrument Range**	**Measurement Frequency**	**Accuracy**	**Completeness**	**How Verified / Determined**
Wet- and Dry-Bulb Temperature	68 to 86 ºF	Psychro-Dyne	10 to 110 ºF	Prior to each test	± 1.0 ºF	100 %	Regular verification checks with NIST-traceable standards
Barometric Pressure	28 to 31 “Hg	Heise 901A pressure transducer	20 to 35 “Hg		± 0.01 “ Hg		

The barometric pressure transducer measures test site pressure directly. Wet-bulb and dry-bulb temperatures are the source data for relative and absolute humidity determinations according to 40 CFR § 86.144.

SwRI will verify meteorological instrument performance with the QA/QC checks outlined in Table 3-8.

Table 3-8. Ambient Instrument QA/QC Checks

QA/QC Check	When Performed/Frequency	Expected or Allowable Result	Response to Check Failure or Out of Control Condition
Test cell barometer calibration verification	Prior to each test	± 0.01" Hg of NIST-traceable standard	Identify cause of any problem and correct; replace transducer if necessary
Wet-bulb and dry-bulb temperature calibration verification	Prior to each test	±1.0 ºF of NIST-traceable standard	Identify cause of any problem and correct; replace thermometer if necessary
Test cell dry-bulb temperature verification	Prior to each test run	68 to 86 ^{o}F	Identify cause of any problem and correct: delay testing until temperature is within spec

SwRI maintains separate NIST-traceable primary standard and secondary standard barometers. Operators will compare the primary and secondary standards with each other to ensure the primary standard's accuracy. The primary standard shall be within ± 0.005 “ Hg of the secondary standard. The test site barometer readout shall be, in turn, within ± 0.01 “ Hg of the primary standard.

Verification of the wet-bulb and dry-bulb thermometers occurs monthly. Comparisons with NIST-traceable thermometers (accurate to ± 0.1 ^{o}F) will ensure that test site temperature measurements are within ± 1.0 ^{o}F.

40 CFR § 86.130 specifies that test site temperatures must be between 68 and 86 °F during vehicle testing. Operators will monitor temperatures prior to the start of and throughout every test run. The VETS system will flag test cell operating temperatures which fall outside of the specifications.

The Field Team Leader will monitor SwRI's QA/QC check performance. Appendix A4-4 presents the required log form.

3.5.1. Test Fuel Specifications

The test gasoline must conform to 40 CFR § 86.113 specifications. SwRI will receive certification-grade test fuel in 55-gallon drums and perform duplicate analysis of one sample per drum in accordance with the methods listed in Table 3-9. Note that the volumetric and gravimetric cross checks described in Section 3.6 require the specific gravity method in Table 3-9. Specific gravity is not included in the CFR specifications. The table also lists the analytical instruments, ranges, and accuracies.

Table 3-9. Test Fuel ASTM Measurement Methods and DQI Goals

					Data Quality Indicator Goals		
Measurement Variable	**ASTM Method**	**Manufacturer**	**Instrument Range**	**Measurement Frequency**	**Accuracy**	**Completeness**	**How Verified / Determined**
Octane, Research	D2699	Waukesha Engine	0 - 100 Octane	Prior to putting fuel into service; duplicate analysis of one sample per 55-gallon drum	± 0.32 Octane	All properties must be confirmed within specifications	Regular verification and calibration according to the relevant ASTM Method.
Octane, Motor	D2700						
Lead	D3237	Perkin Elmer	0.01 to 0.1 g/US gal.		± 0.0004 g/US gal.		
Distillation Range Initial Boiling Point 10 pct. Point 50 pct. Point 90 pct. Point End Point	D86	ISL	Not specified		 ± 2.54 °F ± 2.36 °F ± 1.96 °F ± 1.57 °F ± 5.11 °F		
Sulfur	D2622	Bruker, ARL	0.0003 to 5.3 wt. %		± 0.00042 wt. % @ 0.0050 wt % ± 0.00113 wt. % @ 0.0450 wt. %		
Phosphorus	D3231	Varian	0.0007 to 0.15 g/US gal		± 0.0007 g/US gal.		
Reid Vapor Pressure	D5191	Grabner	1 to 18.6 psi		± 0.070 psi @ 9.96 psi ± 0.048 psi @ 6.40 psi		
Hydrocarbon composition Olefins, max. Aromatics, max. Saturates	D1319	N/A	0 to 100 %		 ± 0.64 % ± 0.54 % ± 0.59 %		
Specific gravity	D1298	N/A	not specified		± 0.5 %		

Table 3-10 lists the expected or allowable results. The Field Team Leader will review the analysis results during the test campaign. Appendix A-2 has the required log form.

Table 3-10. Test Fuel Properties

QA/QC Check	When Performed / Frequency	Expected or Allowable Result	Response to Check Failure or Out of Control Condition
Octane, Research	Prior to being put into service	93 minimum	Repeat analyses to confirm results. Reject fuel and use a different batch meeting CFR requirements.
Sensitivity (Research Octane minus Motor Octane)		7.5 minimum	
Lead		0.050 g/U.S. gal maximum	
Distillation Range			
Initial Boiling Point		75 to 95 °F	
10 pct. Point		120 to 135 °F	
50 pct. Point		200 to 230 °F	
90 pct. Point		300 to 325 °F	
End Point		415 °F maximum	
Sulfur		0.10 wt. percent maximum	
Phosphorus		0.005 g/US gallon maximum	
Reid Vapor Pressure		8.0 to 9.2 psi	
Hydrocarbon composition			
Olefins, max. pct		10 % maximum	
Aromatics, max. pct		35 % maximum	
Saturates		remainder	

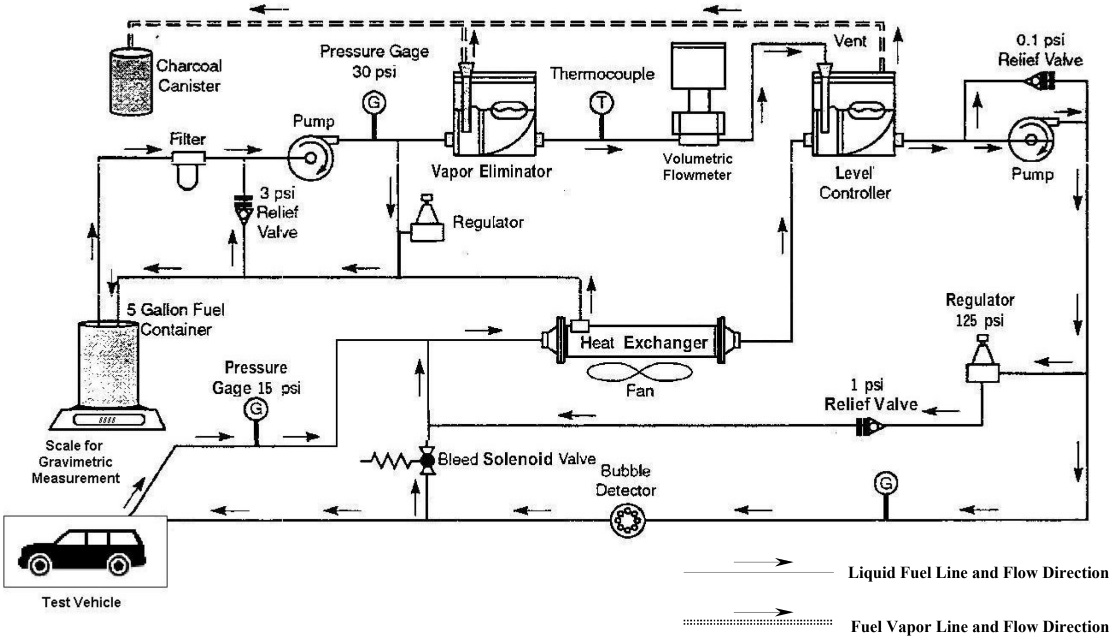
Each SwRI analysis must agree with its duplicate to within two times the accuracy specified in Table 3-9. SwRI will reject fuel lots for testing which do not conform to these requirements. The Field Team Leader will obtain a copy of the manufacturer's certification and compare it with the Table 3-10 specifications and the SwRI test results for information.

3.6. FUEL ECONOMY VOLUMETRIC AND GRAVIMETRIC CROSS CHECKS

SwRI and the GHG Center will cross check the carbon balance method fuel economy results with separate volumetric and gravimetric fuel economy determinations. An external cart will fuel the vehicle from a five-gallon fuel container during testing. Figure 3-1 shows a schematic of the equipment involved.

The fuel container will rest on a Fairbanks Model SB12-0806-5 scale. The scale's range is from 0 to 60 lb, ± 0.5 percent of reading. Test personnel will record each test run's beginning and ending fuel container weights. The weight difference divided by the fuel specific gravity (in lb/gal) will yield the volume of fuel used in gallons. Miles traveled during the test divided by the gallons used will be the gravimetric mpg.

Figure 3-2. Fuel Cart Schematic



The fuel will pass through a Max Machinery Model 213 positive-displacement piston-type volumetric flow meter with maximum flow rate of 0.4 gal/min, ± 0.75 percent of reading. A day tank with a level controller will maintain a constant circulating flow for vehicles equipped with a fuel return system on the engine fuel rail. The flow meter will record the make-up flow to the day tank. Test personnel will record the fuel temperature and volume used during each test run. The distance traveled divided by the corrected volume at standard temperature (20 ^{o}C) will yield mpg.

SwRI will conduct the cross-check for a total of 10 test runs, evenly distributed between the reference oil and FEHP test conditions.

SwRI routinely performs these cross checks for fuel economy evaluations, including the 12 lubrication oil evaluations referenced in Section 2.1. That discussion introduced the COV as an overall measurement of a data set's variability. For this data set, composite gravimetric and volumetric fuel economy COVs were within ± 0.3 percent of the carbon balance method results. This verification will apply the ± 0.3 percent criteria to the composite fuel economy COVs determined during the test campaign.

After the third test run for each lubricant, the Field Team Leader will calculate and compare the carbon balance, volumetric, and gravimetric means and COVs. It is not completely clear to us what level of comparability is appropriate for this test. Mean differences between paired measurements in excess of 0.2 mpg will be investigated for a cause of systematic bias that might compromise the accuracy of the carbon mass balance results. A carbon balance method COV which is more than 0.3 percent greater than those determined via the volumetric or gravimetric methods will indicate that the CFR test methods' variability is more than should be reasonably expected. In this case, the Field Team Leader will declare a testing halt. Testing will not recommence until all possible problems are diagnosed and solved. The Field Team Leader may require that individual test runs be repeated.

Conversely, if either of the volumetric or gravimetric composite COVs are more than 0.3 percent higher than the carbon balance method COV, test personnel will check and repair the appropriate equipment prior to the next test run. Because these methods serve only as cross-checks, the Field Team Leader may or may not declare a testing halt, depending on professional judgement. This process will continue for a total of 5 cross-checks each for the reference oil and FEHP.

Appendices A4-5 and A4-6 contain log forms with which the Field Team Leader will track the volumetric and gravimetric fuel economy results. They also provide space for COV calculations and comparisons.

3.7. INSTRUMENT TESTING, INSPECTION, AND MAINTENANCE

GHG Center personnel, the Field Team Leader, and/or SwRI will subject all test equipment to the QC checks discussed earlier. Before tests commence, operators will assemble and test all equipment as anticipated to be used in the field. They will, for example, operate and calibrate all controllers, flow meters, computers, instruments, and other measurement system sub-components per the specified test methods and/or this Test Plan. Test personnel will repair or replace any faulty sub-components before starting the verification tests. Test personnel will maintain a small amount of consumables and frequently needed spare parts at the test site. The Field Team Leader, Project Manager, and/or SwRI management will handle major sub-component failures on a case-by-case basis (e.g., by renting replacement equipment or buying replacement parts).

3.8. INSPECTION AND ACCEPTANCE OF SUPPLIES AND CONSUMABLES

Field personnel will employ an EPA Protocol 1 gas for the blind audit sample. The supplier certifies audit gas concentrations to within ± 2 percent of the tag value. Copies of the audit gas certification will be available on-site during testing and archived at the GHG Center.

SwRI Calibrations will employ EPA Protocol 1 gases supplied either by a gas-divider dilution system or directly from cylinders. Per EPA protocol gas specifications, the actual concentration must be within ± 2 percent of the certified tag value. Copies of all EPA protocol gas certifications will be available on-site.

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4.0 DATA ACQUISITION, VALIDATION, AND REPORTING

4.1. DATA ACQUISITION AND DOCUMENTATION

Test personnel (responsible parties are noted below in parentheses) will acquire the following types of data and generate the following documentation during the verification:

- Fuel economy and emissions data (SwRI)
- Manually acquired parameters and printed output data from the Horiba VETS such as dynamometer operating traces, CVS sampling rates, exhaust gas analyzer concentration, ambient pressure, exhaust gas pressure, temperature, and ambient conditions (Appendix B-4 provides an example) (SwRI)
- Documents which describe the vehicle, engine, tire pressures, and cold soak temperatures. (SwRI)
- Documents such as fuel composition and density certifications traceable to the test fuel lot and NIST-traceable calibration gas certificates (SwRI)
- QA/QC documentation as described in Section 3.0 (SwRI, GHG Center)
- Field test documentation (GHG Center)
- Corrective action and assessment reports (GHG Center)

SwRI will submit copies of all test-run printed outputs, calibration forms, fuel analyses, certificates, etc. to the Field Team Leader as each test run is completed. These submittals must be complete prior to the Field Team Leader's departure after the final test run.

SwRI will prepare and submit a letter report in printed and electronic (Microsoft Word) format to the GHG Center Field Team Leader within three weeks of the field activities' completion. The report will describe the test conditions, document all QA/QC procedures, include copies of calibrations, calibration gas, and the verification test results. The report will include a signed certification which attests to SwRI's conformance with all QA/QC procedures and the accuracy of the results. SwRI will attach all relevant test data as appendices.

The following subsections discuss each of these items and their role in the test campaign. The GHG Center will archive all electronic data, paper files, analyses, and reports at their Research Triangle Park, NC office in accordance with the QMP.

4.1.1. Fuel Economy and Emissions Data

SwRI will be responsible for all fuel economy and emissions data, associated QA/QC log forms, paper, and electronic files until they are accepted by the Field Team Leader.

SwRI will report fuel economy and emission measurements for each test run to the Field Team Leader as:

- ppmv (percent for CO_2)
- grams per mile of pollutants
- miles per gallon of gasoline

4.1.2. VETS Data Acquisition

The VETS will collect dynamometer data every 0.1 second. It will compute and log instantaneous or averaged values as needed. During field testing, the Field Team Leader will review and validate the electronically collected data at the end of each test run. After the third test run for each fuel condition, he will determine the mean mpg and confidence interval and apply the statistical tests described in Sections 2.1 through 2.3.

4.1.3. Vehicle and Engine Documentation

SwRI will document the applicable vehicle and engine specifications. Documentation will generally conform to 40 CFR §600.005-81 and will include information such as:

- Vehicle, engine, drive train, fuel system, emission control system components, exhaust after-treatment device specifications, vehicle weight, and statement of representativeness with respect to the fleet from which the vehicle was selected
- Odometer mileage prior to the reference oil and FEHP installation
- A description of the mileage accumulation procedures and a detailed mileage accumulation log for the reference oil and FEHP which will include the operator(s) name(s), dates, and times
- Overnight cold-soak temperature synopsis
- Tire pressures prior to each test run

4.1.4. Test Fuel Composition

An independent laboratory (a separate SwRI department) analyzes each lot of test fuel to ensure its conformance with 40 CFR §86.113-04 and §86.113-94. SwRI will provide fuel analysis results as a separate attachment to their report.

4.1.5. QA/QC Documentation

Upon completion of the field test activities, SwRI will provide copies of calibrations, pre-test checks, system response time, NO_2 converter efficiency, and other QA/QC documents to the Field Team Leader. Calibration records will include information about the instrument being calibrated, raw calibration data, calibration equations, analyzer identifications, calibration dates, calibration standards used and their traceabilities, calibration equipment, and names of participating staff. These records will provide source material for the Verification Report's Data Quality section, and will be available to the QA Manager during audits.

4.1.6. Field Test Documentation

The Field Team Leader will obtain copies of all manually and digitally logged data. He will take site photographs and maintain a Daily Test Log which will include the dates and times for setup, testing, teardown, and other activities.

The Field Team Leader will record test run information and observations in the Daily Test Log and on the log forms in Appendix A. The Field Team Leader will submit digital and paper data files, SwRI test results, and the Daily Test Log to the Project Manager.

4.1.7. Corrective Action and Assessment Reports

A corrective action will occur when audits or QA/QC checks produce unsatisfactory results (as defined by the DQO or DQIs) or upon major deviations from this Test Plan. Immediate corrective action will enable quick response to improper procedures, malfunctioning equipment, or suspicious data. The corrective action process involves the Field Team Leader, Project Manager, and QA Manager. The GHG Center QMP requires that test personnel submit a written corrective action request (CAR, Appendix A-5) to document each corrective action.

The Field Team Leader will most frequently identify the need for corrective actions. In such cases, the Field Team Leader will immediately notify the Project Manager. He will then, in collaboration with the QA Manager and other project personnel, take and document the appropriate action.

Note that the Project Manager is responsible for project activities. He is authorized to halt work upon determining that a serious problem exists. The Field Team Leader is responsible for implementing corrective actions identified by the Project Manager and is authorized to implement any procedures to prevent a problem's recurrence.

4.2. DATA REVIEW, VALIDATION, AND VERIFICATION

The Project Manager will initiate the data review, validation, and analysis process. At this stage, analysts will classify all collected data as valid, suspect, or invalid. The GHG Center will employ the QA/QC criteria specified in Section 3.0 and the associated tables. Source material for data classification include factory and on-site calibrations, maximum calibration and other errors, audit gas analyses results, and lab repeatability results.

In general, measurements which:

- meet the specified DQIs and QA/QC checks,
- were collected when an instrument was verified as being properly calibrated,
- are consistent with reasonable expectations (e.g., manufacturers' specifications, professional judgement)

will form the basis for valid data.

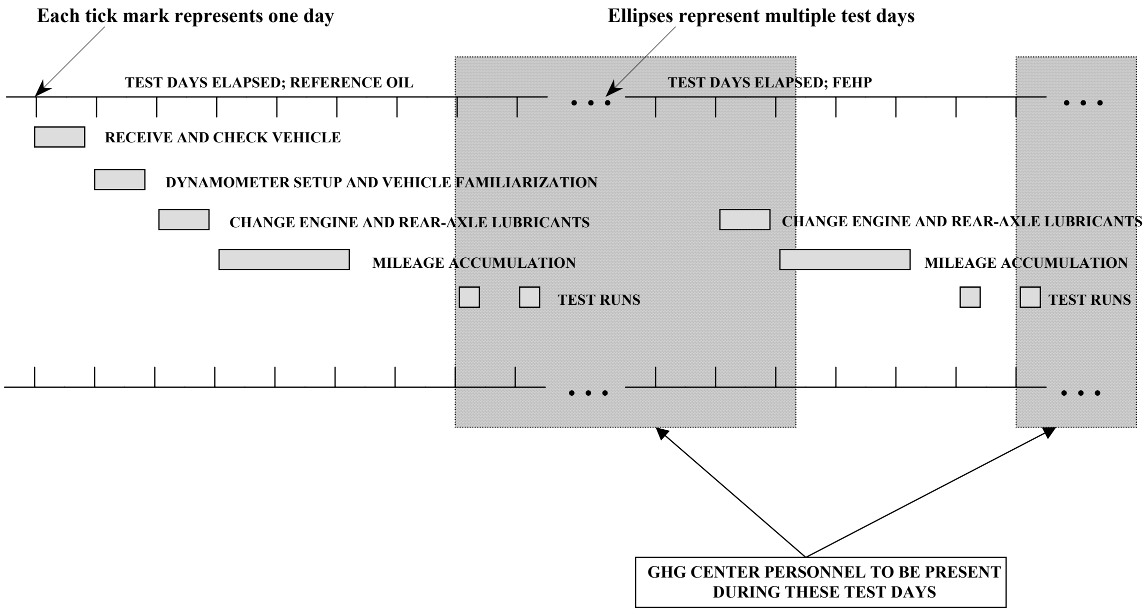
The Verification Report will incorporate all valid data. Analysts may or may not consider suspect data, or it may receive special treatment as will be specifically indicated. If the DQI goals cannot be met due to excessive data variability, the Project Manager will decide to either continue the test, collect additional data, or terminate the test and report the data obtained.

Data review and validation will primarily occur at the following stages:

- On site -- by the Field Team Leader
- Before writing the draft Verification Report -- by the Project Manager
- During draft Verification Report QA review and data audit -- by the GHG Center QA Manager

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 (i.e., VETS file data, QA/QC check results, technical system audits, etc.) during testing. He will plan to be on-site during the test activities as shown in the following figure. This schedule will provide the best opportunity to conduct site audits and the CO_2 analyzer PEA, manage the test campaign's progress, and perform other data validation and/or review. Log forms in Appendix A provide the detailed information he will gather.

Figure 4-1. SRI On-Site Test Activities



The QA Manager will use this Test Plan and documented test methods as references with which to review and validate the data and the draft Verification Report. He will review and audit the data in accordance with the GHG Center's QMP. For example, the QA Manager will randomly select raw data and independently calculate the Performance Verification Parameter. The comparison of these calculations with the results presented in the draft Verification Report will yield an assessment of the GHG Center's QA/QC procedures.

4.3. DATA QUALITY OBJECTIVES RECONCILIATION

A fundamental component of all verifications is the reconciliation of the collected data with its DQO. As discussed in Section 4.2, the Field Team Leader and Project Manager will review the collected data to ensure that they are valid and are consistent with expectations. They will assess the data's accuracy and completeness as they relate to the stated DQI goals. Note that Section 3.0 discussed the verification parameter and each contributing measurement in detail. It also specified the required field procedures for each measurement which would ensure achievement of all DQIs. If the test data show that DQI goals were met, and the resulting fuel economy change confidence interval conforms to the specifications in Section 3.1, then analysts will conclude that DQO was achieved; DQIs and the DQO will therefore be reconciled.

4.4. ASSESSMENTS AND RESPONSE ACTIONS

The Field Team Leader, Project Manager, QA Manager, GHG Center Director, and technical peer-reviewers will assess the project and the data's quality as the test campaign proceeds. The Project Manager and QA Manager will independently oversee the project and assess its quality through project reviews, inspections if needed, a scheduled PEA, and an ADQ.

4.4.1. Project Reviews

The Project Manager will be responsible for conducting the first complete project review and assessment. Although all project personnel are involved with ongoing data review, the Project Manager must ensure that project activities meet measurement and DQO requirements.

The GHG Center Director will perform the second project review. The Director is responsible for ensuring that the project's activities adhere to the ETV program requirements and stakeholder expectations. The GHG Center Director will also review all activities to ensure that the Field Team Leader has the equipment, personnel, and resources to complete the project and to deliver data of known and defensible quality.

The QA Manager will perform the third review. He is responsible for ensuring that the project's management systems function as required by the QMP. The QA Manager is the GHG Center's final reviewer, and he is responsible for assuring the achievement of all QA requirements.

ConocoPhillips, Ford, and selected GHG Center stakeholders and/or peer reviewers will then review the report. Technically competent persons who are familiar with the project's technical aspects, but not involved with project activities, will function as peer reviewers. The peer reviewers will provide written comments to the Project Manager.

The GHG Center will submit the draft report to EPA QA personnel, and the Project Manager will address their comments as needed. Following this review, the Verification Report and Statement will undergo EPA management reviews, including the GHG Center Program Manager, EPA ORD Laboratory Director, and EPA Technical Editor.

4.4.2. Inspections

Although not planned, the Project Manager or QA Manager may conduct onsite or offsite inspections. Inspections assess key verification test activities. These activities may include, but are not limited to, pre- and post-test calibrations, data collection equipment, sample equipment preparation, sample analysis, and/or data reduction. Source material for inspections are the test plan or other established methods. The inspector will document the findings and provide guidance to the Field Team Leader as needed. Test personnel must investigate any deficiencies or problems found during inspections; they will document their responses in a Corrective Action Report (CAR) as shown in Appendix A-5.

4.4.3. Performance Evaluation Audit

The Field Team Leader will conduct a PEA of the emissions analyzer sampling system as described in Section 3.4. He will present the CO and CO_2 in N_2 mixture such that the concentration is blind to the system's operator. Upon receiving the results, the Field Team Leader will evaluate whether they comply with the given specifications. He will report the findings to the QA Manager.

4.4.4. Technical Systems Audit

The Field Team Leader will perform a technical systems audit (TSA) of the following test components:

- Chassis dynamometer equipment, calibrations, and setup
- CVS equipment, calibrations
- Instrumental analyzer system, calibrations
- Fuel delivery system (including volumetric and gravimetric measuring equipment) and calibrations.

During the TSA, the Field Team Leader will verify that the equipment, SOPs, and calibrations are as described in this Test Plan. Appendix A-6 provides equipment and SOP log sheets. Note that the "Calibration and QA/QC Audit Checklist" forms in Appendix A-4 will serve for gathering TSA calibration information.

4.4.5. Audit of Data Quality

The ADQ is an evaluation of the measurement, processing, and data analysis steps to determine if systematic errors are present. During the ADQ, the QA Manager, or designee, will randomly select approximately 10 percent of the data. He will follow the selected data through analysis and data processing. The ADQ's scope is to verify that the data-handling system functions correctly and to assess the quality of the analysis.

The QA Manager will route the ADQ results to the Project Manager for review, comments, and possible corrective actions. Project records will document the results. The Project Manager will take any necessary corrective action needed and will respond by addressing the QA Manger's comments in the final verification Report.

4.5. VERIFICATION REPORT AND STATEMENT

The Project Manager will coordinate preparation of a draft Verification Report and Statement within 8 weeks of completing the field test, if possible. The Verification Report will summarize each verification parameter's results as discussed in Section 2.0 and will contain sufficient raw data to support findings and allow others to assess data trends, completeness, and quality. The report will clearly characterize the verification parameters, their results, and supporting measurements as determined during the test campaign. It will present raw data and/or analyses as tables, charts, or text as is best suited to the data type. The report will also contain a Verification Statement, which is a 3 to 4 page summary of the FEHP technology, the test strategy used, and the verification results obtained.

The Project Manager will submit the draft Report and Statement to the QA Manager and Center Director for review. A preliminary outline of the report is as follows:

Preliminary Outline
Fuel-Efficient High-Performance Rear- Axle Lubricant Verification Report

Verification Statement

Section 1.0:	*Verification Test Design and Description* *Description of the ETV program* *FEHP and test vehicle description* *Overview of the verification parameters and evaluation strategies*
Section 2.0:	*Results* *Fuel Economy Change* *Emissions performance (for information only)*
Section 3.0:	*Data Quality*
Section 4.0:	*Additional Technical and Performance Data (optional) supplied by vendor*
References:	
Appendices:	*Raw Verification and Other Data*

4.6. TRAINING AND QUALIFICATIONS

The GHG Center's Field Team Leader has extensive experience (+25 years) in field testing of air emissions from many types of sources. He is also familiar with engine and vehicle testing, operations, maintenance, and repair. He is familiar with the test methods and standard requirements that will be used in the verification test.

The Project Manager has performed numerous field verifications under the ETV program, and is familiar with EPA and GHG Center QMP requirements. The QA Manager is an independently appointed individual whose responsibility is to ensure the GHG Center's conformance with the EPA approved QMP.

4.7. HEALTH AND SAFETY REQUIREMENTS

This section applies to GHG Center personnel only. Other organizations involved in the project have their own health and safety plans - specific to their roles in the project.

GHG Center staff will comply with all known host, state/local and Federal regulations relating to safety at the test facility. This includes use of personal protective gear (e.g., safety glasses, hard hats, hearing protection, safety toe shoes) as required by the host and completion of site safety orientation (i.e., site hazard awareness, alarms and signals).

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5.0 REFERENCES

1. *40 CFR Part 86, Control of Emissions from New and In-Use Highway Vehicles and Engines*, Federal Register, U.S. Environmental Protection Agency Code of Federal Regulations. Washington, DC. Feb. 18, 2000.

2. *40 CFR Part 600, Fuel Economy of Motor Vehicles*, Federal Register, U.S. Environmental Protection Agency Code of Federal Regulations. Washington, DC. Aug. 3, 1994.

3. *Statistics Concepts and Applications*, D.R. Anderson, D.J. Sweeney, and T.A. Williams. West Publishing Company. St. Paul, MN. 1986.

4. *A Modern Approach to Statistics*, R.L. Iman and W.J. Conover. John Wiley & Sons. New York, NY. 1983.

5. *Fleet Test Evaluation of Fuel Additive Performance on Emissions -- Final Report -- SwRI Project 08-03481*, Southwest Research Institute. San Antonio, TX. 2000

6. *Proposed A, B, C Coefficient Estimation Procedure,* including *Appendix A -- Calculated Dynamometer Coefficients (W. Mears, 4/24/95)*, personal communication from Gerald A. Esper, American Automobile Manufacturer's Association to Phil Lorang of the U.S. EPA and K.D. Drachand of the California Air Resources Board. Detroit, MI. September 28, 1995

SwRI Standard Operating Procedures

SOPs referenced		Revision date:
06-002	NO_X converter efficiency determination	01-13-1998
06-003	Linearity verification of gas dividers	01-19-1998
06-007	Naming monthly calibration gas	10-16-1997
06-010	Barometric pressure verification	04-10-2000
06-011	Propane recovery check	01-22-1999
06-013	Temperature calibration and verification	06-17-1996
06-014	CVS tunnel stratification check	11-03-1995
06-016	Wet CO_2 interference check for CO analyzers	09-09-1996
06-021	FID response for methane	10-20-1995
06-023	Calibration of analyzers using digital readout	03-04-1999
06-036	Verification of zero gases	08-11-1997
06-041	NO_X analyzer CO_2 quench check	04-05-1999
06-042	Verification of SRM or NIST-traceable gases	06-25-1998
06-043	Verification of pure propane gas	06-02-1999
06-044	Hydrocarbon analyzer optimization	04-04-2002
06-048	48" dyno coastdown procedure	01-23-2002
06-049	Load cell calibration check	03-23-2001
07-013	Light-duty FTP	08-07-1998
07-027	Light-duty HFET	11-16-1995
08-004	Verification of driver's trace	02-14-1996
12-001	Quality system and process audits	02-16-2001

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Appendix A

Appendix A-1. Fuel Economy Results and Hypothesis Tests

Notes:
1) Use sample standard deviation (s_{n-1}) throughout; H_o stipulates $\mu_1 - \mu_2 = 0$. Signature:____
2) Minimum number of runs for hypothesis tests is 3 each; maximum is 7 each.
3) Obtain $t_{n1+n2-2}$ distribution values from Table 2-1 or (Anderson 1986)
4) Calculate confidence interval (e) only after sufficient number of runs allow rejection of H_o.

$$s_p^2 = \frac{(n_1 - 1)s_1^{\ 2} + (n_2 - 1)s_2^{\ 2}}{n_1 + n_2 - 2}$$

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

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

$$COV = \frac{s_{n-1}}{\overline{X}} * 100$$

Reference Oil

Run	Date	24 - Hr. time		mpg	Mean ($\overline{X}$)	$s_{ref.oil}$	COV
		Start	End				
1							
2							
3							
4							
5							
6							
7							

FEHP

Run # (n_2)	Date	24 Hr. Time		mpg	$Mean_{FEHP}$ ($\overline{X}$)	$s_{ref.oil}$	COV	Mean Δ mpg ($Mean_{FEHP}$ - $Mean_{ref}$)
		Start	End					
1								
2								
3								
4								
5								
6								
7								

Statistical Significance Calculations: Reject H_o if $t_{test} > t_{0.025,DF}$. Rejection means the difference (Δ) is statistically significant.

Tally ID	$n_{ref.oil}$	n_{FEHP}	Mean Δ mpg	$t_{n1+n2-2}$	s_p^2	t_{test}	Reject H_o?
A							
B							
C							
D							
E							
F							
G							
H							
I							

Confidence Interval Calculations

Tally ID	Mean mpg Δ	e	[e / Mean mpg Δ]*100	< 60 %?

Appendix A-2. Test Fuel Analysis Review

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

Audit Date: ____________ Signature: ______________________________________

Fuel Lot ID: ________________ Date Received: __________ Date Analyzed: _____________

Table A-2. Test Gasoline Specifications

Description	ASTM Test Method No.	Spec. Value	Analysis Value	Duplicate Analysis Value	Mfg. Certified Value	OK?
Research Octane[a]	D 2699	93 Octane				
Sensitivity (Research Octane minus Motor Octane)	D 2699, D 2700	7.5 Octane minimum				
Organic Lead	D 3237	0.05 g/gal, maximum				
Distillation Range:						
IBP		75 - 95 °F				
10 % point	D 86	120 - 135 °F				
50 % point		200 - 230 °F				
90 % point		300 - 325 °F				
Endpoint		415 °F max.				
Sulfur	D 1266	0.10 wt % maximum				
Phosphorous	D 3231	0.005 g/gal, maximum				
Reid Vapor Pressure	D 3231	8.0 - 9.2 psia				
Hydrocarbons:						
Olefins	D 1319	10 % max.				
Aromatics		35 % max.				
Saturates		Balance				
Specific Gravity	D 1298	Approx. 6.1 lb/gal				

[a]Reference value only

Notes: ____

____

____

____

____

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____

Appendix A-3
Rear-Axle Lubricant Change Procedure and Observations

Notes:
Ford Research Laboratory has developed this procedure to yield the most consistent possible run - to - run test results and submitted it for use in this Test Plan.
The same technician will perform all rear axle lubricant changes.
Change engine lubricant and filter at the same time.

1. Remove the axle cover and drain plug; allow the lubricant to drain.

2. Remove rear wheels and brakes and soak up any lubricant in the axle tube (for solid beam axles) with a wick mounted on a cleaning rod or wire.

3. Wipe off the remaining lubricant as much as possible from ring, pinion, and carrier gear surfaces, and from inside the housing surface with a clean rag.

4. Use NAPA "MAX-4800," Brake Clean "Brake-091314" (or equivalent) brake cleaner solvent. Spray brake cleaner inside the axle tube and on a clean wick. Use the wick to clean the remaining oil from the axle shafts and tubes. Repeat with clean wicks and more solvent until they are as clean as is possible.

5. Spray the brake cleaner solvent on all gear surfaces and the inside surface of the housing to remove any residual oil. Repeat several times to remove all oil traces. The brake cleaner will evaporate, and requires no further cleanup. All surfaces should look dry.

6. Reinstall the brakes, wheel, axle cover, and drain plug.

7. Remove the fill plug. Fill the housing with the required lubricant volume as indicated in the Owner's Manual. For consistency, use a calibrated volumetric measuring dispenser. DO NOT follow the normal practice of filling the housing until oil escapes from the oil fill plug opening.

8. Replace the fill plug and prepare the vehicle for the 1000 mile mileage accumulation dynamometer runs.

Observer Notes

Date: ______________ Signature: ____

VIN: ____________ Odometer miles: _______________ Technician Name: __________________

Axle Lubricant: (Reference Oil/FEHP) ________________ Volume Added: _______________

Engine oil changed? (Y/N) __________ Technician Name: __________________

Note whether or not the technician follows all steps outlined above. Enter additional notes below.

Notes:

____

____

____

Appendix A-4
Calibrations and QA/QC Audit Checklists

Signature: ____

Note: No more than one test run per day.

A4-1. Chassis Dynamometer QA/QC Checks

QA/QC Check	When Performed / Frequency	Expected or Allowable Result	SwRI QA/QC Check Date	GHG Center Audit Date	OK?	Audit Data Source (personal observation, data/document review, interview, etc.)
Dyno Cal Cert. Review	Once during testing	Sensor accuracies conform to Table 3-1 specifications				
Road load horsepower calibration	Before initiating test program	Triplicate coastdown checks within ± 1.5 lbf of target				
Parasitic friction verification	Daily prior to testing	± 2 lbf from existing settings				
Dyno warmup verification	Before each test	≥ 15 minutes of operation, at least 30 mph within 2 hours of the start of testing				
Roadload and inertia simulation check	End of each test	± 0.3 % average over the entire driving sequence				
Valid driver's trace	End of each test	No deviation from tolerances given in 40 CFR § 86.115 ≥ 2 seconds				

Appendix A-4, continued
Calibrations and QA/QC Audit Checklists

Signature: ____

Note: No more than one test run per day.

A4-2. CVS System QA/QC Checks

QA/QC Check	When Performed / Frequency	Expected or Allowable Result	SwRI QA/QC Check Date	GHG Center Audit Date	OK? (✓)	Audit Data Source (personal observation, data/document review, interview, etc.)
CVS cal. cert. review	Once during the test campaign	Values must be within those listed in Table 3-3				
Propane critical orifice cal. cert. review						
Propane injection check	Weekly	difference between injected and recovered propane ≤ ± 2%.				
Flow rate verification	Before each test	± 5 cfm of appropriate nominal set point				
Sample bag leak check	Before each test	Maintain 10 " Hg vacuum for 10 seconds				

Appendix A-4, continued
Calibrations and QA/QC Audit Checklists

Signature: ____

A4-3. Emissions Analyzer QA/QC Checks

QA/QC Check	When Performed / Frequency	Expected or Allowable Result		SwRI QA/QC check Date	GHG Center Audit Date	OK? (✓)	Audit Data Source (personal observation, data/document review, interview, etc.)
NIST-traceable calibration gas verifications	Prior to being put into service	Average of three readings must be within ± 1% of verified NIST SRM concentration	CO				
			CO_2				
			NO_X				
			THC				
Zero gas verification	Prior to being put into service	HC < 1 ppmC CO < 1 ppm CO_2 < 400 ppm NO_x < 0.1 ppm O_2 between 18 and 21%					
Gas divider linearity verification	Monthly	All points within ± 2% of linear fit FS within ± 0.5% of known value					
CO, CO_2, NO_X, THC Analyzer calibrations	Monthly	All values within ± 2 % of point or ± 1% of FS; Zero point within ± 0.2 % of FS	CO				
			CO_2				
			NO_X				
			THC				
Wet CO2 interference check	Monthly	CO 0 to 300 ppm, interference ≤ 3 ppm CO > 300 ppm, interference ≤ 1% FS					
NO_X analyzer interference check	Monthly	CO_2 interference ≤ 3 %					
NO_X analyzer converter efficiency check	Monthly	NO_x converter efficiency > 95%					
CO_2 PEA	Once during testing	± 2 % of analyzer span					
Calibration gas certificate inspection	Once during testing	Certs. must be current; concentrations consistent with cylinder tags					

CO_2 Performance Evaluation Audit

Date: ___________Time: __________ Cylinder Value: ___________ Analyzer Response: ________

Analyzer Span: ___________ Accuracy: ([Cyln. Value - Analyzer response]/span)* 100 ___________

Appendix A-4, continued

Calibrations and QA/QC Audit Checklists

Signature: ____

A4-4. Ambient Instrument QA/QC Checks

QA/QC Check	When Performed / Frequency	Expected or Allowable Result	SwRI QA/QC Check Date	GHG Center Audit Date	OK? (✓)	Audit Data Source (personal observation, data/document review, interview, etc.)
Verification of test cell barometer calibration	Weekly	± 0.01" Hg of NIST-traceable standard				
Verification of test cell wet bulb and dry bulb temperature calibration	Monthly	± 1.0 ºF of NIST-traceable standard				
Verification of test cell dry bulb temperature	Prior to each test run	68 to 86 F				

Appendix A-4, continued
Calibrations and QA/QC Audit Checklists

Signature: ____

Notes:

1. Refer to Appendix A-1 for COV formula and test run values.
2. Use sample standard deviation (s_{n-1}) throughout.
3. Budget allows for 10 cross checks, total. Distribute them evenly between reference oil and FEHP.

A4-5. Reference Oil Gravimetric and Volumetric COV Cross Checks

From App. A-1			Gravimetric mpg results					
Run	Date	Test Run COV_{run}	mpg	mpg Mean	s_{n-1}	COV	Diff. (COV - COV_{run})	< 0.3 ?
1								
2								
3								
4								
5								
6								
7								
From App. A-1			Volumetric mpg results					
1								
2								
3								
4								
5								
6								
7								

A4-6. FEHP Gravimetric and Volumetric COV Cross Checks

From App. A-1			Gravimetric mpg results					
Run	Date	COV_{run}	mpg	mpg Mean	s_{n-1}	COV	Diff. (COV - COV_{run})	< 0.3 ?
1								
2								
3								
4								
5								
6								
7								
From App. A-1			Volumetric mpg results					
1								
2								
3								
4								
5								
6								
7								

Appendix A-5. 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

Appendix A-6-1
Technical Systems Audit: Equipment List

Audit Date: ______________ Signature: ____

Test Component (check one)

☐ Chassis Dynamometer Page ___ of ___

☐ CVS Page ___ of ___

☐ Instrumental Analyzers Page ___ of ___

☐ Fuel Delivery System Page ___ of ___

1. Equip.Name: ________________________________Manufacturer:_________________________
   Model #:_____________________________ Serial #:____________________________________

Description:____

____

Note inconsistencies and/or departures from Test Plan:____

____

2. Equip.Name: ________________________________Manufacturer:_________________________
   Model #:_____________________________ Serial #:____________________________________

Description:____

____

Note inconsistencies and/or departures from Test Plan:____

____

3. Equip.Name: ________________________________Manufacturer:_________________________
   Model #:_____________________________ Serial #:____________________________________

Description:____

____

Note inconsistencies and/or departures from Test Plan:____

____

4. Equip.Name: ________________________________Manufacturer:_________________________
   Model #:_____________________________ Serial #:____________________________________

Description:____

____

Note inconsistencies and/or departures from Test Plan:____

____

5. Equip.Name: ________________________________Manufacturer:_________________________
   Model #:_____________________________ Serial #:____________________________________

Description:____

____

Note inconsistencies and/or departures from Test Plan:____

____

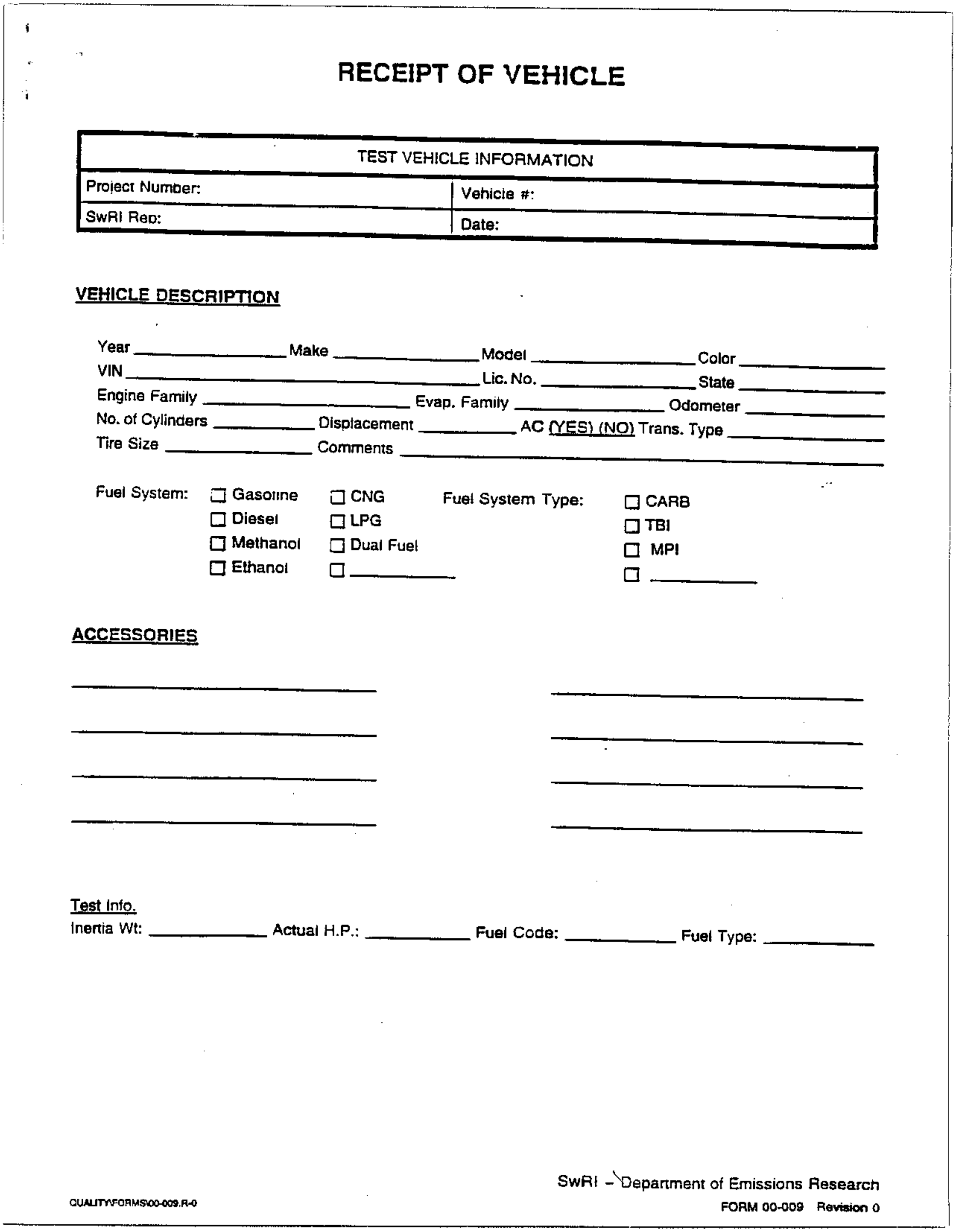
Appendix A6-2
Technical Systems Audit: Standard Operating Procedures

Signature:

SOPs referenced		Revision date:	Audit Date:
06-002	NO$_X$ converter efficiency determination	01-13-1998	
	Inconsistencies?:		
06-003	Linearity verification of gas dividers	01-19-1998	
	Inconsistencies?:		
06-007	Naming monthly calibration gas	10-16-1997	
	Inconsistencies?:		
06-010	Barometric pressure verification	04-10-2000	
	Inconsistencies?:		
06-011	Propane recovery check	01-22-1999	
	Inconsistencies?:		
06-013	Temperature calibration and verification	06-17-1996	
	Inconsistencies?:		
06-014	CVS tunnel stratification check	11-03-1995	
	Inconsistencies?:		
06-016	Wet CO$_2$ interference check for CO analyzers	09-09-1996	
	Inconsistencies?:		
06-021	FID response for methane	10-20-1995	
	Inconsistencies?:		
06-023	Calibration of analyzers using digital readout	03-04-1999	
	Inconsistencies?:		
06-036	Verification of zero gases	08-11-1997	
	Inconsistencies?:		
06-041	NO$_X$ analyzer CO$_2$ quench check	04-05-1999	
	Inconsistencies?:		
06-042	Verification of SRM or NIST-traceable gases	06-25-1998	
	Inconsistencies?:		
06-043	Verification of pure propane gas	06-02-1999	
	Inconsistencies?:		
06-044	Hydrocarbon analyzer optimization	04-04-2002	
	Inconsistencies?:		
06-048	48" dyno coastdown procedure	01-23-2002	
	Inconsistencies?:		
06-049	Load cell calibration check	03-23-2001	
	Inconsistencies?:		
07-013	Light-duty FTP	08-07-1998	
	Inconsistencies?:		
07-027	Light-duty HFET	11-16-1995	
	Inconsistencies?:		
08-004	Verification of driver's trace	02-14-1996	
	Inconsistencies?:		
12-001	Quality system and process audits	02-16-2001	
	Inconsistencies?:		

Appendix B

Appendix B-1
Vehicle receipt Form



RECEIPT OF VEHICLE

TEST VEHICLE INFORMATION	
Project Number:	Vehicle #:
SwRI Rep:	Date:

VEHICLE DESCRIPTION

Year __________ Make __________ Model __________ Color __________
VIN ______________________________ Lic. No. __________ State __________
Engine Family ______________ Evap. Family __________ Odometer __________
No. of Cylinders ________ Displacement ________ AC (YES) (NO) Trans. Type __________
Tire Size __________ Comments ______________________________

Fuel System:
☐ Gasoline
☐ Diesel
☐ Methanol
☐ Ethanol
☐ CNG
☐ LPG
☐ Dual Fuel
☐ __________

Fuel System Type:
☐ CARB
☐ TBI
☐ MPI
☐ __________

ACCESSORIES

______________________ ______________________
______________________ ______________________
______________________ ______________________
______________________ ______________________

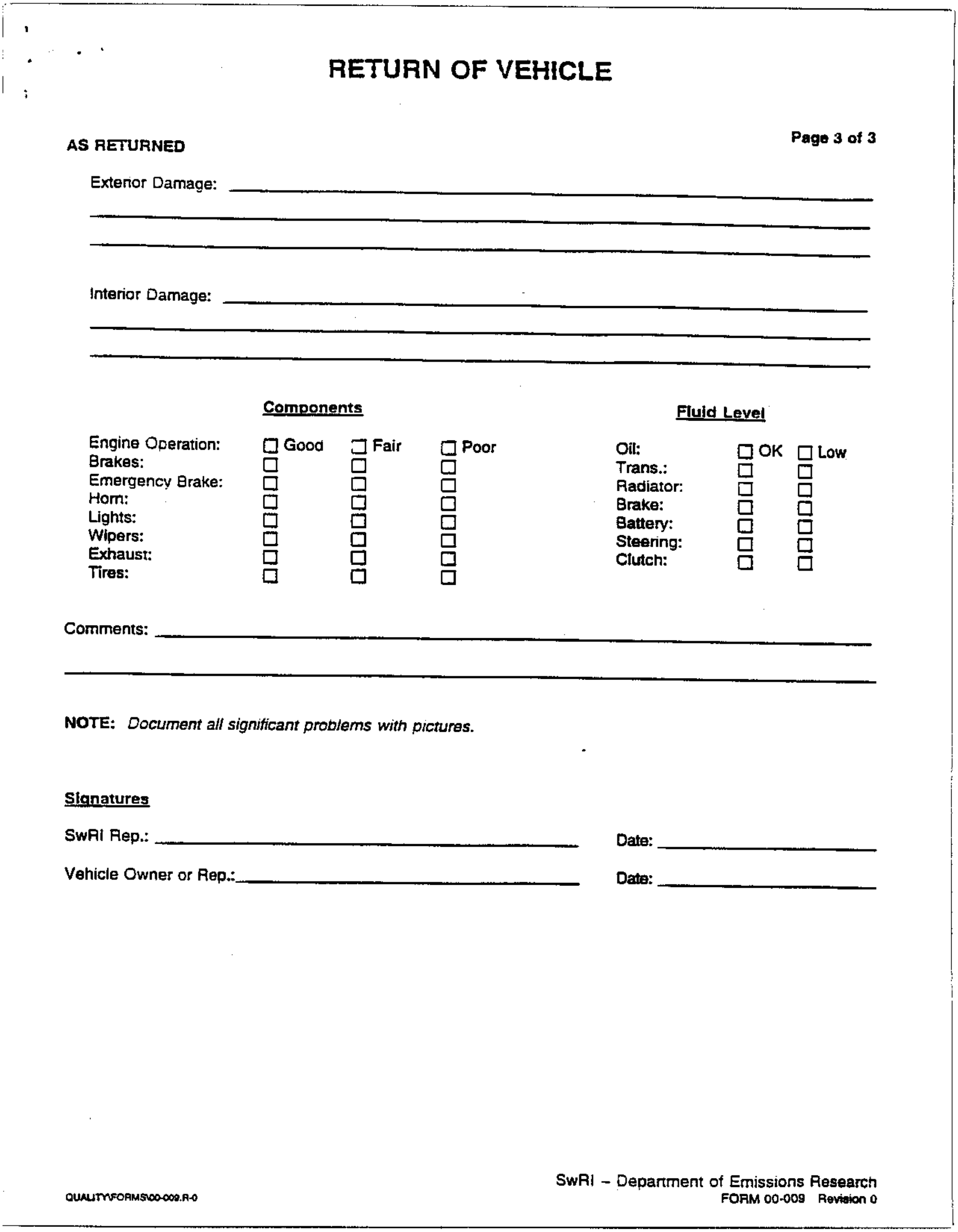
Test Info.

Inertia Wt: ________ Actual H.P.: ________ Fuel Code: ________ Fuel Type: ________

QUALITY\FORMS\00-009.R-0

SwRI – Department of Emissions Research
FORM 00-009 Revision 0

Appendix B-1, continued



RETURN OF VEHICLE

Page 3 of 3

AS RETURNED

Exterior Damage: ____________________

____

____

Interior Damage: ____________________

____

____

Components

Engine Operation:	☐ Good	☐ Fair	☐ Poor
Brakes:	☐	☐	☐
Emergency Brake:	☐	☐	☐
Horn:	☐	☐	☐
Lights:	☐	☐	☐
Wipers:	☐	☐	☐
Exhaust:	☐	☐	☐
Tires:	☐	☐	☐

Fluid Level

Oil:	☐ OK	☐ Low
Trans.:	☐	☐
Radiator:	☐	☐
Brake:	☐	☐
Battery:	☐	☐
Steering:	☐	☐
Clutch:	☐	☐

Comments: ____________________

____

NOTE: *Document all significant problems with pictures.*

Signatures

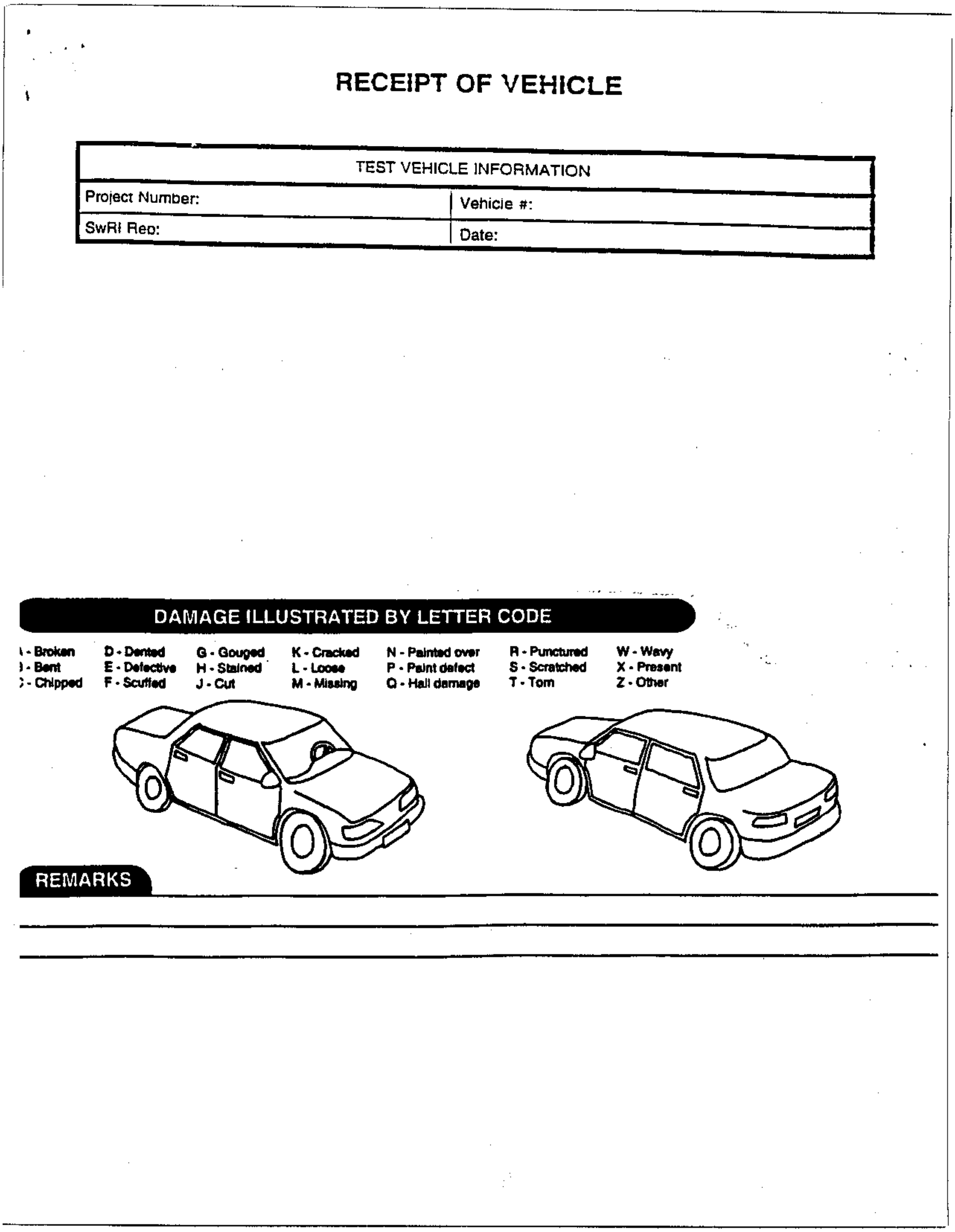
SwRI Rep.: ____________________ Date: __________

Vehicle Owner or Rep.: ____________________ Date: __________

QUALITY\FORMS\00-009.R-0

SwRI – Department of Emissions Research
FORM 00-009 Revision 0

Appendix B-1, continued



RECEIPT OF VEHICLE

TEST VEHICLE INFORMATION	
Project Number:	Vehicle #:
SwRI Rep:	Date:

DAMAGE ILLUSTRATED BY LETTER CODE

- Broken
- Bent
- Chipped

D - Dented
E - Defective
F - Scuffed

G - Gouged
H - Stained
J - Cut

K - Cracked
L - Loose
M - Missing

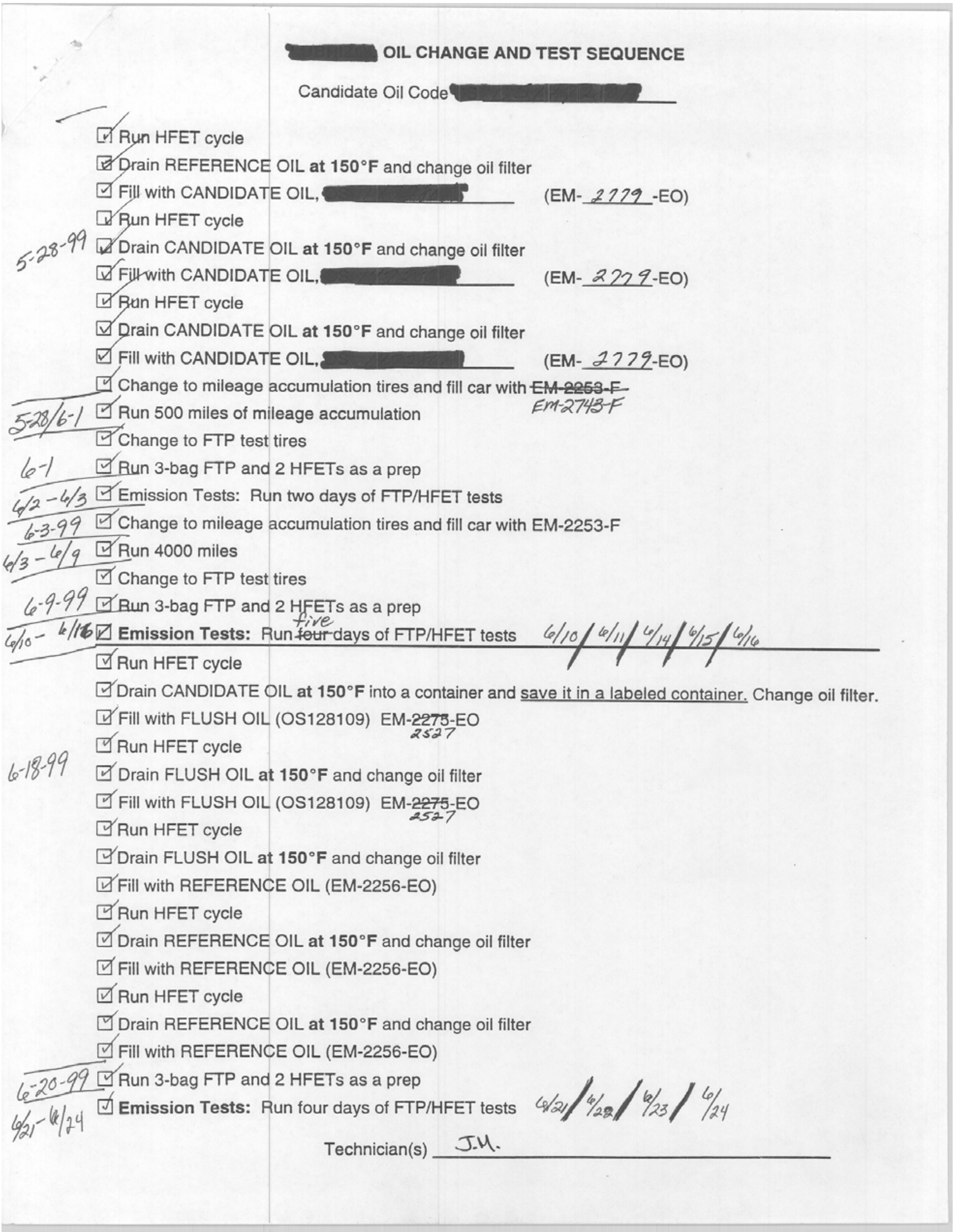
N - Painted over
P - Paint defect
Q - Hail damage

R - Punctured
S - Scratched
T - Torn

W - Wavy
X - Present
Z - Other

REMARKS

Appendix B-2.
Sample Test Sequence Tracking Form



[redacted] OIL CHANGE AND TEST SEQUENCE

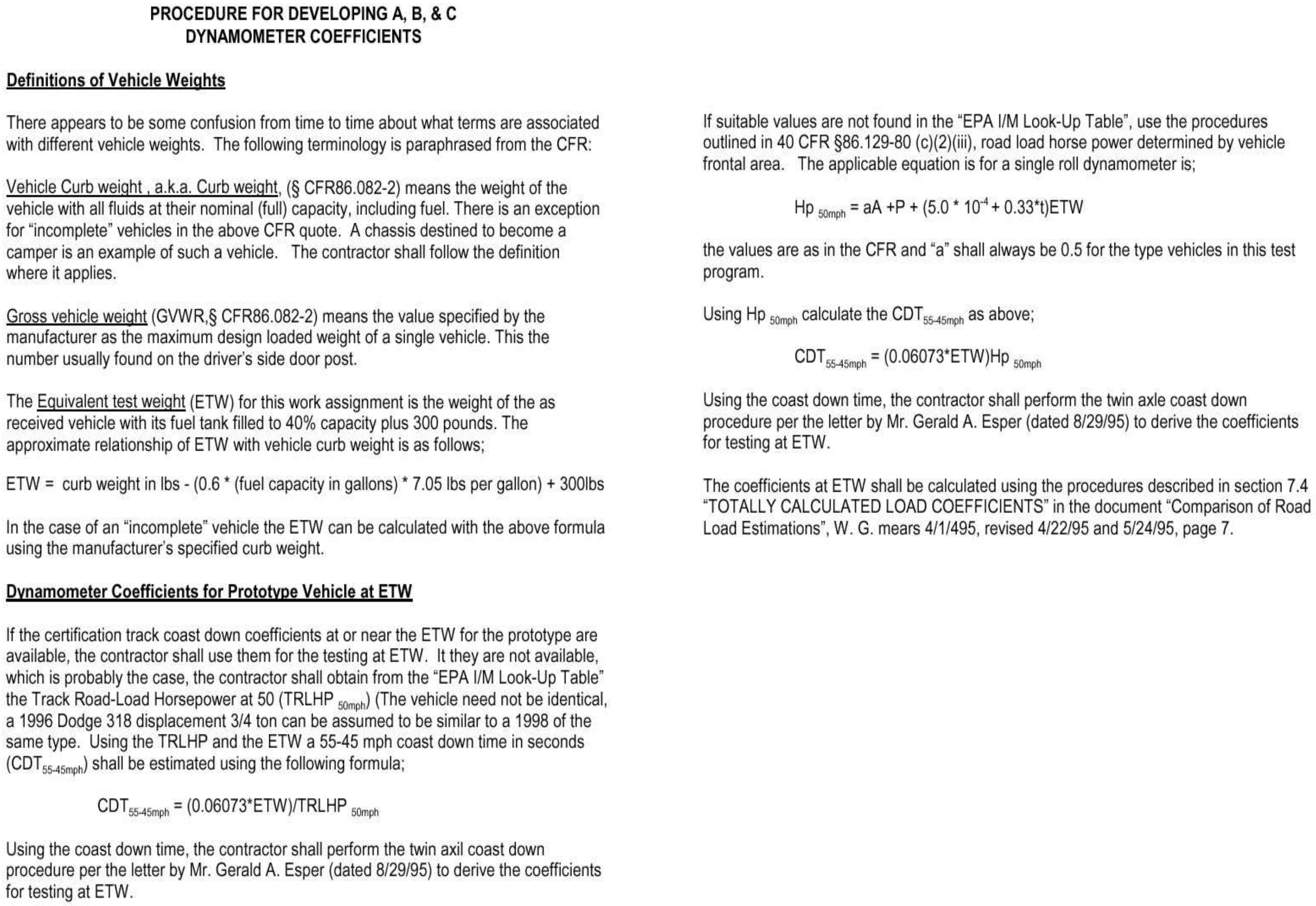
Candidate Oil Code [redacted]

- ☑ Run HFET cycle
- ☑ Drain REFERENCE OIL **at 150°F** and change oil filter
- ☑ Fill with CANDIDATE OIL, [redacted] (EM-2779-EO)
- ☑ Run HFET cycle
- 5-28-99 ☑ Drain CANDIDATE OIL **at 150°F** and change oil filter
- ☑ Fill with CANDIDATE OIL, [redacted] (EM-2779-EO)
- ☑ Run HFET cycle
- ☑ Drain CANDIDATE OIL **at 150°F** and change oil filter
- ☑ Fill with CANDIDATE OIL, [redacted] (EM-2779-EO)
- ☑ Change to mileage accumulation tires and fill car with ~~EM-2253-F~~ EM-2743-F
- 5-28/6-1 ☑ Run 500 miles of mileage accumulation
- ☑ Change to FTP test tires
- 6-1 ☑ Run 3-bag FTP and 2 HFETs as a prep
- 6/2 - 6/3 ☑ Emission Tests: Run two days of FTP/HFET tests
- 6-3-99 ☑ Change to mileage accumulation tires and fill car with EM-2253-F
- 6/3 - 6/9 ☑ Run 4000 miles
- ☑ Change to FTP test tires
- 6-9-99 ☑ Run 3-bag FTP and 2 HFETs as a prep
- 6/10 - 6/16 ☑ **Emission Tests:** Run ~~four~~ five days of FTP/HFET tests 6/10 / 6/11 / 6/14 / 6/15 / 6/16
- ☑ Run HFET cycle
- ☑ Drain CANDIDATE OIL **at 150°F** into a container and save it in a labeled container. Change oil filter.
- ☑ Fill with FLUSH OIL (OS128109) EM-~~2275~~ 2527-EO
- ☑ Run HFET cycle
- 6-18-99 ☑ Drain FLUSH OIL **at 150°F** and change oil filter
- ☑ Fill with FLUSH OIL (OS128109) EM-~~2275~~ 2527-EO
- ☑ Run HFET cycle
- ☑ Drain FLUSH OIL **at 150°F** and change oil filter
- ☑ Fill with REFERENCE OIL (EM-2256-EO)
- ☑ Run HFET cycle
- ☑ Drain REFERENCE OIL **at 150°F** and change oil filter
- ☑ Fill with REFERENCE OIL (EM-2256-EO)
- ☑ Run HFET cycle
- ☑ Drain REFERENCE OIL **at 150°F** and change oil filter
- ☑ Fill with REFERENCE OIL (EM-2256-EO)
- 6-20-99 ☑ Run 3-bag FTP and 2 HFETs as a prep
- 6/21 - 6/24 ☑ **Emission Tests:** Run four days of FTP/HFET tests 6/21 / 6/22 / 6/23 / 6/24

Technician(s) J.M.

Appendix B-3
SwRI Dynamometer Setup Notes

Source documents for these setup notes are personal correspondences between SwRI and EPA contract officers concerning a number of vehicle test contracts. The document below originated from Work Assignment Manager and Project Officer Ms. Christine Keller in May, 1999 under Contract 68-C-98-158.



PROCEDURE FOR DEVELOPING A, B, & C DYNAMOMETER COEFFICIENTS

Definitions of Vehicle Weights

There appears to be some confusion from time to time about what terms are associated with different vehicle weights. The following terminology is paraphrased from the CFR:

Vehicle Curb weight , a.k.a. Curb weight, (§ CFR86.082-2) means the weight of the vehicle with all fluids at their nominal (full) capacity, including fuel. There is an exception for "incomplete" vehicles in the above CFR quote. A chassis destined to become a camper is an example of such a vehicle. The contractor shall follow the definition where it applies.

Gross vehicle weight (GVWR,§ CFR86.082-2) means the value specified by the manufacturer as the maximum design loaded weight of a single vehicle. This the number usually found on the driver's side door post.

The Equivalent test weight (ETW) for this work assignment is the weight of the as received vehicle with its fuel tank filled to 40% capacity plus 300 pounds. The approximate relationship of ETW with vehicle curb weight is as follows;

ETW = curb weight in lbs - (0.6 * (fuel capacity in gallons) * 7.05 lbs per gallon) + 300lbs

In the case of an "incomplete" vehicle the ETW can be calculated with the above formula using the manufacturer's specified curb weight.

Dynamometer Coefficients for Prototype Vehicle at ETW

If the certification track coast down coefficients at or near the ETW for the prototype are available, the contractor shall use them for the testing at ETW. It they are not available, which is probably the case, the contractor shall obtain from the "EPA I/M Look-Up Table" the Track Road-Load Horsepower at 50 ($TRLHP_{50mph}$) (The vehicle need not be identical, a 1996 Dodge 318 displacement 3/4 ton can be assumed to be similar to a 1998 of the same type. Using the TRLHP and the ETW a 55-45 mph coast down time in seconds ($CDT_{55\text{-}45mph}$) shall be estimated using the following formula;

$$CDT_{55\text{-}45mph} = (0.06073*ETW)/TRLHP_{50mph}$$

Using the coast down time, the contractor shall perform the twin axil coast down procedure per the letter by Mr. Gerald A. Esper (dated 8/29/95) to derive the coefficients for testing at ETW.

If suitable values are not found in the "EPA I/M Look-Up Table", use the procedures outlined in 40 CFR §86.129-80 (c)(2)(iii), road load horse power determined by vehicle frontal area. The applicable equation is for a single roll dynamometer is;

$$Hp_{50mph} = aA + P + (5.0 * 10^{-4} + 0.33*t)ETW$$

the values are as in the CFR and "a" shall always be 0.5 for the type vehicles in this test program.

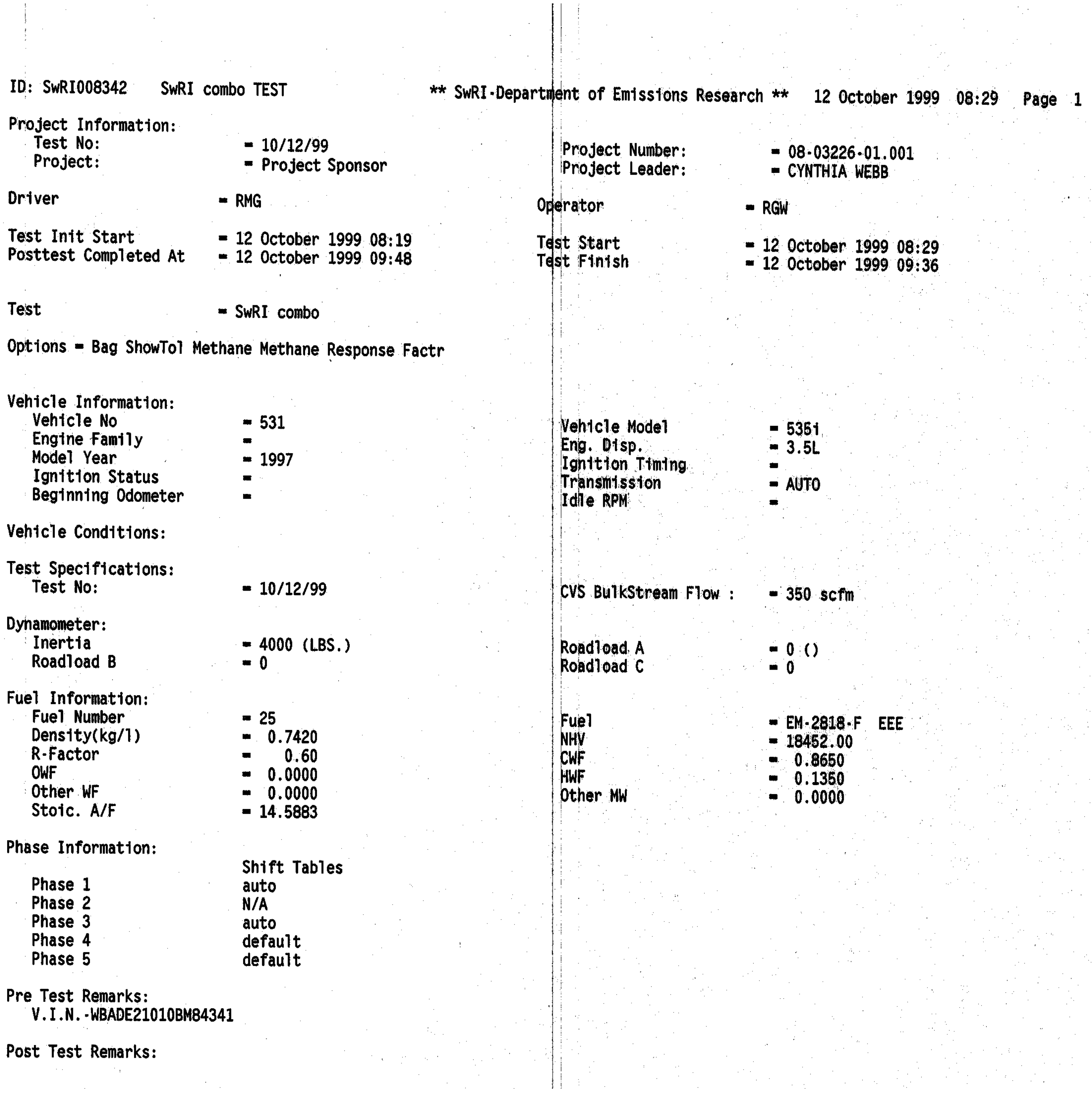
Using Hp_{50mph} calculate the $CDT_{55\text{-}45mph}$ as above;

$$CDT_{55\text{-}45mph} = (0.06073*ETW)Hp_{50mph}$$

Using the coast down time, the contractor shall perform the twin axle coast down procedure per the letter by Mr. Gerald A. Esper (dated 8/29/95) to derive the coefficients for testing at ETW.

The coefficients at ETW shall be calculated using the procedures described in section 7.4 "TOTALLY CALCULATED LOAD COEFFICIENTS" in the document "Comparison of Road Load Estimations", W. G. mears 4/1/495, revised 4/22/95 and 5/24/95, page 7.

Appendix B-4. Sample Test Run Output



```
ID: SwRI008342    SwRI combo TEST          ** SwRI-Department of Emissions Research **   12 October 1999  08:29   Page  1

Project Information:
   Test No:                    = 10/12/99                  Project Number:          = 08-03226-01.001
   Project:                    = Project Sponsor           Project Leader:          = CYNTHIA WEBB

Driver                      = RMG                        Operator                 = RGW

Test Init Start             = 12 October 1999 08:19      Test Start               = 12 October 1999 08:29
Posttest Completed At       = 12 October 1999 09:48      Test Finish              = 12 October 1999 09:36


Test                        = SwRI combo

Options = Bag ShowTol Methane Methane Response Factr


Vehicle Information:
   Vehicle No                  = 531                       Vehicle Model            = 5351
   Engine Family               =                           Eng. Disp.               = 3.5L
   Model Year                  = 1997                      Ignition Timing          =
   Ignition Status             =                           Transmission             = AUTO
   Beginning Odometer          =                           Idle RPM                 =

Vehicle Conditions:

Test Specifications:
   Test No:                    = 10/12/99                  CVS BulkStream Flow :    = 350 scfm

Dynamometer:
   Inertia                     = 4000 (LBS.)               Roadload A               = 0 ()
   Roadload B                  = 0                         Roadload C               = 0

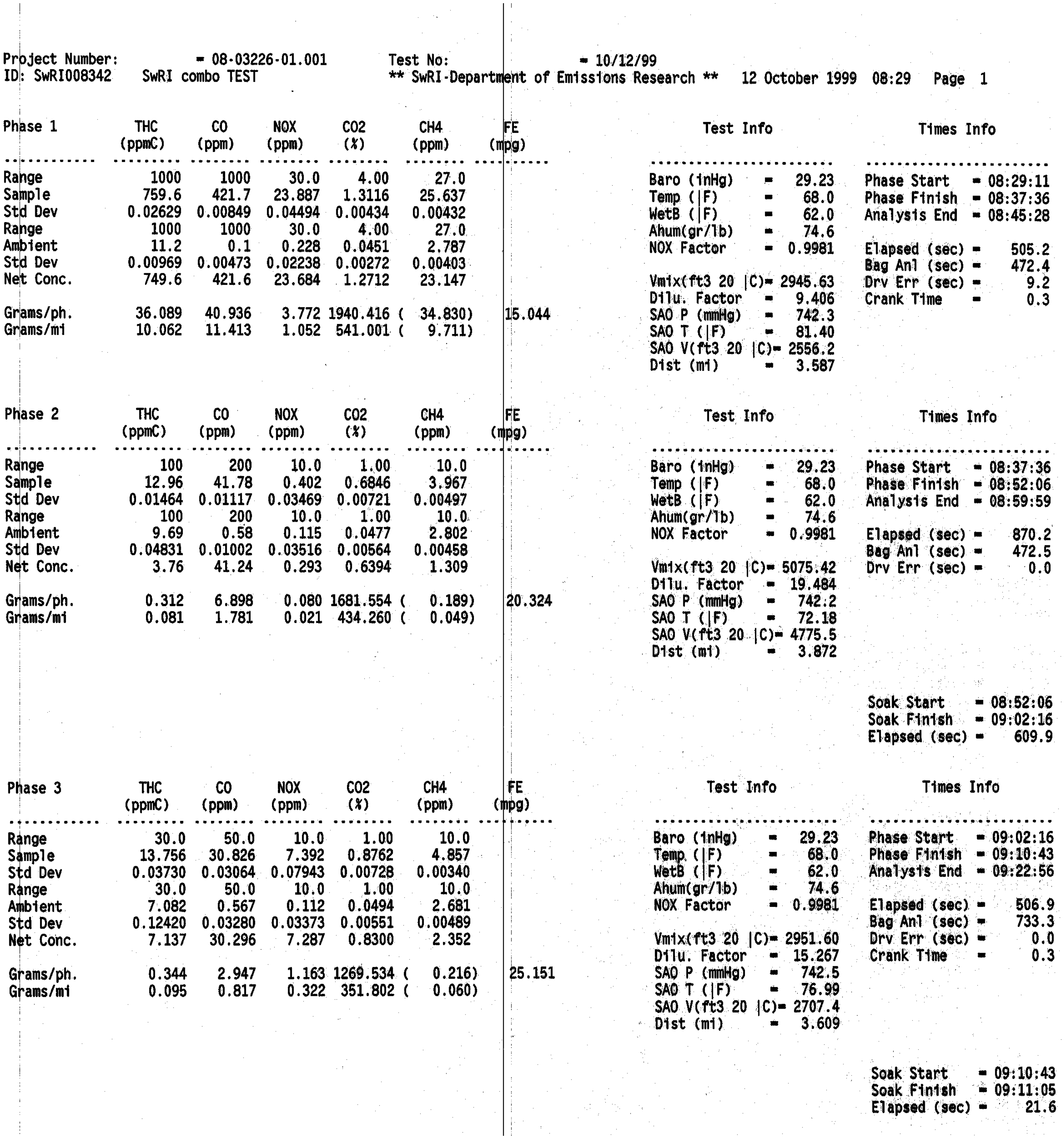
Fuel Information:
   Fuel Number                 = 25                        Fuel                     = EM-2818-F  EEE
   Density(kg/l)               =  0.7420                   NHV                      = 18452.00
   R-Factor                    =    0.60                   CWF                      =  0.8650
   OWF                         =  0.0000                   HWF                      =  0.1350
   Other WF                    =  0.0000                   Other MW                 =  0.0000
   Stoic. A/F                  = 14.5883

Phase Information:
                                 Shift Tables
   Phase 1                       auto
   Phase 2                       N/A
   Phase 3                       auto
   Phase 4                       default
   Phase 5                       default

Pre Test Remarks:
   V.I.N.-WBADE21010BM84341

Post Test Remarks:
```

Appendix B-4. Sample Test Run Output, continued



```
Project Number:          = 08-03226-01.001       Test No:                  = 10/12/99
ID: SwRI008342    SwRI combo TEST                ** SwRI-Department of Emissions Research **   12 October 1999  08:29   Page  1

Phase 1             THC       CO      NOX      CO2      CH4       FE                Test Info                         Times Info
                  (ppmC)    (ppm)    (ppm)     (%)     (ppm)    (mpg)
-------------  --------  -------- -------- -------- -------- ---------      --------------------------    -------------------------
Range             1000     1000     30.0     4.00     27.0                  Baro (inHg)      =   29.23    Phase Start    = 08:29:11
Sample           759.6    421.7   23.887   1.3116   25.637                  Temp (|F)        =    68.0    Phase Finish   = 08:37:36
Std Dev        0.02629  0.00849  0.04494  0.00434  0.00432                  WetB (|F)        =    62.0    Analysis End   = 08:45:28
Range             1000     1000     30.0     4.00     27.0                  Ahum(gr/lb)      =    74.6
Ambient           11.2      0.1    0.228   0.0451    2.787                  NOX Factor       =  0.9981    Elapsed (sec) =     505.2
Std Dev        0.00969  0.00473  0.02238  0.00272  0.00403                                              Bag Anl (sec) =     472.4
Net Conc.        749.6    421.6   23.684   1.2712   23.147                  Vmix(ft3 20 |C)=   2945.63    Drv Err (sec) =       9.2
                                                                            Dilu. Factor     =   9.406    Crank Time     =      0.3
Grams/ph.       36.089   40.936    3.772 1940.416 (  34.830)  15.044        SAO P (mmHg)     =   742.3
Grams/mi        10.062   11.413    1.052  541.001 (   9.711)                SAO T (|F)       =   81.40
                                                                            SAO V(ft3 20 |C)=   2556.2
                                                                            Dist (mi)        =   3.587

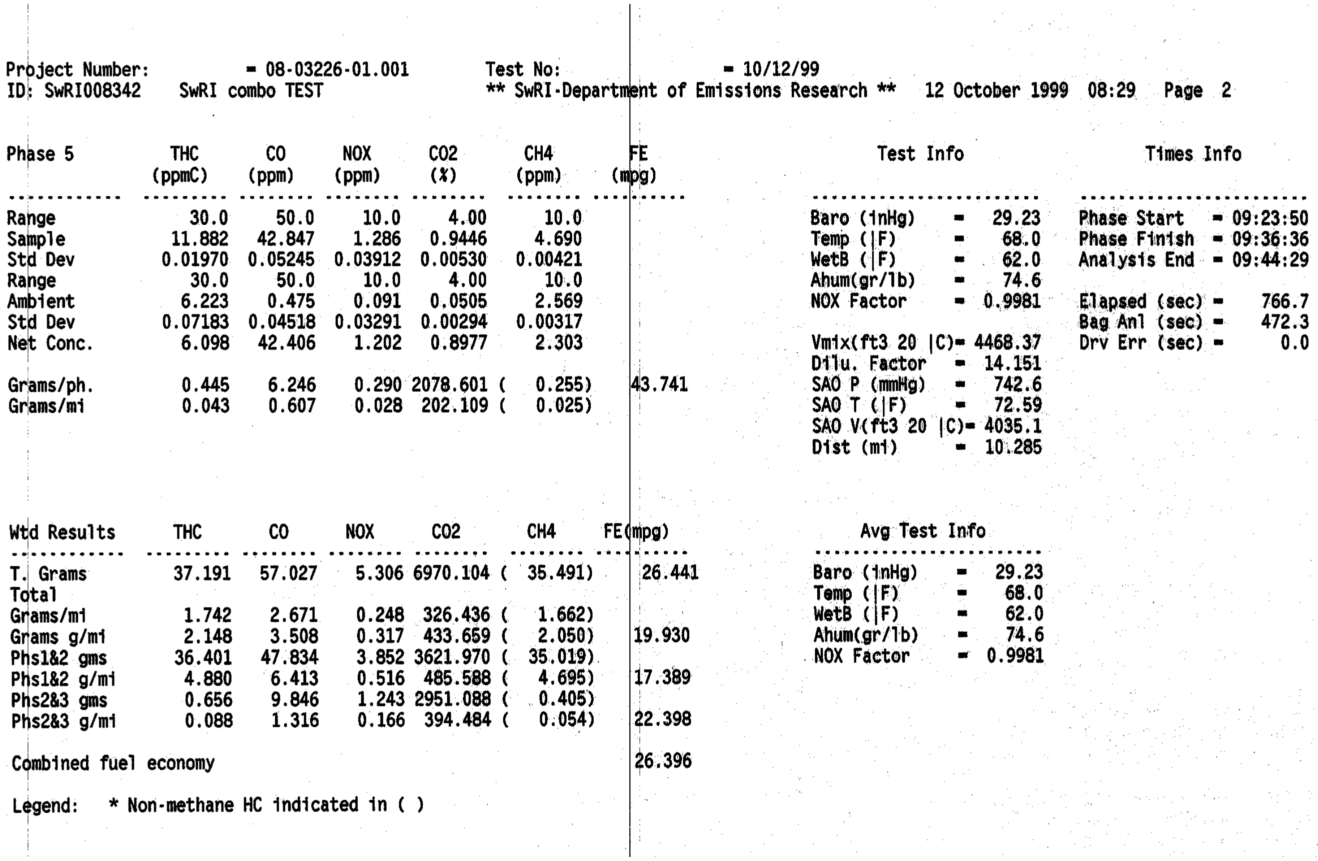

Phase 2             THC       CO      NOX      CO2      CH4       FE                Test Info                         Times Info
                  (ppmC)    (ppm)    (ppm)     (%)     (ppm)    (mpg)
-------------  --------  -------- -------- -------- -------- ---------      --------------------------    -------------------------
Range              100      200     10.0     1.00     10.0                  Baro (inHg)      =   29.23    Phase Start    = 08:37:36
Sample           12.96    41.78    0.402   0.6846    3.967                  Temp (|F)        =    68.0    Phase Finish   = 08:52:06
Std Dev        0.01464  0.01117  0.03469  0.00721  0.00497                  WetB (|F)        =    62.0    Analysis End   = 08:59:59
Range              100      200     10.0     1.00     10.0                  Ahum(gr/lb)      =    74.6
Ambient           9.69     0.58    0.115   0.0477    2.802                  NOX Factor       =  0.9981    Elapsed (sec) =     870.2
Std Dev        0.04831  0.01002  0.03516  0.00564  0.00458                                              Bag Anl (sec) =     472.5
Net Conc.         3.76    41.24    0.293   0.6394    1.309                  Vmix(ft3 20 |C)=   5075.42    Drv Err (sec) =       0.0
                                                                            Dilu. Factor     =  19.484
Grams/ph.        0.312    6.898    0.080 1681.554 (   0.189)  20.324        SAO P (mmHg)     =   742.2
Grams/mi         0.081    1.781    0.021  434.260 (   0.049)                SAO T (|F)       =   72.18
                                                                            SAO V(ft3 20 |C)=   4775.5
                                                                            Dist (mi)        =   3.872


                                                                                                          Soak Start     = 08:52:06
                                                                                                          Soak Finish    = 09:02:16
                                                                                                          Elapsed (sec) =     609.9


Phase 3             THC       CO      NOX      CO2      CH4       FE                Test Info                         Times Info
                  (ppmC)    (ppm)    (ppm)     (%)     (ppm)    (mpg)
-------------  --------  -------- -------- -------- -------- ---------      --------------------------    -------------------------
Range             30.0     50.0     10.0     1.00     10.0                  Baro (inHg)      =   29.23    Phase Start    = 09:02:16
Sample          13.756   30.826    7.392   0.8762    4.857                  Temp (|F)        =    68.0    Phase Finish   = 09:10:43
Std Dev        0.03730  0.03064  0.07943  0.00728  0.00340                  WetB (|F)        =    62.0    Analysis End   = 09:22:56
Range             30.0     50.0     10.0     1.00     10.0                  Ahum(gr/lb)      =    74.6
Ambient          7.082    0.567    0.112   0.0494    2.681                  NOX Factor       =  0.9981    Elapsed (sec) =     506.9
Std Dev        0.12420  0.03280  0.03373  0.00551  0.00489                                              Bag Anl (sec) =     733.3
Net Conc.        7.137   30.296    7.287   0.8300    2.352                  Vmix(ft3 20 |C)=   2951.60    Drv Err (sec) =       0.0
                                                                            Dilu. Factor     =  15.267    Crank Time     =      0.3
Grams/ph.        0.344    2.947    1.163 1269.534 (   0.216)  25.151        SAO P (mmHg)     =   742.5
Grams/mi         0.095    0.817    0.322  351.802 (   0.060)                SAO T (|F)       =   76.99
                                                                            SAO V(ft3 20 |C)=   2707.4
                                                                            Dist (mi)        =   3.609


                                                                                                          Soak Start     = 09:10:43
                                                                                                          Soak Finish    = 09:11:05
                                                                                                          Elapsed (sec) =      21.6
```

Appendix B-4. Sample Test Run Output, continued



```
Project Number:          = 08-03226-01.001       Test No:                 = 10/12/99
ID: SwRI008342    SwRI combo TEST                ** SwRI-Department of Emissions Research **   12 October 1999  08:29   Page  2

Phase 5          THC      CO      NOX      CO2       CH4       FE                   Test Info                      Times Info
               (ppmC)   (ppm)    (ppm)     (%)      (ppm)     (mpg)
------------  -------- -------- -------- --------  -------- ---------          ------------------------     ------------------------
Range             30.0     50.0     10.0     4.00      10.0                    Baro (inHg)     =   29.23    Phase Start   = 09:23:50
Sample          11.882   42.847    1.286   0.9446     4.690                    Temp (|F)       =    68.0    Phase Finish  = 09:36:36
Std Dev        0.01970  0.05245  0.03912  0.00530   0.00421                    WetB (|F)       =    62.0    Analysis End  = 09:44:29
Range             30.0     50.0     10.0     4.00      10.0                    Ahum(gr/lb)     =    74.6
Ambient          6.223    0.475    0.091   0.0505     2.569                    NOX Factor      =  0.9981    Elapsed (sec) =     766.7
Std Dev        0.07183  0.04518  0.03291  0.00294   0.00317                                                 Bag Anl (sec) =     472.3
Net Conc.        6.098   42.406    1.202   0.8977     2.303                    Vmix(ft3 20 |C)= 4468.37     Drv Err (sec) =       0.0
                                                                               Dilu. Factor    =  14.151
Grams/ph.        0.445    6.246    0.290 2078.601 (   0.255)   43.741          SAO P (mmHg)    =   742.6
Grams/mi         0.043    0.607    0.028  202.109 (   0.025)                   SAO T (|F)      =   72.59
                                                                               SAO V(ft3 20 |C)= 4035.1
                                                                               Dist (mi)       =  10.285


Wtd Results      THC       CO      NOX      CO2        CH4     FE(mpg)              Avg Test Info
------------  -------- -------- -------- --------  -------- ---------          ------------------------
T. Grams        37.191   57.027    5.306 6970.104 (  35.491)    26.441         Baro (inHg)     =   29.23
Total                                                                          Temp (|F)       =    68.0
Grams/mi         1.742    2.671    0.248  326.436 (   1.662)                   WetB (|F)       =    62.0
Grams g/mi       2.148    3.508    0.317  433.659 (   2.050)   19.930          Ahum(gr/lb)     =    74.6
Phs1&2 gms      36.401   47.834    3.852 3621.970 (  35.019)                   NOX Factor      =  0.9981
Phs1&2 g/mi      4.880    6.413    0.516  485.588 (   4.695)   17.389
Phs2&3 gms       0.656    9.846    1.243 2951.088 (   0.405)
Phs2&3 g/mi      0.088    1.316    0.166  394.484 (   0.054)   22.398

Combined fuel economy                                          26.396

Legend:   * Non-methane HC indicated in ( )
```

Appendix B-4. Sample Test Run Output, continued

```
ID: SwRI008342    SwRI combo TEST              ** SwRI-Department of Emissions Research **   12 October 1999  08:29   Page  1

Driver Violations
-------------------

     Start    Phase     End     Phase    Duration
    -------   -----    -----   -------
      24.5      1       30.9      1         6.4
      32.0      1       34.8      1         2.8



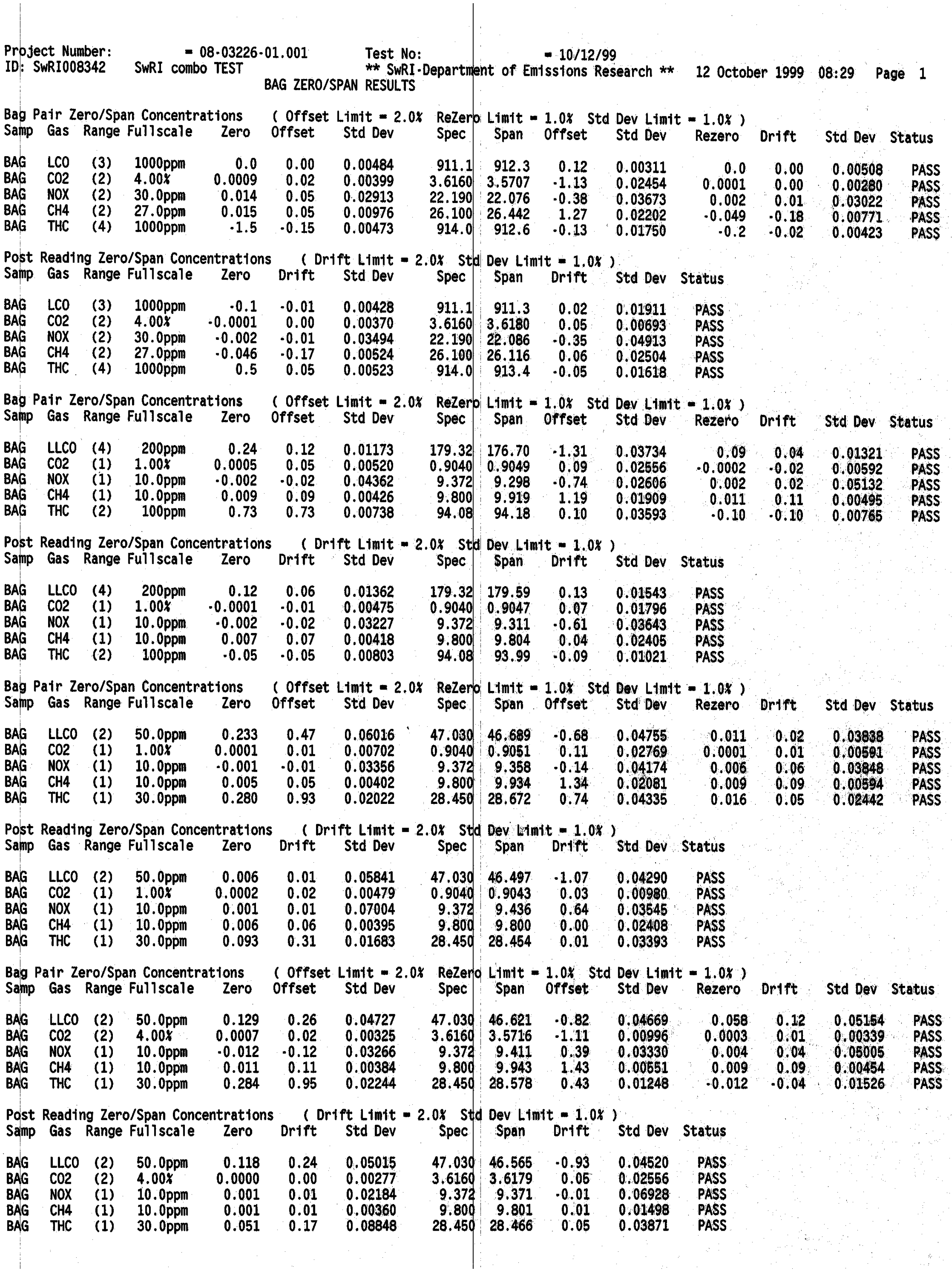






 * - Indicates violation occured near a shift point
```

Appendix B-4. Sample Test Run Output, continued



```
Project Number:          = 08-03226-01.001        Test No:                   = 10/12/99
ID: SwRI008342    SwRI combo TEST                 ** SwRI-Department of Emissions Research **   12 October 1999  08:29   Page  1
                                           BAG ZERO/SPAN RESULTS

Bag Pair Zero/Span Concentrations    ( Offset Limit = 2.0%  ReZero Limit = 1.0%  Std Dev Limit = 1.0% )
Samp  Gas  Range Fullscale    Zero    Offset    Std Dev       Spec   Span   Offset    Std Dev    Rezero   Drift     Std Dev  Status

BAG   LCO   (3)   1000ppm      0.0     0.00     0.00484      911.1   912.3    0.12    0.00311       0.0    0.00     0.00508    PASS
BAG   CO2   (2)   4.00%     0.0009     0.02     0.00399     3.6160  3.5707   -1.13    0.02454    0.0001    0.00     0.00280    PASS
BAG   NOX   (2)   30.0ppm    0.014     0.05     0.02913     22.190  22.076   -0.38    0.03673     0.002    0.01     0.03022    PASS
BAG   CH4   (2)   27.0ppm    0.015     0.05     0.00976     26.100  26.442    1.27    0.02202    -0.049   -0.18     0.00771    PASS
BAG   THC   (4)   1000ppm     -1.5    -0.15     0.00473      914.0   912.6   -0.13    0.01750      -0.2   -0.02     0.00423    PASS

Post Reading Zero/Span Concentrations    ( Drift Limit = 2.0%  Std Dev Limit = 1.0% )
Samp  Gas  Range Fullscale    Zero     Drift    Std Dev       Spec   Span    Drift    Std Dev  Status

BAG   LCO   (3)   1000ppm     -0.1    -0.01     0.00428      911.1   911.3    0.02    0.01911    PASS
BAG   CO2   (2)   4.00%    -0.0001     0.00     0.00370     3.6160  3.6180    0.05    0.00693    PASS
BAG   NOX   (2)   30.0ppm   -0.002    -0.01     0.03494     22.190  22.086   -0.35    0.04913    PASS
BAG   CH4   (2)   27.0ppm   -0.046    -0.17     0.00524     26.100  26.116    0.06    0.02504    PASS
BAG   THC   (4)   1000ppm      0.5     0.05     0.00523      914.0   913.4   -0.05    0.01618    PASS

Bag Pair Zero/Span Concentrations    ( Offset Limit = 2.0%  ReZero Limit = 1.0%  Std Dev Limit = 1.0% )
Samp  Gas  Range Fullscale    Zero    Offset    Std Dev       Spec   Span   Offset    Std Dev    Rezero   Drift     Std Dev  Status

BAG   LLCO  (4)    200ppm     0.24     0.12     0.01173     179.32  176.70   -1.31    0.03734      0.09    0.04     0.01321    PASS
BAG   CO2   (1)   1.00%     0.0005     0.05     0.00520     0.9040  0.9049    0.09    0.02556   -0.0002   -0.02     0.00592    PASS
BAG   NOX   (1)   10.0ppm   -0.002    -0.02     0.04362      9.372   9.298   -0.74    0.02606     0.002    0.02     0.05132    PASS
BAG   CH4   (1)   10.0ppm    0.009     0.09     0.00426      9.800   9.919    1.19    0.01909     0.011    0.11     0.00495    PASS
BAG   THC   (2)    100ppm     0.73     0.73     0.00738      94.08   94.18    0.10    0.03593     -0.10   -0.10     0.00765    PASS

Post Reading Zero/Span Concentrations    ( Drift Limit = 2.0%  Std Dev Limit = 1.0% )
Samp  Gas  Range Fullscale    Zero     Drift    Std Dev       Spec   Span    Drift    Std Dev  Status

BAG   LLCO  (4)    200ppm     0.12     0.06     0.01362     179.32  179.59    0.13    0.01543    PASS
BAG   CO2   (1)   1.00%    -0.0001    -0.01     0.00475     0.9040  0.9047    0.07    0.01796    PASS
BAG   NOX   (1)   10.0ppm   -0.002    -0.02     0.03227      9.372   9.311   -0.61    0.03643    PASS
BAG   CH4   (1)   10.0ppm    0.007     0.07     0.00418      9.800   9.804    0.04    0.02405    PASS
BAG   THC   (2)    100ppm    -0.05    -0.05     0.00803      94.08   93.99   -0.09    0.01021    PASS

Bag Pair Zero/Span Concentrations    ( Offset Limit = 2.0%  ReZero Limit = 1.0%  Std Dev Limit = 1.0% )
Samp  Gas  Range Fullscale    Zero    Offset    Std Dev       Spec   Span   Offset    Std Dev    Rezero   Drift     Std Dev  Status

BAG   LLCO  (2)   50.0ppm    0.233     0.47     0.06016     47.030  46.689   -0.68    0.04755     0.011    0.02     0.03838    PASS
BAG   CO2   (1)   1.00%     0.0001     0.01     0.00702     0.9040  0.9051    0.11    0.02769    0.0001    0.01     0.00591    PASS
BAG   NOX   (1)   10.0ppm   -0.001    -0.01     0.03356      9.372   9.358   -0.14    0.04174     0.006    0.06     0.03848    PASS
BAG   CH4   (1)   10.0ppm    0.005     0.05     0.00402      9.800   9.934    1.34    0.02081     0.009    0.09     0.00594    PASS
BAG   THC   (1)   30.0ppm    0.280     0.93     0.02022     28.450  28.672    0.74    0.04335     0.016    0.05     0.02442    PASS

Post Reading Zero/Span Concentrations    ( Drift Limit = 2.0%  Std Dev Limit = 1.0% )
Samp  Gas  Range Fullscale    Zero     Drift    Std Dev       Spec   Span    Drift    Std Dev  Status

BAG   LLCO  (2)   50.0ppm    0.006     0.01     0.05841     47.030  46.497   -1.07    0.04290    PASS
BAG   CO2   (1)   1.00%     0.0002     0.02     0.00479     0.9040  0.9043    0.03    0.00980    PASS
BAG   NOX   (1)   10.0ppm    0.001     0.01     0.07004      9.372   9.436    0.64    0.03545    PASS
BAG   CH4   (1)   10.0ppm    0.006     0.06     0.00395      9.800   9.800    0.00    0.02408    PASS
BAG   THC   (1)   30.0ppm    0.093     0.31     0.01683     28.450  28.454    0.01    0.03393    PASS

Bag Pair Zero/Span Concentrations    ( Offset Limit = 2.0%  ReZero Limit = 1.0%  Std Dev Limit = 1.0% )
Samp  Gas  Range Fullscale    Zero    Offset    Std Dev       Spec   Span   Offset    Std Dev    Rezero   Drift     Std Dev  Status

BAG   LLCO  (2)   50.0ppm    0.129     0.26     0.04727     47.030  46.621   -0.82    0.04669     0.058    0.12     0.05154    PASS
BAG   CO2   (2)   4.00%     0.0007     0.02     0.00325     3.6160  3.5716   -1.11    0.00996    0.0003    0.01     0.00339    PASS
BAG   NOX   (1)   10.0ppm   -0.012    -0.12     0.03266      9.372   9.411    0.39    0.03330     0.004    0.04     0.05005    PASS
BAG   CH4   (1)   10.0ppm    0.011     0.11     0.00384      9.800   9.943    1.43    0.00551     0.009    0.09     0.00454    PASS
BAG   THC   (1)   30.0ppm    0.284     0.95     0.02244     28.450  28.578    0.43    0.01248    -0.012   -0.04     0.01526    PASS

Post Reading Zero/Span Concentrations    ( Drift Limit = 2.0%  Std Dev Limit = 1.0% )
Samp  Gas  Range Fullscale    Zero     Drift    Std Dev       Spec   Span    Drift    Std Dev  Status

BAG   LLCO  (2)   50.0ppm    0.118     0.24     0.05015     47.030  46.565   -0.93    0.04520    PASS
BAG   CO2   (2)   4.00%     0.0000     0.00     0.00277     3.6160  3.6179    0.05    0.02556    PASS
BAG   NOX   (1)   10.0ppm    0.001     0.01     0.02184      9.372   9.371   -0.01    0.06928    PASS
BAG   CH4   (1)   10.0ppm    0.001     0.01     0.00360      9.800   9.801    0.01    0.01498    PASS
BAG   THC   (1)   30.0ppm    0.051     0.17     0.08848     28.450  28.466    0.05    0.03871    PASS
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