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Environmental Monitoring Series

GUIDELINES FOR QUALITY ASSURANCE PROGRAMS FOR MOBILE SOURCE EMISSIONS MEASUREMENT SYSTEMS:

PHASE IV, HEAVY-DUTY GASOLINE ENGINES - QUALITY ASSURANCE GUIDELINES

U.S. Environmental Protection Agency
Office of Research and Development
Washington, D. C. 20460

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GUIDELINES FOR QUALITY ASSURANCE PROGRAMS FOR MOBILE SOURCE EMISSIONS MEASUREMENT SYSTEMS:

PHASE IV, HEAVY-DUTY GASOLINE ENGINES - QUALITY ASSURANCE GUIDELINES

by

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U.S. ENVIRONMENTAL PROTECTION AGENCY
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and

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EPA REVIEW NOTICE

This volume has been prepared by Olson Laboratories, Incorporated consistent with the Environmental Protection Agency Quality Assurance principles and concepts and with the Environmental Protection Agency Mobile Source Testing Practices at Ann Arbor, Michigan.

The guidelines and procedures are generally applicable to mobile source testing operations and are intended for use by those engaged in such measurement programs

It is requested that recipients and users of this document submit any comments and suggestions to the Project Officers.

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into series. These broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and maximum interface in related fields. These series are:

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FOREWORD

All mobile source testing facilities have some elements (activities) of a quality assurance system built into their routine testing operations. These activities may not have been identified and/or integrated into a formal quality assurance program. It is the objective of these guidelines to provide guidance to both (1) facilities which desire to organize an integrated quality assurance program; and (2) facilities which may have already organized towards an integrated quality assurance program, but may desire to review their program as a result of the recommendations and suggestions included in these guidelines. The extent of implementation of these guidelines will depend upon the requirements of each individual test facility.

EXECUTIVE SUMMARY

Many of the principles of quality assurance described in Phase II, which detailed guidelines for the measurement of heavy duty diesel engine emissions, are generally applicable to all measurement systems. As a supplement to the Phase II report, this document examines the technological aspects of heavy duty gasoline engines, with reference to applicable functions and procedures.

The measurement system used for heavy duty gasoline engines is described in detail in Volume I and test procedures used by the EPA, Ann Arbor facility to meet applicable requirements of the Federal Register for the 1975 model-year, appear in Volume II.

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Section 1

INTRODUCTION

The Quality Assurance Staff of the EPA Quality Assurance and Environment Monitoring Laboratory, Research Triangle Park, North Carolina, is responsible for the administration of a Quality Assurance Program for air measurement systems resulting from the implementation of the Clean Air Act. Standards for the emissions for light and heavy duty mobile sources have been promulgated and procedures published for the measurement of their emissions and certification. Quality Assurance guidelines, however, have not been previously specified of these mobile source emission measurement procedures. Such quality assurance programs are necessary to assure the integrity of the data resulting from these tests. This report presents guidelines for quality assurance programs for measurement systems used in mobile source testing according to the applicable requirements of the Federal Register for the 1975 model-year.

The guidelines for the Quality Assurance Program for mobile source measurement systems were prepared in four phases.

- Phase I - For light duty gasoline-powered vehicles (cars and trucks)
- Phase II - For heavy duty diesel engines
- Phase III - For light duty diesel-powered vehicles (cars and trucks)
- Phase IV - For heavy duty gasoline engines

This document presents the guidelines for implementing a Quality Assurance Program for the measurement of emission from heavy duty gasoline engines (Phase IV). Guidelines for the other phases were reported in separate documents.

1.1 OBJECTIVE AND SCOPE OF GUIDELINES

These guidelines provide information on general quality methods which may be used in emission testing. They were primarily designed for use by management and supervisory personnel involved in the development or operation of quality programs. Upper managment may use the guidelines to evaluate the quality programs which presently exist within their own laboratory or organization.

The measurement system for heavy duty gasoline engines consists of the testing, calibration and analytical requirements, the operational and measurement data obtained. The primary objective of this program was to analyze this system and apply the principles and techniques of modern quality assurance systems to the total testing process to assure the validity and reliability of the tests and the resulting test data.

Many of the guidelines and test procedures described in Phase II of this program are directly applicable to the heavy duty gasoline engine emission measurement system. Consequently, the objective of this supplement is to provide additional information and procedures required specifically for heavy duty gasoline emission tests.

1.2 FORMATION OF QUALITY ASSURANCE GUIDELINES

In order to identify those areas requiring special definition for Phase IV, the report for Phase II was reviewed along with the available information concerning heavy duty gasoline engine emission test procedures to determine necessary revisions or modifications of the Phase II documents. Sections and paragraphs requiring revision are numbered identically to the original document to facilitate cross reference. Sections applicable in their entirety are noted as such.

The quality assurance guidelines for heavy duty engine emission measurement systems are contained in Sections 1 through 8, with all references appearing in Section 9. A summary of the contents of each section is as follows:

1.2.1 Section 1 - Introduction

A description of the background, objective and organization of the guidelines.

1.2.2 Section 2 - Organizing For Quality

A typical Quality Assurance Organization is presented. Quality functions are identified and the various key elements of a quality program are described.

1.2.3 Section 3 - Measurement System Analysis

A description of the measurement system defining the equipment, test procedure specifications and tolerances, quality provisions and other requirements necessary for emission testing of heavy duty gasoline engines.

1.2.4 Section 4 - Guidelines for Performance Audits and Maintenance Procedures

General guidelines are presented for performance inspection and maintenance of instruments and equipment used in the measurement systems. Preventive maintenance programs are described for increasing the reliability and efficiency of the test equipment.

1.2.5 Section 5 - Quality Assurance Guidelines for Documentation Of The Measurement System

Guidelines for the development of a documentation system are presented with representative forms, a description of the manuals, data recording, and failure analyses used by a quality assurance program.

1.2.6 Section 6 - Application Of Statistical Quality Assurance Methods To The Emission Test System

Basic statistical techniques such as control charts, analysis of variance and data validation as applied to a quality system are described.

1.2.7 Section 7 - Analysis Of Variability In The Measurement Of Emissions From Light Duty Vehicles

Sources of variability are identified and, where possible, quantified to show their effect on the data.

1.2.8 Section 8 - Quality Assurance System (On Site) Survey

A procedure and survey form for conducting a quality assurance survey of a laboratory performing heavy duty emission testing is presented.

1.2.9 Appendices

Statistical techniques and nomenclatures appear in Appendix A-1. Appendix A-2 contains control chart multiplication factors. Appendices B-1 and B-2 include a glossary of terms and a list of abbreviations commonly used in the measurement system. Appendix C of Volume I contains general Quality Managment Procedures (QMP) which define those functions identified as being necessary in a quality assurance program.

Section 2

ORGANIZING FOR QUALITY

2.1 Operations Management

2.1.1 Quality Assurance Management

2.1.2 Emission Test Facility Management

Administrative procedures and Quality Assurance functions are identical with those of Phase II

Section 3

MEASUREMENT SYSTEM ANALYSIS

A total Measurement System can be defined as an orderly arrangement consisting of the analytical method, the test sampling procedure, the instruments or analyzers, the supporting functions, the management organization, and the technicians or personnel involved in performing specific functions within the system. Applying this definition to the measurement system for heavy duty gasoline engine emissions the process is composed of:

- The test procedure defined by the Federal regulations
- The preparation of the gasoline engine for the emissions test
- The exhaust emission sample transfer and analytical console consisting of NDIR instruments for the measurement of carbon monoxide (CO) and nitrogen oxides (NO_x), and hydrocarbons (HC)
- The Laboratory Operations management including Test Operations and Support Operations

This measurement system was subjected to a functional analysis to determine and define the basic elements which require attention in a total quality assurance program.

3.1 APPLICABLE FEDERAL REGISTER PROCEDURES

Measurement system for the quality assurance guidelines and procedures have been developed as defined in the Federal Register. The Federal Register which defines the measurement systems covered by this document is Volume 40, Number 40, dated February 27, 1975, pages 8482 to 8495.

The paragraphs which define the test procedure for heavy duty gasoline engines are summarized Table 3-1.

Table 3-1. SUBPART H-EMISSION REGULATIONS FOR NEW GASOLINE-FUELED HEAVY DUTY ENGINES

85.701	General applicability
85.702	Definitions
85.703	Abbreviations
85.774-1	Emission standards for 1974 and later model-year engines
85.774-7	Service accumulation and emission measurements
85.774-9	Test procedures
85.774-10	Gasoline fuel specifications
85.774-11	Dynamometer operation cycle and equipment
85.774-12	Dynamometer procedures
85.774-13	Sampling and analytical system measuring exhaust emissions
85.774-14	Information to be recorded
85.774-15	Calibration and instrument checks
85.774-16	Dynamometer test run
85.774-17	Chart reading
85.774-18	Calculations

3.2 ELEMENTS OF A MEASUREMENT SYSTEM FOR HEAVY DUTY DIESEL ENGINE EMISSION MEASUREMENT

A requirement of a total Quality Assurence Program is to maintain control at all important stages of a process. In this measurement system, an analytical process, it is necessary to first identify its functional elements. In order to categorize these elements and the related tasks, the measurement system was divided into the following operations:

- Engine receiving inspection
- Engine-dyno preparation
- Engine-dyno checkout
- Engine test cycle preconditioning
- Engine test cycle
- Sampling system
- Instrument calibration
- Interference check CO/H_2O
- Measurement of gaseous emissions
- Data collection and reduction

A summary matrix of the emission measurement procedure for gaseous emissions is presented in Table 3-2. The overview represented by this matrix was designed to give a general understanding of the process involved in exhaust emission testing. However, it was not intended to include every detail required for this measurement. The information discussed in this table consist of:

- A brief description of the tasks

- Applicable Federal Register paragraphs

- Applicable EPA, Ann Arbor, test procedure numbers

- Specification and tolerance included in the Federal Register, and from engineering practices such as the SAE recommended practices

- Quality provisions

- Invalid test (determination)

- Corrective action required

- Training and skill level required

Table 3-2. HEAVY DUTY GASOLINE ENGINE EMISSION MEASUREMENT SYSTEM

PROCEDURE OR TASK	BRIEF DESCRIPTION	FR REF EPA TP NO.	SPECIFICATION OR TOLERANCE-FED. REG.	SPECIFICATIONS SAE OR ENG. PRACT	QUALITY PROVISIONS	TEST INVALID	CORRECTIVE ACTION	TRAINING OR SKILL LEVEL
1. Engine, Receiving Inspection	Engine shipped to the EPA from the manufacturer is inspected for damage and conformance to installation	FR. Vol. 40 2-27-75 85.774-29(a) TP 750-G		MSAPC Advisory Circular No 22A Appendix A. 4-23-73	Receiving Inspection check list	Failure to comply with specifications/shipping damage	Contact engine manufacture for disposition of the engine.	Knowledge of engine installation requirements/inspection procedures
2. Engine Installation	The engine and prealigned stand are installed in the test cell and attached to the dynamometer	85.774-11 85.774-16(a)(1) TP-750-G	Dynamometer capable of maintaining constant speed ·100 RPM from full throttle to closed throttle motoring	MSAPC No. 22A	Installation check list/inspection by mfr. rep	Incomplete/Improper installation	Correct Discrepancy	Mechanical skill and knowledge of engine/dyno.
3. Engine/Dyno Check out	The engine is operated at idle and load conditions to check for proper operation. Engine parameters are checked against manufacturer's specifications	85 774-16(2) TP-750-G	Adjustments on engine are limited to unscheduled maintenance listed in Ref. Para.	SAE J8166-Engine test code	Calibration of engine analyzer	Incorrect Engine parameters	Adjust to mfr. specifications	Knowledge of dyno engine analyzer operation
4. Engine preconditioning	Start engine and precondition with one or more cycles, service accumulation or test cycle. Allow to soak prior to test	85.774-7,11,16 TP-757	Engine must reach normal operating conditions, soak time 1-2 hours temp , 60-86°F	Water/oil at equilibrium temp.	Speed/torque/temp. trace, soak time checked by Data Validation	Out of limit soak time/Temp/Cycle	Repeat preconditioning	Knowledge of engine/dyno operation
5. Engine Test Cycle	An initial 5 minute idle, two warmup cycles, and two hot cycles constitute a complete Dyno Run	85.774-11,12,16 TP-757	Amb. Temp 68-86°F 2000· 100 RPM Idle - Mfr spec		Data validation Q.A. audit	Deviation of 2 sec. CT mode, 0.3 inc. Hg. cruise/PTD mode, 0.2 inc. Hg. PTA/FL Mode last 10 sec. of Mode. 200 RPM first 4 sec./100 RPM rest.	Repeat preconditioning and Test	As above
6. Sampling System	Comprised basically of 5 NDIR instruments, Sample pumps, refrigeration, flow controls and pressure and flow meters	85.775-13 TP-758	Instrument ranges LHC 0-1000 ppm Equiv. LHC 0-10,000 ppm Equiv CO 0-10 , CO_2 0-16 NO 0-4000 ppm	Sampling System tubing/hardware/accessories must be made of Teflon, stainless steel or glass only	Approval of system design and parts list, procurement control, inspection of system by Q.C prior to on-line operation	System leak/component failure/incorrect sample flow or pressure/calibration overdue	Correct variance and repeat test	Trained for operation of analytical system.
7. Instrument Calibration	Calibration gases with concentrations varying across the instrument range are used to identify the instrument curve for data reduction	85.775-15 TP-203 TP-758	Calibrated once every 30 days, Flowrate HHC, LHC, NO 10CFH, CO, CO_2 5 CFH Concentration of gas should be known within -2% of true value	Weekly checks, calibration standards traceable to NBS/known to 1 of true value or better Curve generated must be within 2 of all points.	Curve defined mathematically by least squares method. Curve approved by Data validation/Audit.	Overdue calibration, system leak during calibration.	Locate and correct problem, recalibrate.	As above
8. CO_2/H_2O Response check	The Hydrocarbon instruments are checked monthly for interference from water vapor and carbon dioxide	85 775-15 TP-304	CO_2 100% - Response not to exceed 0.5. Sat. N_2 75°F - LHC- 0.5 of full scale, HHC 0.5% of full scale.		Monthly check	Excessive interference from CO_2/H_2O	Recharge filter cell with CO_2 Replace detector	As above
9. Sample Analysis	A portion of the exhaust gases are analyzed continuously from the first idle thru four nine-mode cycles ending with the engine at idle.	85 775-16, 17 TP-758	Chart Speed 6 in./min Min 4-nine mode cycles, 2 Idle modes-before and after test	Visually monitor inst. inlet pressure during sampling 1 in. H_2O Tol.	Data validation, calibration check, Q C audit	Excessive hangup Instrument drift in excess of 2 or other malfunction	Clean sampling system, repair instrument, repeat test	As above. Corrective action may require basic knowledge of electronic instruments.
10. Data Reduction	Direct computer analysis of instruments' output is used to reduce the data to brake specific emissions (gms/hr.)	85 775-16 TP-758	Chart reading should be within 0.5 of full scale. Chart speed 3 in / min. with marker to indicate computed segments		Data validation, Computer program verification, random audit of test data	Incorrect cycle segments used for computer analysis, recorder malfunction	Manually reduce data/repeat test	

Section 4

GUIDELINES FOR PERFORMANCE AUDITS AND MAINTENANCE PROCEDURES

The guidelines presented in this section are applicable to both measurement systems. A listing of additional specifications for heavy duty gasoline engine testing are presented in Table 4-1.

Table 4-1. FEDERAL REGISTER SPECIFICATIONS HEAVY DUTY GASOLINE ENGINE EMISSION MEASUREMENTS - SUBPART H

<table>
<tr><th>REFERENCE PARAGRAPH</th><th>PROCEDURE OR EQUIPMENT DESCRIPTION</th><th>SPECIFICATION OR TOLERANCE</th></tr>
<tr><td>85.702</td><td>Zero Hour Engine-Defined</td><td>That point after normal assembly line operations and adjustment and before one additional operating hour has been accumulated.</td></tr>
<tr><td></td><td>Heavy Duty Vehicle</td><td>Rated at more than 6,000 lbs. GVW or designed for transportation of property or more than 12 persons.</td></tr>
<tr><td></td><td>Heavy Duty Engine</td><td>One used for motive power is a heavy duty vehicle.</td></tr>
<tr><td>85.774-1</td><td>Emission Standards 1974 and later model-year engines</td><td>1. Hydrocarbons plus oxides of nitrogen (as NO_2) - 16 grams per brake horsepower hour.
2. Carbon monoxide. 40 grams per brake horsepower hour.
3. No crank case emissions are allowed.</td></tr>
<tr><td>85.774-7</td><td>Result of Emission Tests</td><td>Reported using two places to the right of the decimal point, rounded off according to ASTM E29-67.</td></tr>
<tr><td></td><td>Emission and Durability 125 hour test point</td><td>±8 hours of 125 hour multiple.</td></tr>
<tr><td>85.774-10</td><td>Gasoline Specifications</td><td>
<table>
<tr><th>ITEM</th><th>ASTM DESIGNATION</th><th>LEADED</th><th>UNLOADED</th></tr>
<tr><td>Octane, Research minimum</td><td>D1656</td><td>100</td><td>96.</td></tr>
<tr><td>Pb. (organic), grams/U.S. gals</td><td></td><td>1.4 min.</td><td>0.00-0.05.</td></tr>
<tr><td>Distillation range</td><td>D86</td><td></td><td></td></tr>
<tr><td>1BP. °F</td><td></td><td>75-95</td><td>75-95.</td></tr>
<tr><td>10 percent, °F</td><td></td><td>126-135</td><td>126-135.</td></tr>
<tr><td>50 percent, °F</td><td></td><td>200-230</td><td>200-230.</td></tr>
<tr><td>90 percent, °F</td><td></td><td>300-325</td><td>300-325.</td></tr>
<tr><td>EP, °F (maximum)</td><td></td><td>415</td><td>415.</td></tr>
<tr><td>Sulfur, weight percent max</td><td>D1368</td><td>0.10</td><td>0.10.</td></tr>
<tr><td>Phosphorus grams/U.S. gals max</td><td></td><td>0.01</td><td>0.005.</td></tr>
<tr><td>RVP, pound</td><td>D323</td><td>8.0-9.2</td><td>8.0-9.2.</td></tr>
<tr><td>Hydrocarbon composition</td><td>D1319</td><td></td><td></td></tr>
<tr><td>Olefin, percent, maximum</td><td></td><td>10</td><td>10.</td></tr>
<tr><td>Aromatics, percent, maximum</td><td></td><td>35</td><td>35.</td></tr>
<tr><td>Saturates</td><td></td><td>Remainder</td><td>Remainder</td></tr>
</table>
</td></tr>
<tr><td>85.774-11</td><td>Dynamometer Specifications</td><td>Capable of maintaining speed ±100 RPM from full throttle to closed throttle</td></tr>
<tr><td></td><td>Exhaust System</td><td>Chassis - type or equivalent</td></tr>
<tr><td></td><td>Cooling</td><td>Radiator to maintain typical engine operating temperatures. Fixed speed fan may be used.</td></tr>
</table>

Table 4-1. FEDERAL REGISTER SPECIFICATIONS HEAVY DUTY GASOLINE ENGINE EMISSION MEASUREMENTS - SUBPART H (Continued)

<table>
<tr><th>REFERENCE PARAGRAPH</th><th>PROCEDURE OR EQUIPMENT DESCRIPTION</th><th>SPECIFICATION OR TOLERANCE</th></tr>
<tr><td>85.774-11</td><td>Test Cycle</td><td>
<table>
<tr><th>SEQUENCE NO.</th><th>MODE</th><th>MANIFOLD VACUUM</th><th>TIME IN MODE-SECS.</th><th>CUMULATIVE TIME-SECS.</th><th>WEIGHTING FACTORS</th></tr>
<tr><td>1. . . . .</td><td>Idle. . . . . . .</td><td></td><td>70</td><td>70</td><td>0.232</td></tr>
<tr><td>2. . . . .</td><td>Cruise.</td><td>16" Hg. .</td><td>23</td><td>93</td><td>.077</td></tr>
<tr><td>3. . . . .</td><td>PTA . .</td><td>10" Hg. .</td><td>44</td><td>137</td><td>.147</td></tr>
<tr><td>4. . . . .</td><td>Cruise.</td><td>16" Hg. .</td><td>23</td><td>160</td><td>.077</td></tr>
<tr><td>5. . . . .</td><td>PTD . .</td><td>19" Hg. .</td><td>17</td><td>177</td><td>.057</td></tr>
<tr><td>6. . . . .</td><td>Cruise.</td><td>16" Hg. .</td><td>23</td><td>200</td><td>.077</td></tr>
<tr><td>7. . . . .</td><td>FL. . .</td><td>3" Hg. .</td><td>34</td><td>234</td><td>.113</td></tr>
<tr><td>8. . . . .</td><td>Cruise.</td><td>16" Hg. .</td><td>23</td><td>257</td><td>.077</td></tr>
<tr><td>9. . . . .</td><td>CT. . . . .</td><td></td><td>43</td><td>300</td><td>.143</td></tr>
</table>
</td></tr>
<tr><td></td><td>Dynamometer</td><td>Operated at a constant speed of 2000 RPM ±100 PRM, ±200 RPM is allowed during first 4 seconds of each mode.</td></tr>
<tr><td></td><td>Idle Speed</td><td>Idle speed at manufacturer's recommended engine speed.</td></tr>
<tr><td></td><td>Closed Throttle Mode (CT)</td><td>2000 RPM ±100 RPM</td></tr>
<tr><td></td><td>Part Throttle Mode (PTD)</td><td>Specified manifold vacuum or closed throttle if vacuum cannot be obtained.</td></tr>
<tr><td></td><td>Full Load Mode (FL)</td><td>Specified manifold vacuum or wide open throttle if vacuum cannot be obtained</td></tr>
<tr><td>85.774-13
85.774-15</td><td>Analytical Equipment</td><td>Consists of the following basic components sample, probe, refrigerated bath, filters, pumps, pressure gauges, water traps, drier for NO, flowmeters and appropriate values and fittings.
Instruments:
CO - NDIR Range 0 - 10 percent
CO_2 - NDIR Range 0 - 16 percent
NO - NDIR Range 0 - 4000 PPM
HC - NDIR(2) 0-1000 PPM hexane equivalent
0-10,000 PPM hexane equivalent
Lower operating ranges may be used as required.</td></tr>
<tr><td>85.774-14</td><td>Recorders-Analyzers, manifold vacuum and Engine RPM</td><td>Automatic 1 second interval marker or preprinted chart paper. Correct chart speed must be verified and the charts for each run.</td></tr>
<tr><td>85.774-15</td><td>Instrument Calibration</td><td>Every 30 days</td></tr>
<tr><td></td><td>Zero Gas</td><td>Air or nitrogen-impurity concentrations should not exceed 10 PPM NO.</td></tr>
<tr><td></td><td>Flow Rates</td><td>10 C.F.H. for HC and NO
5 C.F.H. for CO and CO_2</td></tr>
<tr><td></td><td>Calibration Gases</td><td>Accuracy ±2 percent of nominal value. Diluted prepurified N_2.</td></tr>
</table>

Table 4-1. FEDERAL REGISTER SPECIFICATIONS HEAVY DUTY GASOLINE ENGINE EMISSION MEASUREMENTS - SUBPART H (Continued)

<table>
<tr><th>REFERENCE PARAGRAPH</th><th>PROCEDURE OR EQUIPMENT DESCRIPTION</th><th>SPECIFICATION OR TOLERANCE</th></tr>
<tr><td>85.774-15</td><td>Calibration Gases-Required Concentrations</td><td>Concentration determined with ±2 percent of true value.
<table>
<tr><th>Low range HC analyzer-Hexane equivalent[1]</th><th>High range HC analyzer-Hexane equivalent</th><th>NO analyzer-NO</th><th colspan="2">CO and CO[1] analyzers-Blend of CO and CO[1] containing CO plus CO[1]</th></tr>
<tr><td>ppm</td><td>ppm</td><td>ppm</td><td>Mode percent</td><td>Mode percent</td></tr>
<tr><td>100</td><td>600</td><td>250</td><td>0.5</td><td>16.0</td></tr>
<tr><td>200</td><td>1,000</td><td>500</td><td>1.0</td><td>15.0</td></tr>
<tr><td>300</td><td>1,500</td><td>750</td><td>2.0</td><td>14.0</td></tr>
<tr><td>400</td><td>2,500</td><td>1,000</td><td>3.0</td><td>13.0</td></tr>
<tr><td>600</td><td>4,000</td><td>1,500</td><td>4.0</td><td>12.0</td></tr>
<tr><td>800</td><td>6,000</td><td>2,000</td><td>6.0</td><td>10.0</td></tr>
<tr><td>1,000</td><td>8,000</td><td>2,500</td><td>8.0</td><td>8.0</td></tr>
<tr><td></td><td>10,000</td><td>3,000</td><td>10.0</td><td>6.0</td></tr>
<tr><td></td><td></td><td>3,500</td><td></td><td></td></tr>
<tr><td></td><td></td><td>4,000</td><td></td><td></td></tr>
</table>
[1] The hexane equivalent of propane when used as the normalizing gas for calibrating nondispersive infrared analyzers is prescribed to be 0.52 (propane concentration X 0.52 = hexane equivalent concentration). Minimum storage temperature of the cylinders shall be 60°F; minimum use temperature shall be 68°F.</td></tr>
<tr><td>85.774-15</td><td>Hydrocarbon-NDIR Response to CO_2</td><td>100 percent CO_2 response less than 0.5 percent if greater recharge filter cell. If this does not correct problem, replace detector.</td></tr>
<tr><td></td><td>Response to H_2O</td><td>Saturated nitrogen at ambient temperature. Low range - if it exceeds 5 percent of full scale (75°F), replace detector.
High range not to exceed 0.5 percent of full scale.</td></tr>
<tr><td>85.774-15</td><td>Instrument Check</td><td>Daily - 2 hour warm up - span before and after test - span after test must repeat within ±2 percent of full scale.
Span gas - 80-100 percent accuracy ±2 percent of true value gain - shift in excess of ±3 percent requires analyzer to be retuned and analyzer curve checked. Record actual concentrations on chart.</td></tr>
</table>

Table 4-1. FEDERAL REGISTER SPECIFICATIONS HEAVY DUTY GASOLINE ENGINE EMISSION MEASUREMENTS - SUBPART H (Continued)

REFERENCE PARAGRAPH	PROCEDURE OR EQUIPMENT DESCRIPTION	SPECIFICATION OR TOLERANCE
85.774-16	Dynamometer Test Run	<u>Preconditioning</u>: Service accumlation cycle or 9 mode cycle run until normal operating conditions reached. The engine shall not be exposed to precipitation or condensation after preconditioning. <u>Soak</u>: Min. of 1 hour, Max. 2 hours at 60^{o}-86^{o}F. <u>Sampleline</u>: 2 feet into the tail pipe, dual exhaust requires two probes with no more than 4 inches variation in length. Same material, insertion, diameter and configuration. <u>Chart Speed</u>: 6 inches per minute. <u>Hydrocarbon: Hang Up</u> At the end of the test the HC concentration shall drop to 5 percent or less of full scale within 10 sec., and 3 percent or less of full scale within 3 minutes while being purged with zero gas.
85.774-17	Dynamometer Test Run	<u>Time</u>: ± 2 seconds for CT mode. <u>Manifold</u>: ±0.3 in. Hg-cruise and PTD mode ±0.2 in. Hg-PTA and FL mode during the 10 seconds of the mode. <u>Speed</u>: ±200 RPM, first 4 seconds each mode, ±100 RPM for remainder.
85.774-17	Chart Reading - Manual	All analyzer traces for 3, 10, 16, 19 in Hg and idle modes. Divide last 2 seconds into min. 3 segments and read to within 0.5 percent of full scale - average readings. Initial idle mode used for warmup and cycles 1 and 2, final idle mode used for cycles 3 and 4. Closed throttle mode - all traces - divide into min. 43 segments of equal length and determine deflection within 0.5 percent of full scale - average concentrations values.
85.774-17	Chart Reading Computer	(f) Direct computer analysis of analyzer output may be utilized provided that the analysis is sufficiently similar to the above procedures to result in comparable data results and the analyzer output is continuously recorded at a chart speed of at least 3 inches per minute with an automatic marker being used to identify the time intervals during which data are accepted by the computer for processing.
85.774-17	Brake Horsepower	Horsepower for the idle and closed throttle mode shall be defined as zero for calculation purposes, negative vales are not used.

Section 5

QUALITY ASSURANCE GUIDELINES FOR DOCUMENTATION OF THE MEASUREMENT SYSTEM

Section 6

APPLICATIONS OF STATISTICAL QUALITY ASSURANCE METHODS TO THE EMISSION TEST SYSTEM

The above two sections are directly applicable to both measurement systems. The general guidelines described for documentation and statistical methods may be incorporated into a quality system for all mobile source emission testing. When establishing a quality plan for a particular mobile source testing facility, these two sections of the Phase II report should be consulted for guidance in such areas as control of procedural manuals, recording of results, processing and audit control emission data, initiating control charts, and the implementation of corrective action procedures.

Section 7

ANALYSIS OF VARIABILITY IN THE MEASUREMENT EMISSIONS FROM HEAVY DUTY GASOLINE ENGINES

A knowledge of specific variables significantly affecting the data is a prerequisite for achieving a predetermined goal, improving data reliability and detecting bias factors in the system. These variables are either determinate or indeterminate. Determinate variables may be objectively studied by engineering evaluation of the test procedure and statistical analyses of the data. The nature of indeterminate variables requires them to be evaluated subjectively. Indeterminate variables are usually estimated through experience with the measurement system.

The measurement system for heavy duty gasoline engines consists primarily of an engine-dynamometer test cell and an NDIR analytical console for the measurement of carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC) and nitrogen oxides (NO_x).

The test sequence involves the measurement of HC, CO, CO_2 and NO during several steady-state modes run on an engine dynamometer which are designed to simulate a truck driving pattern in a metropolitan area. Tolerances and specifications for instruments, equipment and test cycle appear in Table 3-2 and Table 4-1 of this report.

In addition to engine inconsistencies, certain measurement system variables have been established as prime source of error. Efforts to reduce these variables include the use of instruments and calibration standards having increased precision and accuracy, and improvement in methods of sampling gaseous emissions.

This section of the guidelines discusses the methods used to identify these major sources of variation, to quantify the effect of the determinate variables, and to define the role of quality assurance in the effort to reduce test variation. However, very little information has been published concerning the test error associated with the heavy duty gasoline engine measurement system.

Presently there are some major differences between the light duty and heavy duty analytical systems. The heavy duty gasoline analytical system requires NDIR measurements for hydrocarbons and nitric oxide. In light duty emissions these testing instruments have been replaced by the Flame Ionization Detector for hydrocarbons and the Chemiluminescent (CL) Analyzer for nitric oxide. A converter is used with the latter instrument to convert NO_2 in the sample to NO. It is likely that the CL method will be specified in the near future in heavy duty testing due to undesirable characteristics of the NDIR system, such as interference from other gases. Until such time as these changes become permissible by Federal Regulations, the manufacturer must continue to certify their engines by the present procedure.

7.1 VARIABLES ASSOCIATED WITH THE MEASUREMENT SYSTEM-TEST CELL EQUIPMENT AND INSTRUMENTS

The primary sources of test-error in the measurement system are the:

- Dynamometer
- Humidity Measurement
- Barometer
- Ambient Conditions
- Fuel Measurement
- Analyzer
- Sampling System
- Calibration of Instruments
- Zero Gas Purity
- Working Standard
- Operator
- Computer
- Engine

Engine, dynamometer, ambient condition and operator variability are interrelated variables, all of which usually vary if any one of them is changed. For example, changes in ambient conditions can affect operation of engine control systems.

Most of the other variables are determinate, but little information is available as to their actual contribution to test error. The gasoline engine measurement system is presently under study at the EPA, Ann Arbor facility.

The light duty measurement systems has been studied extensively by the EPA and the major automobile manufacturers, (References 7-2, 7-3, 7-4, 7-5, 7-6, 7-7).

Some of the variables listed are comparable to those associated with light duty vehicle testing (Reference 7-1). For example, calibrations of the analyzers are performed using the same procedure and checks. The estimate for the light duty analytical system calibration coefficient of variation is 1 percent and would be expected to be nearly the same for heavy duty gasoline emission measurements.

7.1.1 Dynamometer Operations

The dynamometer speed and torque meters are calibrated at monthly intervals. The associated recorders are checked and aligned with the meters prior to each test. The RPM output is checked with a primary standard such as a strobotac with a standard accuracy of ±1 percent. The torque meter is usually calibrated using weights placed on the torque beam. The weights should be traceable to the NBS and should have an accuracy of ±0.1 percent. The test variability associated with the operation of the dynamometer would be difficult to assess without an extensive program involving several operators, dynamometers and engines.

Computer-controlled dynamometers have become quite popular. However, these systems require manual intervention, with its associated inherent variability, to program the computer each time an engine is installed in the test cell.

The test cycle is operated according to engine RPM and manifold vacuum within the specified tolerance for a particular mode. Speed/torque/manifold vacuum traces are made for each test and those not meeting the tolerance are voided and the test is rerun.

An assessment of this dynamometer variable could be achieved by performing ten consecutive tests (cycles) on a well-preconditioned engine using the same computer program or operator followed by ten consecutive tests during which the RPM and manifold vacuum varied within the specified limits during the cycle, using different operators if possible.

This data would give an objective assessment of the variability due to dynamometer operation. Naturally, this would be valid only for that particular engine-dynamometer combination. The test would be repeated with different engine-dynamometer combinations each time a new engine is installed. A coefficient of variation control chart as described in Section 6.2.5.3 could be established using the collected data. The analysis of variance technique, also discussed in Section 6, could be applied to determine significant differences between the various combinations.

7.1.2 Relative Humidity

Test error in the determination of relative humidity could be significant when used to calculate the correction factor for NO_x. The correction factor is applied to adjust for the differences in NO_x emissions as ambient relative humidity changes. This correction factor reduces the variability of the NO_x emission data by normalizing to a standard relative humidity of 75 grains of moisture per pound of dry air.

Relative humidity is almost universally determined in the emission laboratory using the wet bulb-dry bulb hygrometer. Other methods of determining humidity are available but attempts to correlate the various methods have usually met with some unsolved discongruity. Therefore, it is mandatory that the equipment used for humidity determination should be specified. Two basic types are presently used: the fan-type hygrometer with either themocouples or thermometers and electronic or visual read out. The other is the sling-type psychrometer. These two types are known to give equal readings.

A comparison of readings, on an audit basis, of these two types could be used as a check. The sling psychrometer is the preferred audit tool because of its portability.

Other recommended methods of reducing variability include a controlled test lab environment, and continuous recording of humidity during a test. Wicks and water supply should be inspected frequently for contamination. Thermocouples and thermometers should have a calibrated accuracy of ±0.5°F or better.

7.1.3 Barometric Pressure

The temperature-compensated aneroid barometers, calibrated against standard laboratory mercury barometer are frequently used in the measurement system. In laboratories with only a single test cell, a mercury barometer is often used. The two primary sources of error for barometer readings are error in calibrating the aneroid barometer, and errors in the reading of a mercury barometer. Calibration errors are generally controlled through independent checks. Errors in reading the barometer can be reduced by recording the pressure before and after the test. Comparison of the range of the readings could then be done by data validation or computer, utilizing one of the control chart techniques described in Section 6. In addition, comparison to the reading of the previous test on the same day would provide an additional check.

7.1.4 Fuel Measurement and Control

The fuel used in testing the engine is often overlooked as a potential source of test error. Test laboratories usually have a choice of three fuels popularly known as 91 Octane, Idolene 30 and Idolene Clear (HO). Although the specifications for these fuels are regulated by the EPA, this does not assure that the fuel obtained from a supplier meet these specifications. The results of using leaded fuel in a catalyst-equipped engine have been well publicized. Foolproof controls must be implemented to preclude the use of the wrong fuel.

Other characteristics known to have an effect on emissions are the Reid Vapor Pressure (RVP), octane rating and hydrocarbon composition. The RVP can be changed through improper storing, overheating of the fuel, age, and improper handling. The use of "weathered" fuel can cause starting difficulties and, therefore, fresh fuel should always be used for emission test.

In view of these potential sources of test error, fuel delivered to a laboratory should be tested upon receipt for conformance to specifications and should not be released for use if the results of the test differ from the specifications. Storage drums should be clearly marked and color-coded. Care must be taken to contain each type of fuel in separate storage tanks, with thorough drainage of a tank prior to filling with another type of fuel.

Using fuel of the wrong octane may cause "ping" or "knock" in some engines possibly resulting in certification test failure. Hydrocarbon composition, in part, determines fuel octane and the running characteristics of the vehicle. In addition, the response of the FID can be affected by different ratios of paraffins, aromatics and olefins. Therefore, fuel analysis and correct fuel handling are important in controlling test variability. As catalysts are added to control emissions from gasoline engines, the lead content of the fuel becomes of prime concern. Recently the National Bureau of Standards issued Standard Reference Materials for the measurement of lead in fuel (SRMs 1636, 1637, and 1638), which provide a valuable tool for calibrating and checking the lead analyses method used in fuel control systems.

The accuracy of the measurement of the mass of fuel used for each mode will have a direct effect on the data. For example, a measurement error of 2 percent will cause a corresponding error of 2 percent in the determination of mass emissions in grams per hour.

Methods of fuel measurement may vary from one laboratory to another as no single method has been specified. The method used should be subjected to periodic calibrations as recommended by the manufacturer. Fuel flow meters calibrated for a specific temperature and specific gravity require corrections to be made to readings when fuel temperatures and/or the specific gravity are significantly different from the calibration parameters.

Because of volatility and explosive nature of gasoline, "dead weight" type measurement systems are difficult to use. Turbine and displacement type meters are generally used, but care should be taken to avoid vaporization of fuel in the system, which results in erroneous readings and engine malfunction.

7.2 VARIABLES ASSOCIATED WITH THE MEASUREMENT OF GASEOUS EMISSIONS

7.2.1 Variables Associated with the Analytical System

Exhaust emission concentrations are determined using an analytical system calibrated with working gas mixtures which have a specified accuracy of ±2 percent. Usually instrument curves are constructed with calibration gas mixtures having accuracies of ±1 percent or better. Gravimetric standards prepared and used by the EPA have a reported accuracy of ±0.5 percent or better. In addition, reference standards are available from the NBS (SRMs 1665-1669, 1673-1675, 1677-1681, and 1683-1687). Instrument precision and reproducibility are specified by the Federal regulations and, through experience, have been found to conform to these specifications when properly maintained. Successive analyses of the same sample give a precision of ±0.5 percent of the full scale concentration (Reference 7-4).

The primary sources of variability in the analytical system are:

- Accuracy of the calibration gases
- Instrument precision
- Accuracy of working or span gases
- Calibration curve construction
- Condition of the sampling system
- Full scale concentration
- Zero gas purity
- Instrument drift (electronic)
- Operator

The variables are controlled through a system of receiving inspection, performance and audit checks, etc., described in an earlier section. Detailed procedures for these appear in Volume II, the Test Procedure Manual. In determining the effect of error in concentration measurement, a coefficient of variation of 1 percent of the full scale is usually encountered in a repetitive determination of the same sample (Reference 7-3). However, variation between analytical systems has been experienced as high as ±3 percent for the same sample. Correlation values in excess of this are considered to be undesirable and suggest a need for corrective action. Corrective action usually involves a system leak check, reanalysis of the working gas and contruction of a new instrument curve, followed by a systematic check of the sources previously mentioned.

An error in the measurement of an exhaust gas component would obviously have a corresponding direct effect on the mass emission values. Measuring the concentration on the lowest convenient range improves the accuracy of the data. Instrumentation with a capability of multiple range selection is available and used by many laboratories, consequently they are able to select lower ranges than those specified in the Federal Register.

Other sources which need further control are the instrument zero drift, which should be checked periodically and contaminants in the zero gases. Nitrogen and air zero gases should be rigorously analyzed by the receiving laboratory in preference to the present practice of accepting batch analysis from the supplier. The reduction of contaminants in laboratory ambient air concentrations should also be considered. Inspection of the heating system for leaks and proper ventilation will help in achieving more desirable ambient conditions.

Because of the variety of available certified accuracies for calibration gases, a decision must be made based on cost versus desired reliability when obtaining the laboratory standards and "working gases." Naturally, as the certified accuracy of the blend is improved, the cost of the gas increases exponentially. In all cases, however, traceability to the EPA primary standards, either through correlation programs or by direct analysis by EPA, is desirable.

Calibration curves may be checked weekly by using the primary set of gases. However, this is a rather lengthy process involving the use of a large number of cylinders. When correct instrument maintenance procedures are complied with, the instrument curve shape generally remains stable for long periods of time. Consequently, a simpler process would be to check the mid-point of the curve using a primary standard and the span for the most frequently used ranges. These results (the mid-point deflections) are plotted on control charts (Section 6) for each instrument. When an "out of control" situation is detected, the complete calibration curve should be repeated and the span gas reanalyzed.

Nitrogen oxides (NO_x) are presently being detected utilizing the NDIR instrument which is specific for NO. Nitrogen dioxide (NO_2) is not detected by this method. NO in the presence of O_2 will oxidize to NO_2. Consequently, it is important when using this method to minimize the sample transport time by locating the analyzer reasonably close to the engine and using high flow rates. Future standards will most likely be based on the use of a chemiluminescence analyzer using a converter similar to those presently used in light duty testing. This would eliminate the NO - NO_2 conversion problem and the interference from other exhaust components associated with the NDIR method.

7.2.2 Variables Associated with Data Reduction

The determination of emissions from heavy duty gasoline engines is performed by running the engine through a series of cycles

A. $\text{BSHC} = \dfrac{\sum(\text{HC}_{\text{mass}} \text{ x WF})}{(\text{Measured BHP x WF})}$

B. $\text{BSCO} = \dfrac{\sum(\text{CO}_{\text{mass}} \text{ x WF})}{(\text{Measured BHP x WF})}$

C. $\text{BSNO} = \dfrac{\sum(\text{NO}_{\text{x mass}} \text{ x WF})}{(\text{Measured BHP x WF})}$

D. Average the composite BSHC, BSCO, BSNO_x emissions of the first and second cycles.

E. Average the composite BSHC, BSCO, and BSNO_x emissions of the third and fourth cycles.

F. Combine the results of (D) and (E) according to the formula: 0.35 x composite of (D) + 0.65 x composite of (E).

G. Correct the BSNO_x value for the humidity at test conditions by multiplying by conversion factor "K" where:

$K = 0.634 + 0.00654H - 0.0000222H^3$

H = Humidity at test conditions, grain H_2O/lb. dry air.

It is apparent from these formulas that errors in the input data would have a direct effect on the resultant mass emissions. Weighting factors for each mode determine the magnitude of the effect for each mode. Modes having the higher weighting factors would necessarily have the greatest effect on the final numbers.

7.2.3 Computer

Computers, with their built-in checks and reliability, are very useful in reducing test variability. The variety of computers used in mobile source testing ranges from "desk top" to completely automated systems. Although the computer is generally more reliable than manual operations, it is not infallible and should be periodically checked for reliability. One proven method of checking data reduction is the use of a previously prepared, standard set of manually calculated data.

This is fed into the computer and the output is compared with the calculated values. The same set of data could be used in cell-to-cell or laboratory-to-laboratory correlation studies.

7.3 THE ENGINE AS A SOURCE OF VARIABILITY

Heavy duty gasoline engines are themselves sources of variability on a test-to-test basis and during the determination of durability emission data. Emissions are known to change significantly after a break-in period and over the period of 1,000 hours of durability testing. Consequently, deterioration factors are applied to the data submitted to EPA for engine certification.

Engines are affected by ambient conditions and the applied torque of the dynamometers. A reference or correlation engine should be characterized by varying the various operating parameters within the allowable operating ranges. A significant number of tests should be run to characterize the emission profile.

Conditioning and soak time prior to a test are prime sources of test variability. Engine soak time must be specified with ample running time prior to soak to assure equilibrium conditions similar to those encountered in running the engine for 125 hours intervals. The Federal Test Procedure requires the preconditioning of an engine prior to the start of the test. The definition of normal operating conditions is unclear; many engine parameters not normally measured such as oil and transmission temperatures may have a significant effect on emissions. Better definition of this preconditioning procedure would reduce variability and improve correlation between laboratories.

All illustration of the effect of ambient conditions on gasoline engine emissions are presented in Figure 7-1 and Table 7-1. These illustrations were based on the light duty test cycle. However, similar results could be expected with a heavy duty engine-dynamometer test cycle. The engine, as a source of variability is difficult, if not impossible, to control by the average emission test laboratory. Engine variables are the responsibility of the manufacturer, but the testing laboratory must assure that an engine installed in a test cell is set to the correct engine operating specifications in order to achieve a reliable determination of the emissions.

7.4 MEASUREMENT OF VARIABILITY IN THE EMISSION MEASUREMENT SYSTEMS

Variability of the measurement is defined as the inability to achieve identical test results from repeated tests on the same engine without changes to hardware or engine adjustment specifications.

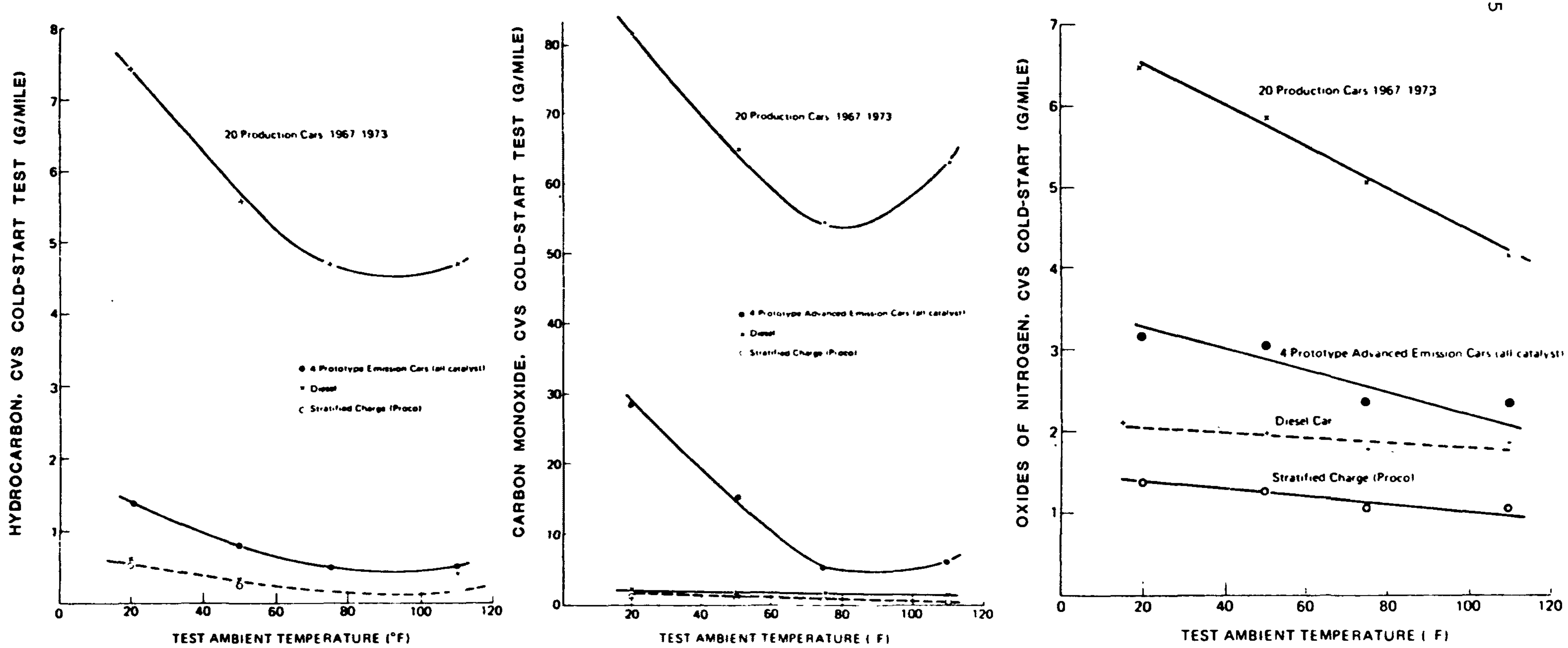

FIGURE 7-1. EFFECT OF AMBIENT TEMPERATURE ON EXHAUST EMISSIONS DURING THE CVS COLD-START TEST

SOURCE: REFERENCE 7-9

Table 7-1. EFFECT OF BAROMETRIC PRESSURE AND HUMIDITY ON EXHAUST EMISSIONS

SOURCE	PERCENT CHANGE HC	CO	NO_x	CO_2	RANGE OF STUDY
One inch Hg increase barometric pressure					
GM environmental chamber data	-10	-30	+5	+2.2	26-30 Hg
Ford data based on[1] multiple regression analysis of three vehicles	-13.6	-21	+12.5	+7.7	28.7-29.51" Hg
50 grains increase in absolute humidity					
GM environmental chamber data	+10	+25	---	-1.5	30-100 grain/ lb dry air

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[1] Data based on FTP-H tests

Source. Reference 7-9 p. 159

Variability exists in test results to varying degrees dependent on the type of variability, test-to-test, cell-to-cell within a laboratory, or laboratory-to-laboratory.

A discussion of the importance of determining variability and its effect on the automobile manufacturers has been presented by Ford (Reference 7-4) and General Motors (Reference 7-5) in their applications for suspension of the 1977 Federal Emission Standards. As the emission requirements become more stringent, the level of variability significance assumes more in affecting the ability to develop and certify emission control systems. Variability factors are affected not only by the vehicle, but also by the test-to-test variability. Determination of the expected variability is important, therefore, to ascertain the actual levels of exhaust emissions for certification of emission control devices. These referenced reports consider both "in house" variability and correlation factors which exist between the manufacturer's laboratory and the EPA laboratory. Variability in emission measurement systems is usually expressed as the coefficient of variation which is defined as the standard deviation (s) divided by the mean of the results, expressed as a percentage (CV = $\frac{S}{\bar{x}}$ (100 percent). Also, variability may be defined for some confidence level; for example, to assess the variability associated with a 90 percent confidence level, 1.96 is used as multiplier in a similar calculation. In other words, as the confidence level is increased, the confidence interval becomes wider. Therefore, in the case of a certification engine, the higher the confidence level selected, the more efficient the emission control system must be in order to obtain the emission values required to be statistically confident that all engines will meet the Federal Emissions Standards.

The Coordinating Research Council has carried out a four-phase cooperative program to evaluate techniques in measuring gaseous emissions in diesel exhaust (Reference 7-12, 7-13).

Each phase involved the measurement of diesel exhaust from a single engine either by circulating the engine among the laboratories or by all participants measuring emissions on the same engine at the same time. Further details of this study are reported in the Phase II Quality Assurance report. To our knowledge, no such data has been published for gasoline engine emission testing laboratories. An important function of quality planning involves studies of the relative contribution of the sources of variability, and interlaboratory correlation programs. Several statistical methods have been designed for performing these studies with a minimum of data. In addition to the statistical methods discussed in Section 6, two other references should be consulted; (1) a recently published "Handbook for Air Pollution Measurement" (Reference 7-10), and) a document prepared by W.J. Youden for the Association of Analytical Chemists (Reference 7-11).

7.5 QUALITY ASSURANCE AND TEST VARIABILITY

Statistical methods for use in controlling test variability have been described extensively in Section 6. Quality assurance has the responsibility for control of test-to-test variability and improving data reliability. Many studies have been completed on methods for reducing test variability. However, further reduction of test variability is impractical in many cases; consequently, quality assurance should advocate the use of procedures such as data validation, calibrations, and maintenance, and assure that these procedures are being complied with. Table 7-2 is a summary of the test variables and the methods used for their control.

Many of the precautions and checks discussed in this section are included in the Test Procedures (Volume II). Each test facility, depending upon its experience and judgment, should carefully review this section to determine if some or all of the additional precautions and checks should be introduced as routine or periodic checks into their operational test procedures.

Table 7-2
Summary of Test
Variables and Methods
Used For Their Control

Method Used To Control Test Variables TEST VARIABLES	CALIBRATION	REF. STANDARDS	DATA VALIDATION	DAILY CHECKS	MONTHLY CHECKS	MAINTENANCE	TRAINING	AUDIT	PRECONDITIONING	CORRELATION	CONTROL CHARTS	RECEIVING INSP.	INSTRUMENT RANGE	ENVIRONMENTAL CONTROL
Engine			X			X	X		X	X		X		X
Dynamometer	X			X	X	X		X						X
Humidity		X	X		X	X		X		X				X
Barometer		X	X		X	X		X		X	X			
Ambient Conditions			X					X						X
Analyzer	X	X	X	X	X	X	X	X		X			X	X
Calibration		X			X					X	X	X		
Zero Gas		X			X			X				X	X	
Working Gas	X		X		X						X			
Operator			X				X	X						
Computer	X						X	X		X				X
Fuel Meter	X		X		X	X				X			X	X
Sampling System			X		X	X	X	X		X	X			X
Recorders	X				X	X		X						X

Section 8

QUALITY ASSURANCE SYSTEM SURVEY

REFER TO PHASE II REPORT

Section 9

REFERENCES

REFERENCES INCLUDED FOR SECTION 7 ONLY
OTHER REFERENCES AS LISTED IN PHASE II DOCUMENT

Appendices, A, B, and C

REFER TO PHASE II REPORT

REFERENCES PHASE IV

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