CHAPTER 8

BIAS AND QUALITY ASSURANCE PROGRAMS

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The ability of a CEM system to provide data representative of "true" emission values depends not only on the design and installation of the system, but also on the adequacy of the CEM system QA program. Although most bias problems will occur during start-up and certification, some problems develop over time. It is the role of the QA program to prevent such problems from developing and to detect them when they do.

8.1 MANAGING BIAS

The goal of the CEM system owner and operator is to maintain optimum performance of the system. This goal can only be achieved by instituting a **working** QA program.

A CEM QA program is required in both 40 CFR 60 Appendix F and 40 CFR 75 Appendix B. These regulations specify that the CEM system owner must develop a QA plan that includes QC procedures for system calibration, preventative maintenance, and system and performance audits. Practically, this means that a QA manual that embodies the plan is to be written. Unfortunately, the QA manual is often viewed as a task that, once completed, can be ignored for the pursuit of more interesting activities. This is not how a CEM program should work. If the CEM system is not routinely inspected, maintained, and audited, the system will degrade, bias will enter into the system, and the data generated will no longer be valid.

Detailed information on developing CEM system QA programs can be found elsewhere (e.g., U.S. EPA, 1977; Jahnke, 1984; Jahnke, 1993; EPRI, 1993). A number of essential points relevant to minimizing bias are summarized here. In the continuing operation of a CEM system, bias can be minimized by following five essential steps:

1. Develop a QA plan that provides for a minimum of three levels of QC:
    a. Calibration and inspection,
    b. Preventive maintenance, and
    c. System and performance audits.
2. Write a QA manual that embodies the plan.
3. Implement the plan.
4. Periodically update the plan and the manual.
5. Record and report.

These five steps can be followed only if the QA program has the support of management, specifically, upper management. QA programs cost money. They take manpower to implement, they take time, and they require resources. These can be provided only if management is willing to provide them, hence the need for management support.

But let us imagine that a QA program has been developed, the manual written, and the QC procedures implemented on a routine basis. These QC procedures will generate a great deal of information, and this information can be used to assess the quality of the data generated by the system. One does not just **do** QC procedures for the sake of doing them, but rather the information obtained is used in the work of the CEM operator. The CEM operator, technician, or auditor is continually looking for evidence of developing biases or system problems.

Fortunately, many useful techniques are available to aid in this search. One of the most powerful is the use of the quality control chart (U.S. EPA, 1976). In this simple technique, daily calibration values are plotted (Figure 8–1).

Control limits are set, which if exceeded, require action. For example, QC limits can be set at 5% for the out-of-control limits for daily calibration error. Most technicians prefer to set lower limits, however, so that action may be taken before the out-of-control limits have been exceeded.

QC charts can be used to detect trends in system performance. A shift in daily calibration drift values may indicate the onset of system bias. A periodic pattern of drift may indicate the effect of nighttime / daytime temperatures on the system. A correlation of control chart data with barometric pressure may indicate that the system is subject to changes of pressure due to incoming weather fronts.

The data obtained from the QC activities are a valuable resource for maintaining data quality. Data should be collected, charted (when applicable), reviewed, and reported. It is useful for more than one person to review the data, since subtle clues to system performance may be more apparent to an independent, unbiased eye, than to one who has been working closely with the system.

Fortunately, CEM system vendors are becoming aware of the utility of incorporating diagnostic routines into the CEM DAHS (White, 1993). QC charts can be generated automatically in such systems, relieving the technician of tediously tracking and entering daily calibration data. In computerized maintenance packages, warnings of equipment malfunction or deterioration can be provided or preventive maintenance schedules can be called up to organize one's program of daily or weekly activities. These features allow for better organization and record keeping and can reduce the hours spent in the CEM system QC activities.

Zero/Span Control Chart

Plant ______________ Analyzer ________________ Operating Range: ppm __________

______________ Serial No. ________________ volts __________

Unit ______________ Zero Gas (I.D.) ________________ Calibration Standard (ID, Conc.) ____

Date																
Initials																
Zero Check Diff.																
Span Gas Conc. (ppm)																
Span Response (ppm)																
Span Check Diff. (%)																
	5.0%															
Span Check Differences (%)	0															
	-5.0%															
	5.0															
Zero Check Differences (ppm)	0															
	-5.0															
Comments (corrective action, etc.)																

Figure 8-1. Example Quality Control Chart.

$$\textit{Span Check Diff.} = \frac{(\textit{Span Response} \ \& \ \textit{Zero Check Diff.}) \ \& \ \textit{Span Gas Conc.}}{\textit{Span}} \times 100$$

$$\textit{Zero Check Diff.} = \textit{Analyzer Response to Zero Air } (ppm) \ \& \ 0 \ ppm$$

8.2 Detecting Bias Through Independent Measurement

Detecting bias in CEM systems requires both independent measurement and common sense. Independent measurements are obtained by applying methods that are not equivalent to those used by the installed CEM system. Various levels of independence are provided by the mandated EPA CEM performance audit procedures. On the other hand, "common sense" is more difficult to define, but it is essential in uncovering and resolving bias problems.

Techniques used to check or audit CEM systems include:

1. Repeating the certification test RATA;

2. Conducting modified relative accuracy tests using manual or automated reference methods;

3. Testing, using portable inspection monitors;

4. Auditing, using independent standards [cylinder gas audits (CGAs), calibration error tests, linearity checks, and opacity monitor zero jig filters]; and

5. Predicting emissions from plant operating parameters.

These techniques are commonly incorporated into CEM system QA plans as performance auditing procedures. Control limits have been established for such audits in both Appendix F of 40 CFR 60 and Appendix B of 40 CFR 75. If these control limits are exceeded, the data may be compromised for regulatory application. For example, for a Part 75 SO_2 monitoring system, if the relative accuracy requirement of 10% is exceeded in an audit, the system is considered to be out-of-control. Or, in a quarterly linearity test, if the error in linearity exceeds 5.0% from a the Protocol 1 gas reference value, the system is also out-of-control. Any data taken from the hour of the completion of the audit is unusable and the Administrator may decertify the system (U.S. EPA, 1993). These audit procedures have been discussed extensively in the literature (see for example, Jahnke, 1993; Plaisance and Peeler, 1987; Reynolds, 1984, 1989).

From a diagnostic viewpoint, the mandated audit methods may be somewhat limited. An ideal audit method should be able to uncover biases in the installed CEM system. In order to do this, the method should provide:

1. An independent means of sampling the flue gas,

2. Analytical techniques different than those used by the CEM system, and

3. Separate sets of certified standards—one for calibrating the CEM system and the other for calibrating the audit method, or for auditing the calibration of the CEM system.

If the CEM system uses a procedure or analytical method, **A**, then the audit method should use a different procedure, **B**, if it is to search for system biases. If the procedures are the same, then the same bias may occur in both the installed CEM and audit systems and the bias will not be detected.

The idea here is for the CEM system to produce data that are representative of the source emissions, i.e., data that are as close as possible to "true" values. Choosing or designing an audit procedure that is similar to that of the installed CEM system may minimize the determination of bias, but may not maximize the determination of truth. In effect, reducing the independence of an audit method to minimize bias may, in fact, mask bias or generate bias. Table 8–1 summarizes the independence of various auditing methods, which are discussed further below.

Table 8–1. Independence of Typical Auditing Methods

	Sampling Method	Analytical Method	Calibration Standard
CEM System	A	A	A
Ideal Audit	B	B	B
RATA - Gases	B	A or B	B
RATA - Flow	A or B	A or B	A or B
Cylinder Gas Audits (Calibration Error, Linearity, CGAs)	A	A	B
Opacity Audit Jigs/Flow-Through Gas Cells	A	A	B
Calculations from Plant Parameters	B	B	B

"A" represents the method used by CEM system.
"B" represents an audit method that is independent of Method A.

8.2.1 RATA for Gases

Sampling Method

The RATA used for certification and subsequent semiannual or annual audits requires the use of either a manual reference method (e.g., Methods 3, 6, and 7) or allows the use of instrumental Reference Methods 3A, 6C, and 7E. Test procedures require that the reference method sample from a minimum of three points, 16.7%, 50.0%, and 83.3% of the distance of a sampling cross-section diameter. The sampling method will therefore be different than that of the CEM system installation, unless the CEM system samples also at these three test points.

In cases of severe gas stratification, sampling at the minimum three points may not be satisfactory for determining all biases. In such instances, a complete Method 1 traverse might be necessary to compare a "truer" reference method determination to the CEM system data.

Analytical Method

EPA does not require in either 40 CFR 60 or 75 that the analytical method used in a RATA be different than the one used for the installed CEM system. Technically, a dilution probe–dilution probe comparison, or a fluorescence monitor–fluorescence monitor comparison is acceptable. Other testing specifications may require that different methods be used (e.g., ISO 7935, 1989). However, as noted in Example 1, depending on the systems, either extractive system biases or analytical biases could be masked in the comparison.

On the other hand, if two different methods are used and the results disagree, the question then arises as to which one is correct. The use of a different method for auditing may in itself introduce bias. For example, if the source tester uses a source-level, dry-basis extractive system to perform Reference Method 6C, the chiller may scrub some of the SO_2 from the sample stream to give a lower result than true. If the sampling system bias measurements fail to correct for the SO_2 loss completely, the CEM system would be considered to be reading high since the reference method results are used as a "reference."

If inconsistent results are obtained between analyzers that employ different monitoring techniques, interfering compounds may be causing the problem. Method 6C does, however, require that the source tester conduct an interference check at a typical source at which the Method 6C analyzer will be used. For SO_2, this check is performed by comparing the instrumental method against a modified form of the manual EPA Reference Method 6. Problems sometimes arise when the source testing firm neglects to conduct this required part of Method 6C.

Problems also occur when the reference method testing is performed incorrectly or sloppily. In such circumstances, the instrumental reference methods are subject to many of the same biases as discussed in this *Guide.*

Calibration Standards

EPA does require that a different set of certified calibration gases (Protocol 1 gases) be used than those used to calibrate the CEM system. The standards used are therefore independent.

8.2.2 RATA - Flow

Sampling Method

In flow monitoring systems, the sampling method may be similar to that used in Reference Method 2 or it may be different. Averaging differential pressure sensing systems may have a sensing port located at each Method 2 traverse point. Thermal sensing systems may also have sensors arrayed at the same reference method points. In these cases, it would be expected that the flow monitoring system would compare well with EPA Reference Method 2

In many systems, however, the flow monitoring points are different. One or two pitot tube sensors or only a few thermal sensors may be used for monitoring the flow. Also, the line averaged measurements made by the ultrasonic sensing systems give equal importance to each point on the measurement line, not to the points of equal area as in the reference method. Nevertheless, these systems can give satisfactory results if the flow is relatively uniform at the cross-section and/or suitable correction factors are introduced.

In practice, the problem of sampling bias is often eliminated through the practice of conducting a pre-RATA or diagnostic test to obtain bias correction factors before certifying the system. Bias may still exist, but more importantly, the validity of the calibration factors depends on their constancy. If they vary over time or do not account for variation of operating conditions, data generated may not be accurate. Such problems would most likely be identified at the time of the semiannual/annual audit. Note that a pre-RATA or diagnostic test should NOT be conducted prior to a mandated semi-annual/annual audit, since readjusting the system prior to audit is neither a technically valid nor an acceptable procedure from a regulatory standpoint.

Analytical Method

The S-type pitot tube is used in EPA Reference Method 2 to measure flue gas velocity. Automated differential pressure sensing systems, being either arrays of pitot tubes connected to a pressure transducer or other averaging devices, utilize the same technique. Although the analytical technique is similar to the reference method, the sensing configurations may be different than those used in the reference method. Thermal sensors and ultrasonic sensors utilize different analytical techniques.

In general, bias introduced by the flow monitoring technique is also calibrated out by conducting the pre-RATA test and correcting subsequent data. Essentially, the cause of any bias, due either to sampling configuration, velocity stratification, sensor angular dependence, etc., is not addressed. The bias is merely accepted and corrected.

Calibration Standards

The S-type or 3-D pitot tubes should be calibrated in a wind tunnel with reference to a standard pitot tube. If the installed flow monitoring system bias is adjusted using data from a pre-RATA test, the flow monitoring system will no longer be independently calibrated. If the same pitot tube used to perform the pre-RATA is used in subsequent RATAs, calibration bias can remain undetected. In such cases, other pitot tubes should be used, or independent test procedures should be designed to check for consistency.

8.2.3 Cylinder Gas Audits (CGAs, Calibration Error, Linearity)

As discussed in Chapter 6, the accepted method of calibrating, or checking the calibration, of a CEM system is to inject calibration gases into the analyzer. For extractive systems, it is required to inject the audit gas at the probe tip, rather than at the analyzer injection port. The intent here is to challenge as much of the CEM system as possible in order to detect both system and analyzer problems. If the calibration gas is injected at the analyzer port, virtually all that is being done is to compare the concentration of the audit gas to the gas used to calibrate the analyzer. However, if the audit gas is injected at the probe tip, system leaks, adsorption effects, and absorption effects might be detected.

Gas audits are limited in what they can reveal about CEM system bias. Because the same CEM sampling system and analyzer are used to determine the value of the audit gas, the auditing method is not completely independent. In fact, once certified, most CEM systems will easily pass a cylinder gas audit. This has been repeatedly reported in the literature (Osborne and Midgett, 1977; Van Gieson and Paley, 1984; Walsh, 1989; von Lehmden and Walsh, 1990).

A CEM technician may, however, wish to extend the mandated gas audit procedures for diagnostic purposes. Some typical examples are:

1. Challenge the CEM system with audit gas both at the probe and at the analyzer port. If the two results do not agree, a problem exists that requires resolution.

2. For dilution systems that use the dilution air as instrument zero air, check the system zero using cylinder zero gas. If the dilution air is contaminated, using an independent source of zero air should uncover the problem.

3. In systems in which the span and / or audit values are considerably higher than the normal range of emissions being measured, use an audit gas corresponding to the average stack gas concentration of the pollutant(s) being measured. Satisfactory results at the lower levels will give increased confidence in the system data.

4. In dilution systems, use permeation tubes or low-level standards to check the ambient gas analyzers independently of the dilution system.

8.2.4 Opacity Audit Jigs/Flow-Through Gas Cells

Methods have been devised for checking the calibration of path in-situ analyzers. Audit jigs, devices that can be placed on the transceiver of a double-pass in-situ monitor, are most commonly used for this purpose (Figure 8–2).

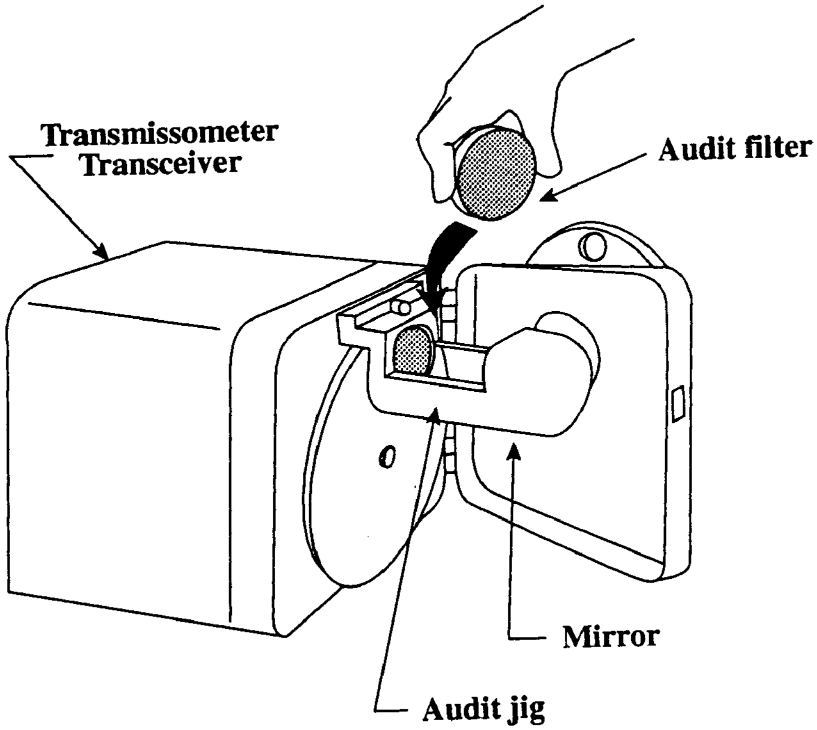

Figure 8–2. A Transmissometer Audit Jig

Transmissometer jigs consist of a slot for holding calibration filters and a short-range retroreflector assembled into a holder that can be attached onto the transceiver. The device and transceiver basically constitute a "mini-transmissometer" that can accommodate audit calibration filters. Certified filters can be placed between this retroreflector and the transceiver head to check the calibration of the instrument over a range of opacities. Detailed guidance for conducting a transmissometer performance audit can be found in Plaisance and Peeler (1987).

Audit gas cells can be used similarly to evaluate instrument performance. The audit gas cell is attached to the transceiver of the double-pass system (Figure 8–3).

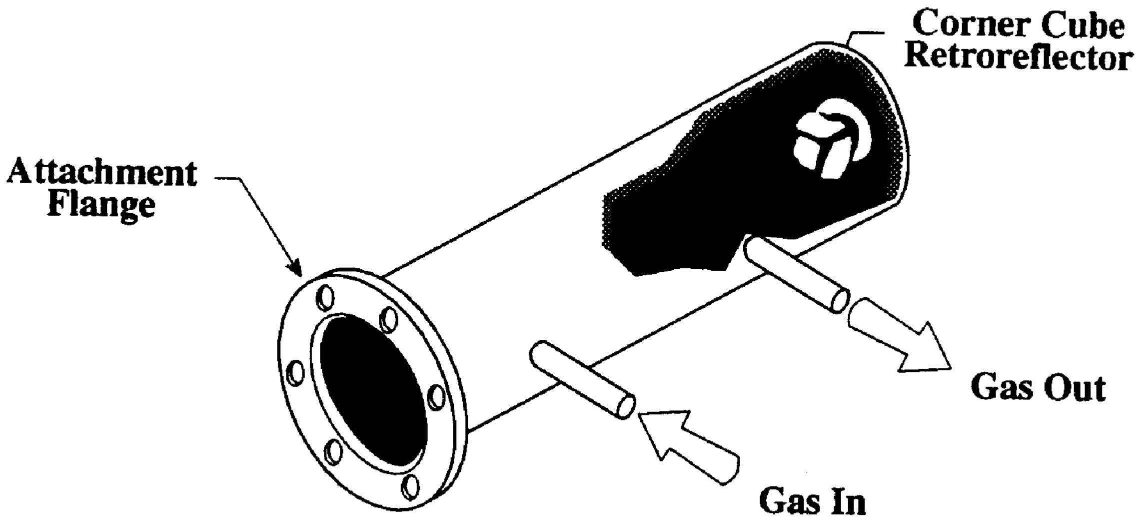

Figure 8–3. Audit Cell for an In-Situ Double Pass Gas Analyzer

As with internal flow-through gas cells (Chapter 4), audit gases, chosen for the appropriate optical depth values, can be used to evaluate the system.

Neither a transmissometer audit jig nor a gas monitor audit cell checks the absolute accuracy of the measurement system. Again, the audit method is not totally independent of the system, because the transceiver of the installed system is actually performing the measurement. Only the measurement standards are independent, as is the case in using audit gases in an extractive gas monitoring system.

There are many other factors involved in cross-stack measurement, such as system alignment and the viability of the cross-stack zero, that cannot be checked using audit jigs or gas cell audit checks. The use of audit jigs may, however, point out problems that affect the measurements, such as optical or electrical problems of the transceiver. One of the most common problems found through the use of transmissometer audit jigs is the incorrect determination of stack exit correlation factors. These factors are used to correct the in-stack opacity measurement to the stack exit values. The necessity for the auditor to calculate correction factors for the audit filters frequently reveals errors in the original determinations for these values.

8.2.5 Calculations from Plant Parameters

A diagnostic tool that should not be ignored is the calculation of emissions values from plant operating parameters. Using information such as fuel sulfur content, fuel feed rate, fan speed, etc., emissions can be at least grossly estimated without conducting an emissions measurement. These estimates can then provide a first-cut consistency check for the instrumented data.

The advantage of this technique is that it is completely independent of the monitoring system and can point out potential CEM system problems that might otherwise have been masked by the non-independent features of other audit methods. The problem with determining emissions from plant parameters is that many assumptions are necessary in the determination or a complex model must be developed to characterize the emissions. The assumptions used must then be valid and the calculations, or the model, must remain valid under varying operating conditions. Another limitation of this approach is that the values of the input parameters may not be precisely known, e.g., the coal sample is often not representative of the actual fuel fired or the laboratory-determined sulfur content of the fuel is imprecise.

Furthermore, the calculated values are only estimates, not direct measurements. Rarely are these estimates and their underlying models rigorously validated to provide a high degree of confidence in their accuracy.

Nevertheless, important generic information on CEM system performance can be obtained by modelling or calculating emissions. If the results do not agree with the measured emissions, the problem may rest either with the calculation or with the CEM system. Although the results may be equivocal, the resolution of the problem may lead to greater insight into the CEM system and plant operations.

8.3 DETECTING BIAS BY USING COMMON SENSE

From a less technical standpoint, it should be understood from the above discussions, that there is no one way that CEM system bias can be determined. Mandated methods provide the impetus for performing certain audit checks, but these checks do not examine all the possibilities where bias might occur.

Obtaining accurate, precise, and unbiased data requires both common sense and intellectual honesty. The goal is not to obtain the lowest possible values for the relative accuracy or the bias correction factor, but rather to obtain the **true value**. Because the true value is usually never known, one must check and cross-check both the CEM equipment and data to gain confidence that bias has been eliminated.

The process of checking and cross-checking is the work of a detective; one must look for clues and leads that may indicate a system problem. It is necessary to maintain objectivity: accepting a result not just because it agrees with one's preconceptions, but because it makes "sense." Rounding off numbers in one's favor, modifying audit methods to give a better result, or selectively reporting data are counter-productive exercises when attempting to uncover bias. Common sense and objectivity must be exercised in both monitoring and auditing in order to build an overall confidence in the monitoring data. Often, it is only over a period of time that the necessary experience is gained before this is understood.

8.4 REFERENCES

Electric Power Research Institute (EPRI). 1993. Continuous Emission Monitoring Guidelines: 1993 Update. Volumes 1 and 2. TR-102386-V1, V2. Palo Alto, CA.

International Standards Organization (ISO). 1989. Stationary Source Emissions - Determination of the Mass Concentration of Sulfur Dioxide - Performance Characteristics of Automated Measuring Methods. ISO Standard 7935. Central Secretariat, Geneva, Switzerland.

Jahnke, J.A. 1984. APTI Course SI:476A, Transmissometer Systems - Operation and Maintenance, An Advanced Course. EPA 450/2-84-004.

Jahnke, J.A. 1993. Continuous Emission Monitoring. Van Nostrand Reinhold. NY.

Osborne, M.C., and Midgett, M.R. 1977. Survey of Continuous Source Emission Monitors: Survey No. 1 NO_x and SO_2. EPA-600/4-77-022.

Plaisance, S.J., and Peeler, J.W. 1987. Technical Assistance Document: Performance Audit Procedures for Opacity Monitors. EPA-600/8-87-025.

Reynolds, W.E. 1984. Development and Evaluation of SO_2 CEM QA Procedures. Quality Assurance in Air Pollution Measurements. Air Poll. Control Assoc./American Soc. for Quality Control. Pittsburgh. pp. 752-760.

Reynolds, W.E. 1989. Field Inspector's Audit Techniques: Gas CEMS's Which Accept Calibration Gases. EPA 340/1-89-003.

U.S. Environmental Protection Agency. 1976 (1/9/84 update). Quality Assurance Handbook for Air Pollution Measurement Systems, Volume I --- Principles. EPA 600/9-76-005.

U.S. Environmental Protection Agency. 1993. Acid Rain Program: Continuous Emission Monitoring. U.S. Code of Federal Regulations - Protection of the Environment. 40 CFR 75. U.S. Government Printing Office.

Van Gieson, J., and Paley, L.R. 1984. Summary of Opacity and Gas CEMS Audit Programs. EPA 340/1-84-016.

von Lehmden, D.J., and Walsh, G.W. 1990. Appendix F DARs for CEMS at Subpart D Facilities. Proceedings - Specialty Conference on: Continuous Emission Monitoring - Present and Future Applications. Air & Waste Mgmt. Assoc., pp. 103-125.

Walsh, G. 1989. Data Assessment Reports for CEMS at Subpart Da Facilities. EPA 600/3-89-027.

White, J.R. 1993. Minimizing Routine Manual Checking with Computerized Maintenance for Continuous Emission Monitoring Systems. Paper presented at the Air & Waste Mgmt. Assoc. Meeting. Denver: Paper 93-FA-164.04.

8.5 ADDITIONAL READING

Butler, A.T., and Willenberg, J.M. 1990. A Method for Quick Validation of Continuous Emission Monitoring Systems. Proceedings - Specialty Conference on: Continuous Emission Monitoring - Present and Future Applications. Air & Waste Mgmt. Assoc., pp. 350-359.

Chapman, J. 1990. Examination of a Transportable Continuous Emission Monitoring System. Proceedings - Specialty Conference on: Continuous Emission Monitoring - Present and Future Applications. Air & Waste Mgmt. Assoc., pp. 327-337.

Cohen, J.B., and Ross, R.C. 1989. Use of Precalibrated Optical Density Filters in the In-situ Calibration of Opacity Monitors. Air Poll. Control Assoc. Meeting Paper. Montreal: 80-42.4.

Logan, T.J., and Rollins, R. 1984. Quality Assurance for Compliance Continuous Emission Monitoring Systems: Evaluation of Span Drift for Gas CEMS. Quality Assurance in Air Pollution Measurements. Air Poll. Control Assoc. / American Soc. for Quality Control Specialty Conference Proceedings. Pittsburgh.

Noland, S., and Reynolds, W.E. 1990. Design and Operation of a Transportable Emission Monitoring System Utilizing Dilution Probe Technology. Proceedings - Specialty Conference on: Continuous Emission Monitoring - Present and Future Applications. Air & Waste Mgmt. Assoc., pp. 136-147.

Peeler, J.W., and Deaton, G.D. 1981. Field Testing of a Transportable Extractive Monitoring System for SO_2, NO / NO_x, CO and CO_2. Proceedings - Continuous Emission Monitoring: Design, Operation and Experience. Air Poll. Control Assoc., pp. 176-186.

U.S. Environmental Protection Agency. 1977. Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III --- Stationary Source Specific Methods. EPA 600 / 4-77-027b.

U.S. Environmental Protection Agency. 1977 (6 / 15 / 78 update). Traceability Protocol for Establishing True Concentration of Gases used for Calibration and Audits of Continuous Source Emission Monitors (Protocol No. 1). Section 3.0.4. Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III --- Stationary Source Specific Methods. EPA 600 / 4-77-027b.

U.S. Environmental Protection Agency. 1977 (6 / 1 / 86 update). Continuous Emission Monitoring (CEM) Systems Good Operating Practices. Section 3.0.9. Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III --- Stationary Source Specific Methods. EPA 600 / 4-77-027b.

U.S. Environmental Protection Agency. 1977 (6 / 9 / 87 update). Procedure for NBS -Traceable Certification of Compressed Gas Working Standards Used for Calibration and Audit of Continuous Source Emission Monitors (Revised Traceability Protocol No. 1). Section 3.0.4. Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III --- Stationary Source Specific Methods. EPA 600 / 4-77-027b.

U.S. Environmental Protection Agency. 1993. Performance Specifications. Code of Federal Regulations - Protection of the Environment. 40 CFR 60 Appendix B.

U.S. Environmental Protection Agency. 1993. Quality Assurance Procedures. Code of Federal Regulations - Protection of the Environment. 40 CFR 60 Appendix F.

U.S. Environmental Protection Agency. 1993. Reference Methods. Code of Federal Regulations - Protection of the Environment. 40 CFR 60 Appendix A.