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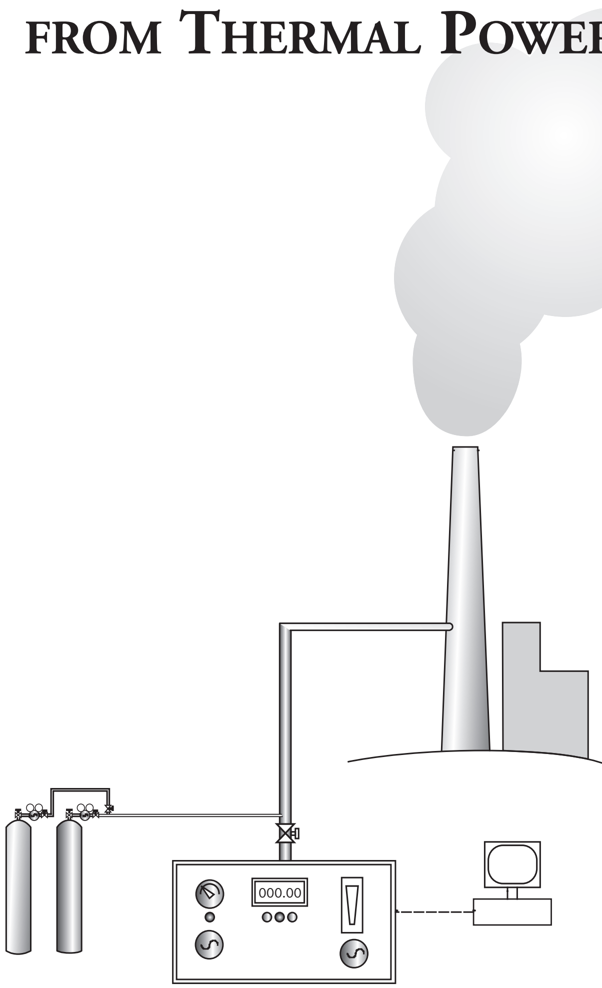

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ABSTRACT

This report outlines specifications for the design, installation, certification, and operation of automated continuous emission monitoring (CEM) systems used to measure gaseous releases of sulphur dioxide and nitrogen oxides from thermal power generation. The procedures used during certification testing of each installed CEM system are also presented. This report also describes quality assurance and quality control (QA/QC) procedures, including the contents of a site-specific QA/QC manual, which must be developed by the system operator for each installed CEM system.

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SECTION 1.0 INTRODUCTION

This report provides specifications for the design, installation, and operation of automated continuous emission monitoring (CEM) systems used to measure releases of sulphur dioxide (SO_2) and nitrogen oxides (NO_X) from thermal power generating facilities. The procedures used to determine the various CEM system parameters during initial certification testing and subsequent long-term operation of the monitoring system are presented.

No specific monitoring system has been designated in this report. Any system that meets initial certification criteria, specified parameters and quality assurance/quality control (QA/QC) requirements is acceptable. In situ or extractive CEM systems based on dynamic dilution technology or direct measurement of the target species may be used. Time-shared CEM systems using a single set of analyzers to determine emission rates for several sources are acceptable.

Guidance has been provided to assist the operator in developing a site-specific QA/QC plan, in conjunction with the appropriate regulatory agency. The resulting plan forms an integral part of the overall requirements for the operation of each CEM system.

This report provides guidance for the acquisition of technically valid CEM data, which may be used for multiple purposes, including emission budget programs. It does not, however, address issues specific to any emission trading program, such as reporting formats, seasonal averaging, data retention requirements, etc., which should be compatible with the policies of the program and defined by the corresponding regulating authority.

While SO_2 and NO_X are the pollutants most often associated with the flue gases released from thermal power generating facilities, some or all of the concepts and procedures described herein could also be used, as appropriate, for the measurement and monitoring of SO_2 and NO_X in other streams or for the measurement of other species, regardless of their origin. In such cases, the appropriate regulatory authority that mandates the monitoring conditions may adjust, expand, or reduce the requirements detailed in this document in order to reflect the specific concerns and/or constraints related to the need to measure and monitor the particular species in question.

The personnel performing the initial certification and subsequent audits must be trained and experienced.

The application of this method will entail health and safety hazards. Individuals performing the certification and audits are responsible for obtaining the required training to meet occupational health and safety standards.

SECTION 2.0 SUMMARY OF SPECIFICATIONS AND PROTOCOLS

The specifications that must be met and the procedures that must be followed for the installation, certification, and continued operation of a CEM system are summarized in Figure 1. This summary is intended to help the operator to plan and carry out the numerous tasks involved in installing and operating the monitoring system and to continue to generate accurate long-term emissions data.

Section 3 outlines the specifications for the overall CEM system and subsystems, along with associated procedures for measuring these parameters. This section will assist the operator during the initial design and/or purchase stages. Specific requirements are provided for the data acquisition system, including emission reporting requirements.

Specifications for installing the CEM system are given in Section 4. These are used to ensure that a test location meets some minimal requirements with respect to the representativeness of the gas flow and the accessibility of the equipment for maintenance.

After installation, the CEM system is tested following the protocols provided in Section 5. The emissions data are compared with those from manual reference methods or acceptable automated measurement techniques to ensure that the specifications have been met. When an installed system has met or surpassed all these specifications, it is deemed to be certified and capable of generating quality-assured emissions data.

A QA/QC plan must be developed for each CEM system by the operator. Section 6 provides the basis for the development of this plan. The QA/QC plan must encompass a diverse range of topics, including calibration procedures, maintenance, performance evaluations, and corrective actions. Each CEM system will require a QA/QC plan; however, if a number of identical CEM systems are operated, a single QA/QC plan is acceptable, provided that appropriate records are maintained for each CEM system.

Figure 1 Summary of Specifications and Protocols for Continuous Emission Monitoring Systems

CEM System Specifications and Protocols

Sections 3 and 4 Design and Installation Information

Section 3 Design Specifications and Test Procedures

3.1 Interface/Conditioning
- Location of Calibration Port

3.2 Gas Analyzer
- Operating Range
- Interference
- Temperature-Response Drift

3.3 Flow Monitor
- Operating Range

3.4 Data Acquisition
- Averaging Time
- Reporting Basis
- Backfilling of Missing Data

3.5 Overall System
- Cycle Time

3.6 Test Procedures
- Interference Rejection
- Temperature-Response Drift
- System Cycle Time
- Manufacturer's Certificate of Conformance

Section 4 Installation Specifications

4.1 Site Location

4.2 Representativeness
- Stratification Test

Section 5 Certification of the System

5.1 Performance Specifications
- Operational Test Period
- Calibration Drift
- Electronic Drift
- System Response Time
- Relative Accuracy
- Bias
- Orientation Sensitivity

5.2 Calibration Gases

5.3 Test Procedures
- Operational Test Period
- Calibration Drift
- System Response Time
- Relative Accuracy
- Bias
- Orientation Sensitivity

Section 6 Quality Assurance and Quality Control

6.1 QA/QC Manual
- QA Activities
- QC Activities

6.2 Daily Performance Evaluations
- Calibration Drift
- Electronic Drift

6.3 Quarterly Performance Evaluations
- Cylinder Gas Test
- Stack Gas Flow Test
- F-Factor System Test

6.4 Semiannual Performance Evaluations
- Relative Accuracy and Bias
- Exemptions

6.5 Annual Performance Evaluations
- Availability
- Independent Inspection

6.6 Acceptance Criteria

6.7 Reporting Requirements

SECTION 3.0 DESIGN SPECIFICATIONS AND TEST PROCEDURES

A CEM system consists of the following three subsystems:

- sample interface/conditioning;
- gas analyzers; and
- data acquisition.

A flow monitor may also be part of the CEM system. When utilizing a flow monitor, if the pollutant concentration is measured on a dry basis whereas the flow rate is measured on a wet basis, a continuous moisture monitoring system for measuring and recording the moisture of the stack gases may be required. Further details on the use of stack gas moisture monitoring systems are presented in Appendix B.

Specifications for these subsystems are given in Sections 3.1 to 3.5, while Section 3.6 outlines the procedures for determining the value of the parameters, where applicable. The parameters and specifications for these subsystems are shown in Table 1.

This protocol does not specify measurement techniques. Components that meet the criteria specified in Sections 3.1 to 3.5 and that allow the overall CEM system to achieve the certification specifications in Section 5 and the performance evaluations in Section 6 are acceptable.

3.1 Sample Interface/Conditioning Subsystem Specifications

3.1.1 Location of the Calibration Gas Injection Port

The location of the system calibration gas injection port is the sole criterion for the sample interface/conditioning subsystem, with the location of this port being specific to the type of CEM system. The location of the ports for the various types of CEM systems is given in Table 2.

3.2 Gas Analyzer Subsystem Specifications

3.2.1 Operating Range

The chosen range of the analyzer must encompass all anticipated concentrations for the gas flow being monitored. The average monthly concentration for each analyzed gas should fall between 40% and 75% of the chosen range. If the average monthly concentration of any pollutant or diluent gas for each specific chosen range falls outside these limits, the analyzer should be adjusted such that the average is brought back within these limits.

Note that numerous performance specifications are defined with reference to the full-scale (FS) setting of the CEM analyzers (see Table 1, Table 3 in Section 5, and Table 6 in Section 6). The gas analyzer of a CEM system may be able to measure levels higher than the defined FS level; however, this higher level cannot be applied to demonstrate conformance to the performance specifications, which are tailored to the characteristics of the emission source.

If concentrations vary widely, the use of multirange analyzers is strongly recommended. The highest range should include the maximum potential concentration anticipated for the process. Note that data that fall outside the range(s) of an analyzer are considered as missing and must be backfilled using the criteria given in Section 3.4.3.

3.2.2 Interference

Each analyzer must exhibit a response of less than 4.0% of FS for the sum of all interferences due to other gas constituents, as measured by the procedures given in Section 3.6.1.

3.2.3 Temperature-Response Drifts

Each pollutant or diluent gas analyzer used in the system must exhibit a zero drift less than 2.0% of the FS setting for any 10°C change over the temperature range of 5–35°C. Additionally, each analyzer must exhibit a span drift of less than

Table 1 Design Specifications for Continuous Emission Monitoring Systems

Subsystem	Parameter	Specification	Text references: Specification	Text references: Test procedures
Sample interface and conditioning	Location of calibration ports	See Table 2	3.1.1	–
Gas analyzers	Operating range	Average monthly concentration between 40% and 75% of full scale (FS)	3.2.1	–
	Interference	<4.0% FS for the sum of all interferences	3.2.2	3.6.1
	Temperature-response drifts	Zero drift <2.0% FS for 10°C change (5–35°C)	3.2.3	3.6.2
		Span drift <4.0% FS for 10°C change (5–35°C)	3.2.3	3.6.2
Flow monitor	Operating range	Maximum potential flow rate equal to 100% FS	3.3.1	–
Data acquisition	Averaging time	1 hour	3.4.1	–
	Reporting basis	720-hour rolling average, as kg/MWh net energy output or as required by appropriate regulatory authority	3.4.2	–
	Missing data	≤168 hours – backfill >168 hours – alternate CEM system	3.4.3	–
Overall system	System cycle time*	≤15 minutes for complete cycle (15/n minutes for any one stream in an n-stream system)	3.5.1	3.6.3

* This design specification applies only to the time-shared systems.

4.0% of the FS setting for any 10°C change in temperature from 5 to 35°C. Both the zero and span drift tests are to be carried out within the acceptable temperature operating range of the analyzer, as specified by the manufacturer. The procedures outlined in Section 3.6.2 must be followed to determine the temperature-response drift.

Analyzers installed and operated in a temperature-controlled environment are exempt from this specification.

3.3 Flow Monitor Subsystem Specifications

The gas flow monitor should have the capability of carrying out daily checks at low and high flow rates as part of the daily system calibration procedures. Electronic simulation of low and high flow may be adequate in some systems, providing that daily zero and span drift can be calculated. The sensor must cover the full range of gas velocities anticipated in the flue or duct. Any flows beyond the range of the sensor are deemed to be missing and must be backfilled, as described in Section 3.4.3 of this report.

Table 2 Location of System Calibration Gas Injection Ports for Specific Continuous Emission Monitoring Systems

System Type	Subsystem	Specification for location of system calibration gas injection port
Extractive	Direct measurement of gas concentrations	Calibration gas must be introduced no further than the probe exit.
	Dilution (in-stack and external)	Calibration gas must be introduced prior to dilution.
In situ	Point	Calibration gas must flood the measurement cavity of the analyzer.
	Path	Calibration gas must provide a check on the internal optics and all electronic circuitry. System may also include an internal calibration device for simulating a zero and an upscale calibration value.

3.3.1 Operating Range

The FS setting should be approximately 100% of the maximum potential flow rate.

Note that various performance specifications are defined with reference to the FS setting of the CEM flow monitor (see Table 1 above, Table 3 in Section 5, and Table 6 in Section 6). The flow monitor of a CEM system may be able to measure levels higher than the defined FS level; however, this higher level cannot be applied to demonstrate conformance to the performance specifications, which are tailored to the characteristics of the emission source.

If flow varies widely, the use of multirange flow monitors may be advisable for a stack serving several units. The highest range should include the maximum potential flow anticipated for the process. Note that data that fall outside the range(s) of a flow monitor are considered as missing and must be backfilled using the criteria given in Section 3.4.3.

3.4 Data Acquisition Subsystem Specifications

The CEM system must include a microprocessor-based data acquisition subsystem that accepts the outputs of the pollutant and diluent gas analyzers and other associated equipment and converts these to emission rates of the pollutant gases in units of the standard. The system must maintain a record of all parameters in a format and time frame acceptable to the appropriate regulatory authority. The system must also record and compute daily zero and calibration drifts, provide for backfilling of missing data, and record any other relevant data that the operator may wish to include.

3.4.1 Averaging Time

Data must be reduced to 1-hour averages for the pollutant and diluent gases and other measured parameters. The 1-hour averages must be used to compute the SO_2 and NO_X — as nitrogen dioxide (NO_2) — emissions, expressed in units of the standard. A variety of methods for calculating emissions are provided in Appendix B.

For time-shared systems, 1-hour averages must be computed from four or more values, equally spaced over each 1-hour period, with the exception of periods during which calibrations, QA activities, maintenance, or repairs are being carried out. During these specific activities, a valid hour must consist of a minimum of two data points for a time-shared system or 30 minutes of data for a CEM system using dedicated analyzers. The calibrations should be conducted in a manner that avoids the loss of a valid hour of emissions data every time that a daily calibration is conducted. This may be achieved by using mixtures of several pollutant/diluent gases; by scheduling the calibration periods so that the emissions data loss is shared by two consecutive hours; or by scheduling the calibration of different analyzers at different hours of the day.

3.4.2 Reporting Basis

Data must be prepared on a quarterly basis and must be expressed as 720-hour rolling averages as kg/MWh net energy output or in any units and averaging periods required by the appropriate regulatory authority. The data must be available in both digital and analog form, with the analog form presented as a trend plot in units of the standard versus time over the reporting period.

3.4.3 Backfilling of Missing Data

Emissions data that are missing due to a malfunction of the CEM system (eg. gas analyzer, flow monitor) may be substituted for a period of up to 168 hours for any single episode using data derived from emissions versus load data and fuel sulphur content correlations that have previously been determined by the certified, quality-assured CEM system. When a CEM system is installed to monitor emissions at the discharge of flue gas control equipment, missing data must be substituted by deriving data from emissions versus operating parameter correlations (e.g., average sulphur content of the fuel, the power load of the unit, or other appropriate parameters). The backfilling technique must be fully described in the QA/QC manual developed for each CEM system and approved by the appropriate regulatory authority.

When a CEM system (eg. gas analyzer, flow monitor) malfunction extends beyond 168 hours for any single episode, data must be generated by another certified CEM system or valid reference method. Other CEM systems used for this purpose must meet all design and performance specifications given in this report. When using another system, the stack gas sample must be extracted from the sample port(s) used for the reference method during certification of the CEM system.

Data that are backfilled using a procedure other than a certified alternate CEM system or reference method cannot be credited towards meeting the CEM system availability criteria specified in Table 3 (in Section 5).

All emissions data should be quality audited to identify suspected data using procedures described in the QA/QC plan (Section 6.1). The procedures may include automatic flagging of a) out-of-range concentrations and flows, b) abnormal system calibration response time, c) abnormal heat rate levels (for systems fitted with fuel flow monitors), d) abnormal flow-to-input or flow-to-output levels (for systems fitted with stack gas flow monitors), and e) abnormal concentrations during periods when the generating unit did not burn fuel.

The QA-flagged data must be investigated and either accepted or backfilled. The QA-flagged data should be identified in the quarterly report, along with a summary of reasons for acceptance or backfilling.

3.5 Overall System Specifications

3.5.1 Cycle Time — Time-Shared Systems

The specification for cycle time applies to time-shared systems measuring emissions from a number of sources using a single set of pollutant and diluent gas analyzers. One complete measurement cycle of all streams must be completed in 15 minutes or less, generating a minimum of four sets of concentration and emissions data for each hour of operation. For a CEM system measuring the emissions from "n" stacks, the maximum time available for each source being monitored would be 15/n minutes, including switching, stabilization, and analyzer output integration times.

3.6 Test Procedures for Verification of Design Specifications

3.6.1 Analyzer Interference

This test may be carried out after the analyzers have been installed in the CEM system or in a laboratory or other suitable location before the analyzers are installed. Sufficient time must be allowed for the analyzer under test to warm up, and then the analyzer must be calibrated by introducing appropriate low- and high-level gases directly to the analyzer sample inlet. After the initial calibration, test gases must be introduced, each consisting of a single interfering gas at a concentration representative of that species in the gas flow to be monitored. The magnitude of the interference of each potential interfering species on the target gas must then be determined.

The analyzer is acceptable if the combined response of all interfering gases is less than 4.0% of the FS setting.

3.6.2 Analyzer Temperature-Response Zero and Span Drifts

The analyzer must be placed in a climate-controlled chamber in which the temperature can be varied from 5 to 35°C. Sufficient time must be allowed for the analyzer to warm up, and then the analyzer must be calibrated at 25°C using appropriate zero and span gases. The temperature of the chamber must be adjusted to 35, 15 and 5°C. It should be ensured that the analyzer temperature has stabilized. The power to the analyzer must not be turned off over the duration of this test.

When the analyzer has stabilized at each climate chamber temperature, each of the calibration gases must be introduced at the same flow or pressure conditions, and the response of the analyzer must be noted.

The temperature-response zero drift is calculated from the difference between the indicated zero reading and the reading at the next higher or lower temperature. The analyzer is acceptable if the difference between all adjacent (i.e., 5/15, 15/25, and 25/35°C) zero responses is less than 2.0% of the FS setting.

The temperature-response span drift is calculated from the differences between adjacent span responses. The analyzer is acceptable if the difference between all adjacent span responses is less than 4.0% of the FS setting.

3.6.3 System Cycle Time

The system cycle time is set by the manufacturer during design and must meet the specification given in Section 3.5.1.

3.6.4 Manufacturer's Certificate of Conformance

It may be considered that specifications for both interference and temperature-response drifts have been met if the analyzer manufacturer certifies that an identical, randomly selected analyzer, manufactured in the same quarter as the delivered unit, was tested according to the procedures given in Sections 3.6.1 and 3.6.2, and the parameters were found to meet the specifications.

SECTION 4.0 INSTALLATION SPECIFICATIONS

This section contains guidance for selecting a suitable sampling site on the flue or duct and determining the representativeness of the desired location with respect to the homogeneity of the gas flow.

4.1 Location of Sampling Site

The probe or in situ analyzer must be installed in a location that is accessible at all times and during any weather conditions, so that routine maintenance can be performed on schedule, as outlined in the QA/QC manual. Sufficient shelter should be provided on outdoor installations so that maintenance can be safely performed during any weather conditions without detriment to either the CEM system or service personnel. The degree of exposure, seasonal weather conditions, servicing and maintenance, susceptibility to lightning strikes, and vibration of the duct and/or platform are some of the considerations when siting a probe or in situ analyzer.

Before a flow rate sensor is permanently installed, it should be ensured that cyclonic flow is not present at the desired sampling location. The presence of a cyclonic flow pattern will add considerable complexity to both certification and operation of the installed sensor. It is recommended that an alternate location be found if cyclonic flow patterns are verified at a proposed site. The protocols given in this report relate only to sources for which the gas flow pattern has been demonstrated to be non-cyclonic.

4.2 Representativeness

The probe or in situ analyzer must be installed in a location where the flue gases are well mixed. The degree of turbulence and mixing time are major factors that influence the extent of stratification of the flue gases.

The extent of stratification of the flue gases at any location must be determined using the applicable test methods. It is therefore highly recommended that the procedures outlined in Section 4.2.1 be carried out at a proposed analyzer installation site to determine the extent of stratification before installing the CEM system. If significant gas stratification of any of the measured species is present at the proposed location, then serious consideration should be given to relocating the system to another location where the flow has been determined to be non-stratified.

If stack flow monitoring is a component of the CEM system, then it is highly recommended that the adequacy of the sampling site be assessed with respect to the selected flow monitoring system as well as to the reference method to be used for the initial certification and for the annual or semiannual evaluations.

Before the flow monitor is installed, a number of velocity traverses must be carried out at the proposed sensor installation location over a range of loads using the equipment and procedures found in Method B of Reference Method EPS 1/RM/8 (Reference Methods for Source Testing: Measurement of Releases of Particulate from Stationary Sources, Environment Canada, December 1993, as amended). The degree of cyclonic flow is determined using the procedures found in Method A of Reference Method EPS 1/RM/8. These measurements will provide a basis for the location of the sensor and will also demonstrate the absence of cyclonic flow (average rotational angle ≥15 degrees). The location of sampling ports must be selected so as to avoid interference between the flow monitor, the concentration measurement point(s) or path, and the RM probes.

If a single-point velocity sensor is being installed, the sensing tip must be located at a point yielding velocity measurements within the specifications over the full range of loads. The velocity profile data must be used to select the optimum measurement point.

4.2.1 Stratification Test Procedure

A minimum of nine sampling points must be used in the stack or duct, applying the procedures for selecting sampling points found in Reference Method EPS 1/RM/8. Using two automated systems with similar response characteristics, the concentration of a target gas must be measured at each of the sampling points in the matrix with one system (traversing system), while simultaneously measuring the target gas concentration at a fixed or reference location, usually at the centre of the flue or duct.

Note that a stratification test must be carried out for each gaseous species measured by the installed CEM system, including the diluent gas(es).

The concentration of the gas measured at the fixed location (stability reference measurement) in the flue/duct is used as an indicator of the stability of the gas flow. If this concentration varies by more than ±10% of the average concentration for longer than 1 minute during this test, the stratification test must be carried out when more stable conditions prevail.

Note that the installed analyzer in the CEM system, which withdraws a sample from a fixed point, may be used as the stability reference measurement for the stratification test. The response characteristics of the reference and the traversing analyzers should be similar.

The concentration of a target gas must be measured at each of the sampling points in the matrix. At the conclusion of the traverses, the measurement of the concentration must be repeated at the initial measurement point. If the concentrations differ by more than ±10% for the pre- and post-test values at this point, stratification must be retested when more stable conditions prevail.

The degree of stratification for each species is calculated at each traverse point within the gas flow using Equation 1.

$$ST_i = \left[\frac{(C_i - C_{avg})}{C_{avg}}\right] x100 \qquad \textbf{Equation 1}$$

where:
ST_i = stratification (%)
C_i = concentration of the measured species at point i
C_{avg} = average of all measured concentrations

The flow in the stack or duct is considered to be stratified if any calculated value using Equation 1 exceeds 10%.

Section 5.0 Certification Performance Specifications and Test Procedures

To achieve certification, an installed CEM system must meet all of the performance specifications outlined in Table 3. The specifications are relevant to each pollutant and diluent gas measured, as well as the stack gas flow measurement (if applicable) and the overall CEM system. A system may be partially certified — for example, for SO_2 or NO_X — and then fully certified at a later date when deficiencies in specific portions of the system have been corrected.

The specifications are described in Section 5.1. The gases used during certification testing are described in Section 5.2, while the applicable test procedures are outlined in Section 5.3.

5.1 Certification Performance Specifications

It is recommended that after the CEM system has been installed according to the manufacturer's written instructions, the entire CEM system should be operated for a conditioning period of not less than 168 hours, prior to the operational test period (OTP), during which the emission source should be operating. During the conditioning period, the entire CEM system should operate normally — that is, analyzing the concentration of the pollutant and diluent gases — with the exception of periods during which calibration procedures are being carried out as well as other procedures indicated in the QA/QC manual.

5.1.1 Operational Test Period

The OTP is a 168-hour cumulative time period during which most of the performance specification tests are carried out. The 168-hour period may be contiguous or fragmented in periods of no less than 24 hours. No unscheduled maintenance, repairs, or adjustments to the CEM system are allowed during the OTP. The procedures in the QA/QC manual must be followed as if the CEM system were generating emissions data.

CEM systems installed at peaking stations are exempted from the OTP and calibration drift tests.

5.1.2 Calibration Drift

The calibration drift specification is applicable at the three concentration ranges indicated in Table 3 and is applicable to each pollutant and diluent gas analyzer. Table 3 also includes flow monitoring calibration drift specifications.

For the gas analyzers, this procedure tests both linearity and calibration drift.

At 24-hour intervals over the 168-hour OTP, the CEM system response to the pollutant or diluent calibration gases, as indicated by the data acquisition system, must not deviate from the certified value of the appropriate gas by an amount exceeding the greater of:

Pollutant gas analyzer

Low level:	2.0% of the FS setting or 2.5 ppm, absolute difference
Mid level:	2.0% of the FS setting or 2.5 ppm, absolute difference
High level:	2.5% of the FS setting or 2.5 ppm, absolute difference

Diluent gas analyzer

Low level:	0.5% O_2 (or CO_2)
Mid level:	0.5% O_2 (or CO_2)
High level:	0.5% O_2 (or CO_2)

At 24-hour intervals over the 168-hour OTP, the CEM system response to the stack gas flow (and stack gas moisture, if applicable), as indicated by the data acquisition system, must not deviate from a concurrent RM measurement by an amount exceeding the greater of:

Flow monitor

Low level:	3.0% of the FS setting or 0.6 m/s, absolute difference
Mid level:	3.0% of the FS setting or 0.6 m/s, absolute difference

Table 3 Certification Performance Specifications

Parameter	Component	Level	Specification	References	
				Specifications	Test procedures
24-hour calibration drift	SO_2/NO_X gas analyzer	 Low level (0–20% FS) Mid level (40–60% FS) High level (80–100% FS)	≤ the greater of 2.0% FS or 2.5 ppm absolute difference 2.0% FS or 2.5 ppm absolute difference 2.5% FS or 2.5 ppm absolute difference	5.1.2	5.3.2
	O_2/CO_2 gas analyzer	Low level (0–20% FS) Mid level (40–60% FS) High level (80–100% FS)	≤0.5% O_2 (or CO_2) ≤0.5% O_2 (or CO_2) ≤0.5% O_2 (or CO_2)		
	Flow monitor	 Low level (0–20% FS) Mid level (40–60% FS) High level (80–100% FS)	≤ the greater of 3.0% FS or 0.6 m/s absolute difference 3.0% FS or 0.6 m/s absolute difference 3.0% FS or 0.6 m/s absolute difference		
	Stack gas moisture monitor*	Low level (0–20% FS) Mid level (40–60% FS) High level (80–100% FS)	≤2.0% of (100 – $\%B_{ws}$) ≤2.0% of (100 – $\%B_{ws}$) ≤2.0% of (100 – $\%B_{ws}$)		
Electronic drift	–	–	≤3.0% FS in 24 hours	5.1.3	–
System response time	Dedicated analyzer	–	≤200 seconds for 90% change	5.1.4	5.3.3
	Time-shared system	–	≤15 minutes for 90% change		
Relative accuracy (RA)	SO_2/NO_X gas analyzer	–	≤ the greater of 10.0% RA or 8 ppm avg. absolute difference	5.1.5	5.3.4
	O_2/CO_2 gas analyzer	–	≤ the greater of 10.0% RA or 0.5% O_2 (or CO_2) avg. absolute difference		
	Flow monitor	 Minimum safe and stable load Mid load (40–60%) Full load (90–100%)	≤ the greater of 10.0% RA or 0.6 m/s avg. absolute difference 10.0% RA or 0.6 m/s avg. absolute difference 10.0% RA or 0.6 m/s avg. absolute difference		
	Stack gas moisture monitor*	Minimum safe and stable load Mid load (40–60%) Full load (90–100%)	≤10.0% RA of (100 – $\%B_{ws}$) ≤10.0% RA of (100 – $\%B_{ws}$) ≤10.0% RA of (100 – $\%B_{ws}$)		
	Mass emission	–	≤ the greater of 10.0% RA or 7.3 g/GJ input avg. absolute difference		

Table 3 Certification Performance Specifications (contd.)

Parameter	Component	Level	Specification	References	
				Specifications	Test procedures
Bias	SO_2/NO_X gas analyzer	–	≤ the greater of 5.0% of FS value or 5 ppm avg. absolute difference	5.1.6	5.3.5
	O_2/CO_2 gas analyzer	–	≤ the greater of 5.0% of FS value or 0.5% O_2 (or CO_2) avg. absolute difference		
	Flow monitor	–	≤ the greater of 5.0% of FS value or 0.6 m/s avg. absolute difference		
	Stack gas moisture monitor*	–	≤5.0% of mean FS (100 – $\%B_{ws}$) value		
Orientation sensitivity	–	–	≤4.0% of value measured at zero orientation	5.1.7	5.3.6

* The performance specifications for stack gas moisture monitoring systems based on wet O_2 and dry O_2 measurement (calibration drift, response time, relative accuracy, and availability) are summarized in Table 3, Section 5, and in Table 6, Section 6. Other moisture monitoring systems may be proposed for use with Equation B-3 in Appendix B, if the proponent demonstrates that the system meets the required specifications. The specific QA activities related to the moisture monitoring system must then be described in the QA/QC manual.

* Further details on the use of stack gas moisture monitoring systems are presented in Appendix B. Note that $\%B_{ws}$ is the moisture content of the stack gas (% v/v).

High level: 3.0% of the FS setting or 0.6 m/s, absolute difference

Stack gas moisture monitor
Low level: 2.0% of (100 – $\%B_{ws}$)
Mid level: 2.0% of (100 – $\%B_{ws}$)
High level: 2.0% of (100 – $\%B_{ws}$)

Calibration drift must be tested according to procedures in Section 5.3.2.

Further details on the use of stack gas moisture monitoring systems are presented in Appendix B.

5.1.3 Electronic Drift
The electronic drift of stack gas flow monitors that do not perform daily flow system calibration checks must not deviate from the value of the electric input signal by more than 3.0% FS.

5.1.4 System Response Time
For CEM systems using dedicated analyzers, the system response time is acceptable if the average of three increasing and three decreasing values is no greater than 200 seconds, for each analyzer, for a 90% response to a step change in concentration of gas at the probe exit. Note that this includes the lag time.

For time-shared systems, the system response time is acceptable if the average of three increasing and three decreasing values is no greater than 15 minutes, for each analyzer on each stream, for a 90% response to a step change in concentration of gas at the probe exit. Note that this includes the lag time.

System response time must be tested according to procedures in Section 5.3.3.

5.1.5 Relative Accuracy
The relative accuracy for an SO_2 and NO_X gas analyzer must not exceed 10.0% or 8 ppm average absolute difference (|d|), whichever is greater.

The relative accuracy for an O_2 (or CO_2) gas analyzer must not exceed 10.0% or 0.5% O_2 (or CO_2) average absolute difference (|d|), whichever is greater.

The relative accuracy for a stack gas flow monitor must not exceed 10.0% or 0.6 m/s average absolute difference (|d|), whichever is greater.

The relative accuracy for a stack gas moisture monitor must not exceed 10.0% of (100 – $\%B_{ws}$).

The relative accuracy for SO_2 and NO_X mass emissions must not exceed 10.0% or 7.3 g/GJ heat input average absolute difference (|d|), whichever is greater.

Meeting the relative accuracy for SO_2, NO_X, O_2, and CO_2 concentrations and stack gas flow does not guarantee meeting the relative accuracy for SO_2 and NO_X mass emissions.

Relative accuracy must be tested according to procedures in Section 5.3.4.

Further details on the use of stack gas moisture monitoring systems are presented in Appendix B.

5.1.6 Bias
The bias for an SO_2 and NO_X gas analyzer must not exceed 5.0% of the FS value or 5 ppm average absolute difference, whichever is greater.

The bias for an O_2 (or CO_2) gas analyzer must not exceed 5.0% of the FS value or 0.5% O_2 (or CO_2) average absolute difference, whichever is greater.

The bias for a stack gas flow monitor must not exceed 5.0% of the FS value or 0.6 m/s average absolute difference, whichever is greater.

The bias for a stack gas moisture monitor must not exceed 5.0% of the FS value for (100 – $\%B_{ws}$).

Bias must be tested according to calculations in Section 5.3.5.

Further details on the use of stack gas moisture monitoring systems are presented in Appendix B.

Should there be any bias as defined in Section 5.3.5, either positive or negative, in any measurements made by the CEM system, the data that are subsequently generated must be corrected for the bias before any subsequent use is made of the data.

5.1.7 Orientation Sensitivity
Some stack gas flow monitors may be sensitive to the probe orientation in the gas stream. For these monitors, the indicated gas flow rate of the sensor at orientations other than that at the zero

degree measurement must not differ from the zero orientation by more than 4.0%.

Orientation sensitivity must be tested according to procedures in Section 5.3.6.

5.2 Calibration Gases

The gases used by both the CEM system and the reference method during the relative accuracy test must be U.S. Environmental Protection Agency (EPA) protocol grade.

Gases used during the calibration drift and response time tests must be certified to an accuracy of 2.0% by the supplier, but protocol gases may be used if desired.

The QA/QC manual should specify a method of cross-referencing successive gas cylinders to identify out-of-specification cylinders before the new cylinders are used to calibrate the CEM system.

5.3 Certification Test Procedures

5.3.1 Operational Test Period

During the OTP, the CEM system must continue to analyze flue gases without interruption and produce a record of the emissions data using the data acquisition system. This record must be kept for the duration required by the appropriate regulatory authority. Sampling may be interrupted during this test period only to carry out system instrument calibration checks and specified procedures contained in the QA/QC manual.

During this period, no unscheduled maintenance, repairs, or adjustments to the CEM system may be carried out; otherwise, the OTP must be restarted. Calibration adjustments may be performed at 24-hour intervals or more frequently if specified by the manufacturer and stated in the QA/QC manual. Automatic zero and calibration adjustments made without operator intervention may be carried out at any time, but these adjustments must be documented by the data acquisition system.

If the test period is fragmented due to process shutdown, the times and dates of this period should be recorded and the test continued when the source resumes operation. If the test is interrupted due to CEM system failure, the entire test period must be restarted after the problem has been rectified.

The performance specification tests outlined in Sections 5.3.2 to 5.3.6 must be carried out during the OTP, with the exception of the relative accuracy test (Section 5.3.4), which may be conducted during the OTP or during the 168-hour period immediately following the OTP. It is recommended that the calibration drift tests be completed before attempting the relative accuracy tests, to minimize the risk associated with repeating the latter.

5.3.2 Calibration Drift Test Protocols

The calibration drift test period may be fragmented in subperiods that are not less than 24 hours each.

The calibration drift must be determined for each pollutant gas analyzer, diluent gas analyzer, and stack gas flow monitor at approximately 24-hour intervals over the 168-hour test period.

The following procedures are used during this test.

5.3.2.1 Calibration Adjustments. Automatic or manual calibration adjustments may be carried out each day. The calibration drift test must be conducted immediately before these adjustments or in such a manner that the magnitude of the drifts can be determined. Since the test is carried out before adjustments, the magnitude of any drift occurring in the system or analyzer over the 24-hour period is incorporated into the reported result.

5.3.2.2 Test Procedures. On the first day of the performance test period, the calibration of the system must be checked by injecting the three calibration gases (Section 5.2) at the primary CEM system calibration port, as indicated in Section 3.1.1 of this report.

The system must be challenged three times daily at approximately 24-hour intervals with each of the low-, mid-, and high-level calibration gases for the pollutant and diluent species, for a total of nine tests each. The three ranges for each gas must not be introduced in succession or in the same sequence, but must be alternated with other reference gases. The response of the system, as indicated by the data acquisition system, must be recorded, and the average system response of the three calibration checks for that day must be calculated.

If the CEM system is fitted with a stack gas flow monitor, then RM flow measurements must be performed three times daily at approximately 24-hour intervals. The concurrent flow from the data acquisition system must be recorded, and the average flow error for that day must be calculated. If the RM flow runs of each day are performed consecutively, then a single moisture determination encompassing the three flow runs may be used.

5.3.2.3 Gas Concentration Calculations. The gas calibration drift for the responses to the low-, mid, and high-level test gases is calculated using Equation 2.

$$D_C = \left[\frac{(A - R)}{FS} \right] x100 \qquad \textbf{Equation 2}$$

where:

D_c = concentration calibration drift (%)

A = average of the three system responses to the low-, mid-, or high-level calibration gas (% or ppm)

R = certified concentration of the low-, mid-, or high-level test gas (% or ppm)

FS = full-scale setting of the analyzer (% or ppm)

5.3.2.4 Gas Flow Calculations. The flow measurement calibration drift is calculated using Equation 3.

$$D_f = \left[\frac{(A_f - RM)}{FS} \right] x100 \qquad \textbf{Equation 3}$$

where:

D_f = flow calibration drift (%)

A_f = average gas velocity or flow rate, as measured by the CEM system (m/s or m^3/s)

RM = average gas velocity or flow rate, as measured by the reference method (m/s or m^3/s)

FS = full-scale setting of the flow monitor (m/s or m^3/s)

Note: The daily drift results must not be averaged when reporting the calibration drift measured during the system certification.

5.3.2.5 Acceptance Criteria for Certification. The performance specifications presented in Section 5.1.2 must be met.

5.3.3 System Response Time Test Protocols

This test is performed for each pollutant and diluent gas analyzed, with the results expressed in concentration units, and on the overall CEM system, with the results expressed in terms of the standard. The test is carried out with the CEM system fully operational. Sample flow rates, pressures, and other parameters must be at the nominal values specified in the manufacturer's written instructions and outlined in the QA/QC manual.

5.3.3.1 Test Procedures. Low- and high-level calibration gases must be introduced alternately at the system calibration gas injection port specified in Section 3.1.1. Sufficient time must be allowed for the system to stabilize, and then the data acquisition system responses to these gases must be recorded. This sequence must be carried out three times, thus generating a total of three increasing and three decreasing concentration changes. When a time-shared system is being tested, the injection of the calibration gases must be timed to produce the longest possible response time for the system.

5.3.3.2 Calculations. Using the output of the data acquisition system, the time required for the system to achieve a 90% response to the concentration difference between the low- and high-level gases for both increasing and decreasing gas concentrations must be determined. The lag time of extractive systems (i.e. the time necessary to convey the gas sample through the sampling line) must be included when determining the time that the system takes to reach 90% response change.

5.3.3.3 Acceptance Criteria for Certification. The performance specifications presented in Section 5.1.4 must be met.

5.3.4 Relative Accuracy Test Protocols

This test is a comparative evaluation of CEM system performance using an independent reference method, which may be either a manual or automated procedure, as specified by the appropriate regulatory authority. The test is carried out on each pollutant and diluent gas analyzer as well as on the stack gas flow monitor and pollutant mass emissions. F-factor-based methods may be used for the certification and for the semiannual performance evaluations for CEM systems that calculate emissions by F-factors (Appendix A). Data from this test are also used to calculate a system bias.

The emission source must be operating at normal capacity or at greater than 50% maximum heat input (the latter for new generating units or units that did not operate in the previous two quarters) while combusting the primary fuel normal for that unit. The CEM system must be operated in a routine manner during this test, and no adjustments, repairs, or modifications to any portion of the system may be carried out other than those actions outlined in the QA/QC manual. As the system includes the hardware and software associated with data acquisition, data manipulation, and system control, parameters in this subsystem may not be modified during the test.

5.3.4.1 Reference Method Sampling Point for Non-stratified Flow. Where it has been demonstrated, using the procedures outlined in Section 4.2.1, that the flue gases are not stratified, the RM testing may be carried out at a single test point in the flue or duct, with the gas extraction point being no closer than 7.5 cm from any wall.

When certifying extractive or in situ point systems, the RM probe tip must be located no closer than 30 cm from the CEM probe. For in situ path systems, the RM probe must be no closer than 30 cm from the inner 50% of the measurement path. The RM probe must be positioned so that it will not interfere with the operation of the CEM system under test.

5.3.4.2 Location of Reference Method Sampling Points in Presence of Stratified Flow. If the gas flow has been found to be stratified using the procedures outlined in Section 4.2.1 or if the stratification test has not been performed, the RM sample must be collected at several points in the gas flow.

A "measurement line" that passes through the centroids of the flue or duct must be established. This line should be located within 30 cm of the CEM sampling system cross-section. Three sampling points must be located at 16.7, 50, and 83.3% along the length of the measurement line. Other sampling points may be selected if it can be demonstrated that they will provide a representative sample of the bulk gas flow over the period of the test.

5.3.4.3 Test Methods. Either integrating manual or automated methods specified by the appropriate regulatory authority may be used as the reference methods for this test.

Manual grab sampling reference methods are not acceptable for CEM system certification.

5.3.4.4 Sampling Strategy. A minimum of nine comparisons of the RM and CEM results must be conducted to evaluate the performance of the CEM system being tested. When manual sampling reference methods are being used, the sampling must be carried out at a fixed sampling rate; that is, the sampling rate must not be adjusted over the duration of the test, except to maintain the flow at the initial rate. Sampling must be carried out for 30 minutes during each test, divided equally over the three sampling points for stratified flow testing or at the single point for non-stratified flow.

The operator may choose to carry out more than nine sets of comparisons. Should this option be exercised, the results of a maximum of three tests may be rejected from the test data if an appropriate statistical test applied to the data demonstrates that these results are outliers. A minimum of nine RM tests must be available after statistical rejection of data. All data must be reported, including the outliers, along with all calculations.

All appropriate diluent gas and moisture measurements must be conducted simultaneously with the RM pollutant concentration measurements.

If the CEM is fitted with a stack gas flow monitor, then RM concentration measurements must be concurrent with RM flow measurements. Two additional sets of flow comparisons must be completed either during the OTP or during the 168-hour period immediately following the OTP, at different load levels.

5.3.4.5 Correlating Reference Method and Continuous Emission Monitoring System Measurements. In order to correlate the data from the CEM system and RM tests, it is imperative that the beginning and end of each test period be clearly marked on the CEM data acquisition record and that the CEM time be synchronized with the RM test crew time. After each test is completed, compare the results from the CEM system with the data derived from the RM results over the exact time period that the test was performed.

The CEM system and RM results must be correlated on the same basis. Thus, corrections may need to be applied for moisture, temperature, pressure, etc. The auxiliary measurements of the RM testing (such as stack gas moisture or barometric pressure) are used to make any adjustments to the RM results. The auxiliary measurements of the CEM system are used to make adjustments to the CEM results.

5.3.4.6 Calculations. The relative accuracy of the system must be calculated for each pollutant and diluent gas measured by the system in terms of concentration in ppm or percent (by volume), as well as stack gas flow in terms of m/s or Sm^3/h. Additionally, the relative accuracy for SO_2 and NO_X emissions in units of the standard must be calculated.

(i) Calculation of relative accuracy
The relative accuracy is calculated using Equation 4.

$$RA = \left(\frac{|d| + |cc|}{RM} \right) x100 \qquad \textbf{Equation 4}$$

where:
RA = relative accuracy (%)
d = mean difference between the CEM system and RM results
cc = confidence coefficient
RM = average of the reference method results

When the pollutant gas concentrations are less than 250 ppm, the FS setting of the analyzer must be substituted for the value of RM when calculating the relative accuracy using Equation 4.

(ii) Calculation of differences
The absolute value of the difference between the CEM system and RM results is calculated using Equation 5.

$$|d| = \left| \frac{1}{n_i} \sum_{i=1}^{n} d_i \right| \qquad \textbf{Equation 5}$$

where:
d_i = difference between an RM value and a corresponding CEM system value ($d_i = CEM_i - RM_i$) for the i^{th} test run
n = number of data pairs

Note: The numeric signs for each data pair must be retained. The absolute value of the sum of differences is used, not the sum of absolute values of the differences.

(iii) Calculation of confidence coefficient and standard deviation
The values of the confidence coefficient and standard deviation are determined from Equations 6 and 7, respectively.

$$|cc| = \frac{t_{0.025} \text{ x Stdev}}{\sqrt{n}} \qquad \textbf{Equation 6}$$

where:
cc = confidence coefficient
$t_{0.025}$ = t value from Table 4 for a one-tailed t-test corresponding to the probability that a measured value will be biased low at a 95% level of confidence
Stdev = sample standard deviation of the differences of the data pairs from the relative accuracy test, calculated using Equation 7
n = number of data pairs

$$Stdev = \sqrt{\frac{\sum_{i=1}^{n} (d_i)^2 - \frac{1}{n}\left(\sum_{i=1}^{n} (d_i)\right)^2}{n-1}} \qquad \textbf{Equation 7}$$

where parameters are as defined above.

(iv) Calculation of reference flow-to-output and heat-to-output ratios
If the CEM system includes a stack gas flow monitor, the flow-to-output or heat-to-output ratio may be required as reference for the

Table 4 t Values

n – 1	5	6	7	8	9	10	11	12	13	14
$t_{0.025}$	2.571	2.447	2.365	2.306	2.262	2.228	2.201	2.179	2.160	2.145

Note: These are t values for a one-tailed t-test at a 95% confidence level.

quarterly stack gas flow test in subsequent quarters.

Depending on the option chosen for the quarterly stack gas flow test, as described in Section 6.3.2, one or more of the following averages must be calculated, based on the process data and the RM measurements obtained during the relative accuracy test of the initial CEM certification or subsequent relative accuracy test audit (RATA):

- flow to electric output ratio;
- heat input (if the CEM system is fitted to perform this calculation on the basis of measured stack gas flow and measured diluent concentration or measured fuel flow rate and fuel gross heating value); and
- heat input to electric output ratio (only for CEM systems that can calculate heat input).

The flow to electric output ratio is calculated with Equation 8, from the results of the RM runs.

$$R_{ref} = \frac{1}{n}\sum_{i=1}^{n}\frac{Q_{wi}}{MW_i} \qquad \textbf{Equation 8}$$

where:

R_{ref} = reference value of flow to electric output ratio on a wet basis, from the most recent RATA (WSm^3/MWh)

Q_{wi} = flow measured during each test run on a wet basis (WSm^3/h)

MW_i = mean gross electric output during each test run (MW)

n = number of data pairs

The heat input is the average of the gross heat input during each RM test run. It may be calculated on the basis of the measured stack gas flow and F-factors (as shown in Table A-1) or, in the case of gaseous and liquid fuel, on the basis of the measured flow rate and gross heating value of the fuel. The heat input corresponding to an RM test run may be calculated with Equations 9 to 12.

$$HI = Q_W\left(\frac{100 - \%B_{WS}}{100F_d}\right)\left(\frac{20.9 - \%O_{2d}}{20.9}\right) \qquad \textbf{Equation 9}$$

$$HI = Q_W\,\frac{1}{F_c}\left(\frac{\%O_{2w}}{100}\right) \qquad \textbf{Equation 10}$$

$$HI = Q_W\left(\frac{100 - \%B_{WS}}{100F_c}\right)\left(\frac{\%CO_{2d}}{100}\right) \qquad \textbf{Equation 11}$$

$$HI = Q_W\left(\frac{0.209\,(100 - \%B_{WS}) - \%O_{2W}}{20.9F_d}\right) \qquad \textbf{Equation 12}$$

where the following values are RM test run averages:

HI = heat input (MJ/h)

Q_W = stack gas flow on a wet basis (WSm^3/h)

$\%B_{WS}$ = moisture content of the stack gas (%)

F_d = fuel-specific F-factor from Table A-1 or calculated as per Appendix A, Section A.7

F_c = fuel-specific F-factor from Table A-1 or calculated as per Appendix A, Section A.7

$\%O_{2W}$ = stack gas oxygen concentration (% wet basis)

$\%CO_{2d}$ = stack gas carbon dioxide concentration (% dry basis)

$\%O_{2d}$ = stack gas oxygen concentration (% dry basis)

The reference heat to electric output ratio (or gross heat rate) is calculated with Equation 13, from the results of the RM runs.

$$GHR_{ref} = \frac{1}{n}\sum_{i=1}^{n}\frac{HI_i}{MW_i}$$ **Equation 13**

where the following values are RM test run averages:

GHR_{ref} = reference value of gross heat rate, from the most recent RATA (MJ/MWh)
HI_i = gross heat input during each test run (MJ/h)
MW_i = mean gross electric output during each test run (MW)
n = number of data pairs

5.3.4.7 Acceptance Criteria for Certification. The performance specifications presented in Section 5.1.5 must be met.

5.3.5 Bias Test Calculations

A bias or systematic error is considered to be present if, in the measurements of a pollutant gas, diluent gas, or stack gas flow:

$$|d| \geq |cc|$$ **Equation 14**

As presented in Section 5.1.6, acceptable bias is

$(|d| - |cc|) \leq 5.0\%$ FS

or
$|d| \leq 5.0$ ppm for pollutant concentration

or
$|d| \leq 0.5\% O_2$ (or CO_2) for diluent concentration

or
$|d| \leq 0.6$m/s for stack gas flow monitor

It is highly recommended that the sources of bias in the system be investigated and remedied.

If bias is present, as determined by Equation 14, and it is within the above levels, then the subsequent measurement of the CEM system must be corrected by a bias adjustment factor (BAF), using Equations 15 and 16.

$$CEM_{adjusted} = CEM_{monitor} \times BAF$$ **Equation 15**

where:

$CEM_{adjusted}$ = data adjusted for bias
$CEM_{monitor}$ = data provided by the monitor
BAF = bias adjustment factor, defined by Equation 16

$$BAF = \frac{RM}{CEM_{RATA\ avg}}$$ **Equation 16**

where:

BAF = bias adjustment factor
$CEM_{RATA\ avg}$ = average CEM results during RATA
RM = average of the reference method results

The use of a BAF in any measurement must be stated in the QA/QC manual.

5.3.6 Orientation Sensitivity Test Protocols

This test is intended as a check for flow monitors that are sensitive to the orientation of the sensor in the gas flow, such as differential pressure flow sensors. This test is carried out at the same three load levels previously defined in the relative accuracy test.

5.3.6.1 Test Procedures. During a period of steady flow conditions at each load, the sensor in the gas flow must be rotated a total of 10 degrees on each side of the zero-degree position (directly into the gas flow with no cyclonic flow patterns) in increments of 5 degrees, noting the response of the sensor at each angle. A total of five flows must be generated for each load condition, at -10, -5, 0, +5, and +10 degrees relative to the zero-degree position.

5.3.6.2 Acceptance Criteria for Certification. The performance specifications presented in Section 5.1.7 must be met.

Section 6.0 Quality Assurance and Quality Control

In cooperation with the regulatory agency, the operator must develop a QA/QC manual for each installed CEM system.

The QA policies (high level) and QC procedures (standard operating procedures, working level) are outlined in the written QA/QC manual. The manual must be followed to ensure and document the quality of the environmental data being collected and reported. Establishing the QA/QC manual ensures that the environmental monitoring and reporting procedures are verified and documented so that uncertainties in the reported data can be controlled and quantified. Figure 2 shows a schematic of a QA/QC manual.

A QA program is defined as a management program to ensure that the necessary QC activities are being adequately performed, while QC activities are those that detail the day-to-day operation of the system.

6.1 Quality Assurance/Quality Control Manual

The QA/QC manual must describe a complete program of activities to be implemented to ensure that the data generated by the CEM system will be complete, accurate, and precise. As a minimum, the manual must include the QA/QC procedures specified in this report. The recommended Table of Contents for the QA/QC manual is shown in Table 5.

6.1.1 Quality Assurance Activities

This section of the manual should describe how the QA program is managed, provide personnel qualifications, and describe the QA reporting subsystem. It must describe the CEM system, how it operates, and the procedures for calibration and inspection. It must also include preventative maintenance and performance evaluation procedures.

6.1.2 Quality Control Activities

This section should provide detailed descriptions of the step-by-step procedures required to operate and evaluate the system, including details about daily, quarterly, semiannual, and annual performance evaluations. Procedures and minimum criteria for a selection of these activities are provided in Sections 6.2 to 6.5. A summary of these performance evaluations is outlined in Table 6.

Figure 2 Quality Assurance/Quality Control Schematic

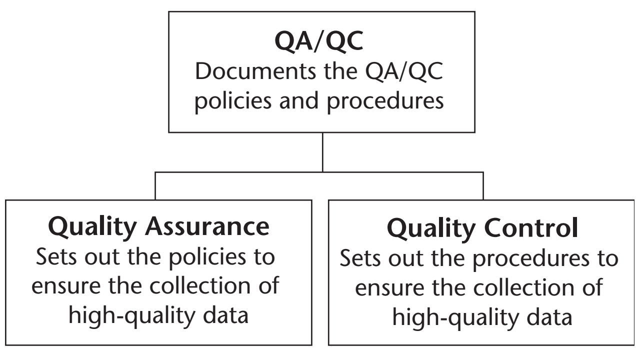

Table 5 Table of Contents for Quality Assurance/Quality Control Manual

Subsection	Contents
Quality assurance policies and system descriptions	
1 Quality Assurance Goals and Objectives	Specific system goals relating to precision, accuracy, and completeness. Specific objectives as laid out in the regulations and guidelines. Emission standards and emission reporting requirements.
2 CEM System Description and Design Considerations	Detailed system description, including principles of operation, sample location layout, flow and temperature measurement, sample conditioning system, analyzer layout, CEM shelter, and data handling system. Design considerations and engineering evaluation of CEM system options, including sample location, extractive vs. in situ, flow monitoring, and supplier. Should also include a detailed list of CEM system component serial and model numbers.
3 Exceptions/Clarifications/Alternate Methods	Any exceptions/clarifications or alternate methods relating to 1/PG/7, reference test methods, or regulations.
4 Organization and Responsibilities	Description of the organization of personnel involved with the CEM system and its quality system. Defines the roles and responsibilities of the personnel involved as related to CEM system operation and maintenance, control of documents/records, and control of data.
5 Calibration and Quality Control Checks	Description of the calibrations and QC checks that are performed on a routine basis, generally daily, to determine whether the system is functioning properly. Includes daily zero and calibration checks and visual checks of system operating indicators, such as vacuum and pressure gauges, rotameters, analyzer displays, LEDs, and so on.
6 Data Acquisition and Analysis	Description of the data acquisition system and analysis program. Includes references to data completeness, validation, reporting, storage, and revision management. Roles and responsibilities of the personnel involved in the data handling should be included.
7 Preventative Maintenance Policy	Description of the CEM system preventative maintenance program, including how preventative maintenance scheduling is determined and maintained along with roles and responsibilities of the personnel involved.
8 Corrective Action Program	Description of the policies for correcting any CEM system non-conformance. Parameters such as CEM system downtime/reliability should be addressed. Roles and responsibilities of the personnel involved in the corrective action program should be included.
9 Performance Evaluations/Audits	Description of the policies and specifications for performance evaluations/audits (i.e., stack quarterly audits and RATAs). Describe the action necessary to ensure that the appropriate evaluations are carried out on the appropriate schedule.
10 Document Control System	Description of the policies and systems used to control all the documents that form part of the CEM system's quality system. Lists how and where the related documents are located, how they are reviewed and revised, and how they are approved for use by authorized personnel prior to issue.
11 Reports and Records	Description of all reports and records collected. Description should contain method of collection, person responsible, data storage location, data security, data distribution, and length of data storage.
12 Modifications and Upgrades	Description of the policies regarding modifications and upgrades to the CEM system. This section should include any regulatory requirements pertaining to modification or upgrade of the CEM system.

Table 5 Table of Contents for Quality Assurance/Quality Control Manual (contd.)

Subsection	Contents
Quality assurance policies and system descriptions	
13 Training and Qualification Policy	Training and qualification policy for CEM system maintainers, CEM system coordinators, computer and programming technicians, data validators, quarterly audit and RATA testers. Includes educational and experience requirements, on-the-job training, job shadowing, and classroom training requirements.
14 References	References for QA/QC plan.
Quality control (standard operating) procedures	
1 Startup and Operation	Lists in detail complete, step-by-step procedures for the startup and operation of the CEM system.
2 Daily CEM System Operation and Inspection	Detailed description of daily routine operation and inspection of the CEM system. Includes descriptions of equipment and data validation procedures. Examples of daily equipment checks and/or logbook entries should be included.
3 Daily and Manual Calibration Procedures	Lists in detail complete, step-by-step procedures for daily and manual calibrations. May make reference to specific OEM documentation/manuals. Includes schedule for manual (mid-point) calibration, if done.
4 Gas Bottle Check Procedures	Description of procedure to cross-reference cylinder gases. Gases can be cross-referenced to previous gas bottles and quarterly bottles. Specifications for rejection of gas bottle to be stated.
5 Preventative Maintenance Procedures	Detailed description of the CEM system preventative maintenance procedures along with the preventative maintenance schedule. This could include a description of such things as a preventative maintenance work order program for those facilities so equipped, along with reference to or examples of preventative maintenance work orders in use.
6 Spare Parts List and Inventory Procedures	Detailed descriptions of the spare parts inventory available for the CEM system, along with a description of the procedures for obtaining spare parts from inventory and ensuring that the spare parts inventory is maintained.
7 Corrective Maintenance Procedures	Detailed descriptions of the non-routine maintenance that is performed when the system or part of the system fails. May make reference to specific OEM documentation/manuals.
8 Data Backfilling Procedures	Procedures for data backfilling when a CEM system is not available. Data backfilling algorithms to be based on process variables.
9 Data Backup Procedures	Procedures for regular backup of data in hard or soft copy.
10 CEM System Security	Includes security actions for CEM equipment software and data.
11 Data Approval and Reporting Procedures	Procedure for approval and reporting of CEM data. Includes any systems for review, modifications, approval, summary, and release of data.
12 Quarterly Audit Procedures	Detailed procedures on conducting quarterly audit procedures. Includes roles and responsibilities, gas bottle requirements, scheduling, and test methods.
13 Semiannual Relative Accuracy Test Audit Procedures	Detailed pretest sampling plan for executing RATAs. Pretest plan to include organization plan, sampling points, scheduling, test methods, calibration requirements, reporting schedule, reporting format, and site safety plan.

Table 5 Table of Contents for Quality Assurance/Quality Control Manual (contd.)

Subsection	Contents
Quality control (standard operating) procedures	
14 Bias Procedures	Describes process of assessing and correcting for bias. Includes roles and responsibilities for assessing and approving bias factors.
15 Annual System Audit Procedures	Describes procedure for annual system audit. Includes selection of auditor, scheduling, audit plan, and reporting.
16 Managing Change	Procedure for managing change when upgrades are required due to failure of equipment, changes in regulation, changes in system management. Includes approval process for accepting changes with roles and responsibilities. Addresses replacement of CEM systems.
Appendices	
1 Facility Environmental Permit/Licence 2 Applicable Environmental Regulations 3 CEM System Specifications 4 Reference Method Procedures 5 Blank Forms	

6.2 Daily Performance Evaluations

6.2.1 Calibration Drift

Calibration of the CEM system is one of the most important aspects of the QA/QC program. The following summarizes the requirements for calibration drift, all of which must appear in the QA/QC manual.

6.2.1.1 Frequency. The drift of each gas analyzer and flow monitor must be determined at least once daily, at 24-hour intervals. It is good practice to determine the drift of each analyzer even during periods when the generating unit is down. The operator may, however, skip the daily calibration during extended periods in which the generating unit does not burn fuel. However the CEM system should be successfully calibrated immediately prior to or during the startup to avoid using the backfilling option (Section 3.4.3).

6.2.1.2 Test Gases. Protocol gases or gases certified to an accuracy of 2.0% may be used for the daily calibration of gas analyzers.

6.2.1.3 Calibration Gas Injection Port. The location of the applicable calibration gas injection port for each type of CEM system can be found in Table 2 of Section 3.1.1. Care must be taken to ensure that the calibration checks are carried out at the same system operating conditions that are used during monitoring (e.g., pressure, flow, temperature, etc.). For path-type analyzers that do not have the capability of accepting a flowing gas, a sealed cell containing a known concentration of gas can be used for calibration checks.

6.2.1.4 Test Procedures. Two concentration/flow levels must be used: low level (0–20% FS) and high level (80–100% FS).

A calibration adjustment for the low-level gas must not be made before checking both the low- and high-level gases. If a multirange instrument is used with a system that automatically selects the range, the drift of each range must be checked daily.

Enough time must be allowed to ensure that the gas analyzer attains a steady output, as indicated by the data acquisition system.

Calibration drift must be tested according to procedures in Section 5.3.2.

Further details on the use of stack gas moisture monitoring systems are presented in Appendix B.

6.2.1.5 Adjustment of Analyzers/Monitors. A gas analyzer, flow monitor, or stack gas moisture monitor must be adjusted whenever the daily low- or high-level calibration drift exceeds the following specifications:

Table 6 Daily, Quarterly, Semiannual, and Annual Performance Evaluations Summary

Parameter	Component	Level	Specification	References: Specifications	References: Test procedures
Daily performance evaluations					
24-hour calibration drift	SO_2/NO_X gas analyzer	 Low level (0–20% FS) High level (80–100% FS) Out-of-control condition	≤ the greater of 2.0% FS or 2.5 ppm absolute difference 2.5% FS or 2.5 ppm absolute difference Exceedance of twice the above levels	6.2.1	5.3.2/6.2.1
	O_2/CO_2 gas analyzer	Low level (0–20% FS) High level (80–100% FS) Out-of-control condition	≤0.5% O_2 (or CO_2) ≤0.5% O_2 (or CO_2) Exceedance of twice the above levels		
	Flow monitor – Systems with flow calibration capability – Systems without flow calibration capability	 Low level (0–20% FS) High level (80–100% FS) – Out-of-control condition	≤ the greater of 3.0% FS or 0.6 m/s absolute difference 3.0% FS or 0.6 m/s absolute difference ≤ the greater of 3.0% FS or 0.6 m/s absolute difference Exceedance of twice the above levels		
	Stack gas moisture monitor* – Dry O_2 – wet O_2 systems	 Low level (0–20% FS) High level (80–100% FS) Out-of-control condition	 ≤0.5% O_2 ≤0.5% O_2 Exceedance of twice the above levels		
Electronic drift	–	–	≤3% FS in 24 hours	6.2.2	–
Quarterly performance evaluations					
Cylinder gas test	SO_2/NO_X gas analyzer (Note: alternate provisions for certain types of in situ analyzers in 6.3.1.7)	Low level (0–20% FS) Mid level (40–60% FS) High level (80–100% FS) Out-of-control condition	≤4.0% FS or 5 ppm absolute difference ≤4.0% FS or 5 ppm absolute difference ≤5.0% FS or 5 ppm absolute difference Exceedance of the above levels	6.3.1	6.3.1

Table 6 Daily, Quarterly, Semiannual, and Annual Performance Evaluations Summary (contd.)

Parameter	Component	Level	Specification	References: Specifications	References: Test procedures
Quarterly performance evaluations (contd.)					
	O_2/CO_2 gas analyzer (Note: alternate provisions for certain types of in situ analyzers in 6.3.1.7)	Low level (0–20% FS) Mid level (40–60% FS) High level (80–100% FS) Out-of-control condition	≤1.0% O_2 (or CO_2) ≤1.0% O_2 (or CO_2) ≤1.0% O_2 (or CO_2) Exceedance of the above levels		
	Stack gas moisture monitor* – Dry O_2 – wet O_2 systems	Low level (0–20% FS) Mid level (40–60% FS) High level (80–100% FS) Out-of-control condition	≤1.0% O_2 ≤1.0% O_2 ≤1.0% O_2 Exceedance of the above levels		
Stack gas flow test	Alternatives: – Flow-to-output evaluation – Heat-to-output evaluation – Abbreviated flow-to-output test – Abbreviated heat-to-output test – Flow RM test	– – – – – Out-of-control condition	≤10%, output ≥ 60 MJ/s ≤15%, output < 60 MJ/s ≤10%, input ≥ 171 MJ/s ≤15%, input < 171 MJ/s ≤10%, output ≥ 60 MJ/s ≤15%, output < 60 MJ/s ≤10%, input ≥ 171 MJ/s ≤15%, input < 171 MJ/s ≤ the greater of 6.0% FS or 1.2 m/s Exceedance of the above levels	6.3.2	6.3.2
F-factor system test	Alternatives: – Heat-to-output evaluation – Heat-to-output test – Heat input to commercial billing evaluation	– – – Out-of-control condition	≤10%, input ≥ 171 MJ/s ≤15%, input < 171 MJ/s ≤10%, input ≥ 171 MJ/s ≤15%, input < 171 MJ/s Demonstration of principles c1 to c4 in Section 6.3.3.2 Exceedance of the above levels	6.3.3	6.3.2/6.3.3

Table 6 Daily, Quarterly, Semiannual, and Annual Performance Evaluations Summary (contd.)

Parameter	Component	Level	Specification	References: Specifications	References: Test procedures
Semiannual and annual performance evaluations					
Relative accuracy	SO_2/NO_X gas analyzer	–	≤ the greater of 10.0% RA or 8 ppm avg. absolute difference	6.4.1	5.3.4/6.4.1
		Out-of-control condition	Exceedance of the above levels		
	O_2/CO_2 gas analyzer	–	≤ the greater of 10.0% RA or 0.5% O_2 (or CO_2) avg. absolute difference		
		Out-of-control condition	Exceedance of the above levels		
	Flow monitor	Representative load level	≤ the greater of 10.0% RA or 0.6 m/s avg. absolute difference		
		Out-of-control condition	Exceedance of the above levels		
	Stack gas moisture monitor*	Representative load level	≤10.0% RA for (100 – $\%B_{ws}$)		
		Out-of-control condition	Exceedance of the above level		
	Mass emission	Representative load level	≤ the greater of 10.0% RA or 7.3 g/GJ input avg. absolute difference		
		Out-of-control condition	Exceedance of the above levels		
Bias	SO_2/NO_X gas analyzer	Representative load level	≤ the greater of 5% of FS value or 5 ppm avg. absolute difference	6.4.1	5.3.5/6.4.1
		Out-of-control condition	Exceedance of the above levels		
	O_2/CO_2 gas analyzer	Representative load level	≤ the greater of 5% of FS value or 0.5% O_2 (or CO_2) avg. absolute difference		
		Out-of-control condition	Exceedance of the above level		

Table 6 Daily, Quarterly, Semiannual, and Annual Performance Evaluations Summary (contd.)

Parameter	Component	Level	Specification	References: Specifications	References: Test procedures
Semiannual and annual performance evaluations (contd.)					
	Flow monitor	Representative load level	≤ the greater of 5% of FS value or 0.6 m/s avg. absolute difference		
		Out-of-control condition	Exceedance of the above levels		
	Stack gas moisture monitor*	Representative load level	≤5% of FS (100 – $\%B_{ws}$) value		
		Out-of-control condition	Exceedance of the above level		
Availability	Non-peaking units	–	≤90% annually in first year ≤95% annually thereafter	6.5.1	6.5.1
	Peaking units	–	≤80% annually		
Independent inspection	–	–	Evaluation by an independent inspector	6.5.2	–

* The performance specifications for stack gas moisture monitoring systems based on wet O_2 and dry O_2 measurement (calibration drift, response time, relative accuracy, and availability) are summarized in Table 3, Section 5, and in Table 6, Section 6. Other moisture monitoring systems may be proposed for use with Equation B-3 in Appendix B, if the proponent demonstrates that the system meets the required specifications. The specific QA activities related to the moisture monitoring system must then be described in the QA/QC manual.

Further details on the use of stack gas moisture monitoring systems are presented in Appendix B. Note that $\%B_{ws}$ is the moisture content of the stack gas (% v/v).

Pollutant gas analyzer
Low level: 2.0% of the FS setting or 2.5 ppm absolute difference, whichever is greater
High level: 2.5% of the FS setting or 2.5 ppm absolute difference, whichever is greater

Diluent gas analyzer
Low level: 0.5% O_2 (or CO_2)
High level: 0.5% O_2 (or CO_2)

Flow monitor
Low level: 3.0% of the FS setting or 0.6 m/s, absolute difference whichever is greater
High level: 3.0% of the FS setting or 0.6 m/s, absolute difference whichever is greater

Stack gas moisture monitor (dry O_2 – wet O_2 systems)
Low level: 0.5% O_2 (24 hours)
High level: 0.5% O_2 (24 hours)

6.2.1.6 Out-of-Control Period. An out-of-control period occurs when either the low- or high-level calibration drift of a gas analyzer, flow monitor, or stack gas moisture monitor exceeds twice the applicable drift specification, as presented in Section 6.2.1.5. This period begins with the minute of the calibration drift check and ends with the minute after corrective action has been taken and when the system has demonstrated that it is operating satisfactorily. When a gas analyzer, flow monitor, or stack gas moisture monitor is out of control, the data generated by the specific component are considered missing and do not qualify for meeting the requirement for system availability. Missing data must be backfilled using the criteria provided in Section 3.4.3.

6.2.1.7 Tabulation of Data. All calibration drift data must be recorded and tabulated by day and month, with the magnitude of the drifts in ppm for pollutant analyzers, % for diluent gas analyzers, and flow-related level for flow monitors. These data must be summarized on a QC chart.

6.2.1.8 Quantification of Drifts. When the data acquisition subsystem automatically compensates data for drifts, the system must be capable of also storing unadjusted concentrations of the calibration gases, unadjusted flow levels, and the magnitude of all adjustments. If strip chart recorder data are reported, any automatic calibration adjustment must be noted on the strip chart record.

For a CEM system that physically resets the analyzer by automatic means, the data acquisition system must store the unadjusted concentrations in addition to the magnitude of the adjustment.

6.2.2 Electronic Drift

The electronic drift of flow monitors that do not perform daily flow system calibration checks must not deviate from the value of the electric input signal by more than 3.0% FS.

6.3 Quarterly Performance Evaluations

During each quarter, a cylinder gas test and one of the options for a stack gas flow test or an F-factor system test must be performed on the CEM system. Special provisions apply to peaking units and to path-type analyzers that do not have the capability of accepting a flowing calibration gas. The following summarizes the requirements for these tests, all of which must appear in the QA/QC manual.

6.3.1 Cylinder Gas Test

This test, which investigates the linearity error of the analyzers, is to be performed on all gas analyzer ranges used during the previous quarter.

Where the type of analyzer used does not allow a test gas to be used (e.g., certain in situ path-type analyzers), an independent check on the CEM system performance must be carried out. Typically, a check on the response for each gas being measured against a reference method or an approved portable analyzer will be satisfactory. The comparison must be carried out over a period of not less than 15 minutes for each test run. Three such comparisons of the gases will be deemed to be equivalent to the cylinder gas test.

6.3.1.1 Frequency. A three-level cylinder gas test must be performed in each quarter of the calendar year, with tests being no closer than 30 days for two adjacent quarters, using the following test gases and procedures. In peaking units, this test must be performed annually, immediately before the relative accuracy test period (RATA).

6.3.1.2 Test Gases. Protocol gases at low (0–20% FS), mid (40–60% FS), and high levels (80–100% FS) for each pollutant and diluent gas analyzer must be used.

6.3.1.3 Calibration Gas Injection Port. The test gases must be introduced at the CEM system calibration gas port specified in Table 2 (in Section 3.1.1).

6.3.1.4 Test Procedures. The CEM system must be operating normally during the test, with all pressures, temperatures, and flows at nominal values. Each test gas must be introduced and the system response allowed to stabilize, then the concentration of the pollutant or diluent gas indicated by the data acquisition system output must be recorded. The three ranges for each gas must not be introduced in succession or in the same sequence, but must be alternated with other reference gases.

The average response of the system, as indicated by the data acquisition system, to the three challenges of each gas for each pollutant or diluent gas analyzer at low, mid, and high levels must be calculated.

Further details on the use of stack gas moisture monitoring systems are presented in Appendix B.

6.3.1.5 Calculations. The average linearity error for the responses to each of the low-, mid-, and high-level test gases should be calculated using Equation 17.

$$L_j = \frac{100}{3xFS}\sum_{i=1}^{3}\left|d_{ji}\right| \qquad \textbf{Equation 17}$$

where:

L_j = linearity error of the low-, mid-, or high-level calibration (%)

FS = full-scale value of the tested CEM range (ppm or %)

d_{ji} = difference between the low-, mid-, or high-level reference gas and the corresponding CEM system measurement for the i^{th} test run (ppm or %)

j = low-, mid-, or high-level reference gas

i = 1 of 3 injections of each low-, mid-, or high-level reference gas

6.3.1.6 Acceptance Criteria. The linearity error must not exceed the greater of:

Pollutant gas analyzer

Low level: 4.0% of the FS setting or 5 ppm absolute difference

Mid level: 4.0% of the FS setting or 5 ppm absolute difference

High level: 5.0% of the FS setting or 5 ppm absolute difference

Diluent gas analyzer

Low level: 1.0% O_2 (or CO_2)

Mid level: 1.0% O_2 (or CO_2)

High level: 1.0% O_2 (or CO_2)

Stack gas moisture monitor (dry O_2 – wet O_2 systems)

Low level: 1.0% O_2

Mid level: 1.0% O_2

High level: 1.0% O_2

6.3.1.7 Alternate quarterly audit. Where the type of CEM does not allow a test gas to be used (e.g., certain in situ path-type analyzers), an independent check on the CEM system performance must be carried out every quarter, when the generation unit is operational. To that effect, the response for each gas being monitored is compared with the measurements of a portable analyzer that meets the specifications of Environment Canada's Reference Method EPS 1/RM/15.

The procedures of this alternate audit are summarized as follows.

The portable analyzer is calibrated in the field, as per the manufacturer's recommended procedure, with low-level and high-level U.S. EPA protocol grade gases. Then the analyzer is fed a stack gas sample extracted from a point within 0.3 m from the CEM sensing point or path. After a stabilization period, the measurements from the portable analyzer are logged every 30 seconds, for a minimum period of 5 minutes. Then the analyzer is fed low-level calibration gas or filtered ambient air until stable readings are obtained. The low-level drift is recorded. The stack gas extraction and logging is repeated for a second sampling period of the same duration, and so on, for a minimum total of six (6) test periods. Finally the analyzer is fed high-level calibration gas until stable readings are obtained. The high-level drift is recorded. The relative accuracy of the concurrent

CEM measurements is calculated using equations 4 to 7 (Section 5.3.4.2).

The relative accuracy for an SO_2 and NO_X gas analyzer must not exceed 15% or 12 ppm absolute difference (|d|), whichever is greater.

The relative accuracy for an O_2 or (CO_2) gas analyzer must not exceed 15% or 0.5% absolute difference (|d|), whichever is greater.

6.3.1.8 Out-of-Control Period. An out-of-control period occurs when a cylinder gas test exceeds the specification as presented in Section 6.3.1.6 or the specification in Section 6.3.1.7, as applicable. This period begins with the minute after the completion of the test and ends with the minute after corrective action has been taken and when the system has demonstrated that it is operating satisfactorily. When an analyzer or system is out of control, the data generated by the specific analyzer or system are considered missing and do not qualify for meeting the requirement for system availability. Missing data must be backfilled using the criteria provided in Section 3.4.3.

6.3.2 Stack Gas Flow Test

The operation of the stack gas flow monitor must be audited quarterly, by one of the following options:

a) evaluation of flow-to-output quarterly data;

b) evaluation of heat-to-output quarterly data;

c) performance of abbreviated flow-to-output or heat-to-output tests; or

d) performance of flow RM tests.

One of options a to d should be selected, taking into consideration the operating conditions of the generating unit during the quarter, including type and variety of fuel(s) combusted, the output types (steam versus electricity), the operating mode (base load versus peaking), the existence of O_2 and CO_2 monitors in the CEM system, and the estimated measurement accuracy of flow-related parameters. Procedures for options a to d are outlined in Sections 6.3.2.4 to 6.3.2.7.

6.3.2.1 Frequency. A stack gas flow test must be performed in each quarter of the calendar year, with tests being no closer than 30 days for two adjacent quarters. In peaking units, this test must be performed annually, immediately before the relative accuracy test audit (RATA).

6.3.2.2 Acceptance Criteria. Acceptance criteria for options a to d are presented at the end of each of Sections 6.3.2.4 to 6.3.2.7.

6.3.2.3 Out-of-Control Period. An out-of-control period occurs when a stack gas flow test exceeds the specifications presented in Sections 6.3.2.4 to 6.3.2.7, as applicable. This period begins with the minute after the completion of the test and ends with the minute after corrective action has been taken and when the system has demonstrated that it is operating satisfactorily. When a flow monitor is out of control, the data generated by the flow monitor are considered missing and do not qualify for meeting the requirement for system availability. Missing data must be backfilled using the criteria provided in Section 3.4.3.

6.3.2.4 Analysis of Flow-to-Output Data. If the quarter includes a minimum of 168 hours of valid CEM data at electric output levels within 10% of the average output of the last RATA, then the average flow-to-output is calculated using Equation 18.

$$R_h = \frac{1}{n}\sum_{h=1}^{n}\frac{Q_{wh}}{MW_h}$$ **Equation 18**

where:

R_h = average value of flow to electric output ratio, from the quarterly hours in which the electric output was within 10% of the average electric output during the last RATA (WSm^3/h/MW)

Q_{wh} = flow from the quarterly hours in which the electric output was within 10% of the average electric output during the last RATA (WSm^3/h)

MW_h = electric output from the quarterly hours in which the electric output was within 10% of the average electric output during the last RATA (MW)

n = number of quarterly hours in which the electric output was within 10% of the average electric output during the last RATA ($n \geq 168$)

Periods of diverse fuel blends, output ramping, scrubber bypass, or other non-representative hourly data may be excluded from the calculation of average R_h. In peaking units, the potential data base must include all the preceeding 12 months of unit operation.

$E_{Q\ to\ MW}$, the absolute percent difference between R_h and R_{ref} (the latter based on previous RATA data and calculated with Equation 8), is calculated using Equation 19.

$$E_{Q\ to\ MW} = \frac{|R_{ref} - R_h|}{R_{ref}} \times 100 \qquad \textbf{Equation 19}$$

Acceptable flow-to-output results are as follows:

$E_{Q\ to\ MW} \leq 10\%$, for output levels ≥60 MJ/s
$E_{Q\ to\ MW} \leq 15\%$, for output levels <60 MJ/s

6.3.2.5 Analysis of Heat Input – Electric Output Data. If the quarter includes a minimum of 168 hours of valid CEM data at levels within ±10% of the average electric output of the last RATA and the CEM system can calculate hourly heat input on the basis of the measured stack gas flow and F-factors (as shown in Table A-1 and Equation 8) or, in the case of gaseous and liquid fuel, on the basis of the measured flow rate and gross heating value of the fuel, then the average heat input to electric output ratio (or gross heat rate, GHR_h) may be calculated using Equation 20.

$$GHR_h = \frac{1}{n}\sum_{h=1}^{n} \frac{HI_h}{MW_h} \qquad \textbf{Equation 20}$$

where:

GHR_h = average value of gross heat rate, from the quarterly hours in which the electric output was within 10% of the average electric output of the last RATA (GJ/MWh)

HI_h = gross heat input from the quarterly hours in which the electric output was within 10% of the average electric output during the last RATA (GJ/h)

MW_h = gross electric output from the quarterly hours in which the electric output was within 10% of the average electric output during the last RATA (MW)

n = number of quarterly hours in which the electric output was within 10% of the average electric output during the last RATA (n ≥168)

Periods of diverse fuel blends, output ramping, scrubber bypass, or other non-representative hourly data may be excluded from the calculation of average GHR_h. In peaking units, the potential data base must include all the preceeding 12 months of unit operation.

$E_{GHR\ to\ MW}$, the absolute percentage difference between GHR_h and GHR_{ref} (the latter based on RATA data and calculated with Equation 13), is calculated using Equation 21.

$$E_{GHR\ to\ MW} = \frac{|GHR_{ref} - GHR_h|}{GHR_{ref}} \times 100 \qquad \textbf{Equation 21}$$

Acceptable heat-to-output results are as follows:

$E_{GHR\ to\ MW} \leq 10\%$, for input levels ≥171 MJ/s
$E_{GHR\ to\ MW} \leq 15\%$, for input levels <171 MJ/s

6.3.2.6 Performance of Abbreviated Flow-to-Output or Heat-to-Output Tests. An abbreviated flow-to-output test consists of a period of 6–12 consecutive hours during which the process conditions reproduce as closely as practicable the conditions of the most recent flow RATA. It is recommended that the output be held constant to within 10% of the average output during the last flow RATA and the diluent concentration (O_2 or CO_2) to within 0.5% O_2 or CO_2.

For a flow-to-output test, for this period, R_h is calculated using Equation 18 and $E_{Q\ to\ MW}$ using Equation 19. Acceptable $E_{Q\ to\ MW}$ levels are the same as in Section 6.3.2.4.

For a heat-to-output test, for this period, GHR_h is calculated using Equation 20 and $E_{GHR\ to\ MW}$ using Equation 21. Acceptable $E_{GHR\ to\ MW}$ levels are the same as in Section 6.3.2.5.

6.3.2.7 Performance of Flow Reference Method Measurements. This test must be carried out using Method B from "Reference Methods for Source Testing: Measurement of Releases of Particulate from Stationary Sources" (Environment Canada, December 1993, as amended). Wall effects and complex velocity patterns may be determined with U.S. EPA Methods 2H, CTM-041, and 2F/2G or with equivalent methods approved by an appropriate regulatory authority. The audit comprises three consecutive RM measurements. CO_2, O_2, and moisture values from a certified CEM system may be used for calculating molecular weights during this testing.

E_f, the average of the absolute difference between the RM value and the corresponding CEM system flow measurement, is calculated using Equation 22.

$$E_f = \frac{1}{3 \times RM} \sum_{i=1}^{n} \left| d_i \right| \qquad \textbf{Equation 22}$$

where:

d_i = difference between an RM value and the corresponding CEM system measurement for the i^{th} test run (m/s or m^3/s)

RM = average gas velocity or flow rate, as measured by the reference method (m/s or m^3/s)

Acceptable results are as follows:
$E_f \leq 6\%$ of FS, or average $|d_i| \leq 1.2$ m/s

6.3.3 F-Factor System Test

CEM systems that rely on F-factors and fuel flow monitors to calculate contaminant emissions in terms of mass per unit time must be audited quarterly by one of the following options:

a) evaluation of heat-to-output quarterly data;

b) performance of abbreviated heat-to-output data; or

c) evaluation of hourly heat input to commercial fuel billing.

One of options a to c should be selected, taking into consideration the operating conditions of the generating unit during the quarter, including type and variety of fuel(s) combusted, the output types (steam versus electricity), the operating mode (base load versus peaking), and the availability and nature of commercial fuel billing data.

6.3.3.1 Frequency. An F-factor system test must be performed in each quarter of the calendar year, with tests being no closer than 30 days for two adjacent quarters, using the following procedures. In peaking units, this test must be performed annually, immediately before the relative accuracy test audit (RATA).

6.3.3.2 Procedures. Procedures for options a and b are presented in Sections 6.3.2.5 and 6.3.2.6, respectively. Procedures for option c are site specific, depending on the configuration of the fuel handling system. The procedures to evaluate quarterly the accuracy of the hourly heat input to the CEM system should be based on the following principles:

c1) The satisfactory accuracy of the hourly fuel flow to the CEM system is 2.0% FS.

c2) A gas or oil flow meter used for commercial billing is satisfactory to provide hourly heat output to the CEM system, providing that <5% of the metered flow is diverted for uses other than the generating unit.

c3) Additional periodic determination of fuel gross calorific value (GCV) may be necessary to demonstrate that the hourly heat input to the CEM system is accurate within 2.0% FS. Fuel FS value is that corresponding to maximum heat input to the generating unit.

c4) When commercial billing is determined by lot, as opposed to continuously, and/or the metered fuel handling system serves more than one unit, then the demonstration of measurement accuracy may be accomplished for one or several lots and/or the composite of all the units served by the fuel handling system.

The quarterly audit procedures of the heat input component of the CEM system must be described in the QA/QC manual.

6.3.3.3 Acceptance Criteria. Acceptance criteria for options a and b are presented in Sections 6.3.2.5 and 6.3.2.6. Acceptance criteria for option c is the demonstrated compliance with principles c1 to c4 in Section 6.3.3.2.

6.3.3.4 Out-of-Control Period. An out-of-control period occurs when an F-factor system test exceeds the specifications presented in Section 6.3.3.3. This period begins with the minute after the completion of the test and ends with the minute after corrective action has been taken and when the system has demonstrated that it is operating satisfactorily. When the system is out of control, the data generated by the system are considered missing and do not qualify for meeting the requirement for system availability. Missing data must be backfilled using the criteria provided in Section 3.4.3.

6.4 Semiannual Performance Evaluations

Two test procedures are involved in the semiannual performance evaluation: a relative accuracy test and a bias test. These are carried out for each pollutant and diluent gas measured, as well as for stack gas flow and stack gas moisture (if the CEM system is fitted with a stack gas flow monitor).

6.4.1 Relative Accuracy and Bias Tests

6.4.1.1 Frequency and Timing of Evaluations. A performance evaluation is carried out twice a year, no less than 4 months apart. It is highly recommended that this evaluation coincide with a scheduled quarterly performance evaluation and be carried out on a day closely following the cylinder gas test.

6.4.1.2 Test Gases. The gases used by both the CEM system and the reference method during the RA test must be U.S. EPA protocol grade.

6.4.1.3 Test Procedures. Relative accuracy and bias must be tested according to procedures and calculations in Sections 5.3.4 and 5.3.5. Only one capacity level needs to be tested.

Further details on the use of stack gas moisture monitoring systems are presented in Appendix B.

6.4.1.4 Acceptance Criteria. The following performance specifications must be met, providing that the CEM system includes the monitored parameter.

Relative accuracy

The relative accuracy for an SO_2 and NO_X monitor must not exceed 10% or 8 ppm average absolute difference (|d|), whichever is greater.

The relative accuracy for an O_2 (or CO_2) monitor must not exceed 10% or 0.5% O_2 (or CO_2) average absolute difference (|d|), whichever is greater.

The relative accuracy for a stack gas flow monitor must not exceed 10% or 0.6 m/s average absolute difference (|d|), whichever is greater.

The relative accuracy for the stack gas moisture stack gas monitor must not exceed 10% for (100 – $\%B_{ws}$).

The relative accuracy for SO_2 and NO_X mass emissions must not exceed 10% or 7.3 g/GJ heat input average absolute difference (|d|), whichever is greater.

Meeting the relative accuracy for SO_2, NO_X, O_2, and CO_2 concentrations and stack gas flow does not guarantee meeting the relative accuracy for SO_2 and NO_X mass emissions.

Bias

The bias for an SO_2 and NO_X monitor must not exceed 5.0% of the FS value or 5 ppm average absolute difference when no BAF is used, whichever is greater.

The bias for an O_2 (or CO_2) monitor must not exceed 5.0% of the FS value or 0.5% O_2 (or CO_2) average absolute difference when no BAF is used, whichever is greater.

The bias for a stack gas flow monitor must not exceed 5.0% of the FS value or 0.6 m/s average absolute difference when no BAF is used, whichever is greater.

The bias for a stack gas moisture monitor must not exceed 5.0% of the FS value for (100 – $\%B_{ws}$).

Should there be any bias as defined in Section 5.3.5, either positive or negative, in any measurements made by the CEM system, the data that are subsequently generated must be corrected for the bias before any subsequent use is made of the data.

6.4.1.5 Out-of-Control Period. An out-of-control period occurs when the relative accuracy or bias tests exceed the specifications as presented in Section 6.4.1.4. This period begins with the minute after the completion of the test and ends with the minute after corrective action has been taken and when the system has demonstrated that it is operating satisfactorily. When an analyzer, monitor, or system is out of control, the data generated by the specific analyzer, monitor, or system are considered missing and do not qualify for meeting the requirement for system availability. Missing data must be backfilled using the criteria provided in Section 3.4.3.

6.4.2 Exemptions from Semiannual Evaluations

The semiannual test may be waived and conducted annually after the first year of operation if all of the following criteria have been met, providing that the CEM system includes the monitored parameter:

- the system availability is greater than 95% annually;
- the previous relative accuracy for the pollutant gas analyzers is less than either 7.5% or 8 ppm mean absolute difference;
- the previous relative accuracy for the diluent gas analyzers is less than either 7.5% or 0.5% O_2 (or CO_2) mean absolute difference;
- the previous relative accuracy for the flow monitor is less than either 7.5% or 0.6 m/s mean absolute difference;
- the previous relative accuracy for the stack gas moisture monitor is less than 7.5% for (100 – $\%B_{ws}$); and
- the previous relative accuracy of the pollutant emission system is less than either 7.5% or 7.3 g/GJ heat input average absolute difference.

6.5 Annual Performance Evaluations

6.5.1 Availability

The percentage availability for the system, for each pollutant and diluent gas analyzer, and for the flow monitor is calculated annually using Equation 23.

$$AVA = \frac{T_a}{T} \times 100 \qquad \textbf{Equation 23}$$

where:

AVA = availability for the system, gas analyzer, or flow monitor (%)

T_a = number of hours during which a) the generating unit burned fuel and b) the system, gas analyzer, or flow monitor generated data that met the valid hour requirements of Section 3.4.1

T = total number of hours during which the generating unit burned fuel during the year

The availability of the system, gas analyzers, and flow monitor must be at least 90% annually for the first full year of operation and 95% annually thereafter. The availability for peaking units must be at least 80% annually.

6.5.2 Independent Inspection

The CEM system and the QA/QC program must be evaluated by an independent inspector every 12 months ± 1 month.

The inspector must review the QA/QC manual, the CEM system operation, reports, and other associated records to determine if the procedures in the QA/QC manual are being followed. The inspector must also note any changes in the system or the procedures since the last yearly evaluation and ensure that these have been included in the QA/QC manual.

The inspector must report the findings and observations to the CEM system management and the appropriate agency within 30 days after the evaluation is completed. This report may include recommendations for improvements in the CEM system or its operation.

6.6 Criteria for Acceptable Quality Assurance/Quality Control Procedures

Repeated excessive out-of-control periods during quarterly or semiannual evaluations indicate that the QA/QC procedures are inadequate or that the CEM system is incapable of generating acceptable data. The system owner must keep track of out-of-control periods. Repeated out-of-control situations from the same cause must be investigated, and corrective action must be taken. Should the out-of-control periods continue to occur after these actions are completed, it may be necessary to replace the monitoring system.

6.7 Quality Assurance Reporting Requirements

Within 30 days of the end of each quarter, the CEM system operator must prepare a report of the results of performance evaluations carried out within the quarter.

For each quarter, the daily drift data must be summarized for each analyzer in the CEM system using a control chart format. The quarterly three-level cylinder gas tests and flow test results must be reported, as well as the results of any relative accuracy and bias tests conducted during the quarter.

As a minimum, the report must contain the following information:

- source/CEM system owner and address;
- identification (manufacturer, model, and serial number) and location of analyzers in the CEM system;
- control charts of daily drift for each analyzer;
- RATA (if applicable) and quarterly three-level cylinder gas test results;
- flow test results;
- system evaluation findings, observations, and recommendations; and
- summary of all corrective actions taken when the CEM system (or analyzers) was found to be out of control.

Every fourth quarter, the report must also include annual availability.

Glossary

In this document,

"**720-hour rolling average**" means, for each pollutant, the average of the consecutive hourly mean emissions, determined for the preceding 720 hours of system operation. Intervals of zero emissions are not to be included in the calculations of rolling averages.

"**accuracy**" means the extent to which the results of a calculation or the readings of an instrument approach the true values of the calculated or measured quantities, and are free from error.

"**analyzer**" is the system that measures pollutant or diluent concentration in the discharge gas stream.

"**appropriate regulatory authority**" means any federal, provincial, territorial, or local government that has or could exercise regulatory or other authority over the monitored emissions.

"**availability**" means the number of valid hours divided by the number of hours that the generating unit burns fuel.

"**backfilling**" means a technique to substitute data during an out-of-control period produced by a technique approved by an appropriate regulatory authority.

"**bias**" means systematic error, resulting in measurements that are either consistently low or high relative to the reference value. Bias exists when the difference between the continuous emission monitoring data and the reference method data exceeds random error.

"**calibration gas**" means a known concentration of (1) a gas that is traceable to either a standard reference material or the U.S. National Institute of Standards and Technology, (2) an authorized certified reference gas, or (3) a U.S. Environmental Protection Agency protocol gas.

"**conditioning period**" means a recommended 168-hour period following the installation of a new continuous emission monitoring system, during which the system samples and analyzes the emissions from the source, prior to the operational test period.

"**continuous emission monitoring system**" means the complete equipment for sampling, conditioning, and analyzing emissions or process parameters and for recording data.

"**drift**" means an undesired change in output, over a period of time, that is unrelated to input or equipment adjustments.

"**flow monitor**" is the system that monitors the actual linear velocity or flow rate of the discharge gas stream. Alternatives to flow monitoring are provided in Appendix B.

"**full scale**" means the upper value of the monitor or analyzer range.

"**generating unit**" means a fuel-fired combustion device used for electricity generation.

"**heat input rate**" means the product of the gross calorific value of the fuel and the fuel feed rate into the combustion device and does not include the heat derived from preheated combustion air, recirculated flue gases, or exhaust from other sources.

"**interference rejection**" means the ability of a continuous emission monitoring system to measure a gaseous species without responding to other gases or substances, within specified limits.

"**net energy output**" means gross energy output minus unit service power requirements.

"**nitrogen oxides**" means all oxides of nitrogen except nitrous oxide, collectively expressed as nitrogen dioxide.

"**operational test period**" means a mandatory 168-hour period following the installation of a new continuous emission monitoring system, during which most of the performance specification tests are carried out.

“**out-of-control period**” means a period when the output from the analyzer, flow monitor, or data acquisition system does not accurately represent the stack emissions.

“**peaking unit**” means a generating unit ordinarily used to supply power at periods of high demand or during unforeseen outages. Such a unit will not operate more than 7500 hours in any 5-year period and, in those years, more than a total of 3000 hours during the months of May, June, July, August, and September.

“**precision**” means the measure of the range of values of a set of repeated measurements; indicates reproducibility of the observations.

“**range**” means the algebraic difference between the upper and lower limit of the group of values within which a quantity is measured, received, or transmitted.

“**reference method**” means any applicable Environment Canada method for the measurement of stack gas flow, contaminant concentration, or diluent concentration, or an equivalent method approved by an appropriate regulatory authority.

“**relative accuracy**” is the absolute mean difference between a series of concurrent measurements made by a continuous emission monitoring system and an appropriate reference method plus the 2.5% error confidence internal coefficient, divided by the mean of the reference method measurements.

“**representative load**” is the typical unit operating level forecasted for the following 6 months.

“**standard conditions**” means at 101.325 kPa pressure and 25°C temperature.

“**units of the standard**” means the emission limits stated by Environment Canada’s New Source Emission Guidelines for Thermal Electricity Generation, or an alternate limit (either as a concentration or mass) set by an appropriate regulatory authority.

“**valid hour**” means an hour during which the generating unit burned fuel and the associated continuous emission monitoring system produced a minimum of 30 minutes of valid data. In the case of a time-shared continuous emission monitoring system, the minimum requirement is two data points per valid hour.

Units, Abbreviations, and Acronyms

In this document,

avg	average
BAF	bias adjustment factor
BTU	British thermal unit
$\%B_{ws}$	moisture content of the stack gas (% v/v)
°C	degree Celsius
CEM	continuous emission monitoring
CFR	U.S. Code of Federal Regulations
cm	centimetre
CO_2	carbon dioxide
|d|	absolute difference
DSm^3/GJ	dry standard cubic metre per gigajoule
DSm^3/MJ	dry standard cubic metre per megajoule
EPS	Environmental Protection Service
F_c	ratio of the carbon dioxide volume generated by the combustion of a given fuel to the amount of heat produced (Sm^3/MJ)
F_d	ratio of the stoichiometric volume of dry gas generated by the complete combustion of a given fuel with air to the amount of heat produced (DSm^3/MJ)
F-factor	F_c, F_d, or F_w
FS	full scale
F_w	ratio of the stoichiometric volume of wet gas generated by the complete combustion of a given fuel with air to the amount of heat produced (WSm^3/MJ)
g/GJ	grams per gigajoule
GCV	gross calorific value
GJ/h	gigajoules per hour
GJ/MWh	gigajoules per megawatt hour
ISO	International Organization for Standardization
K	Kelvin
kg/GJ	kilograms per gigajoule
kg/h	kilograms per hour
kg/MWh	kilograms per megawatt hour
kg/Sm^3	kilograms per standard cubic metre
kJ/kg	kilojoules per kilogram
kPa	kilopascal
LEDs	light-emitting diodes
m/s	metres per second

m^3/GJ	cubic metres per gigajoule
m^3/kg-mol	cubic metres per kilogram mole
m^3/s	cubic metres per second
MJ/h	megajoules per hour
MJ/MWh	megajoules per megawatt hour
MJ/s	megajoules per second
MW	megawatt
MWh	megawatt hour
ng/J	nanograms per joule
NO_2	nitrogen dioxide
NO_X	nitrogen oxides
O_2	oxygen
OEM	original equipment manufacturer
OTP	operational test period
ppm	parts per million
P_{std}	Environment Canada's standard pressure, 101.325 kPa
QA	quality assurance
QA/QC	quality assurance / quality control
QC	quality control
RA	relative accuracy
RATA	relative accuracy test audit
RM	reference method
Sm^3/GJ	standard cubic metres per gigajoule
Sm^3/h	standard cubic metres per hour
Sm^3/MJ	standard cubic metres per megajoule
Sm^3/MWh	standard cubic metres per megawatt hour
SO_2	sulphur dioxide
U.S. EPA	United States Environmental Protection Agency
v/v	volume per volume basis
WSm^3/GJ	wet standard cubic metres per gigajoule
WSm^3/h	wet standard cubic metres per hour
WSm^3/h/MW	wet standard cubic metres per hour per megawatt
WSm^3/MJ	wet standard cubic metres per megajoule

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APPENDIX A CALCULATION OF EMISSIONS BY F-FACTORS

A.1 Introduction

F-factors are used to calculate pollutant emission rates, expressed in units of mass per energy, such as ng/J. They may also be used to give a true mass emission rate (weight per time) if the heat input to the combustion process is known.

The F_c-factor is the ratio of the carbon dioxide volume generated by the combustion of a given fuel to the amount of heat produced. The F_d-factor is the ratio of the stoichiometric volume of dry gas generated for complete combustion of a given fuel with air to the amount of heat produced. The F_w-factor is the ratio of the stoichiometric volume of wet gas generated for complete combustion of the fuel with air to the amount of heat produced.

The F-factor to use in calculating emissions is determined by the diluent gas monitored. CEM systems with CO_2 analyzers should use F_c factors, whereas those with O_2 analyzers should use F_d or F_w factors. CEM systems with both O_2 and CO_2 analyzers should use the F-factor that produces the most accurate exhaust volume estimates, taking into consideration the expected O_2 and CO_2 levels.

Note that the reference conditions for the F-factors are 25°C and 101.325 kPa. Where the results are compared with data generated at other reference conditions, the data must be compensated. Site-specific F-factors may be developed, but any factors so developed will require approval by the appropriate regulatory agency before being applied.

F-factors for specific fuels are provided in Table A-1.

A.2 Oxygen-Based Dry Measurement Systems

The dry oxygen-based factor is employed in CEM systems using analyzers measuring the concentration of pollutants and oxygen as a diluent gas, from which the water vapour in the sample gas has been removed before analysis.

The desired emission rate E in kg/GJ for both NO_X (as NO_2) and SO_2 is calculated using Equation A-1.

$$E_X = C_{d,x} F_d K_x \left[\frac{20.9}{(20.9 - \%O_{2d})} \right] \qquad \textbf{Equation A-1}$$

Table A-1 F-Factors for Selected Canadian Fuels

Fuel	Type	Dry oxygen-based F-factor (F_d) (DSm³/GJ)*	Wet oxygen-based F-factor (F_w) (WSm³/GJ)*	Carbon dioxide-based F-factor (F_c) (Sm³/GJ)*
Coal	Anthracite	277	288	54.2
	Bituminous	267	286	49.2
	Sub-bituminous	263	301	49.2
	Lignite	273	310	53.0
Oil	Crude, residual, or distillate	255	289	39.3
Gas	Natural	240	295	28.4
	Propane	238	281	32.5

* Sm^3 denotes one standard cubic metre (i.e., 1 m^3 at 101.325 kPa and 25°C); GJ = 1 000 000 000 joules.

where:

E_x = emission rate of pollutant x (kg/GJ)

$C_{d,x}$ = dry-basis concentration of pollutant x (ppm, dry)

F_d = ratio of the stoichiometric volume of dry gas generated for complete combustion of a given fuel to the amount of heat produced (DSm^3/GJ)

K_x = conversion factor of pollutant x for ppm into kg/Sm^3 ($kg/Sm^3/ppm$)

$\%O_{2d}$ = dry-basis concentration of oxygen (%, v/v)

The values of K_x for SO_2 and NO_X used in Equations A-1 to A-7 are:

SO_2	2.618×10^{-3} $kg/Sm^3/ppm$
NO_x (as NO_2)	1.880×10^{-3} $kg/Sm^3/ppm$

The values of K_x for other gases can be calculated using the following formula:

$$K_x = (MW_x \times 1\,000\,000) / [22.414 * (T_{std} / 273.15)]$$

where:

MW_x = molecular weight of gas x

T_{std} = Environment Canada's standard temperature (298.15 K)

22.414 = molar volume at 273.15 K (m^3/kg-mol)

A.3 Oxygen-Based Wet Measurement Systems

This factor is used for systems employing wet-basis analyzers, which includes all in situ wet-basis direct-reading CEM systems. This wet-basis factor may be used where no water, other than that generated during the combustion process, is introduced into the gas flow.

The desired emission rate in kg/GJ is calculated using Equation A-2.

$$E_X = C_{w,x} F_w K_x \left[\frac{20.9}{0.209\,(100 - \%B_{wa}) - \%O_{2w}} \right]$$

Equation A-2

where:

E_X = emission rate of pollutant x (kg/GJ)

$C_{w,x}$ = wet-basis concentration of pollutant x (ppm)

F_w = ratio of the volume of wet gas generated by the stoichiometric combustion of the fuel with air to the amount of heat produced (WSm^3/GJ)

K_X = conversion factor of pollutant x for ppm into kg/Sm^3 ($kg/Sm^3/ppm$)

$\%B_{wa}$ = concentration of water in the air present in the combustion process (%, v/v)

$\%O_{2w}$ = wet-basis concentration of oxygen (%, v/v)

Note that this expression cannot be used in any process in which water is added or removed from the flue gas stream. Therefore, it is not applicable for CEM systems installed after wet scrubbers.

If a wet-basis CEM system is installed after a pollution control device that reduces the flue gas temperature so that the exit gas is saturated or contains liquid water, the equation giving the mass-per-energy emission rate may be modified in order to calculate the desired emission rate. The flue gas temperature must be continuously measured at the discharge of the control device, with the gas saturated at that temperature. Note that the wet-basis concentration data from the analyzers may be converted to a dry basis when the water vapour concentration is known, and the calculations can be treated on this basis if so desired.

A.4 Carbon Dioxide-Based Measurement Systems

If carbon dioxide has been selected as the diluent gas, the carbon dioxide-based F-factor (F_c) must be used to determine the pollutant emission rate. The F_c factor may be used on either a dry- or wet-basis system, provided that the pollutant gases and CO_2 are measured on the same basis (wet or dry). The wet method is applicable to in situ, dilution, and extractive direct-reading, wet-basis systems.

The desired emission rate for dry-basis measurements is calculated using Equation A-3.

$$E_X = C_{d,x} F_c K_x \left[\frac{100}{\%CO_{2d}}\right]$$ **Equation A-3**

where:

E_x = emission rate of pollutant x (kg/GJ)
$C_{d,x}$ = dry-basis concentration of pollutant x (ppm, v/v)
F_c = ratio of the carbon dioxide volume generated to the heat produced (Sm^3/GJ)
K_x = conversion factor of pollutant x for ppm into kg/Sm_3 ($kg/Sm_3/ppm$)
$\%CO_{2d}$ = dry-basis concentration of CO_2 (%, v/v)

The desired emission rate for wet-basis measurements is calculated using Equation A-4.

$$E_X = C_{w,x} F_c K_x \left[\frac{100}{\%CO_{2w}}\right]$$ **Equation A-4**

where:

E_x = emission rate of pollutant x (kg/GJ)
$C_{w,x}$ = wet-basis concentration of pollutant x (ppm)
F_c = ratio of the carbon dioxide volume generated to the heat produced (Sm^3/GJ)
K_x = conversion factor of pollutant x for ppm into kg/Sm^3 ($kg/Sm^3/ppm$)
$\%CO_{2w}$ = wet-basis concentration of CO_2 (%, v/v)

Where CO_2 has been chosen as the diluent gas measured after a pollution control technique that adds CO_2 to the gas flow, the equation must be modified to account for the additional CO_2 as follows:

$$E_x = C_{d,x} F_c K_x \left[\frac{100}{\%CO_2 - \%CO_{2lim}}\right]$$ **Equation A-5**

where:

E_x = emission rate of pollutant x (kg/GJ)
$C_{d,x}$ = dry-basis concentration of pollutant x (ppm)
F_c = ratio of the carbon dioxide volume generated to the heat produced (Sm^3/GJ)
K_x = conversion factor of pollutant x for ppm into kg/Sm_3 ($kg/Sm_3/ppm$)
$\%CO_2$ = dry-basis concentration of CO_2 (%, v/v)
$\%CO_{2lim}$ = dry-basis contribution of CO_2 from the limestone used in the scrubber (%, v/v)

A.5 Mixed-Basis Measurement Systems

When a mixed-basis system is employed, the following two equations may be used to determine the desired energy-based emission rates:

Case 1: Pollutant (wet basis), CO_2 (dry basis)

$$E_x = C_{w,x} F_c K_x \left[\frac{100 \times 100}{(100 - \%B_{ws})\,\%CO_{2d}}\right]$$ **Equation A-6**

where:

E_x = emission rate of pollutant x (kg/GJ)
$C_{w,x}$ = wet-basis concentration of pollutant x (ppm)
F_c = ratio of the carbon dioxide volume generated to the heat produced (Sm^3/GJ)
K_x = conversion factor of pollutant x for ppm into kg/Sm^3 ($kg/Sm^3/ppm$)
$\%B_{ws}$ = stack gas moisture content (%, v/v)
$\%CO_{2d}$ = dry-basis concentration of CO_2 (%, v/v)

Case 2: Pollutant (dry basis), CO_2 (wet basis)

$$E_x = C_{d,x} \left[\frac{100 - \%B_{ws}}{100}\right] F_c K_x \left[\frac{1}{\%CO_{2w}}\right]$$ **Equation A-7**

where:

E_x = emission rate of pollutant x (kg/GJ)
$C_{d,x}$ = dry-basis concentration of pollutant x (ppm)
$\%B_{ws}$ = stack gas moisture content (%, v/v)
F_c = ratio of the carbon dioxide volume generated to the heat produced (Sm^3/GJ)
K_x = conversion factor of pollutant x for ppm into kg/Sm^3 ($kg/Sm^3/ppm$)
$\%CO_{2w}$ = wet-basis concentration of CO_2 (%, v/v)

A.6 Combined Combustion of Fuels

For sources simultaneously burning a combination of fossil fuels, a combined F-factor may be calculated using Equation A-8.

$$F_m = \sum_{i=1}^{n} (X_i F_i)$$ **Equation A-8**

where:
F_m = combined F-factor
X_i = fraction of the total heat input from fuel i
F_i = appropriate F-factor for fuel i
n = number of fuels burned

A.7 Calculation of Customized F-Factors

For fuels with compositions differing significantly from typical values or for fuels not listed in Table A-1, F-factors may be calculated using the ultimate analysis and gross calorific value (GCV) of the fuel. Equations A-9 to A-11 can be used to calculate the various F-factors.

It is recommended that F-factors be recalculated when the fuel characteristics change significantly.

$$F_d = 10^4 [(K_{hd}\ \%H) + (K_c\ \%C) + (K_s\ \%S) + (K_n\ \%N) + (K_o\ \%O)] / GCV_d$$ **Equation A-9**

$$F_w = 10^4 [(K_{hw}\ \%H) + (K_c\ \%C) + (K_s\ \%S) + (K_n\ \%N) + (K_o\ \%O) + (K_w\ \%H_2O)] / GCV_w$$ **Equation A-10**

Note: The $\%H_2O$ term must be omitted in the equation for F_w if %H and %O include the unavailable hydrogen and oxygen in the form of H_2O.

$$F_c = 10^4 (K_{cc}\ \%C) / GCV_d$$ **Equation A-11**

where:
F_d, F_w, F_c = volumes of combustion components per unit of heat content (m3/GJ) at 25°C and 101.325 kPa
%H, %C, %S, %N, %O, $\%H_2O$ = concentrations of hydrogen, carbon, sulphur, nitrogen, oxygen, and water, respectively, from ultimate analysis of fuel (weight percent)
GCV_d = gross calorific value of dry fuel (kJ/kg)
GCV_w = gross calorific value of wet fuel (kJ/kg)
10^4 = conversion factor (kJ/GJ/100)
K_{hd} = 22.97 Sm^3/kg, volume of dry exhaust gases resulting from the stoichiometric combustion of hydrogen in the fuel
K_c = 9.75 Sm^3/kg, volume of dry exhaust gases resulting from the stoichiometric combustion of carbon in the fuel
K_s = 3.65 Sm^3/kg, volume of dry exhaust gases resulting from the stoichiometric combustion of sulphur in the fuel
K_n = 0.87 Sm^3/kg, volume of dry exhaust gases resulting from nitrogen in the fuel
K_o = -2.89 Sm^3/kg, volume of dry combustion gases avoided due to oxygen in the fuel
K_{hw} = 35.10 Sm^3/kg, volume of wet exhaust gases resulting from the stoichiometric combustion of hydrogen in the fuel
K_w = 1.36 Sm^3/kg, volume of water vapour resulting from the water contained in the fuel
K_{cc} = 2.04 Sm^3/kg, volume of carbon dioxide produced during the complete combustion of the fuel

Appendix B Determination of Mass Emission Rates

B.1 Introduction

The emission rate of a pollutant, on a mass-per-unit-time basis, may be determined using one of the three methods described in this appendix:

- Method A: Direct measurement of the fuel flow rate to the process, and, therefore, the energy input rate, with the mass emission rate calculated from the mass-per-energy rate derived from F-factors.
- Method B: Measurement of the stack gas flow rate using a real-time gas flow sensor, with the mass emission rate calculated from the gas flow rate and the pollutant and diluent gas concentrations.
- Method C: Determination of the input energy using an overall energy balance around the combustion process. The mass emission rate is calculated from the heat input data so derived, along with the mass-per-energy rate derived from F-factors.

B.2 Method A: Energy Input Method — Metering of Fuel Flows

The calculation of the mass emission rate of a compound is shown as an example in Equation B-1, which applies to the measurement of the pollutant using an oxygen-based dry system:

$$ER_x = HI\ C_{d,x}\ F_d\ K_x \left[\frac{20.9}{(20.9 - \%O_{2d})}\right] \qquad \textbf{Equation B-1}$$

where:

ER_x = emission rate of pollutant x (kg/h)
HI = gross heat input (GJ/h)
$C_{d,x}$ = dry-basis concentration of pollutant x (ppm, v/v)
F_d = ratio of the volume of dry gas resulting from stoichiometric combustion of the fuel with air to the amount of heat produced (DSm^3/GJ)
K_x = conversion factor of pollutant x for ppm into kg/Sm^3 ($kg/Sm^3/ppm$)
$\%O_{2d}$ = dry-basis concentration of O_2 (%, v/v)

The equation is identical to Equation A-1 in Appendix A, with the exception of the additional term HI, the heat input rate, which converts the mass-per-energy rate into units of mass per time. Thus, an accurate heat input rate is required to calculate the desired mass emission rate.

The energy entering the combustion process can be determined by measuring the mass flow rate of the fuel and its gross calorific value (GCV). The appropriate software to input these parameters and to calculate the appropriate mass emission rates must be developed and installed and operational before the CEM system certification testing.

B.2.1 Determination of Heat Input Rate for Liquid Fuels

The flow of oil consumed in the combustion process must be measured and recorded on an hourly basis. The flow of oil is measured using an in-line fuel flow meter with the flow data automatically recorded by the data acquisition system. Any returning fuel flow must be metered by an additional in-line fuel flow meter with the flow data from this unit also automatically recorded by the data acquisition system, so that the hourly fuel consumption can be calculated.

Each fuel flow meter must meet an accuracy specification of 2.0%, as measured by the manufacturer or CEM system operator. Each flow meter must be recalibrated at least annually, or more frequently if so specified by the manufacturer in order to meet the accuracy specification of this protocol.

The as-fired oil must be sampled and analyzed to determine its heat content. Flow-proportional sampling or continuous-drip oil sampling must be carried out when the unit is combusting oil. The hourly samples must be blended into a composite sample and then analyzed for GCV and specific gravity, if necessary.

The protocols used for sampling and analysis for BTU content must be determined in consultation with the appropriate regulatory agency.

The average hourly heat input to the combustion unit is determined by multiplying the hourly mass flow of the oil and the average heat content of the fuel. The applicable pollutant mass emission rate is determined by inserting the average heat input (HI) to the combustion process into Equation B-1. When calculating the mass emission rate for a system using wet-basis analyzers or CO_2 as the diluent gas, the appropriate equations from Appendix A should be used, modified to include the value of HI.

B.2.2 Determination of Heat Input Rate for Gaseous Fuels

The volume of gaseous fuel consumed must be measured and recorded by the data acquisition system and an hourly average flow rate calculated. The fuel flow monitor must meet a 2.0% accuracy specification, as measured by the manufacturer or the system operator. The fuel flow monitor must be calibrated at the frequency indicated by the supplier to maintain the accuracy within the specifications.

The heat content of the fuel must be obtained from the fuel supplier on a weekly basis.

The hourly average heat input to the unit is determined by multiplying the hourly average volumetric flow rate by the heat content provided by the supplier.

The applicable pollutant mass emission rate is determined by inserting the hourly average heat input to the combustion process into Equation B-1. When using wet-basis analyzers or CO_2 as the diluent gas, the equations in Appendix A should be used, modified to include the heat input rate (HI), to calculate the desired mass emission rates.

B.2.3 Determination of Heat Input Rate for Solid Fuels

The weight of solid fuel consumed must be continuously monitored and recorded automatically by the data acquisition system and an hourly mass consumption calculated and recorded. The device used to continuously meter the fuel flow rate must meet a 2.0% accuracy specification and must be calibrated at the frequency indicated by the supplier as adequate to maintain the accuracy within the specifications.

A continuous sample of the solid fuel must be taken and a 24-hour composite of the collected fractions analyzed for GCV. The hourly heat input to the unit is determined by multiplying the daily GCV by the hourly mass flow rate of the fuel.

The mass emission rate of a pollutant is calculated in a manner similar to that for liquid and gaseous fuels.

B.3 Method B: Determination Using Real-Time Stack Gas Flow Monitors

The mass emission rate of the target pollutants can be determined from their concentration and the volumetric flow rate of the flue gas. There are several techniques for measuring the flow rate. Any gas flow rate monitoring system that meets the specifications and passes certification is acceptable and may be used.

The following procedures must be followed to compute hourly pollutant mass emissions.

When both the pollutant concentrations and flow rate are measured on a wet basis, the hourly emissions are calculated using Equation B-2. [remove italics from equation]

$$ER_X = Q_w C_{w,x} K_x$$ **Equation B-2**

where:

ER_x = emission rate of pollutant x (kg/h)

Q_w = wet stack gas volumetric flow rate (WSm³/h)

$C_{w,x}$ = wet-basis concentration of pollutant x (ppm)

K_x = conversion factor of pollutant x for ppm into kg/Sm³ (kg/Sm³/ppm)

When the pollutant concentration is measured on a dry basis whereas the flow rate is measured on a wet basis, the hourly emissions are calculated using Equation B-3.

$$ER_X = Q_w C_{d,x} K_x \frac{(100 - \%B_{ws})}{100}$$ **Equation B-3**

where:

ER_X = emission rate of pollutant x (kg/h)
Q_w = wet stack gas volumetric flow rate (WSm^3/h)
$C_{d,x}$ = dry concentration of pollutant x (ppm, v/v)
K_X = conversion factor of pollutant x for ppm into kg/Sm^3 ($kg/Sm^3/ppm$)
$\%B_{ws}$ = stack gas moisture content (%, v/v)

The mass emission monitoring by Equation B-3 requires the installation, operation, maintenance, and quality assurance of a continuous stack gas moisture monitoring system for measuring and recording the moisture of the stack gases. The following systems are acceptable:

- a combination of a wet O_2 analyzer and a dry O_2 analyzer; and
- a stack temperature sensor and a moisture look-up table (for demonstrably moisture-saturated gas).

If the CEM system includes a wet O_2 analyzer and a dry O_2 analyzer, then the stack gas moisture can be calculated using Equation B-4.

$$\%B_{ws} = 100 - \left(\frac{\%O_{2w}}{\%O_{2d}} \right) \qquad \textbf{Equation B-4}$$

where:

$\%B_{ws}$ = stack gas moisture content (%, v/v)
$\%O_{2w}$ = wet-basis concentration of O_2 in stack gas (%, v/v)
$\%O_{2d}$ = dry-basis concentration of O_2 in stack gas (%, v/v)

In the combustion of fuels of well-defined composition, it is generally possible to estimate stack gas moisture with the required accuracy by monitoring the wet O_2 level of stack gas and the moisture of the combustion air, by means of Equation B-5.

$$\%B_{ws} = 100 - \frac{F_d}{F_w}(100 - \%B_{wa})\frac{\%O_{2w}}{20.9} - \left(100 - \frac{F_d}{F_w}\right) \qquad \textbf{Equation B-5}$$

where:

$\%B_{ws}$ = stack gas moisture content (%, v/v)
F_d = ratio of the volume of dry gas resulting from stoichiometric combustion of the fuel with air to the amount of heat produced (DSm^3/GJ)
F_w = ratio of the volume of wet gas resulting from stoichiometric combustion of the fuel with air to the amount of heat produced (WSm^3/GJ)
$\%B_{wa}$ = ambient air moisture content (%, v/v)
$\%O_{2w}$ = wet-basis concentration of O_2 in stack gas (%, v/v)

The performance specifications for stack gas moisture monitoring systems based on wet O_2 and dry O_2 measurement (calibration drift, response time, relative accuracy, and availability) are summarized in Table 3, Section 5, and in Table 6, Section 6.

Other stack gas moisture monitoring systems may be proposed for use with Equation B-3, if the proponent demonstrates that the system calculates hourly the factor ($100 - \%B_{ws}$) with an error ≤ 2.0%. The specific QA activities related to the moisture monitoring system must then be described in the QA/QC manual.

B.4 Method C: Energy Balance Method

This method involves carrying out an overall energy balance around the combustion process, thereby determining the heat input to the system by difference. The mass emission rate of a pollutant is subsequently calculated from the mass-per-energy rate determined from the pollutant and diluent gas concentrations and the appropriate F-factor, along with the corresponding rate of energy input to the combustion process. The energy input rate must be calculated on the same basis as required for emissions reporting.

The energy balance method requires considerable understanding of the operation of a specific unit, and the procedures used in this method may differ from site to site. Subsequently, each CEM installation will require advance approval by the appropriate regulatory authority and their involvement in the development of the specific procedures to be used.

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