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Environmental Technology Verification Program

Advanced Monitoring Systems Center

Generic Verification Protocol for Mercury Continuous Emission Monitors at a Full-Scale Waste Incinerator

GENERIC VERIFICATION PROTOCOL

FOR

MERCURY CONTINUOUS EMISSION MONITORS
AT A FULL-SCALE WASTE INCINERATOR

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FOREWORD

This generic verification protocol is based upon a peer-reviewed specific test/quality assurance (QA) plan entitled "Test/QA Plan for Field Demonstration of Mercury Continuous Emission Monitors at the TSCA Incinerator," Rev. 3 (dated June 19, 2002). The test/QA plan was developed with vendor and stakeholder input by the ETV Advanced Monitoring Systems (AMS) Center. Peer reviewers for the test/QA plan were AMS Center stakeholders Philip Galvin, Will Ollison, and Roy Owens and Jeff Ryan of EPA's National Risk Management Research Laboratory. In preparing this generic verification protocol, specific names of individuals involved, technology vendors and technologies, test dates, and similar details in the test/QA plan were revised to be generic. The experimental design in the protocol is the same as that in the peer-reviewed test/QA plan.

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ACRONYMS

μg	microgram
AMS	Advanced Monitoring Systems
CEM	continuous emission monitor
CO	carbon monoxide
CO_2	carbon dioxide
dscm	dry standard cubic meter
EPA	Environmental Protection Agency
ETV	Environmental Technology Verification
Hg^o	elemental mercury
Hg_{ox}	oxidized mercury
Hg_T	total mercury
NIST	National Institute of Standards and Technology
O_2	oxygen
OH	Ontario Hydro
PCB	polychlorinated biphenyl
PE	performance evaluation
ppb	parts per billion
PS-12	Performance Specification 12
QA	quality assurance
QC	quality control
QMP	Quality Management Plan
RA	relative accuracy
RCRA	Resource Conservation and Recovery Act
RFA/COC	Request for analysis/chain of custody
RSD	relative standard deviation
TSA	technical systems audit
TSCAI	TSCA Incinerator

1 INTRODUCTION

1.1 Test Description

This protocol provides generic procedures for implementing a verification test and test/quality assurance (QA) plan for continuous emission monitors (CEMs) used to measure gaseous concentrations of mercury from the thermal treatment of waste. Verification tests are conducted under the auspices of the U.S. Environmental Protection Agency's (EPA) Environmental Technology Verification (ETV) program. The purpose of ETV is to provide objective and quality-assured performance data on environmental technologies, so that users, developers, regulators, and consultants have an independent and credible assessment of what they are buying and permitting.

Verification tests of monitoring technologies are coordinated by Battelle, of Columbus, Ohio, which is EPA's verification partner for the ETV Advanced Monitoring Systems (AMS) Center. The scope of the AMS Center covers verification of monitoring methods for contaminants and natural species in air, water, and soil. In performing verification tests, Battelle follows the procedures specified in this protocol and complies with quality requirements in the "Quality Management Plan for the ETV Advanced Monitoring Systems Center" (QMP).(1)

1.2 Test Objective

The purpose of a verification test generated from this protocol is to provide quantitative verification of the performance of mercury CEMs in a field installation setting while monitoring emissions that were generated from the thermal treatment of actual waste. The test facility may be a full-scale municipal, medical, or specialized mixed waste incinerator. The Toxic Substances Control Act Incinerator (TSCAI) at the East Tennessee Technology Park in Oak Ridge, Tennessee, is used as an example test facility in this generic protocol. The TSCAI holds federal and state permits and agreements to incinerate mixed waste, which consists of low-level radioactive and Resource Conservation and Recovery Act (RCRA) hazardous (mixed) wastes contaminated with polychlorinated biphenyls (PCBs). It is the only operational incinerator in the United States that can process PCB-containing hazardous and radioactive waste. The TSCAI currently monitors oxygen (O_2), carbon monoxide (CO), carbon dioxide (CO_2), and radionuclide emissions as required by permit. A developmental system for monitoring metals emissions is also in use.

The mercury CEMs shall be challenged by stack gases generated from the thermal treatment of a variety of actual wastes in a full-scale facility. Depending on the levels of mercury present in the waste, mercury may be injected into the incinerator combustion chambers to adjust the concentration level in the stack for testing purposes. CEM responses shall be compared with reference mercury measurements of total (Hg_T), oxidized (Hg_{ox}), and elemental mercury (Hg°). Mercury standard gases shall be used to challenge the CEMs for calibration purposes, and the stability of the standards themselves shall be evaluated.

1.3 Scope of Work

Since mercury CEMs are a relatively new group of instruments, procedures to assess their performance were not fully established at the time this protocol was written. The EPA had published draft Performance Specification 12 (PS-12) as a proposed description of how to assess the acceptability of newly installed mercury CEMs.[2] However, draft PS-12 is patterned after performance specifications for CEMs for other pollutants, such as sulfur dioxide and nitrogen oxides, and, as a result, includes requirements that may be inappropriate or not feasible for mercury CEMs. The ETV program does not set performance criteria, nor draw pass/fail conclusions on the basis of such criteria, but ETV testing is intended to provide information that is relevant to real-world performance needs. Therefore, the performance parameters addressed by a mercury CEM verification test under this protocol are intended to meet the spirit of quantitative and qualitative performance requirements raised in PS-12.

The following performance parameters shall be addressed by the verification test:

- Relative accuracy
- Correlation with reference method results
- Precision
- Sampling system bias
- Calibration drift
- Zero drift
- Calibration error
- Response time
- Data completeness
- Operational factors.

Relative accuracy, correlation with the reference method results, and precision (i.e., repeatability at stable test conditions) shall be assessed for Hg_T; and, if feasible, for Hg_{ox} and Hg^o in the stack gas emissions. Sampling system bias, calibration and zero drift, response time, and calibration error shall be assessed for Hg° only, using commercial compressed gas standards of Hg°. The basis for establishing the quantitative performance of the tested technologies shall be the Ontario Hydro (OH) method[3] a standard method of measurement currently recognized as the most suitable procedure for speciation of Hg_T, Hg_{ox}, and Hg^o in source emissions.

1.4 Roles and Responsibilities

Verification tests are performed by Battelle in cooperation with EPA and the vendors whose CEMs are being verified. The test procedures may be performed by Battelle, test facility staff, or a qualified subcontractor. An organization chart for the verification test is shown in Figure 1. Vendor representatives should be present during installation of the CEMs to oversee installation and train testing staff in the routine operation and maintenance of the CEMs. It is also recommended that vendors be present during initial and final weeks of CEM performance

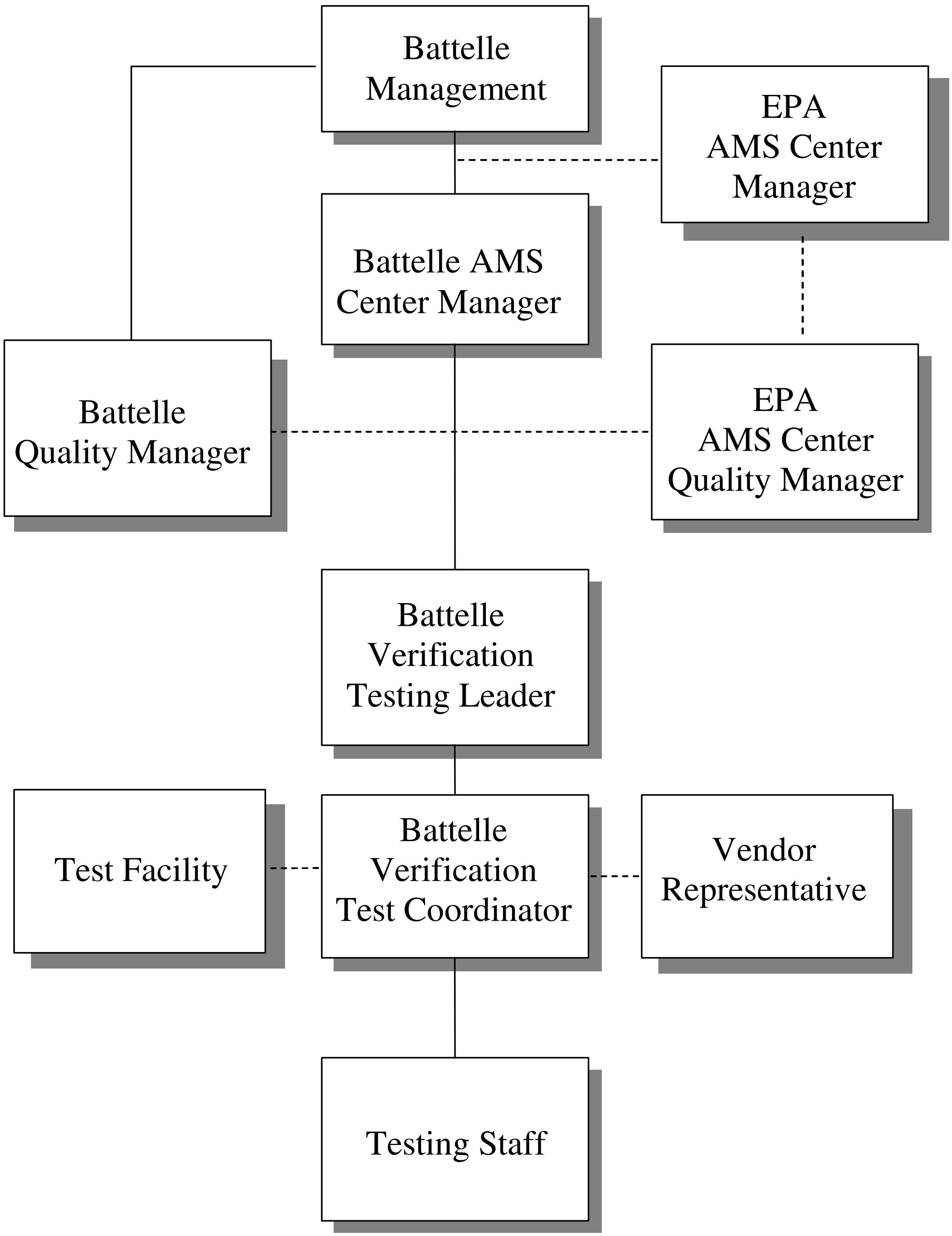

Figure 1. Organization Chart for Mercury CEM Verification Test

monitoring to ensure optimal operation of the CEMs for comparison with reference samples and calibration gas standards. Otherwise, routine daily operation and maintenance of the CEMs, as well as data logging, may be administered by a dedicated on-site technician provided by Battelle, the test facility, or a subcontractor. Throughout this protocol, reference to a test facility's role and responsibilities are representative of any suitably qualified test facility.

Specific responsibilities in each of several areas for verification within ETV are detailed in the following paragraphs.

1.4.1 Battelle

The AMS Center's Verification Test Coordinator has overall responsibility for ensuring that the technical goals, schedule, and budget established for the verification test are met. More specifically, the Verification Test Coordinator shall

- Serve as Battelle's primary point of contact for vendor and test facility representatives
- Coordinate with the test facility to conduct the verification test, including establishing a subcontract as necessary
- Ensure that procedures in this protocol are followed during the verification test
- Prepare draft verification reports and verification statements, revise according to reviewer comments, and be responsible for distribution of final copies
- Coordinate with the test facility, including collection and review of all data provided by the test facility.
- Respond to any issues raised in assessment reports and audits, including instituting corrective action as necessary
- Ensure that vendor confidentiality is maintained.

The Verification Testing Leader for the AMS Center provides technical guidance and oversees the various stages of the verification test. The Verification Testing Leader shall

- Support the Verification Test Coordinator in organizing the test
- Review the draft verification reports and statements.

The Battelle AMS Center Manager shall

- Review the draft verification reports and statements
- Ensure that necessary Battelle resources, including staff and facilities, are committed to the verification test
- Ensure that vendor confidentiality is maintained
- Support Verification Test Coordinator in responding to any issues raised in assessment reports and audits
- Maintain communication with the EPA AMS Center Manager and EPA AMS Center Quality Manager.

The Battelle Quality Manager for the verification test shall

- Conduct a technical systems audit (TSA) once during the verification test
- Review results of performance evaluation audit(s) specified in this protocol
- Audit at least 10% of the verification data
- Prepare and distribute an assessment report for each audit
- Verify implementation of any necessary corrective action
- Issue a stop work order if internal audits indicate that data quality is being compromised; notify Battelle's AMS Center Manager if such an order is issued
- Provide a summary of the audit activities and results for the verification reports
- Review the draft verification reports and statements
- Interface with test facility QA staff
- Ensure that all quality procedures specified in this protocol and in the QMP[1] are followed.

1.4.2 Test Facility

The responsibilities of the test facility personnel are to

- Identify a point of contact for the test who will serve as the primary interface with the Verification Test Coordinator
- Coordinate test facility involvement in the verification test in accordance with this protocol
- Ensure that necessary test facility resources are committed to the verification test
- Assemble and oversee trained technical staff to operate the incinerator during the verification test; provide incinerator monitoring equipment
- Ensure that the incinerator is fully functional prior to the times and dates of the verification test and that operating conditions and procedures for the incinerator are recorded during the verification test
- Review and approve all data and records related to incinerator operation
- Provide daily on-site support (e.g., access to telephone or office facilities; basic laboratory supplies) to vendor, EPA, and Battelle representatives as needed
- Review the draft verification report and statement.

1.4.3 Vendors

Vendor representatives shall

- Document acceptance of the test procedures specified in this protocol prior to the test
- Interface with the Battelle Verification Test Coordinator to make all arrangements for the verification test
- Sign an AMS Center vendor agreement for the verification process and pay a verification fee that will partially cover the costs of the testing
- Provide a CEM for the duration of the verification test

- Commit a trained technical representative to operate, maintain, and repair the CEMs throughout the verification test or train testing staff to perform these tasks and sign a consent form indicating training occurred
- Review their respective draft ETV verification report and statement.

1.4.4 EPA

EPA's AMS Center Quality Manager shall

- Perform, at EPA's option, one external TSA during the verification test
- Notify the EPA AMS Center Manager to facilitate a stop work order if the external audit indicates that data quality is being compromised
- Prepare and distribute an assessment report summarizing results of any external audit
- Review the draft verification reports and statements.

EPA's AMS Center Manager shall

- Notify Battelle's AMS Center Manager if a stop work order is warranted, based on data quality issues identified by the EPA AMS Center Quality Manager
- Review the draft ETV verification reports and statements
- Oversee the EPA review process on the draft test/QA plan, reports, and verification statements
- Coordinate the submission of ETV verification reports and statements for final EPA approval.

1.4.5 Testing Staff

Testing staff will be provided by Battelle, the test facility, and/or a qualified subcontractor. Responsibilities of testing staff may include

- Observe and document, as necessary, operation of the CEMs during unattended operation
- Conduct all experimental procedures specified in this protocol, including reference method sampling and analysis
- Document any repairs and maintenance conducted on the CEMs, including description of repair and maintenance performed, vendor time required to perform repair or maintenance, and amount of CEM down time.
- Convert CEM and reference data from electronic spreadsheet format into appropriate file format for statistical evaluation
- Assist in the performance of TSAs, performance audits, and pre-test facility reviews by the Battelle and EPA Quality Managers
- Perform such audits and data reviews as are necessary to assure data quality in all verification testing
- Assist the Verification Test Coordinator in responding to any issues raised in assessment reports and audits, including instituting corrective action as necessary
- Assist vendors or trained operator in setting up the CEMs for verification tests.

2 TEST FACILITY

The test facility shall be designed and permitted for receiving, sorting, storing, preparing, and thermally destroying waste. A schematic of the TSCAI is shown in Figure 2 as an example of a type of facility that may be used to perform verification tests of mercury CEMS. At the TSCAI, these wastes are treated in a rotary kiln incinerator with a secondary combustion chamber and off-gas treatment system for cleaning combustion effluent gases.

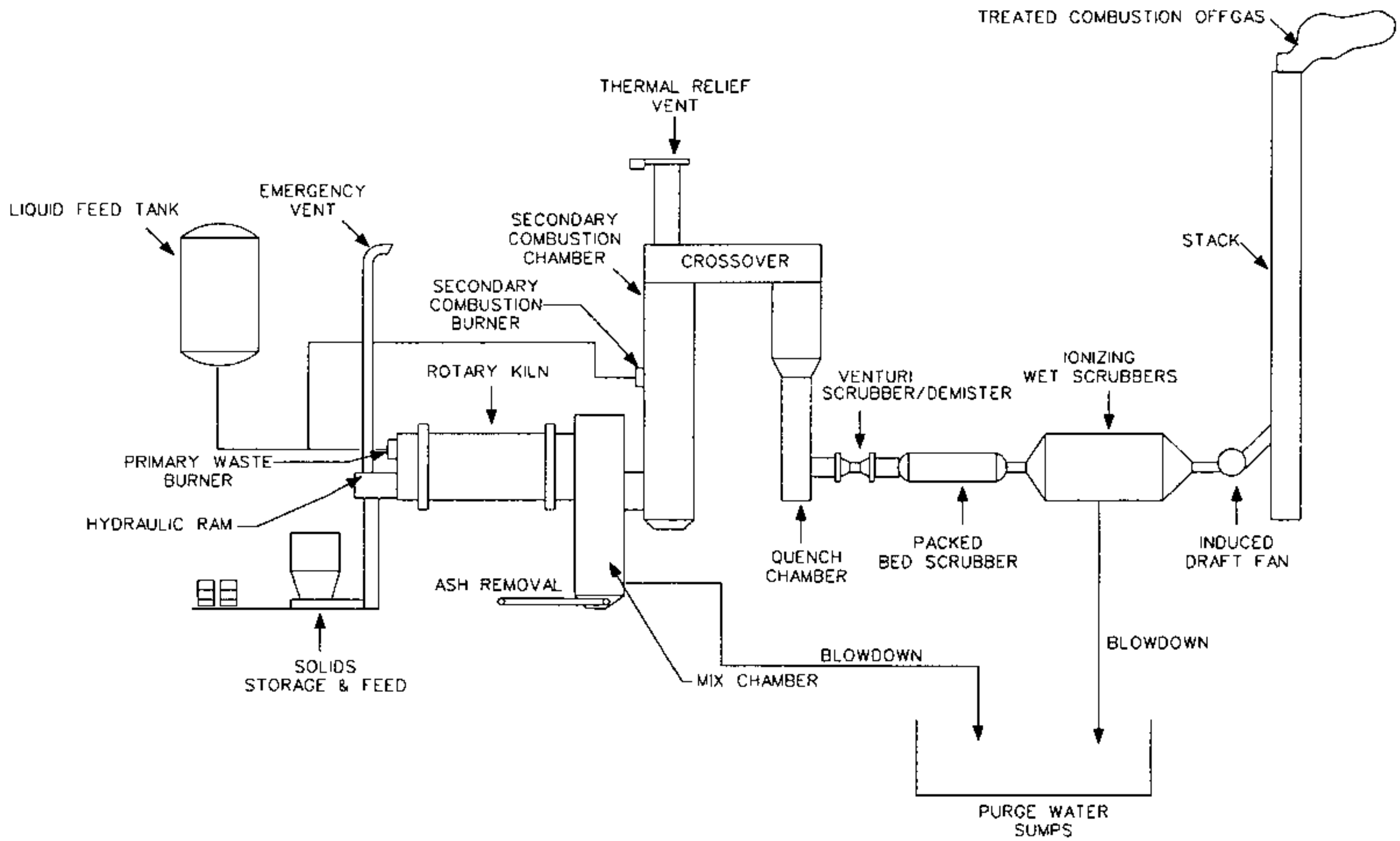

Figure 2. Schematic of Example Test Facility Incinerator and Off-Gas Cleaning System

2.1 Incineration Process

Although not the only type, one type of incineration process uses a rotary kiln as at the TSCAI. This kiln receives and thermally processes solid and non-pumpable sludge wastes. The kiln is fired by an auxiliary natural gas burner to maintain a minimum combustion temperature and ensure stable combustion of liquids. Steam atomizes the waste fed through the burners. A mixing chamber separates the primary combustion chamber (rotary kiln) and the secondary combustion chamber, collects the flue gases and ash discharged from the rotary kiln, and passes the hot flue gases into the secondary combustion system. An ash handling system conveys ash and residue from a water-filled trough beneath the mixing chamber to an ash hopper for subsequent disposal. The secondary combustion system receives hot process gases from the mixing chamber. The secondary combustion chamber also can accept wastes pumped from primary liquid waste feed tanks, from a fuel oil tank, or directly from a tanker. After secondary combustion, the off-gases pass through a refractory-lined duct into an off-gas cleaning system.

2.2 Off-Gas Cleaning System

In the example TSCAI test facility, a quench chamber receives and cools the hot flue gas from the secondary combustion chamber. A venturi scrubber receives the cooled and water-saturated flue gas and removes particulates. A mist eliminator between the venturi scrubber and a packed-bed scrubber removes the entrained water from the saturated flue gas and minimizes interference with the cross-flow liquid/gas flow in the packed-bed scrubber. From the mist eliminator, effluents flow by gravity to a quench tank. The packed-bed scrubber removes additional soluble and reactive acid gases. Recirculated scrubber water irrigates the packing. A water recycle system serving ionizing wet scrubbers provides the recycle water. The ionizing wet scrubbers remove fine particulates of less than 1 μm from the flue gas stream. From the flow control damper section at the outlet of the ionizing wet scrubber, the flue gas stream passes to an induced-draft fan. The induced-draft fan pulls the combustion and flue gases through the incineration and process gas cleaning systems at subatmospheric pressure. A stack receives the water-saturated flue gas and vents it to the atmosphere.

3 EXPERIMENTAL DESIGN

A mercury CEM verification test generated from this protocol will take between six to nine months, as seen in Table 1. Test planning and site preparation shall take place over a period of three to four months. Field testing, involving the installation and testing of the mercury CEMs, shall be conducted over about a three-month period at the test facility. The CEMs go through a start-up and shakedown period, followed by the initial performance monitoring during the first month of field activities. The CEMs then operate for six to nine weeks with minimal attention. The final performance monitoring takes place during the last week of the field test. Field activities are concluded with removal of the CEMs from the facility. The final phase of the test consists of reduction of the data and report preparation. The primary activities are described in further detail in the following sections.

3.1 Mercury CEMs

CEMs for mercury are typically designed to determine Hg_T and/or chemically speciated mercury in combustion source emissions. Strictly speaking, Hg_T is the sum of mercury in all phases and chemical forms in the combustion gas, including Hg°, Hg_{ox} (primarily mercuric chloride) vapors, and particulate-phase mercury. However, most commercial mercury CEMs do not measure particulate-phase mercury; instead, they filter out particulate matter and measure the total of the vapor-phase mercury species. As a result, in this protocol Hg_T represents the total of all vapor-phase mercury species. (Should verification be conducted on a CEM that determines particulate-phase mercury, then the strict definition of Hg_T must be employed.) Commercial CEMs may also provide chemical speciation data, i.e., the Hg_T and Hg° (or Hg_{ox} and Hg°) fractions of the mercury vapor species may be determined separately. This separation is commonly accomplished by a difference measurement, in which Hg_{ox} is intermittently or continuously chemically or thermally reduced to Hg° for detection.

Table 1. Schedule for Mercury CEM Verification Test

Month	Verification Test Activity	
	Test Planning and Site Preparation	
NA	Identify test facility Sign up vendors Procure mercury calibration gases Prepare specification for data acquisition system and procure the system Establish facility interfaces with mercury CEMs Set up data acquisition system	
	CEM Field Activities	**Data Analysis and Reporting**
1	Set up/install mercury CEMs CEMs startup/shakedown Initial performance monitoring Unattended CEMs operation	Sample analysis – Initial performance monitoring
2	Unattended CEMs operation	Data reduction – Initial performance monitoring Evaluate initial performance monitoring results Adjust procedures if necessary for final performance monitoring
3	Unattended CEMs operation Final performance monitoring Demobilize CEMs	NA
4	NA	Sample analysis – Final performance monitoring Evaluate final performance monitoring results
5, 6	NA	Prepare and issue draft report and verification statement
7, 8	NA	Distribute ETV verification reports for vendor, EPA, and peer review
9	NA	Finalize and issue ETV verification reports

NA = Not applicable.

The commercial mercury CEMs also use a variety of final analytical approaches to detect mercury. Cold vapor atomic absorption spectroscopy, cold vapor atomic fluorescence spectroscopy, and differential optical absorption spectroscopy are all used, but can detect only Hg°, and so require the speciation approaches outlined above to determine Hg_{ox}. Atomic emission spectroscopy can also be used. In this technique, all forms of mercury, including particulate mercury, are converted to Hg° and detected equally. This approach provides a true Hg_T measurement, but does not provide any information on speciation.

The CEMs tested according to this protocol may be verified for their measurement of any and all of the applicable mercury components listed above. For example, a CEM that determines total vapor phase mercury and Hg°, and by difference determines Hg_{ox}, may be evaluated for measurements of all three components. In the United States, emission regulations on combustion sources are expected to address only Hg_T. However, there are valuable non-regulatory uses of mercury speciation data; therefore, speciation capabilities of the CEMs shall be evaluated if the degree of speciation is great enough to produce quantifiable measurements of various forms of mercury.

3.2 Reference Method

The performance of the mercury CEMs shall be evaluated by comparison against mercury measurements made using the OH reference method. The OH reference method is designed for determination of Hg°, Hg_{ox} , particle-bound mercury, and Hg_T emissions from coal-fired and other stationary sources. This method is applicable to Hg°, Hg_{ox} , particle-bound mercury, and Hg_T concentrations ranging from approximately 0.5 to 100 micrograms per dry standard cubic meter (µg/dscm). The method involves withdrawing a gas sample from the flue gas stream isokinetically through a probe/filter system, followed by a series of impingers. Particle-bound mercury is collected in the front half of the sampling train. Hg_{ox} is collected in the first impingers, which contain a chilled aqueous potassium chloride solution. Hg° is collected in subsequent impingers, which contain hydrogen peroxide solution and potassium permanganate solution. Samples are recovered, digested, and then analyzed for mercury using cold-vapor atomic absorption or fluorescent spectroscopy.

3.3 Equipment Setup and CEM Installation

Each of the mercury CEMs shall have a dedicated sampling port on the stack. Vendor-supplied extractive sampling probes shall be connected to the CEMS by means of heated Teflon sample lines. Trained and experienced site personnel shall install the vendor-supplied extractive probes and run the heated Teflon sample lines to the CEM cabinets. If they so choose, the vendors may provide their own heated sample line if they have special requirements or use a patented system.

Vendor representatives shall be present to oversee the installation of the mercury CEMs; field technicians shall install the probes in the stack. Test facility maintenance staff shall support setup and installation of the field hardware.

3.4 Start-up/Shakedown

Vendors have the option of being on site for the entire test or to train an operator. At a minimum, vendor representatives shall be on hand to start up the CEMs. The vendor representatives should plan to spend about one week in shaking down the CEMs and training a dedicated field technician in operating, calibrating, and servicing the units. Mercury calibration gas standards shall be introduced during the shakedown period, and a baseline response from the CEMs using the mercury standards shall be obtained while the vendors are present. Routine calibrations shall be performed to ensure proper setup and operation of the CEMs and to train the dedicated field technicians in calibration procedures. Adequate time shall be provided to the vendors during the shakedown period to troubleshoot any problems that occur before proceeding to performance monitoring.

3.5 CEM Performance Monitoring Schedule

Performance monitoring using mercury calibration gas standards and OH reference method measurements shall be conducted immediately following the shakedown period and at the end of the field test, respectively. As shown previously in Table 1, performance monitoring would be expected to occur in the first month of testing, followed by one month of unattended CEM operation, then a final performance monitoring. The concentrations and purities of these standards will be chosen based upon the expected range and accuracy of the CEMs being tested. The schedule for performance monitoring is shown in Table 2. The initial and final weeks of performance monitoring shall follow this same testing format. An additional factor for evaluation in the final week of the test shall be determining whether the CEM response has changed, drifted, or shifted between the initial and final test periods. It is recommended that the vendor representatives be present to oversee operation of their CEMs and to validate their CEMs' responses during the two weeks of performance monitoring.

Table 2. Weekly Schedule for Performance Monitoring

Day	CEM Performance Monitoring Parameter
1	Challenge with Hg° standard/zero gas (Calibration/Zero Drift) Flue gas sampling (Relative Accuracy, Correlation, Precision)
2	Challenge with Hg° standard/zero gas (Calibration/Zero Drift) Flue gas sampling (Relative Accuracy, Correlation, Precision)
3	Challenge with Hg° standard/zero gas (Calibration/Zero Drift) Flue gas sampling (Relative Accuracy, Correlation, Precision)
4	Challenge with Hg° standard/zero gas (Calibration/Zero Drift) Flue gas sampling (Relative Accuracy, Correlation, Precision)
5	Challenge with Hg° standard/zero gas (Calibration/Zero Drift, Response Time, Sampling System Bias, Calibration Error)

3.6 CEM Performance Monitoring Procedures

The test facility shall be operated continuously during the entire period of performance monitoring and shall not be shut down overnight. At the beginning of each test day, the CEMs undergoing testing shall be supplied with zero gas and then with a commercial compressed gas standard containing Hg^o. The response to each gas shall be recorded on each test day to assess the zero and calibration drift of the CEMs. On one test day in each week of testing, the rise and fall times of the CEMs shall be determined to assess response time by recording their readings as the mercury calibration gas is first turned on, and later turned off. Also on one day in each week of testing, the mercury calibration gas standards shall be delivered first directly to the CEM mercury analyzer, and then through the CEM sample interface, to assess sampling system bias and calibration error introduced by the interface itself.

After the CEMs have been challenged with the calibration gas standards, they shall extract flue gas from the stack in preparation for conducting reference method measurements. Waste feeds shall be fed to the test facility incinerator for at least 30 minutes before initiating reference method sampling. The CEMs shall begin recording data as soon as they are brought on-line. However, the reference method sampling will start no sooner than a time previously agreed upon with the CEM vendors. The CEM vendors shall be given at least 15 minutes notice prior to initiation of reference method sampling.

OH method sampling shall be performed while burning liquid, solid, and/or a combination of liquid and solid waste. Testing shall be done at a low and high mercury stack concentration, approximately 10 µg/dscm and 60 µg/dscm, respectively. Mercury stack concentrations shall be varied by varying the waste feed rate, by injecting mercury solutions into the waste feeds, or by a combination of both. Injection of mercury is an alternative that shall be used as necessary depending on the levels of mercury in the wastes. The waste feeds to be used for the test shall be selected based on realism and availability and will not be determined until the time of testing draws near. An attempt shall be made to select liquid waste that generates a steady, constant level of mercury in the stack and solid waste that produces intermittent spikes of mercury due to the batch-wise nature of solid waste feeds.

Reference method measurements shall be made using paired sampling trains located at a point in the stack near the CEM probes that would be expected to have the same mercury concentrations as the point at which the CEM probes are placed. The reference method sampling time shall be at least three hours with the low mercury levels and at least two hours with the higher mercury levels or of a duration that will ensure detectable levels of mercury. A total of 10 test runs using paired sampling trains shall be conducted during each week of performance monitoring. A summary of the reference method sampling events planned is provided in Table 3. To ensure that the reference method and CEM data sets are parallel and comparable for each performance monitoring period, the CEM vendors shall be notified of the start and stop times of each reference method period so that average analyte concentrations corresponding directly to the reference method measurement period can be reported.

Table 3. Requirements for Paired Train Ontario Hydro Sampling

Day	Stack Mercury Concentration (µg/dscm)	No. of Test Runs	Sample Time (hr)
1	10	2	3
2	10	2	3
3	60	3	1
4	60	3	1

The OH sampling trains shall sample isokinetically and traverse the stack at points determined by EPA Method 1. The CEMs undergoing testing will sample at a single (fixed) point in the stack. Each CEM will operate with an extraction probe provided by the vendor. As necessary, the CEM probes shall be connected to their respective analyzers by means of a heated sample line maintained at a temperature specified by the vendor.

3.7 Unattended Operation

Between the initial and final week of performance monitoring, the vendor representatives shall leave the site and a trained field technician shall assume routine operation, calibration, and maintenance of the CEMs. The CEMs will be challenged with the mercury calibration gas standards during this period to confirm that the CEMs are continuing to respond properly. Calibration and zero drift checks will be made as often as possible, while assuring that sufficient calibration gas is available to complete the final week of testing. Routine maintenance checks will be made according to a documented schedule and checklist determined by each CEM vendor.

Should problems arise with the CEMs, the field technician shall first attempt to troubleshoot the problem either alone or with instructions from the vendor by telephone, fax, or e-mail. If the field technician is unsuccessful in resolving the problem, then the vendor representative shall be requested to visit the site to investigate and resolve the problem.

Information shall be recorded to document the reliability and performance of the CEMs during the unattended operational period. The information recorded may include the extent of operational down time; the support and maintenance requirements, including labor hours and costs; the expendable supplies required; the extent of CEM drift or adjustments needed; and the effort required from the manufacturer to resolve any problems.

4 DATA GENERATION AND CALCULATIONS

Measurement results from both the reference method and the mercury CEMs to be evaluated shall be reported in units of µg/dscm at 7% O_2 (i.e., µg/m^3 on a dry basis, corrected to 20°C and 7% O_2). The following paragraphs describe how the data shall be generated and what calculations shall be made to assess the performance of the CEMs. A summary of the data requirements is provided in Table 4.

Table 4. Data Requirements for Mercury CEM Performance Evaluation

Performance Parameter	Objective	Comparison Based On
Relative Accuracy	Determine degree of quantitative agreement with reference method	Reference method results
Correlation	Determine degree of correlation with reference method	Reference method results
Precision	Determine repeatability of successive measurements at fixed mercury levels	Repetitive measurements under constant facility conditions Repetitive mercury standard sampling
Calibration/Zero Drift	Determine stability of zero gas and span gas response	Zero gas and Hg^o standards
Relative Calibration/Zero Drift	Determine relative response to zero gas and span gas over successive days	Zero gas and Hg^o standards
Sampling System Bias	Determine effect of the CEM's sample interface on response to zero gas and Hg° standard	Response to zero gas and Hg^o standards at analyzer *vs*. through sample interface
Calibration Error	Determine effect of the CEM's sample interface on response to zero gas and Hg° standard	Response to zero gas and Hg^o standards through sample interface
Response Time	Estimate rise and fall times of the CEMs	CEM results at start/stop of Hg addition

4.1 Relative Accuracy

Relative accuracy (RA) shall be verified by comparing the CEM results against the reference results for each parameter that the CEM measures. The OH method results shall be reviewed before performing statistical calculations to identify individual outliers from the full set of reference method results. The OH results shall be screened for precision of results from co-located sampling trains. OH test results identified as outliers shall be reported, but may not be used for performance evaluation. The intent of this approach is to provide a valid set of reference data for evaluation purposes, while also illustrating the degree of variability of the reference method. Identification of outliers shall be based on statistical tests such as a t-test

$$RA = \frac{\left| \bar{d} \right| + \frac{t_{0.975}}{\sqrt{n}} SD}{\bar{R}_{RM}}$$

comparison of means or a Q-test evaluation of divergent results. In any case where rejection of a reference result is suggested, effort shall be made to find a cause for the divergent result.

The RA of the CEMs with respect to the reference method shall be calculated using

where

$\bar{d}$	=	arithmetic mean of the differences, d, of the paired CEM and reference method results
$\bar{R}_{RM}$	=	arithmetic mean of the reference method result
n	=	number of data points
$t_{0.975}$	=	the t-value at the 97.5% confidence with n-1 degrees of freedom
SD	=	standard deviation of the paired CEMs and the reference results.

RA shall be calculated separately for each parameter measured by each CEM. Depending on the number of OH reference method samples that are available for determining RA, the RA procedure specified in PS-12 may be used to exclude up to three of the results from the RA calculation. The impact of the number of data points (n) on the RA value shall be discussed in the data report.

4.2 Correlation with Reference Method Results

Correlation of the CEM with the OH method results shall be calculated using the same data used to assess RA. Correlation shall be calculated for each parameter measured by the CEM. The coefficient of determination (r^2) shall be calculated to determine the degree of correlation of each CEM with the reference method results. Coefficient of determination is the square of the correlation coefficient (r). The coefficient of determination shall be calculated for each parameter measured by each CEM to be evaluated.

4.3 Precision

Precision of the CEMs shall be assessed based on the individual measurements performed by each CEM over the duration of applicable OH method sampling runs. For example, if a CEM provides an updated measurement every five minutes, then a total of 12 readings would be obtained over a one-hour sampling run. The average and standard deviation of those readings shall be calculated to assess precision. This procedure shall be applied to all applicable OH method sampling intervals during times of stable incinerator operation.

Precision (P) of the CEMs to be evaluated shall be determined by calculating the percent relative standard deviation (RSD) of a series of CEM measurements made during stable operation of the test facility incinerator, with mercury injected at a constant level into the combustion zone. During each reference method sampling run, all readings from each CEM shall be recorded. RSD is the ratio of standard deviation of those readings over the mean of the readings,

where

$$P = RSD = \frac{SD}{\overline{X}} \times 100$$

SD = standard deviation of the readings from the CEM

$\overline{X}$ = mean of the CEM readings.

Precision shall be calculated for each CEM using data from every reference method sampling run. The calculated precision values include all sources of variability (e.g., test facility incinerator fluctuations, instability in mercury injection), and not just the CEM variability. Any known variability of the test facility and the CEMs shall be reported with the calculated precision. All CEM data from the periods of precision testing shall be reviewed to determine whether the consensus of the CEM data indicates a variation in the test facility itself. An additional precision assessment may be made by sampling a mercury standard from the probe inlet for one hour. These repeated measurements may be reported along with the precision assessment made from measuring the flue gases.

4.4 Sampling System Bias

The sampling system bias shall be tested as part of the calibration/zero drift procedure in each week of performance evaluation. Sampling system bias (B) reflects the difference in CEM response when sampling mercury standard gas through the CEM's entire sample interface, compared with sampling the same gas directly at the CEM's pollutant analyzer, i.e.

$$B = \frac{R_i - R_d}{R_d} \times 100$$

where

R_i = CEM's reading when the standard gas is supplied at the sampling inlet, and

R_d = CEM's reading when the standard is supplied directly to the analyzer.

4.5 Calibration and Zero Drift

If the composition of the mercury standard gas is accurately known and stable, the following procedure should be used to evaluate calibration and zero drift. Calibration and zero drift shall be determined based on challenging the CEMs with zero gas and with a compressed gas standard of Hg° on each test day in each week of the performance evaluation. Calibration and zero drift checks also shall be done periodically during the unattended operational period between the initial and final weeks of performance monitoring. Calibration drift (CD) describes the difference in the mercury CEM's output readings from the established reference value after a stated period of operation during which no unscheduled maintenance, repair, or adjustment took place.

$$CD = \frac{\left(R_{CEM} - R_V\right)}{R_V} \times 100$$

where

R_{CEM} = CEM response

R_V = reference value of the calibration standard.

Zero drift (ZD) represents the difference in the mercury CEM's output readings for zero input after a stated period of operation during which no unscheduled maintenance, repair, or adjustment took place.

$$ZD = \frac{\left(R_{CEM} - R_V\right)}{R_{EM}} \times 100$$

where

R_{CEM} = CEM response for zero input

R_V = reference response for zero input

R_{EM} = emission limit.

4.6 Relative Calibration and Zero Drift

Since mercury calibration gas standards have not been widely used, their absolute quantitation for assessing accuracy of mercury CEMs has not been universally accepted at this time. Section 5.2 describes the validation procedure to be used to test the stability of the mercury calibration gas standards. Depending on the stability of the mercury standards, it may not be appropriate to use them as absolute calibration standards. With this in mind, an alternative method of evaluating calibration and zero drift in a relative sense also may be used, rather than as deviations from an absolute standard. That is, calibration and zero drift shall be reported in terms of the mean, RSD, and range (maximum and minimum) of the readings obtained from the CEM in the daily sampling of the same Hg° standard gas and of zero gas. The RSD shall be calculated as

$$RSD = \frac{SD}{\overline{X}} \times 100$$

where $\overline{X}$ is the mean and SD the standard deviation of the daily readings on standard or zero gas. This calculation, along with the range of the data, shall indicate the variation in zero and standard readings from day to day, from week to week, and from the start of the verification test to the end.

4.7 Calibration Error

Another way to express sampling system bias is by means of the calibration error. Calibration error (CE) is used to determine the difference between the concentration measured by the CEM and the known concentration generated by a calibration source when the entire CEM (including the sample interface) is challenged,
where

$$CE = \frac{d}{R_v} \times 100$$

d = difference of the paired data points from the CEM and the reference method
R_V = reference concentration value.

The above procedure is applicable only if the mercury standard gas is accurately known and stable.

4.8 Response Time

The response time refers to the time interval between the start of a step change in mercury input and the time when the CEM reading has reached 95% of the final value. Both rise and fall times shall be determined. CEM response times shall be obtained, in conjunction with a calibration/zero drift check or sampling system bias check, by starting or stopping delivery of the mercury standard gas to the CEM analyzer or sampling interface, recording all readings until stable readings are obtained, and then estimating the 95% response time. For those CEMs whose measurement process is not truly continuous, the estimation process shall require interpolating between successive readings.

4.9 Data Completeness

No additional test activities shall be required to determine the data completeness achieved by the CEMs. Data completeness shall be assessed by comparing the data recovered from each CEM with the amount of data that would be recovered upon completion of all portions of these test procedures.

4.10 Operational Factors

Setup and maintenance needs shall be documented qualitatively, through both observation and communication with the vendors during the test. Factors to be noted include the frequency of scheduled maintenance activities, the down time of the CEM, and the staff time needed for maintaining it during the verification test. Table 5 is an example of a table showing down time and service time for the CEMs being tested.

Table 5. Example Table Showing Extent of Down Time and Service Time for CEMs

Date	Down Time	Service Time	Activity
8/12/03	45 minutes (min)	15 min	Adjusted the range for measurements.
8/13/03	1 hour (hr)	1 hr	Prepared reagents. Changed out reagent containers.
8/19/03	10 min	10 min	Per vendor's instructions, performed troubleshooting to investigate cause of low flow.

5 MATERIALS AND EQUIPMENT

5.1 High Purity Nitrogen/Air

The high purity gas used for zeroing the CEMs shall be commercial ultra-high purity (i.e., minimum 99.999% purity) air or nitrogen.

5.2 Mercury Standard Gases

Compressed gas standards containing Hg° shall be obtained from a suitable supplier for use in assessing drift. These shall consist of Hg° in a nitrogen matrix, at levels of about 1 ppb (8 $\mu g/m^3$) and 5 ppb (40 $\mu g/m^3$). Multiple cylinders of uniform concentration shall be obtained to meet the gas consumption rates of the CEMs during testing. The gas supplier shall determine the concentrations of the gas standards.

As a result of uncertainties with respect to compressed gas standard stability and instrument drift, a procedure has been developed to audit the stability of the compressed gas standards prior to beginning the verification test, during the test, and at the end of the test. The objective of the audit process shall be to identify any drift in the stability of the compressed gas standards independently of the drift that also may occur within the actual CEMs. The procedure consists of the following tasks:

- The gas supplier shall provide the cylinders of compressed gas standards. These shall be analyzed at the gas supplier's facility using its standard procedure.

- Upon receipt of all compressed gas cylinders at the test facility site, the response of all cylinders shall be measured by an independent mercury analyzer. The ratio of the response of each cylinder shall be compared with the ratio of the values of the concentrations provided by the gas supplier. The intent of this step is to ensure that all cylinder concentrations are in the same relative proportion as the values provided by the gas supplier. This shall also establish a control that can be repeated periodically to ensure that the standards remain stable or, if they do not, that the rate of degradation has been established.

- Each cylinder shall be taken out of service at a predetermined final cylinder pressure with sufficient gas remaining to conduct the following tests:

  — Analysis of the cylinder by the independent analyzer at the date that the cylinder is taken out of service—this shall determine the cylinder concentration at the end of its service.

  — If a cylinder is taken out of service early in the verification test (i.e., after the initial performance monitoring), it shall remain at the site until a shipment of cylinders is ready to be returned to the gas supplier. Prior to shipment, cylinders stored for extended periods of time will again be analyzed by the independent analyzer.

  — Upon return to the gas supplier, each cylinder's final response and calibration value shall be determined using the gas supplier's mercury analyzer.

- Data analysis shall be conducted on all cylinder response values obtained to determine the stability of the gases and to determine the degradation rate, if any, that has occurred during the test.

This procedure ensures that the degradation rate can be quantified both as a function of time and as a function of quantity of gas remaining in the cylinder. The information shall be used to factor out any effects of calibration gas stability from the analyses associated with CEM response, drift, and other required performance analyses.

The compressed gas cylinders shall be located near the CEM instrument cabinets for ease of access while performing calibrations and kept at room temperature while in use to ensure uniform gas concentration throughout the test. Cylinders may be stored outdoors before testing or while waiting for return shipment to the gas supplier.

5.3 Mercury Injection for Adjusting Mercury Levels in Waste Feeds

The mercury solutions used to inject mercury into the waste feed lines for reaching target concentrations of mercury in the stack shall be aqueous solutions of mercury (II) acetate. The solutions shall be injected into the waste feed lines downstream of the mass flow meters and upstream of the waste feed cut-off valves. A dedicated pumping system shall control and record the injection rate of the solution into the waste feed line. In terms of performance evaluation, while mercury injection solution concentrations and feed rates aid in establishing the appropriate flue gas mercury concentrations, the actual flue gas mercury content shall be determined by OH reference method sampling, and not by calculation of the injected mercury.

5.4 Mercury Spiking Standard for Reference Method Performance Evaluation

A National Institute of Standards and Technology (NIST)-traceable aqueous mercury standard, obtained from a commercial supplier, shall be used as the spiking solution in the performance evaluation of the reference method.

5.5 Sampling Trains Handling and Tracking

Multiple trains shall be prepared each day so that as many as six trains (i.e., three sampling runs with two trains each) may be sampled in a single day, in addition to at least one blank train. Samples from OH method trains shall be recovered in a laboratory facility. Containers for collecting and storing samples shall be purchased and labeled for tracking by an analytical laboratory and subsequently supplied to the field sampling team. Request for analysis/chain of custody (RFA/COC) forms afford the necessary documentation to record sample possession from the time of collection by the testing staff through analysis by the laboratory. Specifications for the analysis of these samples and special instructions to the laboratory also are included on the RFA/COCs. The testing staff shall track the samples using a numbering system provided by the analytical laboratory for numbering and tracking samples. The original RFA/COC form shall remain with the sample at all times.

Samples shall be packaged and delivered by the testing staff from the field to the analytical laboratory. RFA/COC forms and samples shall be directly delivered to laboratory personnel, who shall review and confirm the samples in the presence of field sampling team personnel prior to acceptance by the laboratory.

5.6 Analysis Equipment

Laboratory equipment shall include all chemicals and solutions for rinsing train components and recovering impinger samples, as well as equipment for mercury determination.

5.7 Miscellaneous Materials and Equipment

Other materials, equipment, and support services needed to complete the verification test include calibration gas regulators, heated sample lines, tubing, telephone connection in the laboratory trailer, photography, and report publication services.

6 QUALITY ASSURANCE/QUALITY CONTROL

6.1 Equipment Calibrations

6.1.1 Incinerator Monitoring Equipment

The equipment that provides measurements for operation of the incinerator, verification of permit compliance, and determination of the reference method results requires compliance-level calibration procedures. Such measurements include waste feed rates, combustion chamber temperatures, off-gas scrubber liquid flows, and stack O_2, CO, and CO_2 content. Calibration procedures, along with calibration schedules, must be in place and followed during the field test. Calibration results shall be made available if requested for auditing purposes.

6.1.2 Reference Method

Reference method sampling must be performed according to the QA/QC requirements stated in the draft OH standard test method.[3] Examples of such requirements include use of blank sampling trains and blank sampling materials, such as filters and reagent solution blanks. QA/QC activities shall be recorded.

6.1.3 Analytical Laboratory

Calibration records for the mercury analysis equipment shall be included with the analytical results. Calibration approaches for the mercury analysis shall be as specified in Sections 8.9 and 12.2 of the OH method, and calibrations shall be documented in the same way as are continuing calibration procedures.

6.2 Audits

6.2.1 Technical Systems Audits

Battelle's Quality Manager shall perform a TSA once during the verification test. The purpose of this TSA is to ensure that the verification test is being performed in accordance with this protocol, the test/QA plan, the Battelle AMS Center QMP,[1] and all associated methods and standard operating procedures. In this audit, the Battelle Quality Manager will review the calibration sources and reference methods used, compare actual test procedures to those specified in this protocol, and review data acquisition and handling procedures.

At EPA's discretion, EPA QA staff also may conduct an independent TSA of the verification test. In any case, EPA QA staff will review Battelle's TSA report and provide comments on the findings and actions presented in that report.

6.2.2 Performance Evaluation Audit

A performance evaluation (PE) audit shall be conducted to ensure that OH reference method sampling equipment and incinerator stack monitoring instrumentation used for producing reference method results provide quality measurements. Table 6 shows the key measurements that may be audited. As can be seen from Table 6, the audit shall be conducted by comparing data from the reference method sampling train or incinerator with that from an independent analyzer or monitor, operated simultaneously and sampled at the same point in the duct.

This audit shall be the responsibility of Battelle staff. Battelle will supply the staff and equipment needed to make the independent audit measurements. If agreement outside the indicated tolerance is found, the test shall be repeated. Further failure to achieve agreement will result in use of a different independent measurement device. If adequate agreement between independent measurements cannot be reached, the affected reference data shall be flagged in the data analysis and reports.

Table 6. Summary of Performance Evaluation Audits

Parameter	Audit Method	Expected Tolerance
O_2	Compare with independent O_2 measurement, operated simultaneously and sampled at the same point of the duct	±1% O_2
CO_2	Compare with independent CO_2 measurement, operated simultaneously and sampled at the same point of the duct	±10% of CO_2 reading
Temperature	Compare with independent temperature measurement, operated simultaneously and sampled at the same point in the duct	±2% absolute temperature
Barometric Pressure	Compare with independent pressure measurement, operated simultaneously and sampled at the same point in the duct	±0.5 inch of H_2O
Flue Gas Differential Pressure	Compare with independent pressure measurement, operated simultaneously and sampled at the same point in the duct	±0.5 inch of H_2O
OH Gas Flow Rate	Compare with independent flow measurement, operated simultaneously on the same flow	5%
Mass (H_2O)	Check balance with calibrated weights	±1% or 0.5 g, whichever is larger
OH Method	Spike one sampling train in each week of OH sampling using an NIST-traceable mercury solution	± 10%

6.2.3 Data Quality Audit

The Battelle Quality Manager shall audit at least 10% of the verification data acquired in the verification test. The Battelle Quality Manager shall trace the data from initial acquisition, through reduction and statistical comparisons, to final reporting. The data quality audit will determine that data are in conformance with all aspects of the protocol, applicable Quality Management Plan, reference method, and any applicable standard operating procedures. The audit shall include recalculation of representative reported data values, comparison of the QC data to the data quality criteria specified in the protocol, and verification that instrumentation and equipment were calibrated and operated as appropriate. The data shall then be compared to the results in the report to ensure exactitude of data reporting. The audit shall examine how the data were handled, what judgments were made, and whether uncorrected mistakes were made.

6.2.4 Audit Reports

All Battelle audits shall be documented in accordance with Section 3.3.4 of the Quality Management Plan for the AMS Center.[1] An audit report shall include the following sections:

- Identification of any adverse findings or potential problems
- Space for response to adverse findings or potential problems
- Possible recommendations for resolving problems
- Citation of any noteworthy practices that may be of use to others
- Confirmation that corrective actions (if necessary) have been implemented and are effective.

6.2.5 Corrective Action

The Battelle Quality Manager, during the course of any assessment or audit, shall identify to the technical staff performing experimental activities any immediate corrective action that should be taken. If serious quality problems exist, the Battelle Quality Manager is authorized to stop work. Once the assessment report has been prepared, the Battelle Verification Test Coordinator, working with the test facility as necessary, shall ensure that a response is provided for each adverse finding or potential problem and implement any necessary follow-up corrective action. The Battelle Quality Manager shall ensure that follow-up corrective action has been taken.

7 DATA ANALYSIS AND REPORTING

7.1 Data Acquisition

Data gathered during the field evaluation can be divided into three categories: reference method data, mercury CEM data, and process operational data, such as combustion source conditions, test temperatures, the times of test activities, etc. Table 7 lists the types of data to be recorded, recording frequency, and responsible party.

Mercury CEM response data shall be recorded by a dedicated data logger. The CEM vendors shall be responsible for reviewing and validating their respective CEM response data at the end of each RA test day. The vendors must include all individual readings of all tests conducted on that day.

Other data shall be recorded either in laboratory record books or in standard data sheets provided by the analytical laboratory. These records shall be reviewed on a daily basis to determine the validity of the sampling runs and resolve any inconsistencies. All written records must be in ink. Any corrections to notebook entries, or changes in recorded data, must be made with a single line through the original entry. The correction is then to be entered, initialed, and dated by the person making the correction. The majority of the data shall be input to validated computer spreadsheets.

In all cases, strict confidentiality of data from each vendor's CEM, and strict separation of data from different CEMs, shall be maintained. Separate files (including manual records, printouts, and/or electronic data files) shall be kept for each CEM.

7.2 Data Validation

Records generated in this test shall be reviewed within two weeks after generation and before those records are used to calculate, evaluate, or report verification results. Those records may include laboratory record books, operating data from the test facility, data from the CEMs,

Table 7. Summary of Data Recording Process

Data to be Recorded	Responsible Party	Where Recorded	Recording Frequency	Disposition of Data
Dates and times of test events	Testing staff	Laboratory record books	Start and end of each test, and every time a test parameter is changed	Used to organize/check test results; Manually incorporated in data spread sheets as necessary
Operating parameters such as waste feed rates, combustion chamber temperatures, flue gas composition, etc.	Test facility	data logger	Continuous at set acquisition rate	Used to organize/check test results; Manually incorporated in data spreadsheets as necessary
Mercury gas standards	Testing staff	Laboratory record books	When received from manufacturer	Manually entered into spreadsheets
Mercury CEM readings - digital display - printout - electronic output	Vendor or Testing staff	Data sheets Dedicated data logger	At specified points during each test Continuously at specified acquisition rate through each test	Used to validate the electronic record Electronically transferred to spreadsheets
Reference method sampling data	Testing staff	Laboratory record books, data sheets, or data acquisition system, as appropriate	Throughout reference method sampling	Used to organize/check test results; manually incorporated in data spreadsheets as necessary
Reference method sample analysis, chain of custody and results	Testing staff	Laboratory record books, data sheets, or data acquisition system, as appropriate	Throughout sample handling and analysis process	Transferred to spreadsheets

or reference analytical results. The person doing this review will document it by adding his or her initials and the date to a hard copy of the record and returning that record to the person who generated or is storing it.

All data acquired during the verification test shall be reviewed against a set of established criteria to provide a level of assurance of its validity prior to use. All measurement data shall be validated based on process conditions during sampling or testing, adherence to prescribed sampling, testing and QA procedures, consistency with expected and/or reference results, and other test-specific acceptance criteria. The data shall be labeled as valid or invalid based on how well it meets these criteria. The QC criteria for data validation include consistency, duplicate sample calibrations, tests for outliers, transmittal error, and uncertainty analysis.

Data validation shall be conducted by the following means:

- Field checks of raw and reduced data
- Standard analytical laboratory QC checks, including those specifically called for by the OH method
- QA audits on overall testing and sampling procedures
- Comparison of summary tables with raw data
- Comparison of actual results with expected results
- Determination of consistency of results among multiple measurements at the same location
- Review of all input to spreadsheets
- Verification of calculation results
- Review of draft and final reports.

Any data that become invalid through data validation shall be discussed in the data report in conjunction with the reason for disqualifying the data. Examples of such reasons include suspected sample contamination and drift data exceeding acceptance criteria.

7.3 Reporting

Data collected during calibration, comparisons with reference method measurements, and routine unattended operation between performance monitoring shall be evaluated using the parameters in Section 4.0 to assess the performance of each of the monitoring systems. After the data have been assimilated, each of the vendors shall have an opportunity to review and comment on the results of their respective monitor's performance.

Separate verification reports shall be prepared, each addressing a CEM provided by one commercial vendor. Each verification report shall present the test procedures and test data, as well as the results of the statistical evaluation of those data. The draft verification reports shall be submitted to EPA project management, QA staff, and the CEM vendors for review. The verification reports and draft data report shall be revised, based on all review comments received. The ETV verification reports shall then undergo a second round of review by EPA and external peer reviewers. Following revisions based on those reviews, the ETV verification reports and verification statements shall be submitted to EPA for final approval.

8 HEALTH AND SAFETY

All participants in the verification test shall adhere to the health and safety requirements of the test facility.

9 REFERENCES

1. Quality Management Plan for the ETV Advanced Monitoring Systems Center, Version 4.0, Battelle, Columbus, Ohio, December 4, 2002.
2. Proposed Performance Specification 12 for Total Mercury Emission Monitoring Systems, U.S. EPA, Washington, D.C., April 19, 1996.

3. Standard Test Method for Elemental, Oxidized, Particle-Bound, and Total Mercury in Flue Gas Generated From Coal-Fired Stationary Sources (Ontario Hydro Method), American Society for Testing and Materials, Draft Method, September 3, 2001.