United States Environmental Protection Agency | Office of Air Quality Planning and Standards Research Triangle Park, NC 27711 | EPA-454/R-00-039 September 2000

Air

CURRENT KNOWLEDGE OF PARTICULATE MATTER (PM) CONTINUOUS EMISSION MONITORING

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Current Knowledge of Particulate Matter (PM) Continuous Emission Monitoring

FINAL REPORT

For U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emission, Monitoring and Analysis Division
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EPA Contract No. 68-W6-0048
Work Assignment No. 3-07 and 4-03
MRI Project Nos. 104702-1-007-07-15
104703-1-003-07

September 8, 2000

PREFACE

This document was prepared by Midwest Research Institute (MRI) for the U. S. Environmental Protection Agency (EPA) under Contract No. 68-W6-0048, Work Assignments 3-07 and 4-03. Mr. Dan Bivins was the EPA Work Assignment Manager (WAM). This document summarizes the EPA's current knowledge of particulate matter continuous emission monitoring. The document consists of one volume with 98 pages and one appendix.

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EXECUTIVE SUMMARY

Continuous monitoring of particulate matter (PM) concentrations in smoke stacks started during the 1960s in Germany and became a German Federal requirement in the mid 1970s. In the United States, PM concentrations were correlated to opacity monitor readings during the 1970s. Then, in the mid 1970s, the EPA dictated the use of transmissometers for continuous monitoring of the opacity of emissions from sources. Opacity is used as a surrogate for PM emissions and provides qualitative information on the operation and maintenance of particulate control equipment. Continuous particulate mass monitoring was proposed as an EPA regulatory requirement on April 19, 1996, as part of the proposed Hazardous Waste Combustion MACT standard (61 FR 17358). The EPA also proposed performance specification (PS)-11, Specifications and Test Procedures for Particulate Matter Continuous Emission Monitoring Systems in Stationary Sources, to evaluate the acceptability of a PM continuous emission monitoring system (CEMS). The Portland Cement Manufacturing MACT Final Rule (64 FR 31898, June 14, 1999) in section 63.1250(k) makes mandatory the use of PM CEMSs although not until the EPA has finalized PS-11.

Five analytical principles (light scattering, beta attenuation, probe electrification, light extinction, and optical scintillation) used in instruments to measure PM concentrations are described in this document. The following monitors are described in detail and are commercially available from manufacturers as “off-the-shelf” PM continuous emission monitors:

Durag F904K Beta Attenuation

Environment S.A. 5M Beta Attenuation

Mechanical Systems Inc. BetaGuard PM Beta Attenuation

Sigrist KTNR and CTNR Extractive Light Scatter

Durag DR-300-40 In-situ Light Scatter

Environmental Systems Corporation P5 In-situ Light Scatter

Sick Inc. RM210 In-situ Light Scatter

Sick Inc. FW 100 and FWE 200 Light Scatter

Grimm Technologies Inc. Model 6300 In-situ Light Scatter

Monitor Labs Model 300L In-situ Light Scatter

BHA Group CPM 5000 Scintillation

PCME Scintilla SC600 Scintillation

Insitec TESS In-situ or Extractive Laser Light Extinction-Scatter

PCME DustAlert 90 Electrostatic Induction

Auburn International Triboguard III or II In-situ Triboelectric

Codel StakGard Triboelectric Dust Monitor

Several opacity monitors are included for completeness.

PS-11 is used for evaluating the acceptability of an installed PM CEMS. This performance specification requires site-specific correlation of the PM CEMS response against manual gravimetric EPA Methods. PS-11 outlines the procedures and acceptance criteria for installation and operation of instrumentation and for calculations and reporting of data generated during a PM CEMS correlation. PS-11 is unique, relative to the performance specifications for other CEMS, because it is based on a technique of correlating a PM CEMS's response to emissions determined by the manual PM method. In conjunction with PS-11, Procedure 2, which was also proposed in 1996 with PS-11, stipulates the quality assurance (QA) and quality control (QC) measures that must be applied to a PM CEMS.

In Germany to meet regulatory monitoring requirements for a particular industry type, a specific model PM CEMS must pass a suitability test and be approved by the German Federal Environmental Agency before it can be installed and used as a PM CEMS. The suitability test consists of both a laboratory evaluation and a field evaluation. The United Kingdom has a similar approval mechanism for a PM CEMS.

The EPA and industry have done the following recent field evaluations of PM CEMS:

- EPA/Office of Solid Waste (OSW) – 3 PM CEMSs at a mixed solid and liquid hazardous waste incinerator located in Bridgeport, New Jersey during March 1995.
- EPA/OSW – 2 PM CEMSs at a hazardous waste cement kiln located in Fredonia, Kansas during May through July 1995.
- EPA/OSW – 5 PM CEMSs at the DuPont Experimental Station's hazardous waste incinerator located in Wilmington, Delaware during September 1996 through May 1997.
- Electric Power Research Institute – 4 PM CEMSs at Georgia Power Company's Plant Yates coal-fired boiler located in Newnan, Georgia during June through September 1998.

- Eli Lilly, the Chemical Manufacturers Association, and the Coalition for Responsible Waste Incineration – 2 PM CEMSs at a liquid hazardous waste incinerator at the Eli Lilly Clinton Lab in Clinton, Indiana during February through June 1998 and November through December 1998.
- EPA/OAQPS – 3 PM CEMSs at a coal-fired boiler located in Battleboro, North Carolina during June 1999 through February 2000.

Results of the EPA and industry field evaluations are described in this document.

1.0 INTRODUCTION

This report provides detailed information on the current knowledge of PM CEMSs. This information was gained from literature reviews; attendance at many meetings and conferences where the use of PM CEMSs was discussed; shared knowledge between the EPA, industry, and consultants experienced with PM CEMSs in both the United States and Europe; discussions with PM CEMS vendors; and personal experiences from performing a field demonstration of PM CEMSs. The report will be maintained as a "living document" with periodic updates as needed.

The report is primarily written to provide information useful to State permitting authorities and EPA Regional personnel. However, the information contained herein will be useful to all persons involved with a PM CEMS program. It includes (1) technical information on the monitors and their principal of operation, (2) their use history, (3) a summary of recent PM CEMS field demonstrations, (4) recommendations for future field demonstrations, (5) recommendations on how to implement a PM CEMS program, (6) a summary of the performance specification for PM CEMSs, and (7) cost information.

A draft of this report was sent to 14 individuals with different view points and knowledge in the field of continuous PM monitoring. The EPA received comments from nine reviewers, and their comments were incorporated into this final report.

2.0 HISTORICAL PERSPECTIVE OF CONTINUOUS PM MONITORING

2.1 OVERVIEW OF REGULATORY USE

Continuous monitoring of PM concentrations in smoke stacks started during the 1960s in Germany. In the United States during the 1970s, PM concentrations were correlated to opacity monitor readings, but the EPA dictated the use of transmissometers to continuously monitor the opacity of emissions from sources. For the EPA's emission monitoring regulations and State Implementation Plans (SIP), opacity is used as a surrogate for PM emissions and provides qualitative information on the operation and maintenance of particulate control equipment. The EPA's New Source Performance Standards (NSPS) require continuous monitoring of opacity of emissions from the 11 source categories presented in Table 2-1.

TABLE 2-1. NSPS REQUIRING COMS

Source category	40 CFR Part 60 Subpart
Electric Power Plants	D, Da, Db, Dc
Portland Cement Plants (Kiln and Clinker cooler)	F
Petroleum Refineries (FCCU)	J
Primary Copper Smelters (Dryer)	P
Primary Zinc Smelters (Sintering machine)	Q
Primary Lead Smelters (Blast furnace, Dross reverberatory furnace, and Sintering machine)	R
Ferroalloy Production (Control device)	Z
Electric Arc Furnace in steel mills (Control device)	AA
Kraft Pulp Mills (Recovery furnace)	BB
Lime Kilns (Rotary lime kiln)	HH
Phosphate Rock Plants (Dryer, Calciner, Grinder)	NN

In Germany, the first laws to require continuous monitoring of PM emissions came on December 29, 1959 in the German Federal Law for Citizens (Act to Amend the Industrial Code..., 1959). Then in 1964, a more concrete requirement for continuous PM monitoring that included many types of industrial plants was amended in the Technical Instruction for Air Pollution Control

(TA Luft, 1964). Plants with emissions exceeding 55 pounds per hour were required to continuously monitor PM concentration in mg/acm "as soon as a suitable instrument becomes available." The requirements in TA Luft of 1964 initiated field studies of continuous PM emission monitoring instrumentation. Several field-based research projects were completed by the German federal government in the years following the German Federal Law of Environmental Protection (BlmSchG, March 15, 1974). These field studies were completed to correct deficiencies found in the measurement technology and formed the basis for the German's instrument approval process (see Section 2.3). Additional legislative rules detailed the monitoring requirements for power plants (13^{th} BlmSchV, 1983) and waste incinerators (17^{th} BlmSchV, 1990) (Breton, 1989, Martin, 1994, Jockel, 1998, and Jockel, 1999).

In the United States in 1975, the EPA promulgated Performance Specification - 1 (PS-1), Specifications and Test Procedures for Opacity Continuous Emission Monitoring Systems in Stationary Sources, to govern the design, performance, and installation of COMS (40 FR 64250, October 6, 1975). In 1983, the EPA amended PS-1 (48 FR 13322, March 30, 1983), and in 2000, the EPA amended PS-1 again by incorporating ASTM D6216-98 design and monitor manufacturer performance specifications (65 FR 48914, August 10, 2000).

Continuous particulate mass monitoring was proposed as an EPA regulatory requirement April 19, 1996, as part of the proposed Hazardous Waste Combustion MACT emission standard (61 FR 17358). As part of the Hazardous Waste Combustion MACT, the EPA proposed PS-11, Specifications and Test Procedures for Particulate Matter Continuous Emission Monitoring Systems in Stationary Sources, to evaluate the acceptability of a PM CEMS. The Portland Cement Manufacturing MACT Final Rule in section 63.1250(k) (64 FR 31898, June 14, 1999) makes mandatory the use of PM CEMSs although not until the EPA has finalized PS-11.

2.2 PAST STUDIES

During the 1970s, the EPA sponsored several studies to examine the applicability of transmissometers to sources and the potential to correlate opacity to PM mass concentrations. Some of those studies are summarized below. Into the 1980s, philosophies changed within the EPA, and continuous PM monitoring was not a priority. Work on the PM CEMS in this country stopped until new initiatives started in the mid 1990s.

In a 1974 publication from the EPA's National Environmental Research Center, Conner (1974) showed that smoke's opacity is related to (1) the size of the particles and (2) the light wavelength used by a transmissometer. Particles much smaller than the light wavelength (particle diameter < 0.05 μm in white light) contribute little to the opacity (extinction coefficient < 0.01). For particles much larger than the light wavelength (particle diameter > 2 μm in white light), the opacity is not a function of the light wavelength, and the mean extinction coefficient is about 2. For particles about the same size as the light wavelength ($0.05 < d < 2$ μm in white light), opacity has a strong dependence on the particle diameter, that is, the extinction coefficient increases from 0.01 to as high as 3 or 4 as the particle diameter increases from 0.05 μm to 2 μm. Also, Conner detailed the effect of a transmissometer's light wavelength on the opacity of fine particles (Conner et al., 1967). Opacity determined from a blue light source has a positive bias (e.g., in a white plume, an opacity of 25 percent, as determined by white light, is seen as about 40 percent by blue light), and opacity determined from a red light source has a negative bias (e.g., in a white plume, an opacity of 25 percent, as determined by white light, is seen as about 18 percent by red light). Opacity determined from an infrared light source has a strong negative bias (e.g., in a white plume, an opacity of 25 percent, as determined by white light, is seen as about 5 percent by infrared light). A black plume demonstrates the same biases but to a lesser degree.

As of 1974, the EPA had not resolved a transmissometer's ability to monitor PM mass concentrations from sources. Some investigators reported good empirical correlations between mass concentration and light transmittance while others indicated that the effect of particle characteristics on the correlation was too strong for a meaningful correlation. At that time, the researchers clearly understood that for a useful correlation to exist between opacity and PM mass concentration, the particle characteristics (size, shape, and composition) needed to be sufficiently consistent and to remain consistent over time (Conner, 1974). Conner (1974) showed mass concentration versus opacity for a kraft pulp mill recovery furnace, a cement plant kiln, and a coal-fired boiler. The concentration versus opacity graphs showed that a strong linear relationship existed between mass concentration and opacity at those three sources. Conner noted that particulate emission control devices would likely control the particulate characteristics that most affect the opacity to mass concentration correlation sufficiently enough that a transmissometer could be used as a mass monitor.

In a 1975 journal article, John Nader, Chief of the Stationary Source Measurements Research Section of the EPA's National Environmental Research Center, published a summary of the current technologies for continuously monitoring PM emissions. In his paper, he discussed electromagnetic techniques, beta attenuation techniques, optical techniques (both light attenuation and light scatter), and electrical techniques. At the time his paper was published, most of the instruments were prototypes. Nader concluded that a performance specification for particulate mass concentration monitors would be developed in the near future.

In a 1979 publication from the EPA's Environmental Sciences Research Lab, Conner, Knapp, and Nader (1979) presented, in addition to other things, the existence of a functional relationship between in-stack transmissometer-measured opacity and mass concentration of PM emissions. This examination was done at Portland cement plants and oil-fired power plants. Their paper contained the following equation that demonstrates that the opacity-mass concentration relationship depends on the chemical and physical characteristics of the particles, as well as the pathlength of the opacity measurement:

$$O = 1 - e^{-AC\ell}$$

where:

O = opacity

A = attenuation per unit path length per unit mass concentration

C = mass concentration

ℓ = pathlength of opacity measurement

Tests to correlate opacity and mass concentration were done at three cement plants; two used the wet-process rotary kiln with PM emissions controlled with ESPs and one used the dry-process rotary kiln with a baghouse for PM emissions control (Conner, Knapp, and Nader, 1979). Opacity measurements were made with either a Lear Siegler RM4 or RM41P. Mass concentrations were determined by EPA Reference Method 5. The results of their study indicate that the light attenuation coefficient of PM emissions at cement plants is linearly related to the PM mass concentration for both wet and dry processes. However, for the correlation done at actual stack conditions, the slopes of the curves (attenuation coefficient/mass concentration) were distinctly different for the wet process (1.55 ± 0.02 $m^{-1}/g/m^3$) and the dry process

(0.92 ± 0.08 $m^{-1}/g/m^3$). Note, the correlation for the process controlled by the baghouse was developed from only three data points within a narrow opacity range of about 6 percent to 8 percent. This suggests caution when interpreting these results.

Other tests to correlate opacity and mass concentrations were done at three oil-fired power plants (Conner, Knapp, and Nader, 1979). The boilers had no PM emission control equipment installed. Two plants combusted low-sulfur oil, and the boilers were fired at excess oxygen levels between 1.5 percent and 3.0 percent. The third plant combusted high-sulfur oil, and the boiler excess oxygen was at 0.2 percent. Opacity measurements were made with a Lear Siegler RM41P. Mass concentrations were determined by EPA Method 5. The data from the two similar plants were combined, and a light attenuation coefficient per mass concentration ratio (at actual stack conditions) of 0.43 $m^{-1}/g/m^3$ was calculated. This relationship was calculated over an opacity range from about 2.5 percent to 6.7 percent and forced through the origin. The data for the high-sulfur, oil-fired boiler produced a light attenuation coefficient per mass concentration ratio (at actual stack conditions) of 0.20 $m^{-1}/g/m^3$. This relationship was calculated from data collected during two sampling efforts 6 months apart covering an opacity range from about 6 percent to 11 percent. This relationship was also forced through the origin. The authors stated their reason for the difference in the correlations as follows: the low excess oxygen combustion produced a greater portion of particles (unburned carbon) in the large size fraction (mean diameter of about 3 μm compared to less than 0.3 μm) and therefore, as expected, produced lower opacity readings.

In a 1980 article, Uthe published the results of an evaluation of a relatively inexpensive infrared transmissometer used as a PM mass concentration monitor. Uthe's results showed that the extinction-to-mass concentration for a given aerosol type is dependent on particle size within the visible light spectrum but nearly independent of particle size at the infrared wavelength. Uthe tested his IR transmissometer in an aerosol chamber with three distinct particle size ranges: 0-2.5 μm, 2.5-5 μm, and 5-10 μm. His particles were composed of fly ash, iron oxide, and silica. For fly ash particles in the size range of 0-10 μm, the IR extinction to mass concentration ratio varied by a factor of 1.6 while the variability for visible light was a factor of 4.4. For silica particles, the IR extinction to mass concentration ratio was nearly constant while the variability

for visible light was about a factor of 3. Personal communication with Uthe revealed that the IR transmissometer was never evaluated on a real emission source.

During a 1-year period in 1976-1977, a group of researchers from the Industrial Research Institute, University of Windsor (Gnyp et al., 1978), conducted a field evaluation of five different PM monitors. The test was done at a secondary lead smelter. The stack exhaust consisted of particulate from uncontrolled lead alloying kettles and a reverberatory furnace controlled with a fabric filter. Thirty-two PM test runs were conducted over a 9-month period from June 4, 1976 to March 7, 1977. Twelve tests accounted for the reverberatory furnace mode of operation (i.e., controlled emissions). The remaining 20 tests were conducted while refining processes were in progress (i.e., uncontrolled emissions). The arithmetic mean particle diameter of the baghouse emissions was 0.43 μm with a standard deviation of 0.13 μm. The arithmetic mean particle diameter of the emissions from the lead kettles was 18.9 μm with a range from 0.05 μm to 150 μm. The particulate consisted primarily of lead, tin, and zinc. The results of the PM monitor evaluation are summarized in Table 2-2.

TABLE 2-2. PM MONITOR EVALUATION RESULTS AT A SECONDARY LEAD SMELTER

PM monitor	Results
Lear Siegler RM41 transmissometer	Impossible to correlate all 32 tests to one curve
	Three distinct linear correlations were evident
	Most reliable of all monitors tested
	Not applicable for sources where process variations cause changes in PM size, color, or refractive indices
Contraves Goertz with RAC transmissometer	Impossible to correlate all 32 tests to one curve, basically the same results as the RM41
	Not capable of detecting large particles greater than 25 μm in diameter
Environmental Systems Corporation PILLS V light scatter monitor	Correlation was relatively independent of changes in particle size, color, and refractive index
	More useful than the best transmissometers
	Some of the variability in the data was attributed to changes in absorptive components of refractive indices

TABLE 2-2. (CONTINUED)

PM monitor	Results
IKOR 2710 charge transfer	Limited sensitivity to particles smaller than 1 μm diameter; particles must contact sensor
	At the stack conditions, only particles larger than 4 μm in diameter made contact with the sensor surface
	Orienting the sensing element with its axis perpendicular to the flow did not improve the contact of small particles
Research Appliance Co. (RAC) beta gauge monitor	Expected a single correlation curve, but instrument was more sensitive to smaller particles less than 1 μm in diameter
	Substantial amounts of PM were recovered from the sampling system at the end of the test program
	Experienced many operational breakdowns, only functioned for 13 test runs

The developmental testing of PM CEMSs in Germany started during the 1960s when the TÜV-Rheinland (the German "technical inspection agency," a not-for-profit organization similar to Underwriters Laboratories in the United States) first investigated continuous PM monitors (Draft Technical Support Document, 1996). The early tests involved transmissometers. Initially, eight devices were evaluated, but all failed to perform to the satisfaction of TÜV. After improvements were made, TÜV Rheinland certified two transmissometers in 1968 (Peeler et al., 1995). The first certification of a PM CEMS (a transmissometer) was issued in 1974 and prompted the German Federal Law of Immission Protection to require continuous monitoring of PM emissions at power plants. A further reduction in particulate emissions was required with the passage of the First Regulation of General Administration Procedures to the Federal Law of Immission Protection on February 27, 1986. This latter act spurred the use of more sensitive monitors to measure PM emissions from well-controlled waste incinerators.

As previously noted, during the early period of continuous PM monitoring in Germany, transmissometers were used to measure extinction ($b = 2.303 * \log(1/T) / PL$) and were correlated to PM concentration. A key advantage of using extinction rather than opacity is that extinction relates linearly to particulate matter. Extinction also results in an output that is more sensitive to increases in PM concentration at low levels. The transmissometers were typically

operated at two measuring ranges, 0-9 percent or 0-33 percent opacity. For a 1-meter pathlength, a transmissometer's minimum quantifiable PM concentration is about 30 mg/acm (Peeler et al., 1995). From 1968 through 1985, approximately 1,000 to 2,000 transmissometers, measuring extinction, were installed on all types of sources in Germany measuring PM emission limits in the range of 30 mg/m^3 to 150 mg/m^3. Furthermore, approximately 5,000 transmissometers, measuring opacity, were installed for monitoring control equipment performance. Then, as PM concentrations decreased to levels too low to be accurately measured with transmissometers, use of the light scattering type PM CEMS came into favor. Light scatter monitors are 100 to 1,000 times more sensitive than transmissometers. A light scattering monitor's output is directly proportional to PM concentration, and thus inversely proportional to a transmissometer output (i.e., it cannot be used as a substitute for an opacity monitor). Since 1986, light scatter monitors represent about 80 percent of new PM monitors installed in Germany (Peeler et al., 1995). During the 1990s, many existing transmissometers were replaced with light scattering type PM CEMS as facilities updated their pollution control equipment to come into compliance with more stringent regulations. The suitability testing for transmissometers is governed by VDI Guideline 2066, Part 4. The suitability testing of light scattering type PM CEMSs is governed by VDI Guideline 2066, Part 6.

2.3 CURRENT EUROPEAN EXPERIENCE

In Germany, a specific model PM CEMS must pass a suitability test and be approved by the Federal Environmental Agency before it can be installed and used as a PM CEMS to meet regulatory monitoring requirements. The suitability test follows guidelines in a Standard Practice regarding the monitoring of emissions (Standard Practice, 1990, revised June 8, 1998). The source-specific acceptance of a suitability test is based on a hierarchy of difficulty in passing the test; incinerators are most difficult, followed by coal, oil, and gas-fired plants. Thus, if a monitor passes suitability for an incinerator, the monitor is also approved for all the less difficult sources. However, sources such as cement kilns and metal recovery furnaces are separate and require their own suitability test (Draft Technical Support Document, 1996). The specifications that a PM monitor must meet to gain approval are presented in Table 2-3. The suitability test consists of both a laboratory evaluation and a field evaluation. In most cases, the suitability test is done by

the TÜV branch in Rheinland; however, TÜV is not the only organization that can do the suitability test.

TABLE 2-3. GERMAN SUITABILITY TEST SPECIFICATIONS FOR APPROVAL

Test	Specification[a]
Normative conditions	Suitability testing must be done according to guidelines in VDI 2449 part 1 dated February 1995.
Endurance test	Conduct an endurance test for at least 3 months. If possible, conduct the test at a single test site for a continuous period.
Analytical function	In suitability testing, the relationship between the instrument reading and mass concentration from a reference measuring method must be determined by regression analysis. Each instrument must be supplied with a characteristic curve plotted by the manufacturer.
Protection from changing settings (Security)	The instrument and control units must be secured against unauthorized or inadvertent change during operation.
Zero and reference point position	The zero point should be 10 percent to 20 percent of full scale on the instrument display and recording device. The reference point should be 70 percent to 90 percent of full scale.
Full scale readout range	The readout range should equal: • 2.5 to 3 times the applicable emission limit for a coal-fired furnace • 1.5 times the applicable emission limit for a waste incinerator
Measured value output	The instrument must have two readout channels.
Status signals	The instrument must have status signals for 1. Operation 2. Service 3. Malfunction
Availability	The instrument must achieve 90 percent data availability during continuous operation and 95 percent availability during the evaluation test.
Maintenance interval	The instrument's maintenance period must be at least 8 days (i.e., no operator intervention for at least 8 day intervals). Maintenance period is determined during the field evaluation.
Reproducibility - for all PM CEMS since 1998	$R_D \geq 50$ for a measuring range ≥ 20 mg/m^3 $R_D \geq 30$ for a measuring range < 20 mg/m^3
Complete system	The suitability test covers the entire CEMS.

TABLE 2-3. (CONTINUED)

Test	Specification[a]
Normal operating conditions	Evaluate the instrument under the following conditions over the manufacturer's recommended range for each: 1. Supply voltage variation 2. RH in ambient air 3. Liquid water in the air 4. Vibration and shock
Automatic readjustment	For instruments with self-testing of proper operation and automatic readjustment, test these features in the evaluation test. If an adjustment range of ±6 percent of span is exceeded during autocorrection, an alarm must be given.
Ambient temperature range	For instruments installed unprotected from ambient conditions, the instrument must operate over the range of $-20^{o}C$ to $50^{o}C$. For temperature-controlled installations, the instrument must operate over the range of $5^{o}C$ to $40^{o}C$. Test instrument in a climate chamber.
Effect of sample gas flow	For instruments using a bypass for sampling, the effect of changes in sample gas flow rate on the measured signal must not exceed ±1 percent of span. Neither the total volumetric flow sampled during the operating cycle nor the dilution air volumetric flow may deviate from the expected value by more than ±8 percent.
Multicomponent instrument	Each component must fulfill the requirements, even when all measuring channels are operating simultaneously.
Drift between servicing intervals	The zero point must not drift more than ±2 percent of full scale for range ≥ 20 mg/m^3 ±3 percent of full scale for range < 20 mg/m^3 The reference point must not drift more than ±2 percent of the reference value for range ≥ 20 mg/m^3 ±3 percent of the reference value for range < 20 mg/m^3
Linearity	The difference between the actual value and the reference value must not exceed ±2 percent of full scale (for a 5 point check).
Contamination check	If the measurement principle depends on optical methods, the instrument must check for optical surface contamination during operation. Use clean purge air to keep optical surfaces clean.
Outward migration of measurement beam	If the measurement principle is based on optical methods, any impairment due to outward migration of the measurement beam must be stated and must not exceed 2 percent of full scale in an angular range of ±0.3°.

TABLE 2-3. (CONTINUED)

Test	Specification[a]
Automatic correction of zero and reference points	The instrument must automatically initiate and record the zero and reference points at regular intervals. For instruments with automatic zero point correction, the correction amount must be recorded as a measure of contamination.
Exhaust gas volume	For extractive instruments, the sample volume must be within ±5 percent of the set point.
Dead time, setting time (similar to cycle time)	Measure the dead time to include: response time, analysis time, and reporting time.

[a] Specifications derived from TÜV Suitability Test Reports for the Sigrist CTNR, Verewa F-904, and Durag D-R 300-40.

After a PM CEMS is installed, its output is correlated to manual gravimetric particulate data. The stability of the correlation is checked by conducting additional manual gravimetric tests at 3- to 5-year intervals, depending on the source type. A linearity check of the instrument's response is also done annually (Peeler et al., 1995). The TÜV has guidelines for establishing correlation curves. Most of the manual particulate emissions measurements are done by an isokinetic, in-stack filter test method (similar to Method 17 - VDI 2066, Part 7); however, in-stack sampling is limited to stacks with no entrained water droplets. The following guidelines are used for a correlation test in Germany (personal communication with Dr. Wolfgang Jockel, TÜV, Rheinland):

- The test program consists of 12 to 20 test runs.
- A few paired train test runs are completed to demonstrate an ability to maintain precision. If the testing team has experience at a source, they do not do any test runs with paired trains.
- Test runs are short, no longer than 30 minutes (this is so that any variability in PM concentrations is noticeable and not averaged out by a long test run).
- If the facility cannot achieve any variability in PM concentration, the correlation test program is stopped after 6 test runs. Typically, waste combustion facilities have extensive air pollution control systems (e.g., a water spray drier for cooling, a fabric filter, an acid gas (HCl) scrubber, a lime scrubber SO_2 control, a dual catalyst SCR and dioxin oxidizer,

and an activated charcoal "police" filter), and the particulate emissions cannot be artificially adjusted to obtain a range of PM concentrations.

In cases with emissions that are very low relative to the limit, the guidelines allow extrapolation of the correlation; however, data measured beyond the correlation range trigger only additional testing, not noncompliance. For a correlation data set with only a cluster of data points very much below the emission limit, the emission limit becomes related to the mA signal of the PM CEMS. For example, if a PM CEMS output during the testing ranged from 4 mA to 4.5 mA, no 30-minute average may exceed 4.5 mA during plant operations. If an average exceeds 4.5 mA, a new correlation test that includes values above 4.5 mA would have to be done. For a limited correlation data set with little variability in PM concentration, the German guidelines require the use of a hypothetical zero point (i.e., 4 mA = 0 mg/m^3) in the correlation data set for an in-situ light scatter type PM CEMS using little or no purge air and for an extractive type PM CEMS (i.e., either beta gauge or light scatter).

The German approach to using a PM CEMS is to build the statistical uncertainty of the PM CEMS measurement (due to the factors of particle composition and size distribution) into the emission limit value. The correlation relation is not required to achieve a specific statistical accuracy (e.g., a confidence interval $\leq$10 percent at the emission limit value) to be approved. This approach is illustrated in the following example. A municipal waste combustion facility has a base PM emission limit (EL) of 30 mg/dscm. Assume a specific source's PM CEMS correlation has a confidence interval (CI) at the emission limit of 4 mg/dscm (13 percent) and a tolerance interval (TI) at the emission limit of 11 mg/dscm (37 percent). Then, that specific source would have the following PM limitations (from personal communication with Dr. Wolfgang Jockel, TÜV, Rheinland):

- No 30-minute average may exceed: 2*EL + TI = 60 + 11 = 71 mg/dscm.
- 97 percent of the annual 30-minute averages may not exceed: 1.2(EL + CI) = 36 + 5 = 41 mg/dscm.
- No daily average may exceed: EL + CI = 30 + 4 = 34 mg/dscm.

Even with the uncertainty in the PM CEMS measurement, the correlation relationship can still be used as a basis for compliance. Traditionally, the EPA regulations have taken this uncertainty into account when a CEMS-based standard is adopted.

In addition to the suitability testing specifications that exist in Germany, the International Standards Organization (ISO) has developed standards for PM CEMSs. The ISO committee TC146/SC1/WG1 finalized ISO 10155 "Stationary Source Emissions - Automated Monitoring of Mass Concentrations of Particles - Performance Characteristics, Test Methods, and Specifications" on April 1, 1995. ISO 10155 specifies conditions and criteria for the automated monitoring of PM mass concentrations in stationary sources. The specifications are general and not limited to a specific measurement principle or system. The Central European Normalization (CEN) Committee TC264/WG5 has developed requirements applicable to continuous PM monitoring. CEN adopted ISO 10155 for hazardous waste incinerators.

The Environment Agency (EA) in the United Kingdom (UK) has established a monitoring certification scheme (MCERTS) for all CEMSs, including PM CEMSs. The MCERTS program is similar to the program used in Germany and began on April 22, 1998. The performance standards have been specified for the following sources:

- Large combustion plants
- Municipal and hazardous waste combustors
- Solvent-using processes

The instrument performance standards are based on relevant sections of several ISO and CEN standards. These standards are published as EA standards under the MCERTS program. Instrument testing is done in two parts; laboratory tests and a 3-month field evaluation. The standards cover the performance characteristics presented in Table 2-4.

TABLE 2-4. MCERTS PM CEM EVALUATION CHARACTERISTICS

Laboratory test	Field evaluation
Use a wind tunnel test with well characterized and reproducible particle-size distribution with mass concentration variable from 0 to 500 mg/m^3 at a gas flow velocity of 1.5 to 50 ft/s	Accuracy - as calibrated according to ISO 10155
Response time	Reproducibility from two identical PM CEMS
Calibration to PM generated in wind tunnel	Zero and upscale drift during the field test period - average of daily drifts over a month
Linearity of PM CEM response to changes in PM concentration at 5 levels	Data availability

TABLE 2-4. (CONTINUED)

Laboratory test	Field evaluation
Cross-sensitivity to gases, velocity changes at a fixed PM concentration, and particle size changes	Maintenance interval - time over which the zero and upscale drifts remain within specification
Establishment of a lower detection limit	
Repeatability of the PM CEM's output to a continuous PM concentration in tunnel	
Change in zero value to variations in • Ambient humidity • Ambient temperature • Vibration • Mechanical shock • Magnetic field • Aging	

3.0 ANALYTICAL PRINCIPLES

Five analytical principles used in instruments to measure PM concentrations are described below. These principles are light scattering, beta attenuation, probe electrification, light extinction, and optical scintillation.

3.1 LIGHT SCATTERING

Light is both absorbed and scattered by particles in the path of the light. Scattering is due to reflection and refraction of the light by the particle. The amount of light scattered is based on the concentration of particles and the properties of the particles in the light's path (e.g., the size, shape, and color of the particles). If the wavelength of the incident light is much larger than the radius of the particle, a type of scattering called "Rayleigh" scattering occurs. Rayleigh scattering causes the blue color of the sky because visible sunlight is scattered by very small particles and gases in the upper atmosphere. If the wavelength of the incident light is about the same size as the radius of the particle, a type of scattering called "Mie" scattering will occur. Mie scattering causes the haze seen on a hot summer day and the reduction of visibility by car headlights in a fog.

A light scatter type instrument measures the amount of light scattered in a particular direction (i.e., forward, side, or backward) and outputs a signal proportional to the amount of scattering material (e.g., particulate matter) in the sample stream. The PM concentration is derived by correlating the output of the instrument to manual gravimetric measurements. In a scatter light instrument, a collimated beam of visible or near infrared (IR) light is emitted into a gas stream. The light is scattered by particles in the light path (i.e., Mie scattering), and the receiving optics focus an area of that light onto a detector that generates a current proportional to the intensity of light it receives. The angle of the source to the receiving optics and the characteristics of the optics determine the volume of space from which the scattered light is measured.

Some components included in these instruments to minimize the effect of interference and degradation of the light source are: (1) the use of a pulsed light and (2) parallel measurement of the light source intensity. The use of the pulsed light source limits the possibility that light from some other source (e.g., ambient light) will be measured, because the instrument only measures the reflected light while the instrument light source is on. The parallel measurement of the light

source intensity accounts for degradation of the light source because a reference of the source intensity is measured along with each scattered light measurement.

3.2 BETA ATTENUATION

When beta rays pass through a material, they can be absorbed, reflected or pass directly through. The attenuation of intensity in beta rays is proportional to the amount of material present. The attenuation through most materials is relatively consistent and is based on the electron density of the material (calculated by dividing the atomic number by the atomic mass). The attenuation for most materials is about 0.5, except for hydrogen and heavy metals. Beta attenuation has been used in production lines as a quality control check of product thickness for more than 40 years. For example, in the production of cellophane plastic wrap, a beta gauge is used to ensure that the thickness of the cellophane remains within specification.

The principle behind beta attenuation particulate sampling instruments (beta gauge) is that energy is absorbed from beta particles as they pass through PM collected on a filter media. Beta gauge instruments have been designed to take advantage of this scientific principle to monitor/measure PM concentrations. The attenuation due to only the PM is measurable if a baseline beta count through just the filter can be established prior to sampling. The difference between the baseline beta count and the beta count after sampling is directly proportional to the mass of PM in the sample.

The two main components of a beta attenuation measuring system are the beta source and the detector. The beta source must be selected so that: it has an energy level high enough for the beta particles to pass through the collection media (i.e., the filter tape) and the particulate, it has enough source material so that a high count rate is present, it is stable over long periods of time, and it does not present a danger to the health of personnel that come into contact with the instrument. The source of choice has been Carbon-14 because: it has a safe yet high enough energy level, it has a half-life of 5,568 years, and it is relatively abundant. Many different types of detectors can quantify beta particle counts, but the ones most widely used are the Geiger Mueller counter or a photodiode detector.

The beta gauge works by measuring beta counts before and after collecting PM on a filter media. The instrument will measure a clean area of the filter media for a fixed period to determine the baseline (e.g., 2 minutes), then it will advance that area of the filter to a sampling apparatus

for another set period of time (e.g., 8 to 9 minutes), and finally return that area of the filter to the detector for the same period used to establish the baseline reading. The difference in the beta count can be directly correlated to particulate mass through calibration of the instrument using a filter media containing a known mass of a particulate-like material.

The beta gauge instrument is designed to provide a mass concentration. The instrument measures the volume of gas extracted from the stack/duct for each sample interval and calculates mass concentration in the specified units (e.g., mg/dscm).

3.3 PROBE ELECTRIFICATION (TRIBOELECTRIC EFFECT)

Probe electrification takes advantage of the fact that all particles have a charge. Electrostatic charges from the friction of particles contacting a probe will electrify the probe (i.e., a small current is produced in the probe). This is called triboelectricity. Another applicable mechanism is based on a small current being induced in the probe when charged particles pass near a probe.

A triboelectric particulate monitoring device measures the direct current (DC) produced by the charge transfer when particles strike the probe. The DC is measured by an electrically isolated sensor probe that is connected to amplification electronics. Multiple particle strikes create a small flow of current through the instrument; current is proportional to the momentum (mass times velocity squared) of the particles. Amplification electronics convert the current to an instrument output signal. Monitors that rely on inducing a current in the probe, rather than particle contact with the probe, work similarly except an alternating current (AC) is measured.

Because the signal produced by these monitors may be affected by several factors, the instrument output must be correlated to manual gravimetric measurements. Some of the primary factors that may affect the relationship between particle mas and the monitored signal are particle velocity for triboelectric devices, particle characteristics (e.g., composition and size), and particle charge. Probe electrification does not work well in wet gas streams with water droplets or when the particles are subject to a varying electrical charge. The AC component of the induced current is being used to minimize the effect of velocity on the measurement.

3.4 LIGHT EXTINCTION (TRANSMISSOMETER)

Light extinction is a common method in use today; the instruments that incorporate this technology are referred to as transmissometers or opacity monitors. These instruments measure

the loss of light intensity across a particulate laden gas stream as a function of Beers-Lambert's Law. The intensity of the light at the detector, I, is compared with the reference light intensity, I_O, to give the transmittance, $T = I/I_O$. Transmittance can be converted to opacity, Op = 1-T, or optical density, D = log(1/T). The loss of light intensity can be correlated to particulate mass concentration measured by manual gravimetric sampling. In general, the measurement sensitivity of transmissometers is not fine enough to detect small changes in PM concentration. For example, in a 2 meter diameter stack (4 m path length) the smallest emission standard that should be measured with a transmissometer is 15 mg/m^3 (personal communication with Dr. Wolfgang Jockel, TÜV Rheinland, email dated March 20, 2000).

The basic operational principle of these instruments is that a collimated beam of visible light is directed through a gas stream toward receiving optics. The receiving optics measure the decrease in light intensity, and the instrument electronics convert the signal to an instrument output. An instrument incorporating the components described in the previous sentences would be considered a single pass system. For better resolution and higher accuracy, a dual-pass transmissometer and a modulating light source are used. The dual-pass transmissometer (with a reflector mirror on the opposite side of the stack from the light source) allows all of the instrument electronics to be incorporated into one unit. A high frequency modulation of the light source limits the possibility of interference because the instrument only reads the loss of light while the light source is on. When an LED light source is used, electronic modulation of the light (instead of chopping) is possible. Incorporating the light source and detector into one instrument also allows direct measurement of the loss of light by comparison of the source intensity and the loss of light at the same time. This helps prevent inaccurate readings due to the degradation of the light source intensity (a common problem in basic transmissometers).

A transmissometer used as a PM CEMS should use a red or near infrared light source, and not the white light source used on traditional opacity monitors (see Section 2.2, the discussion of Uthe's work, for an explanation). Some manufacturers have started using a green LED to monitor both opacity and PM concentration simultaneously. Furthermore, the opacity monitor's correlation to PM concentration as measured by the Reference Method should be done versus opacity or optical density.

3.5 OPTICAL SCINTILLATION

Optical scintillation, like light extinction, utilizes a light source and a remote receiver that measures the amount of received light. The difference is that the scintillation monitor uses a wide beam of light, no focusing lenses, and the receiver measures the modulation of the light frequency due to the movement of particles through the light beam and not the extinction of light. The principles at work here are that the particles in a gas stream will momentarily interrupt the light beam and cause a variation in the amplitude of the light received (scintillation). The greater the particle concentration in the gas stream the greater the variation in the amplitude of the light signal received. The scintillation monitor must be calibrated to manual gravimentic measurements at the specific source on which it is installed.

4.0 SUMMARY OF KNOWN PM CEMS

Based on the analytical measurement principles presented in Section 3.0, instrument manufacturers have developed monitors to continuously measure PM concentrations in source emissions. Most of these monitors measure a property of the particulate matter in the stack (e.g., scatter of light, transfer of charge, or modulation of transmitted light) and the concentration is then inferred based on a correlation to manual gravimetric samples. In contrast, the beta attenuation monitors produce results on a concentration basis from the mass of particulate matter collected on a filter divided by the volume of gas sampled through the filter.

This section presents a summary of most of the monitors that are commercially available from manufacturers as "off-the-shelf" PM CEMS, as listed below. Mention of specific manufacturers equipment is not an endorsement of the product by the EPA. These descriptions are solely for informational purposes.

4.1 Durag F904K Beta Attenuation

4.2 Environment S.A. 5M Beta Attenuation

4.3 Mechanical Systems Inc BetaGuard PM Beta Attenuation

4.4 Sigrist KTNR and CTNR Extractive Light Scatter

4.5 Durag DR-300-40 In-situ Light Scatter

4.6 Environmental Systems Corporation P5 In-situ Light Scatter

4.7 Sick Inc. RM210 In-situ Light Scatter

4.8 Sick Inc. FW 100 and FWE 200 Light Scatter

4.9 Grimm Technologies 6300 In-situ Light Scatter

4.10 Monitor Labs 300L In-situ Light Scatter

4.11 BHA Group CPM 5000 Scintillation

4.12 PCME Scintilla SC600 Scintillation

4.13 Insitec TESS In-situ or Extractive Laser Light Extinction-Scatter

4.14 PCME DustAlert 90 Electrostatic Induction

4.15 Auburn International Triboguard III or II In-situ Triboelectric

4.16 Codel StakGard Triboelectric Dust Monitor

4.17 Opacity/Transmissometers

Many of these PM CEMSs have been in use for 10 or more years while others are relatively new. Source specific applicability of each of these PM CEMSs is presented in Section 7.0, PM CEMS Implementation.

4.1 DURAG F904K BETA ATTENUATION

The F904K extracts a sample from the stack, transports the sample to the instrument through a heated line, and deposits PM on a filter tape during user-selected sampling periods (e.g., 4 to 8 minutes). Before and after each sampling period, the filter tape is moved between a carbon 14 beta particle source and Geiger-Mueller detector. The amount (in units of mg) of PM on the filter is determined by the reduction in transmission of beta particles between the readings for the dirty tape and the clean tape. This instrument measures the sample gas volume on a dry basis, and therefore outputs PM concentration in units of mg/dscm. The F904K samples isokinetically at normal stack gas velocity, but isokinetic sampling is not actively maintained (i.e., when the stack gas velocity decreases, the F904K's sampling rate remains constant creating a superisokinetic sampling condition and a low bias to the measured PM concentration). To minimize particulate loss in the sampling system, the F904K introduces dilution air after the sampling nozzle and samples at a high rate of about 3,000 liters per hour (~ 1.75 cfm); however, this sampling rate can be modified as needed for site-specific conditions. The measuring range is determined by the length of the sampling period, but the instrument can only accommodate up to 6 mg to 8 mg of particulate deposited on the filter tape during each sampling period. If too much particulate is collected during a sampling interval, a high vacuum is created, and the sampling is curtailed. This instrument does automatic zero and upscale drift checks to meet daily QC check requirements.

The distance between the probe and instrument is recommended to be less than 20 feet. The footprint of the F904K is approximately 30 inches by 48 inches with clearance needed in front and behind the case to open the doors. The instrument weighs about 400 pounds. A single, 6-inch port is needed for the probe installation into the stack. This instrument also requires a supply of high-pressure air and 230V of electrical power.

The F904 version was approved by the German TÜV in 1990 for all sources. The F904 version was evaluated by the EPA/OSW at the long-term field test at the DuPont Experimental Field Station liquid waste incinerator and by Eli Lilly (only during phase II) at a liquid waste

incinerator. The F904K was evaluated by the EPA/OAQPS at a coal-fired boiler and by the Department of Energy at the radionuclide incinerator at Oak Ridge National Lab. The instrument is relatively insensitive to changes in the PM composition and PM properties and is not affected by the presence of condensed water droplets in the gas stream. Although the instrument output is in units of mg/dscm, a correlation to manual gravimetric data is recommended to account for any particulate stratification at the sampling point.

4.2 ENVIRONMENT S.A. 5M BETA ATTENUATION

The Beta 5M extracts a sample from the stack through a heated probe and deposits PM on a filter tape during user defined sampling periods (e.g., 4 to 8 minutes). The instrument mounts onto the end of the probe and thus does not have a sampling line. At the end of each sampling period, the filter tape is moved between a carbon 14 beta particle source and a detector. The amount (in units of mg) of PM on the filter is determined by the decrease in beta particles passing through the dirty tape as compared to the clean tape. This instrument measures the sampled volume on a wet basis, and therefore, outputs PM concentration in units of mg/acm. Since the sampled volume is measured on a wet basis, the instrument is susceptible to clogging in the volume measurement lines when used in high-stack-gas-moisture environments. The Beta 5M maintains isokinetic sampling with real-time ΔP and temperature measurements. Before the analysis is done at the end of each sampling period, the probe nozzle is closed, opened, and closed again creating a vacuum to re-entrain any PM deposited in the probe. The measuring range is determined by the length of the sampling period, but the instrument does have a lower detection limit. Currently, this instrument does not do automatic zero and upscale drift checks, but the manufacturer is reportedly developing this capability.

The footprint of the Beta 5M is a box attached to the probe with dimensions of approximately 15 inches by 30 inches by 30 inches that hangs from a support frame attached to the stack. The instrument weighs about 180 pounds. A single, 6-inch port is needed for the probe installation into the stack. This instrument also requires a supply of high-pressure air and either 115V or 230V of electrical power.

The Beta 5M was evaluated by the EPA/OSW at the long-term field test at the DuPont Experimental Field Station liquid waste incinerator, by Eli Lilly at a liquid waste incinerator, and by the Department of Energy at the radionuclide incinerator at Oak Ridge National Lab. The

instrument is relatively insensitive to changes in the PM composition and properties and is not affected by the presence of condensed water droplets in the gas stream, except for the potential of clogging the sample volume lines. Although the instrument output is in units of mg/acm, a correlation to manual gravimetric data is recommended to account for any particulate stratification at the sampling point.

4.3 MECHANICAL SYSTEMS INC. BETAGUARD PM BETA ATTENUATION

The BetaGuard PM extracts a sample from the stack, transports the sample to the instrument through a heated line, and deposits PM on a filter tape during user-selected sampling periods (e.g., 4 to 8 minutes). Before and after each sampling period, the filter tape is moved between a carbon 14 beta particle source and Geiger-Mueller detector. This instrument uses a dual beta source-detector arrangement to minimize lost sample time (i.e., sampling is occurring on a second "spot" while a measurement is being made on the first "spot"). The amount (in units of mg) of PM on the filter is determined by the reduction in transmission of beta particles between the readings for the dirty tape and the clean tape. This instrument measures the sample gas volume on both a wet and dry basis, and therefore outputs PM concentration in a variety of units. The BetaGuard PM actively samples isokinetically by receiving a stack gas flow rate signal from a flow monitor. Isokinetic sampling is maintained by holding the total sample flow rate constant and then varying the amount of dilution air that is added to the sample gas. The measuring range is determined by the length of the sampling period and the selected nozzle size. The instrument can measure in a range from 1 to 500 mg/dscm. If too much particulate is collected during a sampling interval, a high vacuum is created, but, instead of aborting the sampling cycle, the amount of PM is measured and a new sampling cycle is started. This instrument does automatic zero and upscale drift checks to meet daily QC check requirements. Additionally, this instrument automatically does daily sample flow rate checks.

The distance between the probe and instrument is recommended to be less than 50 feet. The footprint of the BetaGuard PM is approximately 12 inches by 30 inches with clearance needed in front of the case to open the door. The instrument weighs about 350 pounds. A single, 6-inch port is needed for the probe installation in most stacks. This instrument also requires a supply of high-pressure air and 120V of electrical power.

The BetaGuard PM has undergone field trials done by the vendor and is being evaluated in a second Electric Power Research Institute (EPRI) field evaluation at a coal-fired boiler. The instrument is relatively insensitive to changes in the PM composition and PM properties and is not affected by the presence of condensed water droplets in the gas stream. Although the instrument vendor asserts that a site specific correlation to manual gravimetric data is not needed for a representative sample location, the EPA requires a PS-11 correlation test to account for any particulate stratification at the sampling point.

4.4 SIGRIST KTNR AND CTNR EXTRACTIVE LIGHT SCATTER

The KTNR and CTNR (newer version) are both PM CEMSs that use the principle of forward light scattering at 15° in the visible to near infrared light spectrum. The measuring ranges are from 0 to 0.1 mg/dscm up to 0 to 1000 mg/dscm. These instruments extract a heated slipstream (1 m^3/min) from a single point in the stack and pass a small portion (35 lpm) through a photometer. The extracted gas is then returned to the stack. The extraction sample rate is over-isokinetic at normal stack gas flow rate. The vendor notes that over-isokinetic sampling significantly reduces the error caused by velocity fluctuations and is an alternative to continuous monitoring of the stack gas velocity and adjustment of the sampling rate. The KTNR and CTNR do not perform automatic zero and upscale drift checks, but manual drift checks can be done on the CTNR.

The minimum space requirement for this instrument is a height of 8.5 feet, width of 5 feet, and a depth of 3.5 feet. For outdoor installations, a shelter must be provided. Two 4-inch ports are needed for the extraction and return probes. The electrical power requirement is 3-phase 400V and 230V. A transformer is offered to facilities that do not have the required power.

Both instruments were approved by the German TÜV for all source categories. The KTNR was evaluated by the EPA/OSW at the long-term field test at the DuPont Experimental Field Station liquid waste incinerator, and the CTNR was evaluated by Eli Lilly at a liquid waste incinerator and by the Department of Energy at the radionuclide incinerator at Oak Ridge National Lab. The instrument response can be correlated in mg/acm by comparison to manual gravimetric data. This instrument is sensitive to changes in particle characteristics (e.g., size, shape, and color), but because it heats the extracted sample gas to vaporize condensed water, it is not affected by the presence of condensed water droplets in the gas stream.

4.5 DURAG DR-300-40 IN-SITU LIGHT SCATTER

The DR-300-40 PM CEMS uses the principle of side light scattering at 120° in the visible light spectrum. This instrument's measuring ranges are from 0 to 1 mg/m^3 up to 0 to 100 mg/m^3, depending on the size of the aperture installed. It is therefore recommended for measurements of low PM concentrations. The "sampled volume" (i.e., the volume of stack gas where the scatter of light due to particles is detected) is located in an area 3 to 11 inches (centered at 6 inches) from the instrument's face. The DR-300-40 does automatic zero and upscale drift checks to meet daily QC check requirements.

The footprint of the DR-300-40 is a protective covering box attached to the stack with dimensions of approximately 36 inches high by 24 inches wide by 30 inches deep. A separate purge air blower and filter are needed near the instrument. The instrument weighs about 60 pounds, and the protective covering weighs about 15 pounds. A single, 5-inch by 12-inch port with a supplied mating flange is needed for installation of this instrument onto the stack. If this instrument is installed in a stack or duct less than 5 feet in diameter, an anti-reflective device (light trap) should be installed in the opposite wall in line with the incident light. The electrical power requirement is 110V.

This instrument was approved by the German TÜV in 1992 for all source categories. It was evaluated by the EPA/OSW at the long-term field test at the DuPont Experimental Field Station liquid waste incinerator and by the EPA/OAQPS at a coal-fired boiler. The instrument response can be correlated in mg/acm by comparison to manual gravimetric data. This instrument is sensitive to changes in particle characteristics (e.g., size, shape, and color) and presence of condensed water droplets in the gas stream.

4.6 ENVIRONMENTAL SYSTEMS CORPORATION P5 IN-SITU LIGHT SCATTER

The P5 uses the principle of backward light scattering at 175° in the near infrared light spectrum. This instrument's measuring range is 0.5 mg/acm up to 20,000 mg/acm. The measuring volume is located 4.75 inches from the physical end of the probe that contains both the transmitting and receiving optics. The P5 does automatic zero and upscale drift checks to meet daily QC check requirements.

The footprint of the P5 is a box attached to the port flange with dimensions of approximately 18 inches high by 12 inches wide by 36 inches deep. Also, additional clearance beyond the physical depth is needed for the drive rod (the same length as the probe). With a 3-foot probe, the instrument weighs about 160 pounds. A single, 4-inch port with flange is needed for installation of this instrument onto the stack. If the opposite wall of the stack is less than 48 inches away from the end of the probe, an anti-reflective device (light trap) should be installed in the opposite wall. The electrical power requirement is 110V.

This instrument was approved by the Korean Ministry of the Environment (non-technical evaluation) for use as a source PM monitor. This instrument was evaluated by the EPA/OSW at the long-term field test at the DuPont Experimental Field Station liquid waste incinerator and by the EPA/OAQPS at a coal-fired boiler. It is also part of a second EPRI field evaluation at a coal-fired boiler. The prototype to this instrument was evaluated at a secondary lead smelter by the University of Windsor in 1976-1977. The instrument response can be correlated in mg/acm by comparison to manual gravimetric data. Since this instrument measures in the near infrared, it is less sensitive to changes in particle size, and it has a roughly constant response to particles in the 0.1 to 10 µm range. The P5 will measure condensed water droplets in the gas stream as particulate.

4.7 SICK INC. RM210 IN-SITU LIGHT SCATTER

The RM210 uses the principle of side light scattering at 90° in the visible light spectrum. This instrument is ideally suited for measuring extremely low PM concentrations in the range of 0.0001 mg/acm up to 200 mg/acm. This instrument is available in the following three versions depending on the needed penetration of the sampled volume:

- Version 1, the sampled volume is 0.5 to 7 inches from the instrument's face,
- Version 2, the sampled volume is 6.7 to 27.5 inches from the instrument's face, and
- Version 3, the sampled volume is 13.4 to 63.8 inches from the instrument's face.

The RM210 does automatic zero and upscale drift checks using light attenuators. This instrument is essentially the same size and shape as the Durag DR-300-40.

This instrument was approved by the German TÜV for all source categories, and it was evaluated by the EPA/OSW at an early, short-term field test. The instrument response can be correlated in mg/acm by comparison to manual gravimetric data. This instrument is sensitive to

changes in particle characteristics (e.g., size, shape, and color) and the presence of condensed water droplets in the gas stream.

4.8 SICK INC. FW 100 IN-SITU AND FWE 200 EXTRACTIVE LIGHT SCATTER

The Sick FW 100 and FWE 200 are new, state-of-the-art PM CEMS that use the principle of forward light scattering at 15° using a red laser light source. The FW 100 measures particulate concentrations in-situ with a 31.5-inch probe. The FWE 200 extracts stack gas using an eductor at over-isokinetic conditions, heats the sample gas in a thermal cyclone, then guides the sample gas to the measurement cell where the PM concentration is measured with the FW 100 probe. The sample gas is then deposited back into the stack. These instruments have two measuring ranges: 0 to 5 mg/acm and 0 to 200 mg/acm with a resolution of 0.1 mg/acm.

The footprint for the FWE 200 is two boxes (a measurement and control cell and a blower unit) with dimensions of approximately 33 inches high by 30 inches wide by 16 inches deep and 22 inches high by 22 inches wide by 11 inches deep. For outdoor installations, a cover is needed for the blower unit. The measurement and control cell weighs about 150 pounds and the blower weighs about 30 pounds. One 4-inch port is needed for the probe. The electrical power requirement is 115 or 230V.

The FWE 200 is being evaluated by TÜV for type certification. The instrument response can be correlated in mg/acm by comparison to manual gravimetric data. This instrument is sensitive to changes in particle characteristics (e.g., size, shape, and color), but because it heats the extracted sample gas to vaporize condensed water, it is not affected by the presence of condensed water droplets in the gas stream.

4.9 GRIMM TECHNOLOGIES 6300 IN-SITU LIGHT SCATTER

The Model 6300 uses the principle of backward light scattering in the red light spectrum (660 nm). An electronically modulated laser-diode is the light source. Since this instrument uses a laser-light, a light trap must be installed on the opposite side of the stack to prevent backscattering from reflection of the light on the opposite wall. This instrument's measuring range is 0 to 1 mg/dscm up to 0 to 10,000 mg/dscm. The instrument contains both the transmitting and receiving optics within a single box. The Model 6300 does not do automatic zero and upscale drift checks to meet daily QC check requirements, these must be done manually.

The footprint of the Model 6300 is a box with dimensions of approximately 8 inches by 6 inches by 10 inches attached to a 3-inch port flange. The instrument assembly weighs about 30 pounds. The electrical power requirement is 110V.

This instrument was tested and approved by the German TÜV at a waste incineration source in accordance with the 17th BImSchV in the 0 to 20 mg/dscm measuring range. The instrument response must be correlated by comparison to manual gravimetric data. The manufacturer asserts that water droplets are widely ignored by the instrument, due to the specially selected laser wavelength.

4.10 MONITOR LABS 300L IN-SITU LIGHT SCATTER

The 300L uses the principle of backward light scattering in the red light spectrum. An electronic modulated laser emitting diode provides the light source. The laser light is directed into the stack at a slight angle, so that, for stacks larger than about 6 feet, a light trap is not needed. This instrument's measuring range is 0 to 20 mg/acm up to 20,000 mg/acm. Manual zero and upscale drift checks can be done to meet daily QC check requirements.

The footprint of the 300L is a single optical head assembly attached to a special port flange (provided by the vendor) with dimensions of approximately 15 inches long by 8 inches high by 36 inches wide and weighing about 34 pounds. A single, 3.5 to 6-inch port with the special flange is needed for installation of this instrument onto the stack. A purge air system (about 17 inches wide by 8 inches deep by 37 inches high and weighing about 71 pounds) is needed to keep the optical surface clean. The electrical power requirement is 120V.

The instrument response must be correlated in mg/acm by comparison to manual gravimetric data. The 300L will measure condensed water droplets in the gas stream as particulate.

4.11 BHA GROUP CPM 5000 SCINTILLATION

The CPM 5000 uses the principle of scintillation or modulation in the intensity of the transmitted light beam. The receiver senses the light signal modulation and converts it to PM concentration (i.e., signal modulation is proportional to PM concentration). The transmitter and receiver are located on opposite sides of the duct; therefore, this instrument measures across stack PM concentration. As the PM concentration increases, the amplitude of the signal modulation increases, and the instrument response can be correlated in mg/acm by comparison to manual

gravimetric data. Because the CPM 5000 measures signal variations resulting from moving particles rather than from a diminished intensity of the incident light beam, the instrument is relatively unaffected by particulate accumulation on the optics windows, optical misalignment, or aging of the transmitter and receiver. The CPM 5000 has zero and upscale drift check capabilities for daily QC checks.

The footprint of the CPM 5000 is a box containing the microprocessor controls with dimensions of approximately 24 inches square and 6 inches deep. The transmitting and receiving optical heads are small and are attached to 2.5-inch port flanges on opposite sides of the stack. The microprocessor control box weighs about 30 pounds and the optical heads each weigh about 3 pounds. Two 2.5-inch ports are needed for installation of this instrument onto the stack. The electrical power requirement is 110V.

This instrument was tested as part of the short-term field test done by EPRI at a coal-fired boiler, and it is also being evaluated in a second EPRI field test. The CPM 5000 was approved by the German TÜV to meet the requirements for accuracy and repeatability for power plant applications. The CPM 5000 will measure condensed water droplets in the gas stream as particulate.

4.12 PCME SCINTILLA SC600 SCINTILLATION

The Scintilla SC600 uses optical scintillation technology coupled with advanced design techniques to monitor PM concentration. The SC600 can measure PM concentration as low as 2.5 mg/acm per meter of path length. The scintillation technology and advanced techniques reduce zero and upscale drift. The instrument uses modulated light to eliminate effects of stray or ambient light. The transmitter and receiver are located on opposite sides of the duct; therefore, this instrument also measures across-stack PM concentration. The instrument response increases with PM concentration and can be correlated in mg/acm by comparison to manual gravimetric data. The SC600 has zero and upscale drift check capabilities for daily QC checks.

The footprint of the SC600 is a small control module with dimensions of approximately 10 inches wide by 7 inches high by 4 inches deep. The transmitting and receiving optical heads are small and are attached to 2-inch port flanges on opposite sides of the stack. The control module weighs about 8 pounds and the optical heads each weigh about 12 pounds. Two 2-inch

ports are needed for installation of this instrument onto the stack. The electrical power requirement is 110V.

This instrument was tested as part of the short-term field test done by the EPRI at a coal-fired boiler, and it is also part of a second EPRI field evaluation at another coal-fired boiler. The SC600 has MCERTS approval meeting the accuracy and repeatability requirements for power plant applications. The SC600 will measure condensed water droplets in the gas stream as particulate.

4.13 INSITEC TESS IN-SITU OR EXTRACTIVE LASER LIGHT EXTINCTION-SCATTER

The Insitec TESS provides real-time PM concentration data for particles ranging in size from 0 to 20 microns. The TESS can measure PM concentrations in-situ with an up to 8-foot-long probe or in a sample extracted from the stack. The in-situ TESS has been evaluated in both laboratory and field studies by the Department of Energy (DOE), Southern Research Institute, and the EPA (Giel et al., 1995). The in-situ TESS is capable of measuring PM concentration as low as 1.3 mg/acm. A prototype of the extractive TESS was demonstrated in a short-term field test done by EPRI at a coal-fired boiler. The manufacturer indicates the instrument is insensitive to particle variations (particle size distribution) and to process changes (particle composition).

4.14 PCME DUSTALERT 90 ELECTROSTATIC INDUCTION

The DustAlert 90 uses a patented electrostatic induction measurement principle; where particles in the gas stream interact with a probe inserted in the duct and induce charge movement in the probe. The AC current generated by charge induction in the probe can be directly related to the PM concentration. This instrument filters out the DC current generated by the particulate/probe interaction. The manufacturer asserts that the DustAlert 90 can measure PM concentration as low as 0.02 mg/acm. Unlike triboelectric technology, the particles do not need to collide with the probe to be detected. The instrument's output can be correlated to mg/acm from manual gravimetric data. However, it is more often used to display and record in a relative "Emission Factor" scale, which indicates emissions as a multiple of "reference" emissions (i.e., as a baghouse bag leak detection device). The DustAlert 90's correlation to PM concentration is affected by changes in particle size distribution, particle type, and particle charge, thus eliminating applications on wet exhaust gas stacks and sources controlled by electrostatic precipitators.

The footprint of the DustAlert 90 is a small module with dimensions of approximately 10 inches wide by 7 inches high by 4 inches deep. The module extends about 6.5 inches back from the port. A 7/8-inch diameter sensor probe extends into the stack and is attached by a 1.5-inch NPT port. The electrical power requirement is 110V.

This instrument has been type certified by the Environment Agency under the MCERTS program in the United Kingdom. Also, TÜV notes that this instrument should only be used in constant velocity and constant gas composition environments; however, the velocity restriction does not apply to the DustAlert 60 model.

4.15 AUBURN INTERNATIONAL TRIBOGUARD III OR II IN-SITU TRIBOELECTRIC

The Triboguard II and III use proven triboelectric technology, invented nearly 25 years ago. These instruments are low maintenance and can detect baseline PM concentrations as low as 0.005 mg/acm (as established by the manufacturer). The Triboguard instruments are primarily used for baghouse broken bag detection (Fabric Filter Bag Leak Detection Guidance, 1997). Since triboelectric type instruments are sensitive to changes in stack gas velocity, particle size, and particle characteristics (e.g., charge and composition), the Triboguard instruments are not commercially marketed as potential PM CEMS; however, they are used in some applications in the United Kingdom. This instrument is roughly the same size as the DustAlert 90.

4.16 CODEL STAKGARD TRIBOELECTRIC DUST MONITOR

The StakGard uses triboelectric technology (i.e., the AC current generated by particles flowing around the probe) to detect PM concentration. The AC current generated by charge induction in the probe can be directly related to the PM concentration. This instrument filters out the DC current generated by the particulate/probe interaction. The manufacturer asserts that the StakGard can measure PM concentration as low as 0.1 mg/acm. The instrument's output can be correlated to mg/acm from manual gravimetric data; however, it is more often used as a baghouse bag leak detection device. The StakGard's correlation to PM concentration is affected by changes in particle size distribution, particle type, and particle charge; however, Codel has designed a metal mesh housing around the probe to reduce the effect of particle charge after an ESP. This instrument has been type certified by the Environment Agency under the MCERTS program in the United Kingdom. This instrument is also roughly the same size as the DustAlert 90.

4.17 OPACITY/TRANSMISSOMETERS

For completeness, and because some opacity monitors have been type certified as particulate CEMSs, opacity monitors have been included in this section on known PM CEMSs. Although each opacity monitor is not presented separately as the other PM CEMS presentations above, Table 4-1 includes a comparison on many opacity monitors that could be applicable as a PM CEMS in specific applications.

TABLE 4-1. COMPARISON OF OPACITY MONITORS AS PM CEMSs

	Land Combustion 4500 mkII	Durag DR-280	Durag DR-290	KVB-Enertec MIP	Monitor Labs - USI 560 LightHawk	Rosemount OPM 2000R	Sick OMD 41	Phoenix Instruments OPAC 20/20
Dual Pass	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Light Source	LED - Green	Tungstun Lamp - White	Wide Band Diode-White	Helium-Neon Laser - Green	LED - Green	Frosted, incandescent lamp - White	LED - Yellow	LED - Green
Electrical/ Mechanical Modulation	Electrical 3k Hz	Mechanical 1.2k Hz	Electrical 2kHz	Electrical	Electrical 2.4k Hz	Liquid crystal windows (electrical)	Electrical	Electrical 2.5k Hz
PM Measurement Concentration	As low as 1.5 mg/acm (1 µm dust)	From 0-0.1 to 0-1.6 extinction	1 mg/acm resolution for 1 µm dust and 10-foot path length		For 1 µm dust and 20-foot path length - single-digit mg/acm	From 0 to 3 extinction	From 0-0.1 to 0-2 extinction; PM concentration as low as 1.2 mg/acm	From 0-0.1 to 0-2 extinction
Footprint	30" long x 18" wide x 24" high including purge system and shutters	Transceiver 7" wide x 9" high x 22" deep Retroreflector 7" x 9" x 13"	Transceiver 7" wide x 13" high x 16" deep Retroreflector 7" x 10" x 11"	Transmitter 12" wide x 18" high x 6" deep Receiver 5" x 5" x 8" without purge system	22" long x 20" wide x 33" high including purge system and weather cover	34" long x 13" wide x 29" high including purge system	Transceiver 15" x 8" x 11" Reflector 11" x 8" x 11" without purge system and protective cover	Both sides 22" wide x 30" high Transceiver 27" long Retroreflector 18" long Includes weather cover and air purge system with shutters

TABLE 4-1. (CONTINUED)

	Land Combustion 4500 mkII	Durag DR-280	Durag DR-290	KVB-Enertec MIP	Monitor Labs - USI 560 LightHawk	Rosemount OPM 2000R	Sick OMD 41	Phoenix Instruments OPAC 20/20
Weight	60 lb per side	Transceiver 35 lb Retroreflector 13 lb Purge air blowers 65 lb each	Transceiver 22 lb Retroflector 15 lb Purge air with weather hood 65 lb each side		Transceiver 27 lb Retroreflector 7 lb Purge air blower 22 lb Weather cover and mounting plate 43 lb	Transceiver 80 lb Retroreflector 40 lb	Transceiver 27 lb Retroreflector 18 lb	Transceiver 26 lb Retroreflector 9 lb Weather enclosure and air purge system 125 lb/side
Electrical Power Requirement	110 V	115 V 220 V for blowers	90-264 V 48-62 Hz	110 V 110 V for blowers	115 V 220 V for blowers	110-240 V	90 … 267 V 120 V/3 or 230 V/3 for purge air system	115 V or 220 V
Type Approval	German TÜV - 1997	German TÜV - 1978	German TÜV - 2000 expected				German TÜV - 1995	

5.0 SUMMARY OF PM CEMS DEMONSTRATION FIELD STUDIES

Many field studies demonstrating the performance of PM CEMSs have been conducted. TÜV conducted most of the early evaluations and type certifications of PM CEMSs. Later, as the EPA considered their use, the EPA performed several field evaluations of PM CEMSs. Also, at least two industry groups have done field evaluations of PM CEMSs. This section presents a summary of those field studies.

5.1 TÜV CERTIFICATION TESTING OF PM CEMS

In Germany, all CEMSs, including PM CEMSs, are type certified and approved for use at a particular industry type. A PM CEMS cannot be used on a source in Germany unless it has been certified. TÜV is the principle agency that conducts CEMS certifications in Germany.

5.1.1 Sigrist CTNR

The Sigrist CTNR, a light scattering type PM CEMS, was evaluated by TÜV Rheinland in the laboratory and in the field (Report on the Suitability Testing . . . CTNR, 1997). The laboratory test checked the following using two identical instruments:

- All instrument functions,
- Instrument characteristics (linearity and common response),
- Stability of the zero and reference filter values,
- Effect of variations in supply line voltage,
- Effect of relative humidity, rain, vibrations, and operating position, and
- Proper operation of the self-monitoring feature.

The field test was done using the same two instruments from the laboratory test at a refuse incinerator from April 16, 1997 to June 4, 1997 and at a coal-fired furnace from June 12, 1997 to August 12, 1997. The field test evaluated the following:

- Dead time and setting time,
- Detection limit,
- Correlation capability,
- Reproducibility,
- Stability of instrument characteristics,
- Maintenance interval,

- Data availability, and
- Functional test and correlation.

The results of TÜV's evaluation of the Sigrist CTNR PM CEMS indicate that it met all of the applicable requirements with the exception that it does not have the capability of doing automatic zero and upscale calibration checks. However, TÜV recommended the CTNR for monitoring PM emissions from incinerators and power plants, noting the reservation about the lack of an automatic calibration feature.

5.1.2 Durag F-904

The Durag F-904, a beta gauge type PM CEMS, was evaluated by TÜV Rheinland in the laboratory and in the field (Performance Testing of the F-904 Beta Gauge). The laboratory test checked the following:

- Effect of variations in supply line voltage, and
- Effect of changes in ambient temperature on (1) the zero and span signals, (2) the total volumetric flow sampled during the measuring cycle, and (3) the dilution air volume.

The field test was done on two identical instruments at a municipal waste combustor from July 31, 1989 to December 31, 1989. The instruments were installed downstream of an ESP and wet scrubber and operated in the following stack gas conditions:

- Stack diameter 78.7 inches
- Average stack gas velocity 45.9 feet per second
- Dew point of stack gas 149°F
- Stack gas temperature 154.4°F
- PM concentration < 10 mg/acm

The TÜV report notes that the F-904 was tested under recognizably difficult operating conditions. The field test evaluated the following monitor features:

- Correlation capability,
- Reproducibility,
- Maintenance interval, and
- Data availability.

The results of TÜV's evaluation of the Durag F-904 PM CEMS indicate that it met all of the applicable requirements with the exception of the sample volume audit. On two of 13 tests,

the sample volume deviated from the expected volume by more than the allowable 8 percent. However, this test was done at a dilution ratio of 4 to 1, and TÜV determined that the monitor could fully meet the sample volume accuracy requirement at a dilution ratio of 2 to 1.

5.1.3 Durag DR-300-40

The Durag DR-300-40, a light scatter type PM CEMS, was evaluated by TÜV Rheinland in the laboratory and in the field (Report on the Performance Testing of the D-R 300-40 Dust Concentration Monitor, 1992). The laboratory test checked the following:

- Calibration capability in a test duct, where the effect of changes in particulate size was evaluated,
- Effect of variations in supply line voltage,
- Effect of changes in ambient temperature,
- Testing of the dirty window correction,
- Linearity check, and
- Effect of ambient light.

The field test was done on two identical instruments at a secondary lead smelter kiln from February 27, 1992 to June 3, 1992. The instruments were installed downstream of a baghouse and operated in the following stack gas conditions:

- Stack diameter 41 inches
- Stack gas velocity 30 to 59 feet per second
- Dew point of stack gas 50 to 122°F
- Stack gas temperature 140 to 230°F

The field test evaluated the following monitor features:

- Correlation capability and effect of process changes on the correlation stability,
- Reproducibility,
- Maintenance interval ,
- Data availability, and
- Necessity of a light trap.

The results of TÜV's evaluation of the Durag DR-300-40 PM CEMS indicate that it met all of the applicable requirements with the following notes:

- For installations on thick or double-walled stacks, the scattering volume must be within the flowing stack gas.
- Since the scattering volume is only 3 to 11 inches from the instrument face, for installations on stacks greater than 6.5 feet in diameter, the monitor must be shown to provide a representative sample.
- A light trap may be omitted if the interference from reflected light is demonstrated to be less than 2 percent of the measuring range.

5.2 EPA/OSW FIELD DEMONSTRATION – HAZARDOUS WASTE INCINERATORS

The OSW wanted to propose PM CEMSs as part of their Hazardous Waste Combustion MACT rule. Before proposing PM CEMSs, OSW did two preliminary field studies and a comprehensive field evaluation.

5.2.1 Mixed Solid and Liquid Hazardous Waste Incinerator

The first preliminary test examined three PM CEMSs at a mixed solid and liquid hazardous waste incinerator located in Bridgeport, New Jersey. The three PM CEMSs were chosen to represent three different measurement techniques: light scattering, time-dependent optical attenuation, and beta attenuation. The CEMSs were installed downstream of a pilot scale wet electrostatic precipitator (ESP). The focus of this test was to determine the PM CEMS's viability at a wet ESP installation.

The test was conducted in three phases during March of 1995. First, the PM CEMSs were calibrated according to ISO 10155 using EPA Method 5. Three paired Method 5 tests were done at each of three operating conditions designed to produce different PM loadings. The PM concentrations ranged from a low of about 1 mg/m^3 to a high of about 30 mg/m^3. Second, the CEMSs were operated for 2 weeks. Finally, another set of Method 5 tests were done to check the stability of the original calibration. The final Method 5 testing consisted of four paired test runs at only two operating conditions. PM concentrations were less than 1 mg/m^3 during all four test runs (i.e., the change in operating conditions did not change the PM concentration).

The PM CEMSs evaluated were the following:

- Sick Inc. RM200,
- BHA Group CPM1000^{TM}, and
- Environment S.A. Beta M5.

The Sick RM200 and BHA CPM1000 were operating for the initial Method 5 tests, during the 2-week experimental period, and the final Method 5 tests. The Beta M5 was not operating during the initial Method 5 tests but operated during the experimental period and final Method 5 tests.

The OSW reported the following conclusions from this brief test:

- The calibration data did not meet ISO 10155 requirements for (1) three or more different PM concentration levels and (2) nine or more data points.
- With proper care, an optical device used in conjunction with a heated bypass can be calibrated in a wet exhaust stream.
- For a low-temperature, saturated stack gas stream, extracting and drying a slipstream is more appropriate than attempting to make in-situ optical measurements. The CPM1000 responded to liquid droplets in the exhaust stream.
- Not enough data were obtained to properly evaluate the performance of the Beta M5.
- The PM CEMSs responded to changes in PM concentration levels.

More information on this test can be found in the document entitled "Draft Technical Support Document for HWC MACT Standards, Volume IV: Compliance with the Proposed MACT Standards," February 1996, Pages 4-2 to 4-9.

5.2.2 Hazardous Waste Burning Cement Kiln

The OSW chose a hazardous waste cement kiln in Fredonia, Kansas for another evaluation of PM CEMSs and a test of the initial draft PM CEMS performance specification (PS-11) criteria. The facility manufactures cement from raw materials in a two-phase wet process kiln. Particulate emissions are controlled with an ESP. The PM CEMSs selected included two light-scattering monitors: the ESC P5A and the Sick RM200. The tests involved triplicate testing at three different ESP power settings ranging from 55 to 140 KW; each Method 5 test run had paired trains. Initial Method 5 correlation tests were done in May and June 1995. A final test was done in July 1995 and served as a simulated response correlation audit (RCA). The test contractor had extreme difficulty obtaining consistent results between the paired Method 5 trains. A concerted effort was made to achieve an appropriate test matrix and distribution over three PM levels for each calibration test. During each test period, data from one of the Method 5 trains was disregarded as suspect.

The OSW reported the following conclusions from this brief test:

- The correlation is highly sensitive to errors that can occur in making the manual method measurements.
- The ESC P5A correlation test produced encouraging but inadequate results in terms of meeting the draft PS-11 criteria. Also, the P5A's RCA test results did not meet the performance criteria.
- The Sick RM200 experienced some operational problems attributed to the heated, purge-air system. The instrument was removed during the initial correlation test program. When the instrument was reinstalled, the response continued to deteriorate.

More information on these tests can be found in the document entitled "DRAFT Particulate Matter CEMS Demonstration, Volume I: DuPont, Inc. Experimental Station On-site Incinerator," Wilmington, DE, December 1997, Pages 2-42 to 2-44.

5.2.3 DuPont Hazardous Waste Incinerator

The preliminary tests presented above encouraged OSW to conduct a long term (6 months to 9 months) demonstration to determine what PM CEMS performance could be achieved at a reasonable worst-case source. Because the work would be used to support a proposed requirement that a PM CEMS be used on a hazardous waste combustion device, OSW chose the DuPont Experimental Station's hazardous waste incinerator for this demonstration. Among such sources, a source like DuPont's would cause the particulate matter in the stack to be more variable, thus causing a more variable response from the PM CEMS than at other sources under consideration (e.g., cement kilns and light-weight aggregate kilns). The EPA also obtained information to characterize PM CEMS installation needs, data availability, maintenance and personnel requirements, and costs. One particularly important piece of information learned from this test was that the PM CEMS can be sensitive to emissions variability on a real-time basis. Neither periodic short-term manual testing nor operational parametric monitoring would provide an adequate picture of this variability for standard setting purposes. Only PM CEMS data collected over a relatively long period of time would provide data sufficient for the statistical analyses necessary for establishing achievable continuous compliance emissions limits.

In addition to the importance of long term data gathering in setting standards, the EPA also learned from this test the importance of precise manual particulate matter measurements. The variability associated with manual method imprecision can mask the true performance of the PM CEMS. In response to this issue and to improve sample recovery and analysis time, the EPA chose to redesign the Method 5 equipment when used at low particulate concentration sources. These changes became EPA's Method 5i. To evaluate method precision, the EPA used dual Method 5i trains (two Method 5i trains conducted simultaneously from different ports) and established acceptable paired train precision criteria.

The EPA also learned much about PM CEMS performance characteristics. This information included the need to address the performance characteristics of different technologies, the need to use data flags as indicators of potential problems, the importance of instrument set-up and a "debugging period." This knowledge led to changes in the draft performance specification criteria and associated QA/QC requirements.

The DuPont tests extended over a 9-month period, from September 1996 to May 1997. Tests conducted from September to November, 1996 were an extension of the learning experience started in the EPA's preliminary test program. Data collected from September to November 1996 were not considered in the final analysis of results. Forty-four Method 5i paired train tests were conducted from December 1996 through May 1997. The EPA conducted the initial correlation testing in 1-week periods each month from December 1996 through March 1997. A second correlation was done in April 1997. Finally, the 9-month demonstration program ended with a RCA in May 1997.

In summary, these tests led the EPA to believe that PM CEMS are a viable accurate measure of real-time particulate matter emissions. The EPA believes the approach to correlating emissions to gravimetric manual methods can result in an adequate correlation. The EPA also believes that data availability, maintenance and personnel, and overall costs associated with particulate matter CEMSs are representative of other CEMSs, such as SO_2 analyzers for utility boilers. However, site decisions, such as the technology employed for a given application, the QA/QC capabilities of the CEMS, and the accuracy of the manual method data collected, can affect the viability of a given PM CEMS at a particular source. More information on the DuPont

tests can be found in the Particulate Matter CEMS Demonstration final report at the EPA Office of Solid Waste's Web site: http://www.epa.gov/epaoswer/hazwaste/combust/CEMS.

5.3 ELECTRIC POWER RESEARCH INSTITUTE – COAL-FIRED BOILER WITH ESP

Another field test program was sponsored by EPRI and conducted at Georgia Power Company's Plant Yates. Yates Unit 7 uses a conventional Combustion Engineering tangentially fired boiler with a rated generating capacity of 360 MWe. The unit burns eastern bituminous coal and is equipped with low NO_X burners and separate overfire air. The particulate emission limit for Unit 7 is 0.24 lb/mmBtu, and particulate emissions are controlled by an ESP. This program was designed to provide data for use in a rigorous evaluation of both ESP performance models and PM CEMS.

The following five devices were tested:

- BHA CPM 5000,
- PCME SC600,
- Insitec extractive TESS,
- Spectrum Systems (via Sabata), and
- Lear Seigler RM41 opacity monitor.

Of the four instruments classified as a PM CEMS, only the BHA CPM 5000 and PCME SC600 were commercially available at the time of the EPRI test, and only the BHA CPM 5000 had been used on other field evaluations. The PCME SC600 has since received MCERTS approval. The Insitec extractive TESS and Spectrum System devices were prototypes.

The test plan was to evaluate three different ESP power conditions, which would result in three different particulate mass emission levels, during three separate weeks of testing, for a total of nine independent test conditions. Testing was done in June and September 1998. During each week, 15 paired Method 17 test runs were conducted. The first 2 weeks of testing were performed during consecutive weeks and the third week of testing was approximately 3 months later. The fundamental premise of this field evaluation was to use the initial week of testing to develop correlation equations for the PM CEMSs. The second week of testing, conducted immediately following the initial week, provided information regarding the short-term accuracy and stability of the PM CEMSs. The third week of testing, conducted approximately 3 months following the initial 2 weeks, provided information regarding the long-term accuracy and stability

of the correlations. Unfortunately, during the 3-month period between the week 2 and week 3 tests, the four PM CEMSs were not properly maintained.

PM concentrations were varied by (1) deenergizing ESP fields (i.e., simulating the complete loss of ESP sections, the most common failure mode of an ESP) and (2) turning down power on all ESP sections in increments (i.e., simulating problems attributable to high-resistivity ash or close clearance). PM concentrations during the 3 weeks of testing are presented in Table 5-1.

TABLE 5-1. PM CONCENTRATIONS FOR THE THREE WEEKS OF THE EPRI PM CEMS TEST

PM concentrations	Week 1	Week 2	Week 3
Low	~ 0.002 lb/10^6 Btu, 1.8 mg/m^3 and 3 percent opacity	~ 0.012 lb/10^6 Btu, 9.1 mg/m^3 and 6.7 percent opacity	~ 0.019 lb/10^6 Btu, 15.3 mg/m^3 and 7.4 percent opacity
Mid	~ 0.06 lb/10^6 Btu, 49.5 mg/m^3 and 15 percent opacity	~ 0.057 lb/10^6 Btu, 42.3 mg/m^3 and 16.0 percent opacity	~ 0.121 lb/10^6 Btu, 94.5 mg/m^3 and 18.3 percent opacity
High	~ 0.23 lb/10^6 Btu, 174 mg/m^3 and 25 percent opacity	~ 0.121 lb/10^6 Btu, 87.5 mg/m^3 and 21.5 percent opacity	~ 0.149 lb/10^6 Btu, 119 mg/m^3 and 19.2 percent opacity

The high-PM-concentration condition during week 1 produced a significant number of “chunky” carbon particles; therefore, this condition was not repeated in the other test periods.

The conclusions from this EPRI study were the following (Roberson et al., 1999):

- The paired Method 17 sampling trains showed very good measurement precision and a tolerance interval of 12 mg/m^3 at an emission limit value of 75 mg/m^3 (~ 0.10 lb/mmBtu).
- The BHA CPM 5000, PCME SC600, and prototype Insitec extractive TESS passed the draft PS-11 correlation criteria. The prototype Spectrum and opacity monitor had confidence intervals and tolerance intervals well outside the draft PS-11 requirements. The PM CEMSs correlation statistics from the week 1 test are presented in Table 5-2.
- The week 3 tests that were used for the RCA, showed that none of the three PM CEMS that passed the initial correlation met the RCA criteria.

- The ESP inlet particle size distribution ranged from 21.5 to 24.4 microns for the first two weeks of testing and was 30.9 during the third week. EPRI believes the skewed particle size distribution and geometric standard deviation is due to either the retrofit of low-NO_X burners in a short furnace or the wearing of the coal pulverizes.

TABLE 5-2. PM CEMSs CORRELATION STATISTICS FOR THE EPRI PM CEMS TEST

Instrument	Correlation Coefficient	Confidence Interval	Tolerance Interval
BHA CPM 5000	0.986	6.7 %	18.2 %
PCME SC600	0.984	6.9 %	19.2 %
Insitec extractive TESS	0.991	9.4 %	19.2 %
Spectrum Systems (via Sabata)	0.939	21.1 %	45.5 %
Lear Seigler RM41 opacity monitor	0.937	13.6 %	41.1 %

More detailed information on the EPRI test at Plant Yates can be found in a paper written for the EPRI CEM Users Group Meeting at the following RMB Consulting Web site: http://www.rmb-consulting.com/cinnati/rlrpaper.htm

5.4 ELI LILLY – HAZARDOUS WASTE INCINERATOR

Eli Lilly and Company (Eli Lilly), the Chemical Manufacturers Association (CMA), and the Coalition for Responsible Waste Incineration (CRWI) jointly sponsored a two-phase test program of PM CEMSs. The summary presented below was taken from a draft report provided by Eli Lilly. This test was done at a liquid hazardous waste incinerator at the Eli Lilly Clinton Lab in Clinton, Indiana. The instruments assessed in this study were an Environment S.A. (ESA) Model Beta 5M and a Sigrist Photometer AG (Sigrist) Model KTNRM/SIGAR4000.

Phase one of the program demonstrated that the instruments, as initially configured, would not meet the requirements of draft PS-11. During the same period as Phase One, Eli Lilly purchased and installed two Sigrist monitors at a facility in Ireland. Eli Lilly contracted TÜV Rheinland to calibrate the instruments which led to new knowledge on the calibration of PM CEM

instruments. Eli Lilly conducted Phase Two testing using knowledge gained from the Phase One testing, the DuPont testing, and the TÜV Rheinland calibration in Ireland.

5.4.1 Phase One

Phase One of the Eli Lilly evaluation was designed to duplicate the testing conducted at the DuPont Hazardous Waste Incinerator, but on a source that was saturated with water vapor. The evaluation was conducted over a 5-month period from February to June 1998. During this period, a total of 74 paired Reference Method 5i (M5i) sample runs were completed at varying particulate levels from 17 to 45 mg/dscm at 7 percent O_2. Of the 74 test runs, 70 test runs produced acceptable paired M5i results.

The Reference Method data was compared to the output of the two instruments and the requirements of draft PS-11 with the following conclusions:

- None of the data sets met the draft PS-11 criteria for correlation coefficient but most passed the CI and TI criteria.
- The Sigrist had a significantly higher correlation coefficient than the ESA monitor did.
- The "best fit" correlation relation for the ESA was polynomial, versus little difference between the linear and polynomial correlations relations for the Sigrist.
- Use of the polynomial correlation relation for the ESA would significantly limit the range of the instrument.
- Evaluation of quarterly sets of the Sigrist data showed different slopes and correlation coefficients.

The data availability of the instruments was 78 percent for the ESA and 96 percent for the Sigrist. The ESA instrument, as designed and operated, had trouble dealing with the high moisture level. Finally, both instrument's measuring range was set too wide for the range of PM concentrations.

In general, Lilly believes that the Phase One test was a learning experience, and the Phase One results should not be used to judge the performance of these PM CEMSs.

5.4.2 Phase Two

Phase Two of the Eli Lilly program was designed using lessons learned from previous testing. Phase Two incorporated new instrument operating procedures as well as design changes to the ESA instrument. Eli Lilly noted the following changes were included:

- The Sigrist instrument was limited to operate on a single range that spanned the known particulate concentration (i.e., multi-ranging capability was eliminated because of non-linearity between ranges).
- The ESA instrument had some design changes incorporated to make it operate better at the high moisture levels.
- The sample period for the ESA instrument was changed from 6 to 15 minutes, changing the sample collection time from 2.5 to 8.5 minutes.

During Phase Two (November to December 1998), 40 sets of paired train data were collected using M5i with particulate concentrations ranging from 1 to 64 mg/dscm at 7 percent O_2. Of the 39 paired test runs (after one run, train 2 failed its leak check), four failed the precision criteria. The paired train bias comparison had a correlation coefficient of 0.99 and a slope of 0.97, indicating no bias.

The Method 5i test data was compared to the output of the two instruments and the requirements of draft PS-11 with the following conclusions:

- Both instruments met the draft PS-11 correlation criteria. The correlation statistics are presented in Table 5-3.
- Successful correlation required operating the incinerator at abnormal conditions to obtain the needed range of PM concentration (i.e., the waste feed was stopped and only natural gas was combusted to produce the low PM concentrations).
- During the Phase Two test, the incinerator was operated in excess of the proposed PM standard for a hazardous waste combustor.
- Successful correlation required a substantial site-specific operational learning process with the instruments (i.e., supporting the need for the shakedown period and correlation test planning period in PS-11, see Sections 7.3 and 8.3 of this report).

Evaluation of the data collected shows that the best correlation relationship of the Sigrist monitor was logarithmic with a correlation coefficient of 0.97. The ESA monitor was found to have a linear relationship with a correlation coefficient of 0.99.

TABLE 5-3. PM CEMSs CORRELATION STATISTICS FOR
THE LILLY PHASE TWO PM CEMSs TEST

Instrument	Correlation coefficient	Confidence interval	Tolerance interval
ESA Beta 5M	0.99	2.6 %	9.1 %
Sigrist KTNR	0.97	6.7 %	24.3 %

Although both instruments met the correlation criteria, Eli Lilly had concerns because the Sigrist was at the maximum tolerance level, 25 percent, of draft PS-11. Also, the ESA did not track with the Sigrist 12.3 percent of the time. The trend analysis was based on an analysis of the data using mA output of the monitor and the regression equation calculated using the data from this test. During the periods in which the two instruments did not trend together, data from the ESA were higher than the Sigrist. The difference was assumed to be in the ESA data because in several instances the ESA had a sample volume error, but this error was not recorded.

The data availability of the instruments for Phase Two were 98.1 percent for the Sigrist and 85.8 percent for the ESA. The data for the periods that the ESA did not trend with the Sigrist were treated as an instrument malfunction for the ESA.

5.5 EPA/OAQPS FIELD DEMONSTRATION – COAL-FIRED BOILER WITH BAGHOUSE

The EPA's Office of Air Quality Planning and Standards (OAQPS) may require the use of PM CEMSs in future standards. Also, States may require them for State Implementation Plan (SIP) monitoring and Economic Incentive Program (EIP) monitoring. Additionally, industry sources may use PM CEMSs for Title V monitoring. The EPA, therefore, desired additional evaluations of PM CEMS technology on a long-term continuous basis. Also, the EPA wanted additional data to support revisions to draft PS-11 and Procedure 2. The EPA initiated a demonstration program to setup and operate PM CEMSs over an extended time to gather data for assessing their performance against draft PS-11 and Procedure 2. The EPA chose a coal-fired power plant that used a baghouse for particulate control for the test site.

The test site was Cogentrix of Rocky Mount Inc., located in Battleboro, North Carolina. This facility is an electric utility plant consisting of four identical boilers powering two electric generating units. Each generating unit is rated at approximately 55-60 MWe for a total plant electrical capacity of 115 MWe. Each of the generating units is powered by a pair of Combustion Engineering stoker-grate power boilers. Each of the four boilers fires bituminous coal and is

rated for 375 mmBtu/hr heat input and steam output of 250,000 lb/hr. Each is equipped with a Joy Technologies, Inc. dry type SO_2 absorber (lime slurry scrubber) and a Joy Technologies pulse-jet fabric filter (baghouse) for particulate control. The particulate emission limit for each boiler is 0.02 lb/mmBtu.

The following three commercially available PM CEMSs (two light scattering types and one beta gauge type) were included in the demonstration:

- ESC P5B,
- DURAG DR-300-40, and
- DURAG F904K.

The demonstration project proceeded as follows:

- The PM CEMSs were installed in early June 1999.
- A shakedown period lasted from June 12 through June 30, 1999.
- A 7-day drift test was done on each PM CEMS, an ACA was done on the two light scatter type PM CEMSs, and a sample volume audit (SVA) was done on the beta gauge type PM CEMS.
- A correlation test planning period consisting of nine preliminary Method 17 runs, which were used for assessing the range of emissions (i.e., how to obtain three levels of PM concentration) and setting the measurement range on the PM CEMS, was carried out over the period of July 9-14, 1999.
- The initial correlation test consisting of 15 paired Method 17 runs was carried out during the period of July 15-19, 1999.
- An RCA and ACA/SVA were done in late August 1999, about 1 month after the initial correlation test.
- A second RCA and ACA/SVA were done in November 1999 to evaluate discrepancies between the initial correlation and the first RCA.
- A final ACA/SVA was done on February 7, 2000 with project completion on February 16, 2000.

The duration of the demonstration project was approximately 8 months, with continuous operation of the PM CEMSs and emissions data collection over the 6-month period following the

initial correlation test. All PM CEMSs were maintained in proper operating order during the demonstration with daily zero and upscale drift evaluations.

PM concentrations were varied by adjusting a multi-position butterfly valve to bypass PM from the inlet duct (dirty side) to the outlet duct (clean side) of the baghouse. The PM concentrations during the initial correlation test and the RCAs are presented in Table 5-4.

TABLE 5-4. PM CONCENTRATIONS FOR THE EPA/OAQPS PM CEMS TEST[a]

PM concentrations	Initial correlation	First RCA	Second RCA
Low	~ 4.5 mg/dscm and 3.7 percent opacity	~ 3.6 mg/dscm and 5.1 percent opacity	No tests done at low PM conc.
Mid	~ 16.4 mg/dscm and 4.1 percent opacity	~ 18.6 mg/dscm and 4.7 percent opacity	~ 22.5 mg/dscm and 9.3 percent opacity
High	~ 24.4 mg/dscm and 4.7 percent opacity	~ 38.6 mg/dscm and 5.5 percent opacity	~ 38.2 mg/dscm and 9.6 percent opacity

[a] Opacity readings were taken in the stack which discharges emissions from both boilers 2A and 2B.

Conclusions from this EPA/OAQPS demonstration were the following (Evaluation of Particulate Matter Continuous Emission Monitoring Systems, 2000):

- The 37 paired Method 17 sampling trains during the initial correlation and the first RCA showed very good measurement precision with an RSD of no greater than 4.3 percent. The bias between Trains A and B was only 2 percent for the initial correlation test and 2.3 percent for the first RCA. Except for one test run to demonstrate precision, paired trains were not used during the second RCA.
- Three levels of PM concentrations could be obtained for a baghouse controlled unit by using a baghouse bypass system that simulated a typical baghouse failure. When using a particulate bypass system to increase the PM concentration, the point where the dirty gas mixes with the clean gas must be well upstream of the manual reference method and the PM CEMS measurement locations to avoid possible stratification of the PM.
- All three PM CEMSs passed the draft PS-11 initial correlation criteria at an emission limit of 17 mg/acm (used for the light scattering instruments) or 25.5 mg/dscm (used for the beta gauge instrument) using a linear regression relation. The correlation statistics are

presented in Table 5-5. Note, the DR-300-40 had a confidence interval of 10.4 percent compared to a criteria limit of 10 percent.

- All three PM CEMSs passed the initial QC checks for the 7-day drift, ACA, and SVA.
- All three PM CEMSs failed to meet the RCA criteria after 1 month of operation. Based on results from the second RCA, a likely cause in the discrepance between the initial correlation data and the first RCA data was a shift in the PM stratification at the PM CEMS measurement location (which did not meet PS-11 siting criteria).
- Correlations generated using the combined initial correlation data and the RCA data failed to meet the draft PS-11 criteria, and the correlations generated using only the RCA data were just outside the draft PS-11 criteria bounds. During the second RCA, data collected during 5 of the 6 test runs done at full boiler operating load fell within the tolerance interval of the first RCA correlations.
- At reduced and variable boiler load conditions, the three PM CEMSs did not respond to the higher PM concentrations as expected.
- The two light scatter type PM CEMSs met the ACA criteria after 1 month, 4 months, and 6 months of operation.
- The beta gauge PM CEMS met the SVA criteria after 1 month, 4 months, and 6 months of operation.
- Assuming that plant personnel could have responded to the observed maintenance issues in a reasonable time, the light scatter PM CEMSs achieved 99 percent data availability and the beta gauge PM CEMS achieved over 96 percent data availability.

TABLE 5-5. PM CEMSs CORRELATION STATISTICS FOR THE OAQPS PM CEMSs FIELD EVALUATION

Instrument	Correlation coefficient	Confidence interval	Tolerance interval
ESC P5B	0.964	9.20 %	17.9 %
DURAG DR-300-40	0.955	10.4 %	20.2 %
DURAG F904K	0.988	5.37 %	10.7 %

6.0 FUTURE FIELD DEMONSTRATIONS

The EPA anticipates that additional field demonstrations of PM CEMSs will be done by both the EPA and industry. To facilitate a successful field demonstration, this section presents some guidelines that should be considered.

6.1 TEST PLAN GUIDELINES

A field demonstration or evaluation of PM CEMSs should be done in accordance with a written test plan. In general, a written test plan should follow the outline provided in the Emission Measurement Center's 1991 Guidebook: "Preparation and Review of Site Specific Test Plans." The site specific test plan (SSTP) should contain the following information:

1. Introduction
    - Summarize the test program and what criteria will be used to evaluate the PM CEMS(s)
    - Show a test program organization
2. Source Description
    - Describe the process that is generating PM emissions
    - Describe the control equipment
3. Test Program
    - Describe the test objectives (e.g., demonstrate that a PM CEMS provides reliable and accurate data for this source over an extended period, evaluate maintenance requirements, determine if a PM CEMS satisfies PS-11 and Procedure 2 criteria)
    - Show the test matrix, including personnel responsibilities (e.g., site modifications, shakedown and planning periods, initial correlation test period, Procedure 2 audits, instrument maintenance)
    - Describe how the source and control equipment will be operated and how PM concentrations at different levels will be obtained
4. Sampling Locations
    - Include a diagram or photograph of the Reference Method sampling location
    - Include a diagram or photograph of the PM CEMS measurement location,
5. Sampling and Analytical Procedures

- Describe the PM CEMS(s), including what instrument data will be logged (e.g., daily calibration drift, operational flags, data averaging periods)
- Describe the Reference Method used, including dual/paired train arrangement, and how on-site results will be obtained (as applicable)
- Present what process operating data will be collected to evaluate operation of the source and control equipment

6. QA/QC Activities
   - Present QC procedures that will be applied to the Reference Method sampling
   - Present QC procedures that will be applied to the PM CEMS (e.g., daily calibration drift checks, ACA, SVA) and who will do them
   - Describe how the PM CEMS(s) measurement range will be properly set
   - Conduct an independent check of the regression analysis
7. Safety Issues

6.2 MONITOR SELECTION GUIDELINES

When selecting a PM CEMS for a field demonstration project, the following should be considered:

- What technology is to be demonstrated?
- Is that technology known to be affected by site specific conditions (see Section 8.2)? If no, then the technology can be considered; if yes, then only consider the technology if precautions are taken to offset the effect.
- Considering the measurement location, can the potential PM CEMS be installed (i.e., consider platform size and location versus the size of the instrument, stack/duct diameter, weight limitations, installation efforts, exposure effects, the need for a light trap, etc.)?
- Select a PM CEMS that is commercially available. If a prototype PM CEMS is to be evaluated, a second PM CEMS that uses the same technology and has been proven should also be used.
- Only use a PM CEMS that does zero and upscale drift checks and one that has operational fault indicators.
- Ensure the vendor can provide adequate support and assistance.

6.3 TEST PLAN APPROVAL AND DATA ANALYSIS

The final test plan should be completed at least 45 days before the initial correlation testing is planned. For a field demonstration sponsored by the EPA, the industry group affected should be given the opportunity to review the test plan. The industry group can provide comments to the EPA. The industry group will also be invited to witness the initial correlation testing and any other part of the program they desire. For a field demonstration sponsored by an industry, the industry should submit the final test plan to the EPA and State agency for review at least 45 days before the initial correlation testing. In reciprocation, the EPA and the State agency should be invited to witness the initial correlation testing and any other part of the program they desire.

Results of the field demonstration should be shared between the industry group and the EPA. The industry group and the EPA are encouraged to separately analyze the data. Finally, a consensus should be reached regarding the conclusions of the demonstration.

7.0 PM CEMS IMPLEMENTATION

Once PS-11 is finalized and published in the Federal Register, the EPA, State regulatory agencies, and industry will be tasked with implementing PM CEMS programs. This section provides guidance on the following topics: source applicability, how to select the appropriate PM CEMS, how to conduct the initial correlation, what does the correlation mean and how accurate are the data generated by the PM CEMS, what QA/QC measures to apply to PM CEMS, and finally, issues to be addressed case by case.

7.1 SOURCE APPLICABILITY

PM CEMSs have three main applications: (1) process monitoring, (2) compliance assurance, and (3) compliance monitoring. As a process monitor, a PM CEMS can be used to improve process performance by providing an indication that a setpoint has changed and an adjustment is needed or to improve air pollution control device performance by indicating when maintenance is needed. As a compliance assurance monitor, a PM CEMS can be used as an indicator for reasonable assurance that an emission limit is not exceeded. A small amount of testing would be needed to establish the not-to-exceed level, but a full correlation test can be avoided. As a compliance monitor, the PM CEMS would provide a continuous record of actual PM concentration. To be used as a compliance monitor, a full correlation test is needed. Specific source applications of the PM CEMS in each of these areas are presented below.

The ESC P5B light scatter PM CEMS has been used as an ESP performance monitor at many large electric utility plants in the U.S. (personal communication with Robert Nuspliger, ESC). Furthermore, a PM CEMS has been used to monitor for product losses through an exhaust stack during process changes (e.g., in the exhaust duct of a potato chip manufacturing process to monitor for oil losses during process changes).

In Canada, many PM CEMSs are in use at pulp and paper mills with some being used as environmental compliance assurance monitors in lieu of more frequent Reference Method testing for compliance. In the United Kingdom, PM CEMSs are used at municipal waste combustors, power plants, and cement kilns in a compliance assurance manner (personal site visits at two facilities and personal communication with the U.K. Environment Agency, September 1999). Also, in Korea, PM CEMSs are used in a compliance assurance manner.

PM CEMS have been applied in Germany to industrial furnaces (i.e., coal- and oil-fired units larger than 50 MW and gas-fired units greater than100 MW) following the requirements of the 13th BlmSchV and to waste incinerators following the requirements of the 17th BlmSchV. In Denmark, PM CEMSs are used at coal-fired power plants. In the United States, PM CEMSs have been installed and evaluated on liquid hazardous waste burning sources, cement kilns, copper smelters, a glass furnace, and oil- and coal-fired boilers.

When a PM CEMS is used for compliance monitoring, the PM emission limit that is used as a compliance set point should be based on PM CEMS data collected from many representative sources over an extended period (e.g., at least 6 months). The accuracy limitations of a PM CEMS must also be considered when setting an emission limit. For example, in Germany the PM CEMS's confidence interval (e.g., 4 mg/dscm) is added to the baseline PM emission standard (e.g., 30 mg/dscm) to determine the facility's daily emission limit (e.g., 34 mg/dscm). Also, the averaging period and whether the average is a block or rolling average are critical choices to be made. These choices will have an effect on sources ability to remain in compliance (Joklik, 1999). Furthermore, the definition of particulate itself can be problematic at some sources, especially when comparing in-situ PM CEMS measurements to extractive Reference Method measurements (i.e., because of condensible particulate).

7.2 PM CEMS SELECTION

Since a PM CEMS determines PM concentration by measuring secondary properties of the particulate, selecting the appropriate PM CEMS technology for the source is a critical first step. Site-specific conditions must be considered (see Section 6.2 of this report). Also, different types of PM CEMSs can report different PM concentrations for the same sample stream just because of the concentration units (i.e., mg/dscm versus mg/acm) used in the correlation test. Some of the factors that affect PM concentration measurements made by the PM CEMSs presented in Section 4 of this report are offered below (Joklik, 1999) along with some practical suggestions.

- Opacity and light scattering monitors have responses that are functions of the particulate's index of refraction and size distribution. However, in addition to being more sensitive than opacity monitors, light scatter monitors also provide more degrees of design freedom. Parameters such as light wavelength, scattering angle, and solid angle of detection affect

the response of the instrument, which makes it possible to minimize the influence of index of refraction and size distribution over certain specified size ranges. However, since optical techniques effectively measure particle volume, using them to infer PM concentrations introduces an additional dependence on particle density. Since these instruments respond to liquid droplets in the sample gas stream, in-situ devices of this type are inappropriate for saturated or nearly saturated exhaust streams. Extractive devices of this type that heat the sample gas may be used on saturated or nearly saturated exhaust streams. Additionally, using these types of instruments on sample gas streams that are likely to have varying particle size distributions is less desirable, unless precautions are taken to avoid the effects of changing particle sizes (e.g., multiple correlation curves). These instruments are most appropriate for sources controlled by fabric filters (i.e., baghouse) or multi-stage air pollution control systems in which the particle size distribution at the outlet of the device does not vary much.

- Beta gauge monitors have a weak dependence on particle composition. This effect arises because of the composition dependence of the electron mass-attenuation coefficient (the atomic number versus atomic mass ratio). The main issues associated with the use of a beta gauge PM CEMS are practical ones: maintaining isokinetic sampling may be necessary and sample loss may occur in the probe. The importance of these issues will be site dependent. Since beta gauge type instruments are much less sensitive to changes in particle size than optical based instruments, these instruments are more appropriate for sample gas streams that are likely to have varying particle size distributions (e.g., following an ESP or sources that use many different fuels). Also, since beta gauge type instruments extract and heat the sample gas, these instruments are appropriate for sample gas streams that are saturated or nearly saturated. If a beta gauge instrument is used at a source that varies its exhaust gas stream velocity a great deal (e.g., load following electric power plant), the instrument must have the capability to adjust its sampling rate to maintain isokinetic sampling.
- The response of probe electrification devices is a function of resistivity of the particles, which depends on particle composition and humidity. The response is also affected by flow velocity, particle size, and particle charge. Also, since a physical probe is inserted

into the sample gas stream, effects due to erosion and deposition must be considered. A PM CEMS of this type should only be used in exhaust streams that do not have varying particle sizes, do not have varying velocity, do not have saturated or near saturated conditions, and do not have varying particle charge (e.g., cement kiln controlled by a fabric filter). Probe electrification devices based on the AC portion of the current are not as sensitive to gas velocity changes as DC measuring devices.

- The PM CEMS measurement location is critical, especially if the PM concentration will be artificially increased for purposes of developing the correlation relation. The point where high-PM-concentration gas is mixed with low-PM-concentration gas must be well upstream of both the PM CEMS and the manual Reference Method measurement location. This is to ensure the particulate is evenly distributed and well mixed across the stack area at the measurement location. Also, devices that can introduce dilution air or otherwise disturb the air flow pattern must be well upstream of the PM CEMS measurement location.

7.3 SITE-SPECIFIC CORRELATION TEST

Since a PM CEMS measures secondary properties of particulate (with the possible exception of the beta gauge type monitors) and outputs a signal that is proportional to the PM concentration, a PM CEMS must be correlated to the site specific conditions at the measurement location. Also, a site-specific correlation will account for any PM stratification that may exist at the PM CEMS measurement location. The procedure for carrying out a correlation test is described in PS-11. Some specific issues related to the correlation test are presented in this section. A correlation test consists of the following steps:

1. Install an appropriate PM CEMS at a representative location and start it according to the manufacturer's instructions.

2. Operate the PM CEMS and record the output for a Shakedown Period and then a Correlation Test Planning Period (up to a 6-month period may be needed). Establish a proper measurement range at the end of the Correlation Test Planning Period. The Shakedown Period and Correlation Test Planning Period must not extend beyond the date when the PM CEMS must be used to report emissions.

3. Carefully, conduct 15 paired train Reference Method tests for particulate while simultaneously collecting PM CEMS output values over the range of PM CEMS responses recorded during the Correlation Test Planning Period. Higher PM CEMS responses may be tested to increase the effective range of the correlation equation by perturbing the air pollution control system or other means.

4. Evaluate the Reference Method data for precision and bias, and calculate the statistically appropriate correlation equation (linear or polynomial) from the valid, concurrent PM CEMS responses and Reference Method PM concentrations.

5. For the selected correlation equation, compare the statistical parameters to the PS-11 criteria.

The main issues to resolve during the Shakedown Period and Correlation Test Planning Period are the following:

- Plant people must learn how to properly operate the PM CEMS.
- The process should operate over its full operating envelope, especially in the areas that are suspected to affect PM composition and concentration (e.g., all expected waste feeds, all fuels, start-up and shutdown, sootblowing).
- The proper measuring range or sensitivity level must be set such that normal operations are approximately 6 to 10 mA output but that concentrations at and just above the emission limit do not exceed the upper measurement point (i.e., 20 mA). Also, the measuring range must never be exceeded for a 15-minute average period. Completing this task will likely require some Reference Method testing before the initial correlation test.
- The operating conditions that produce low and high PM concentrations must be documented so that those conditions can be reproduced for the correlation test. If changes in operation cannot produce a range of PM concentrations, some technique of perturbing or bypassing the pollution control system can be used.

During the initial correlation test, the most critical task is to carefully and properly perform the manual Reference Method tests and laboratory analysis. This task is critical because the accuracy of the PM CEMS correlation can be no better than the accuracy of the Reference Method measurements. The sole reason for requiring dual sampling trains is to help ensure the accuracy of the Reference Method values by checking that the precision between the paired

Reference Method results is sufficiently high and that the bias between the two sampling systems is sufficiently low. Although having a high level of precision between paired numbers does not guarantee that either number is accurate, the chance that the number is accurate is greater than with a single value. Another important point is to coordinate starting and stopping of the test runs with the sampling interval of the PM CEMS. This point is most important for a batch type, extractive PM CEMS (i.e., a beta gauge). Also, if port changes during the Reference Method tests take a long time (e.g., 5 minutes or more), the PM CEMS data during port changes can be discarded from the PM CEMS's average output.

Since the paired Reference Method results must be evaluated for their precision before the run can be considered valid, getting PM concentration results in the field is highly recommended. This requires sample recovery and laboratory analysis in the field. Furthermore, checking the progress of the test program by plotting the Reference Method values against the PM CEMS's output during the correlation test is highly recommended.

Another requirement for a valid correlation test per draft PS-11 is to collect PM concentrations over the full range of PM CEMS responses recorded during the Correlation Test Planning Period. At most sources, some effort (e.g., operational changes or adjustments to the pollution control system) will be needed to obtain the full range of PM concentration levels. Testing at PM concentrations above the emission limit is not required. Some examples of how a source might obtain lower and higher PM concentrations are the following:

- For low PM concentrations:
    - Burn only natural gas
    - Stop product feed
    - Shut off process and only run the fans
    - Use filtered sample air
- For high PM concentrations:
    - Change fuels combusted
    - Change product or waste feed
    - Perturb or bypass the pollution control system to simulate normal, unpreventable upsets

The EPA is aware that some sources will not be able to create a wide range of PM concentration levels for the correlation test. Therefore, draft PS-11 allows a source to perform the correlation test over the range of PM concentrations normally experienced. The PM CEMS is then limited to how far its response can be used for reporting PM emissions (i.e., 125 percent of the highest PM CEMS response during the correlation test) before additional data must be collected to extend the correlation. For example, if the PM CEMS responses ranged from 4.5 mA to 5 mA during the correlation testing, the corresponding correlation equation from this data could be used up to a PM CEMS response of 6.25 mA. When three hourly averages exceed 6.25 mA, additional test data at PM CEMS responses around 6.25 mA would have to be added to the correlation data. This approach is particularly appealing when the limited range of PM concentrations is much lower than the standard. This approach is used in Germany.

7.4 UNDERSTANDING THE MEANING OF THE CORRELATION

After a successful correlation test and development of the correlation relation equation, one must understand the meaning and appropriate use of the regression equation (Joklik, 1999). The estimated regression equation that correlates the manual gravimetric PM concentration measurements (e.g., mg/dscm) and PM CEMS measurements (e.g., mA) has associated with it a degree of uncertainty expressed by two hyperbolae around the fitted line of the regression equation (i.e., the mean of the estimated PM concentration values.) The first is a confidence interval, defined in PS-11 as a 95 percent confidence level. The second is a tolerance interval, defined in PS-11 as a 95 percent tolerance interval that contains at least 75 percent of the entire population of PM concentration values. In other words, a tolerance interval will bracket at least a certain proportion (e.g., 75 percent) of the population with a specified degree of confidence (e.g., 95 percent). The width of the band determined by these bounds is narrowest at the point defined by the mean of PM CEMS measurements and mean of PM concentration measurements. The farther one moves away from the mean, the wider the bounds become. Thus, extrapolating the estimated regression line and its confidence and/or tolerance bounds will necessarily result in decreased precision in PM concentration measurements estimates. Therefore, the EPA's policy decision to limit the amount of extrapolation of a regression equation developed from data over a narrow range of PM CEMS responses to 125 percent of the largest PM CEMS response is supported by the statistical meaning of the correlation.

For a given PM concentration (i.e., mg/acm), several different PM CEMS responses (i.e., mA signal) can occur within the bounds of the tolerance interval (following along a horizontal line from the upper tolerance interval to the lower tolerance interval, this is based on inverse regression). Conversely, for a given PM CEMS output, several different PM concentrations can occur (following along a vertical line from the lower tolerance interval to the upper tolerance interval). Thus, the uncertainty in the PM concentration reported by a PM CEMS's correlation relation equation that meets PS-11 acceptance criteria is limited to ± 25 percent of the emission limit value.

7.5 QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance (QA) has two functions in the PM CEMS program:

1. Assessment of the continued quality of the PM CEMS's data, and
2. Maintaining data quality by implementing quality control (QC) policies and corrective action.

When the assessment function indicates a reduction in data quality, the QC procedures must be revised until the PM CEMS produces data of acceptable quality. The specific QA/QC activities found in Procedure 2 for a PM CEMS program are the following:

- Quality check of Reference Method data,
- Daily zero and upscale drift checks,
- Daily sample volume check (where applicable),
- Relative response audit (RRA),
- Response correlation audit (RCA),
- Absolute correlation audit (ACA), and
- Sample volume audit (SVA), where applicable.

As noted earlier, collecting quality manual Reference Method data is key to a successful PM CEMS program. The quality of the Reference Method data applies to the initial correlation test described earlier and to the RCA test. The quality of the Reference Method data is first evaluated by the population relative standard deviation (RSD) between the paired Reference Method data points from each individual test run. The RSD must meet the following criteria:

IF	THEN
the average PM concentration > 10 mg/dscm	RSD < 10 percent
the average PM concentration < 1 mg/dscm	RSD < 25 percent
the average PM concentration is between 1 and 10 mg/dscm	RSD < the percentage determined from the following equation: -(15/9) * mg/dscm + 26.667 (i.e., the linear interpolation between 25 percent at 1 mg/dscm and 10 percent at 10 mg/dscm)

If the pair of Reference Method PM concentration values meets the RSD criteria, the data are deemed acceptable. At the conclusion of the test program (either initial correlation or RCA), all valid pairs are evaluated for systematic bias. The bias is evaluated by calculating the linear regression of all valid pairs (Train B versus Train A), and comparing the slope from the linear regression to the range of 0.93 to 1.07. If the slope is between 0.93 and 1.07, the bias is acceptable, and the averages of each paired train are used in the initial correlation relation or RCA.

On a daily basis, the PM CEMS is subjected to zero and upscale drift checks. This routine check is done to assess system electronics and optics, light and radiation sources and detectors, electric or electro-mechanical systems, and general stability of the system calibration. Basically, the zero and upscale drift check is a daily health check of the instrument (i.e., is it still responding to a reference value today as it did yesterday and the day before that, etc?). In general, the instrument must be adjusted when the daily drift exceeds 4 percent, but it may be adjusted at lower drift values. The instrument is considered out-of-control (i.e., the data are not valid for compliance determination) when either the zero or upscale drift exceeds 4 percent for 5 consecutive days or exceeds 8 percent on any one day.

For extractive type PM CEMS that measures the sample volume and uses the measured sample volume as part of calculating the output value, a check of the sample volume measuring equipment must be done on a daily basis. This sample volume check is done at the normal sampling rate of the PM CEMS. The PM CEMS sample volume measurement must be adjusted whenever the daily sample volume check exceeds 10 percent. The instrument is considered out-

of-control (i.e., the data are not valid for compliance determination) when the sample volume check exceeds 10 percent for 5 consecutive days or exceeds 20 percent on any one day.

At least once each calendar quarter (but no closer than 2 months), the PM CEMS must have an ACA and a SVA (as applicable) done. The ACA applies to all types of PM CEMSs, and the SVA applies to extractive type PM CEMSs that use the measured sample volume to calculate PM concentration. An ACA and a SVA are higher level performance checks than the daily checks. The ACA is designed to evaluate the performance of the PM CEMS across its full measuring range by checking the instrument's response at three audit points. If any of the ACA audit points have an error in excess of ± 10 percent of the audit value, the instrument must be repaired and a new audit done to confirm the proper operation of the instrument. The PM CEMS manufacturer should provide the source with materials for the audit. A SVA is done by measuring the instrument's sample volume with a calibrated device (e.g., dry gas meter) and comparing the audit value to the volume reported by the instrument. If the SVA shows an error in excess of ± 5 percent of the audit value, the instrument must be repaired and a new SVA done to confirm the proper operation of the instrument. Procedure 2 provides the method for performing the SVA.

At the frequency specified in the regulation that requires the PM CEMS, at least 12 paired manual Reference Method tests for the RCA must be conducted following the same procedures described for the initial correlation test. Each paired train result must meet the same RSD criteria as for the initial correlation. The RCA must include PM concentrations within the range obtained during the initial correlation test. For the RCA, at least 9 of the 12 sets of PM CEMS/Reference Method measurements must fall within the initial correlation's tolerance interval bounds. If the PM CEMS fails to meet this RCA criteria, the PM CEMS is out-of-control, and the following two actions must be taken:

1. Combine the RCA data with the initial correlation data and perform the regression analysis in PS-11 to develop a new correlation relationship. If this new correlation meets the PS-11 criteria, the new correlation must be used, or

2. Do the PS-11 regression analysis on the new RCA data. If this new correlation relation meets PS-11 criteria, it must be used.

Once every four calendar quarters, a RRA must be conducted. The RRA consists of collecting three simultaneous Reference Method PM concentration measurements and PM CEMS measurements at the as-found source operating conditions and PM concentration. Paired trains for the Reference Method sampling are not required but are recommended to avoid failing the test due to imprecise and inaccurate Reference Method results. For the RRA, at least 2 out of the 3 test runs must fall within the tolerance interval to ensure the PM CEMS correlation is still applicable and accurate. EPA believes the RRA is a cost effective means to ensure that the PM CEMS correlation remains applicable without the need to complete a costly RCA on an annual basis. If the PM CEMS fails to meet this RRA criteria, the PM CEMS is out-of-control, and a full RCA must be completed.

7.6 PS-11 ISSUES TO BE ADDRESSED CASE BY CASE

As discussed previously, the EPA produced a draft performance specification (PS-11) to govern the installation and calibration of a PM CEMS. The EPA has been revising PS-11 based on the results of its and industry's field evaluations of PM CEMSs and comments received to the proposed PS-11. Many issues have been resolved, but several issues need to be resolved on a case by case basis. The PS-11 case by case issues are the following:

1. How to vary the source's PM emission concentrations during the correlation test.
    - How to simulate a normal, unpreventable, expected failure of the APCD?
    - If adjusting the APCD changes the characteristics of the PM in the stack, some types of PM CEMSs will not be applicable.
    - What effect does fuel changes have on the PM concentration?
    - Can sootblowing be used to increase the PM concentration?
    - Can and should the product feed be stopped to get near zero emissions?
    - Is testing during start-up and shut-down viable?
    - Can clean sample gas be used for a zero point?
    - Is the zero point hypothesis (i.e., 0 mg/m^3 = 4mA) valid? The zero point hypothesis is used by the German agency, and the tests done by Eli Lilly while only combusting natural gas support the zero point hypothesis concept.
2. Can and should multiple correlations be used in some instances when clearly the PM characteristics change?

3. For sources having condensible materials in the exhaust stream, the PM CEMS must be able to measure PM at the Reference Method filter temperature. If condensible PM is included in the total particulate, in-situ PM CEMS (e.g., light scattering, probe electrification, light extinction, and optical scintillation) may not be applicable.

In addition to PS-11, the EPA also produced QA and QC measures designed to ensure that the ongoing PM data collected by the PM CEMS is valid. These QA/QC measures are found in Procedure 2. The following QA/QC and data handling issues must be specified in the applicable regulation:

1. What is the appropriate frequency for confirming the correlation (e.g., annually, every 18 months, every 5 years)? In Germany, many correlations are not checked for 5 years. The EPA added a 3-run Reference Method check of the correlation equation, called a relative response audit, to be done annually.
2. What is continuous data (e.g., are four 15-minute block averages needed for an hourly average), and how does continuous apply to batch type monitors (i.e., beta attenuation)? If a batch type PM CEMS samples stack gas for 9 minutes out of each 15-minute period, is this CEMS collecting continuous data?

8.0 SUMMARY OF PS-11 AND PROCEDURE 2

The initial proposed versions of PS-11 and Procedure 2 were published in the Draft Technical Support Document for HWC MACT Standards, Volume IV: Compliance with the Proposed MACT Standards dated February 1996. Public comment was received, and additional revisions were made. PS-11 and Procedure 2 were published again in December 1997. Additional comments were received, and EPA has continued to learn about the capabilities and performance of PM CEMS. The following sections present EPA's latest approach to PS-11 and Procedure 2. EPA intends to publish a supplemental proposal for PS-11 and Procedure 2 by the end of 2000.

8.1 PS-11

PS-11 is used for evaluating the acceptability of a PM CEMS at the time of or soon after installation, and whenever specified in the source's applicable regulation. This performance specification requires site-specific correlation of the PM CEMS response against manual gravimetric Reference Method measurements (including those made using EPA Reference Methods 5 or 17). PS-11 outlines the procedures and acceptance criteria for installation, operation, calculations, and reporting of data generated during a PM CEMS correlation. PS-11 is unique, relative to the performance specifications for other CEMS because it is based on a technique of correlating PM CEMS response to emissions determined by the Reference Method. This differs from a CEMS measuring gaseous pollutants which has available calibration gases of known concentration.

As presented in Section 4 "Summary of Known PM CEMS," several different types of PM CEMSs, which use different operating principles, are available. The selection of an appropriate PM CEMS is dependent on site-specific configurations, flue gas conditions, and PM characteristics (see Section 7 "PM CEMS Implementation" for source applicability). After an appropriate PM CEMS is selected, it must be installed at an accessible location downstream of all pollution control equipment. The PM CEMS concentration measurements must be performed from a location considered most representative or from one that can provide data that can be corrected to be representative of the total PM emissions as determined by the manual Reference Method. The site-specific correlation developed during the Performance Specification testing must relate specific PM CEMS responses to integrated particulate loadings.

After completing the initial field installation, the PM CEMS is operated for a Shakedown Period. The objective of the Shakedown Period is for the facility operators to become familiar with the PM CEMS and its routine operation for providing reliable data. The Shakedown Period continues until the instrument technicians are comfortable with the operating characteristics of the PM CEMS and that the PM CEMS is operating within the manufacturer's specifications. After completing the Shakedown Period, the PM CEMS is operated for a Correlation Test Planning Period. The objective of this period is to identify the full range of operating conditions and PM emissions to be used in the PM CEMS correlation test. During the Correlation Test Planning Period the process and air pollution control equipment are operated in their normal set of operating conditions, except when attempts are purposely made to produce higher emissions. The Correlation Test Planning Period continues until the source owner is satisfied that the complete range of PM emissions have occurred. During the Correlation Test Planning Period, the operators must establish whether the monitor is operating in a suitable range(s) relative to the source's emission profile. The objective here is to assure that the monitor's measurement range is broad enough to measure peak emissions yet sensitive enough to address low-emission conditions. Ideally the monitor should be reading near mid-scale during normal conditions but never reading off-scale during peak emissions.

The performance of the PM CEMS is judged from the results of two tests: (1) 7-day drift test and (2) initial correlation test. The 7-day drift test is to validate the internal performance of the PM CEMS relative to its own zero and upscale drift checks for seven consecutive days. The purpose of the 7-day drift measurement is to verify that the PM CEMS response is the same as that established during the development of the initial correlation and to determine whether the PM CEMS is in control during day-to-day operation. The initial correlation test is done to develop the relationship between the PM CEMS responses and the manual Reference Method results over a range of PM concentrations. Collection of Reference Method PM data using paired trains is required. Each set of paired train results must achieve a specific level of precision to be used in the correlation data set.

For the correlation relation tests, a minimum of 15 valid runs must be conducted, each consisting of simultaneous PM CEMS and Reference Method measurements sets and covering the full range of PM concentrations identified during the Correlation Test Planning Period. The

Reference Method measurements consist of paired trains operated simultaneously. For acceptable Reference Method measurements, the paired trains must meet precision and bias criteria. Ideally, the manual Reference Method data would be distributed over the complete operating range experienced by the facility, with at least 20 percent of the minimum 15 measured data points in each of the following three levels:

- Level 1: From zero PM concentration to 50 percent of the maximum PM concentration.
- Level 2: 25 to 75 percent of the maximum PM concentration.
- Level 3: 50 to 100 percent of the maximum PM concentration.

Although the above levels overlap, individual run data may only be applied in one level. Lower and higher than normal PM concentrations may be intentionally created by operating the facility outside of its normal operation, but, at a minimum, the correlation data must include the range of PM CEMS responses observed during the Correlation Test Planning Period. The correlation relation can only be extrapolated to 125 percent of the highest PM CEMS reading observed during the correlation test. If the PM CEMS records readings higher than 125 percent of the highest PM CEMS reading observed during the correlation test for three consecutive hours, three additional Reference Method test runs must be made at the higher PM CEMS response. The correlation relation must be revised within 30 days of the occurrence.

Developing a PM CEMS correlation will affect plant operations for about a week while the correlation tests are being performed. PS-11 does not require the source to emit PM that exceeds the PM emission limit during the correlation test.

From the complete set of correlation data, the correlation coefficient, confidence interval, and tolerance interval are calculated for a polynomial and a linear regression. A test to determine if the polynomial regression offers a statistically significant improvement to the preferred linear regression is done. The correlation coefficient, confidence interval, and tolerance interval for the selected regression must meet the performance criteria in PS-11.

8.2 PROCEDURE 2

40 CFR Part 60, Appendix F, Procedure 2 describes the procedures used to evaluate the effectiveness of QA and QC procedures and the quality of the data produced by any PM CEMS that is used for compliance monitoring. The QA/QC practices of Procedure 2 consist of

- daily drift and sample volume checks
- quarterly audit of the PM CEMS's accuracy in response to reference standards
- quarterly audit of the measured sample volume
- longer-term assessment of the stability and applicability of the initial correlation relation.

Also included in Procedure 2 are assessments of the accuracy and precision of the Reference Method data used in the correlation relation assessment.

Procedure 2 requires a written QA Plan that includes complete detailed QA/QC procedures. If the PM CEMS fails to meet the acceptable criteria for any Procedure 2 audit, the PM CEMS is called out-of-control. When the PM CEMS is out-of-control for two consecutive periods, procedures in the QA Plan must be enhanced to prevent a repeat of the out-of-control condition.

9.0 PM CEMS COST

The data on Tables 9-1 and 9-2 are based on actual expenditures experienced by the EPA in field studies, information gained from interviews with users, and the expected costs of appropriate QA/QC requirements in the draft performance specifications and associated procedures. The tables point out that costs can vary widely, mainly according to the frequency of the RCA. Since the costs in Tables 8 and 9 were developed, the EPA has received new information about PM CEMS costs. The EPA believes the First Costs may be a little low because of the potential need for more Reference Method particulate testing than originally anticipated. Additional test runs may be needed during the Correlation Test Planning Period in order to assess the proper measurement range for the PM CEMS.

TABLE 9-1. IN-SITU (LIGHT SCATTERING) PM CEMS COSTS[a]

Task	Total cost $
Total First Costs (Equipment, installation, initial testing, correlation)	102,600 - 132,600
Total Annual Costs – RCA done every year	51,800 - 82,800
RCA done every 18 months	40,700 - 71,700
RCA done every 3 years	29,600 - 60,600

TABLE 9-2. EXTRACTIVE (BETA GAUGE) PM CEMS COSTS[a]

Task	Total cost $
Total First Costs (Equipment, installation, initial testing, correlation)	140,000 - 170,000
Total Annual Costs – RCA done every year	58,200 - 88,800
RCA done every 18 months	47,100 - 77,700
RCA done every 3 years	36,000 - 66,600

[a] Assumptions for these tables are given in Appendix A

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APPENDIX A

BREAKDOWN OF PM CEMS COSTS

LIGHT SCATTERING PM CEMS COSTS

Task	Total Cost $
Planning	3,500
Select Equipment	10,300
Provide Support Facilities	1,000 - 8,100
Purchase CEMS	36,000 - 47,100
Install & Check CEMS	9,900
Performance Spec. Tests	25,000 - 36,800
Prepare QA Plan	16,900
Total First Costs	**102,600 - 132,600**
Operation & Maintenance	12,900
Annual RATA (O_2 monitor)	0 - 5,800
PM Monitor RCA	15,000 - 26,300
Quarterly ACA	1,000 - 7,000
Record Keeping	7,500
Annual Review & Update	1,000 - 4,400
Capital Recovery	14,364 - 18,880
Total Annual Costs	**51,800 - 82,800**
If RCA done every 18 months	**40,700 - 71,700**
If RCA done every 3 years	**29,600 - 60,600**

BETA GAUGE PM CEMS COSTS

Task	Total Cost $
Planning	3,500
Select Equipment	10,300
Provide Support Facilities	1,000 - 8,100
Purchase CEMS	71,000 - 82,100
Install & Check CEMS	12,300
Performance Spec. Tests	25,000 - 36,800
Prepare QA Plan	16,900
Total First Costs	**140,000 - 170,000**
Operation & Maintenance	13,700
Annual RATA (O_2 monitor)	0 - 5,800
PM Monitor RCA	15,000 - 26,000
Quarterly ACA	1,000 - 7,000
Record Keeping	7,500
Annual Review & Update	1,000 - 4,600
Capital Recovery	20,000 - 24,200
Total Annual Costs	**58,200 - 88,800**
If RCA done every 18 months	**47,100 - 77,700**
If RCA done every 3 years	**36,000 - 66,600**