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Air

EVALUATION OF PARTICULATE MATTER (PM) CONTINUOUS EMISSION MONITORING SYSTEMS (CEMS)

Final Report

Volume 1—Technical Report

MRI

Evaluation of Particulate Matter Continuous Emission Monitoring Systems

Final Report

Volume I—Technical Report

For U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emissions, Monitoring and Analysis Division
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Preface

This report was prepared by Midwest Research Institute (MRI) for the U.S. Environmental Protection Agency (EPA) under Contract No. 68-W6-0048, Work Assignment 4-02. Mr. Dan Bivins is the EPA Work Assignment Manager (WAM). This report covers the 6-month endurance test period for the PM-CEMS (July 20, 1999 to February 16, 2000) and includes the initial correlation tests as well as the two RCA/ACA tests.

All of this work would not have been possible without the full cooperation of Cogentrix personnel. The Cogentrix staff (especially Tracy Patterson, Air Quality Manager, Steve Carter, Plant Manger, and Mike Chaffin, I&C Supervisor) were very helpful and provided every possible assistance to make this a successful project.

This report consists of 1,238 pages, including the appendices.

MIDWEST RESEARCH INSTITUTE

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Executive Summary

EPA's Office of Air Quality Planning and Standards (OAQPS) is considering particulate matter continuous emission monitoring systems (PM-CEMS) for use in future standards. Also, states may require them for State Implementation Plans (SIP) and Economic Incentive Program (EIP) monitoring, and industry sources may use PM-CEMS for Title V monitoring. EPA therefore desired evaluation of PM-CEMS technology on a long-term, continuous basis.

The purpose of this demonstration program was to assess the performance of PM-CEMS over an extended time. The program included three PM-CEMS and a moisture CEMS installed at the Cogentrix coal-fired cogeneration facility in Battleboro, North Carolina. These CEMS were:

- ESC P5B light scatter PM-CEMS
- Durag DR 300-40 light scatter PM-CEMS
- Durag F904K Beta gauge PM-CEMS
- Vaisala HMP 235 moisture CEMS

Due to limited space for installing the devices at this test site, they were necessarily located only 2.1-2.6 diameters downstream of a 90° bend in the ductwork, which minimally met the location guidance in draft PS-11. It was recognized that this location might involve particulate stratification, but it was believed that any such stratification would likely be constant rather than variable, and thus would inherently be accounted for in development of the correlation relations for each PM-CEMS.

In addition to installing the PM-CEMS, a perturbing device was also installed that allowed bypassing part of the flue gas from the baghouse inlet to the outlet in order to increase the range of particulate emissions for the testing.

Following installation and startup of the monitors, data were downloaded daily, and three sets of tests were carried out: the initial correlation tests per draft Performance Specification 11 (PS 11)[1] and two Response Correlation Audits/Absolute Correlation Audits (RCA/ACA tests) per draft Procedure 2.[2] These tests are discussed below, with the two RCA/ACA tests referred to as "RCA #1" and "RCA #2." It should be noted that all three PM-CEMS provided good data availability (over 95%) throughout the 6-month period of their operation. The moisture CEMS did exhibit some problems with data availability, probably due to constant vibration at the test location. All three PM-CEMS met the daily drift criteria. They also met the applicable criteria in draft Procedure 2 for the four separate ACAs performed on the light scatter PM-CEMS and the Sample Volume Audits (SVAs) performed on the beta gauge PM-CEMS.

Initial correlation relation testing of the three PM-CEMS was carried out in July 1999, and results met the draft PS-11[1] correlation criteria for all three PM-CEMS. An ACA was also completed just before the initial correlation testing. In late August 1999, the first RCA (RCA #1) and a second ACA of the PM-CEMS were carried out per draft EPA Procedure 2.[2] For all three PM-CEMS, only 7 of the 12 RCA data points fell within a 25% tolerance interval of the initial correlation relation (Procedure 2 requires that 9 of the 12 data points fall within a ± 25% tolerance interval). The 12 RCA data points were then used to develop a new correlation relation for all three PM-CEMS. These new correlations were within the draft PS-11 correlation criteria for the F904K beta gauge but were just outside the confidence interval and tolerance interval criteria for the ESC P5B and DR 300-40 light scatter monitors.

Because the results from the first RCA, as discussed above, did not meet the draft Procedure 2 criteria, the second RCA/ACA test objective was revised to include

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[1] PS-11, Performance Specification 11—Specifications and Test Procedures for Particulate Matter Continuous Emission Monitoring Systems in Stationary Sources (draft Revision 4, November 1998).

[2] Procedure 2—Quality Assurance Requirements for Particulate Matter Continuous Emission Monitoring System (40 *CFR* 60, App. F, draft Revision 2, November 1998).

investigation of possible reasons for the differences between the initial correlation and the first RCA. The test plan was revised accordingly, and the test was carried out in mid-November 1999. The revised plan included use of one traversing train and one single point train in each run. The traversing train was intended to provide data like that obtained in the previous tests, while the single point train would provide data to assess possible stratification of particulate, and variability in that stratification, at the test location. Also included were tests at reduced boiler load in order to obtain lower duct velocity and determine any effects on particulate stratification.

Results from the second RCA test (RCA #2) showed that 5 of the 6 data points obtained at full boiler load fell within the ± 25% tolerance interval of the first RCA correlation relation. These 5 runs had a nearly constant particulate stratification ratio, ranging from 0.57 to 0.63 (see **NOTE**). The remaining run had a higher stratification ratio of 1.09 and fell within the tolerance interval of the initial correlation relation. This finding offers a plausible explanation for why the RCA #1 data did not fall within a 25% tolerance interval of the initial correlation relation (i.e., the stratification ratio may have been different in the two sets of tests). Sufficient data are not available to confirm this explanation, but the difference may be related to the location of the perturbing device and its possible effect on the particulate stratifications and/or particle size distribution, as discussed below.

NOTE— Particulate stratification ratio is the particulate concentration measured by a single point sampling train divided by the concentration measured by a simultaneous multipoint traversing train.

The second RCA test also included 6 runs at reduced boiler load, and 5 of these 6 runs did not match any of the previous test results (i.e., did not fall within a ± 25% tolerance interval of either the initial correlation or the RCA #1 correlation) even though the stratification ratio was essentially the same as in 5 of the 6 full load tests. Thus, the reduced boiler load test results provided an indication of changes in particulate characteristics and consequently the response of the three specific PM-CEMS used in this test program, as explained further in this report.

Results from the second RCA certainly showed that the particulate concentration is stratified when the perturbing device is open in order to increase the particulate concentration (as was done for the initial correlation relation testing and the RCA tests). Close proximity of the perturbing device and baghouse compartment outlet ducts to the PM-CEMS was undoubtedly the cause of the stratification.

As far as the primary objective of this project is concerned, the test results have shown that the three PM-CEMS did meet the draft PS-11 initial correlation criteria, but did not meet the draft Procedure 2 criteria for either of the two RCA tests.

One peer reviewer of this report believed that close proximity of the PM-CEMS to the baghouse outlet and perturbing device (i.e., stratification) was the cause of the non-agreement of the two RCA test results with the initial correlation. Conversely, a second reviewer stated that he was not convinced by the information presented in the report that stratification was responsible for the non-agreement. A third reviewer stated that the initial correlation and RCA data suggest that several different correlations exist. These comments illustrate the fact that no definite conclusion can be made as to the cause of the non-agreement of the results.

It should be noted that one of the objectives of the project was to determine whether the PM-CEMS satisfy all the requirements of draft PS-11 and draft Procedure 2, or determine if changes are needed in those requirements. As a consequence of the non-agreement discussed above, and related uncertainty about the effects of the perturbing device on the test results, one of the changes that has been recommended in PS-11 is to allow correlation data to be collected over the normal range of a facility's emissions (without using a perturbing device), even if that range is very narrow (e.g., a baghouse outlet). However, extrapolation of the resulting correlation relation is limited to 125% of the highest PM-CEMS response, above which additional data must be collected. It is believed that this recommended change in draft PS-11 will help avoid problems that may be associated with artificially increasing PM emissions (for correlation test purposes).

Section 1.
Introduction

1.1 Summary of Test Program

1.1.1 Overall Purpose of the Program

EPA's Office of Air Quality Planning and Standards (QAQPS) is considering the possible use of particulate matter continuous emission monitoring systems (PM-CEMS) in future standards. Also, states may require them for State Implementation Plans (SIP) and Economic Incentive Program (EIP) monitoring, and industry sources may use PM-CEMS for Title V monitoring. EPA therefore desired evaluation of PM-CEMS technology on a long-term, continuous basis.

The purpose of this demonstration program was to assess the performance of PM-CEMS over an extended time (i.e., 6 months).

The objectives of this EPA-sponsored PM-CEMS demonstration were to:

- Demonstrate whether the PM-CEMS can provide reliable and accurate information over an extended period of time

- Evaluate the PM-CEMS for durability, data availability, and setup/maintenance requirements

- Determine whether the PM-CEMS satisfy all the requirements of draft PS-11[1] and QA criteria specified in draft Procedure 2,[2] or determine if changes are needed in the requirements of PS-11 and/or Procedure 2

Other related objectives of the project were to:

- Determine if the PM-CEMS exhibit at least 80% data availability
- Document PM-CEMS maintenance requirements and operating and maintenance (O & M) costs
- Determine if the PM-CEMS correlation remains true for a long period of time after initial correlation, per draft Procedure 2
- Determine reliability and accuracy of the moisture CEMS

This report presents all the results of the project with emphasis on the results of the initial correlation testing and comparison with results from the first and second RCA/ACA. The report also contains daily results for the PM-CEMS during the entire period from July 20, 1999, to February 16, 2000, and data availability during that period (excluding the period of September 15-October 7, 1999, when no data were available due to Hurricane Floyd and associated plant shutdown).

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[1] PS-11, Performance Specification 11—Specifications and Test Procedures for Particulate Matter Continuous Emission Monitoring Systems in Stationary Sources (draft Revision 4, November 1998).

[2] Procedure 2—Quality Assurance Requirements for Particulate Matter Continuous Emission Monitoring Systems (40 *CFR* 60, App. F, draft Revision 2, November 1998).

All of the initial correlation testing and RCA testing involved manual reference method determination of particulate concentration, which was carried out in accordance with EPA Method 17 (M17).[3]

1.1.2 Test Site

The test site was Cogentrix of Rocky Mount, Inc., located in Battleboro, NC. Cogentrix is an electric utility cogeneration plant consisting of four identical boilers powering two electric generating units. Each generating unit is rated at approximately 55-60 megawatts, for a total plant electrical capacity of 115 megawatts. Each of the generating units is powered by a pair of Combustion Engineering stoker-grate power boilers designated as Boilers A and B. Figure 1-1 is a simplified schematic of the generating unit effluent flow. Each of the four boilers fires bituminous coal and is rated for 375 million BTU/hr heat input and 250,000 lb stream/hr output. The combustion flue gas from each boiler passes through a mechanical dust collector and a Joy Technologies, Inc. dry SO_2 absorber (scrubber) before entering the Joy Technologies pulse-jet fabric filter (baghouse) for particulate control. The effluent from each pair of boilers is combined downstream of the baghouses, exhausting through a common stack. Testing was carried out on Unit 2-A boiler/baghouse.

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[3] 40 *CFR* 60, Appendix A, Method 17—Determination of Particulate Emissions from Stationary Sources (In-Stack Filtration Method).

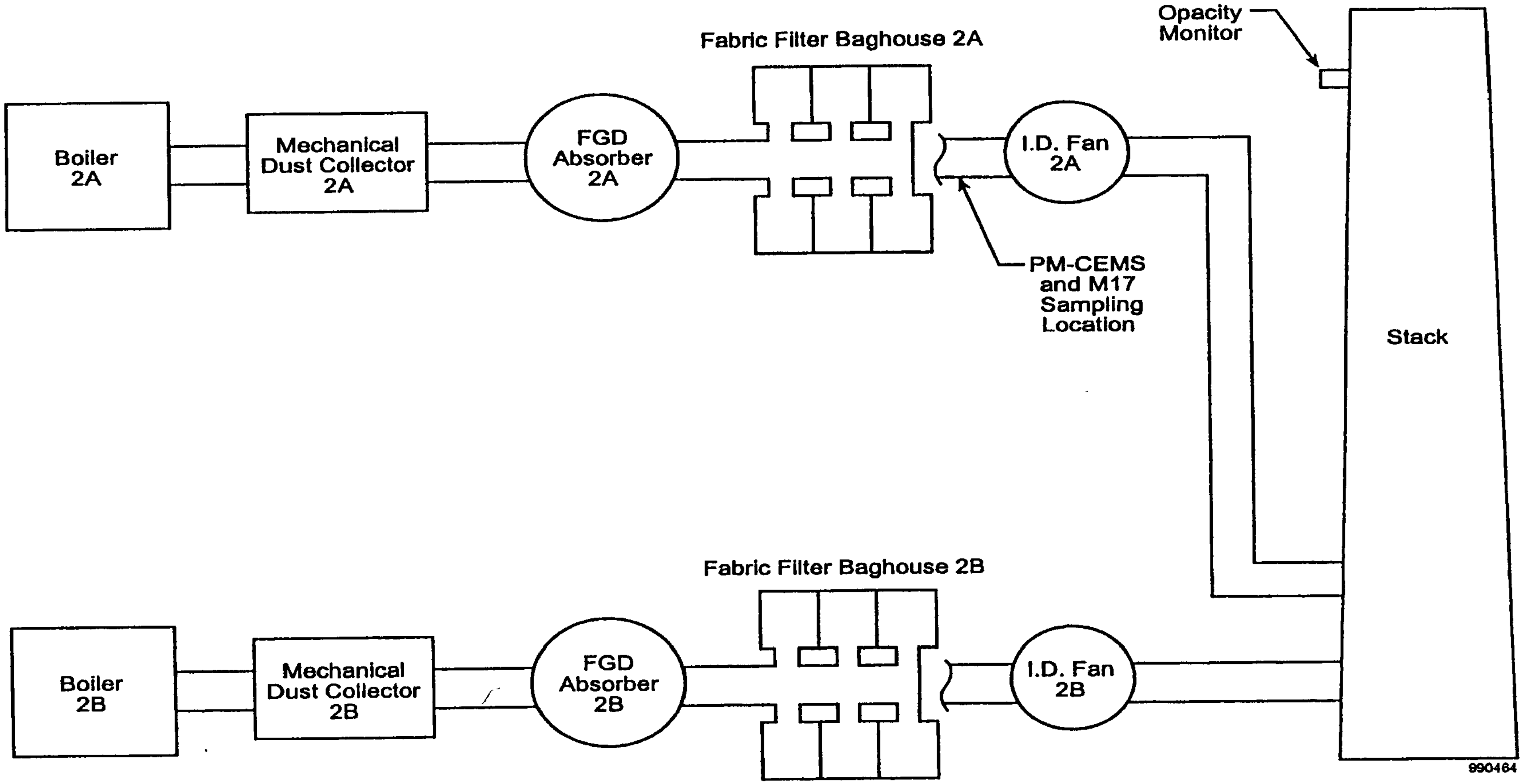


Figure 1-1. Unit 1 Effluent Schematic (Units 1 and 2 are identical)

1.1.3 Summary of CEMS Evaluated

For this PM-CEMS demonstration project, EPA purchased a total of three PM-CEMS from two vendors. The following criteria were used by EPA to choose the PM-CEMS:

1. EPA wanted to demonstrate the viability of both a light scattering type and beta gauge type PM-CEM and wanted at least one duplicate technology.
2. EPA wanted instruments that had been previously demonstrated on another test.
3. EPA wanted instruments capable of doing an automatic daily zero and upscale calibration drift check.
4. EPA wanted instruments that were commercially available (i.e., no prototypes).

EPA decided to use the following PM-CEMS:

- Environmental Systems Corporation (ESC) model P5B light-scattering type PM-CEM,
- Durag model DR 300-40 light scattering type PM CEM,
- Durag model F904K beta gauge type PM CEM.

Descriptions of the PM CEMS are provided below. In addition to the three PM CEMS, one additional CEMS, for monitoring stack gas moisture, was used (Vaisala HMP 235 moisture CEMS).

1.1.3.1 ESC P5B PM CEM

The Environmental Systems Corporation model P5B light-scattering type PM-CEMS detects particulate matter in the stack by reading the back-scattered light (175°) from a collimated, near-infrared light emitting diode (LED). 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 P5B does have an interference from condensed water droplets in the gas stream. This instrument's measuring range is 0.5 mg/m^3 up to 20,000 mg/m^3, and it has dual range capability; however, the dual range feature was not used for this demonstration. The measuring volume is located 4.75 inches from the physical end of the probe that contains both the transmitting and receiving optics. The P5B is inserted into the flow through a four-inch port and flange with a bolt hole at the 12 o'clock position. The probe is purged with air to keep the optics clean and cool. The P5B does automatic zero and upscale drift checks to meet daily QC check requirements. This instrument was evaluated by EPA/OSW at the long-term field test at the DuPont Experimental Field Station incinerator. The prototype to this instrument was evaluated at a secondary lead smelter by the University of Windsor in 1976-1977. ESC has sold over 100 of these instruments worldwide.

1.1.3.2 Durag DR 300-40 PM CEM

The Durag model DR 300-40 light scattering type PM-CEMS detects particulate matter in the stack by reading the light scattered by the particulate at 120°. The light beam is generated by halogen lamp (400-700 nm) modulated at 1.2 kHz. The Durag DR 300-40 is sensitive to changes in particle characteristics (e.g., size, shape, and color) and presence of condensed water droplets in the gas stream. This instrument's measuring ranges are dependent on the size of aperture installed, and are approximately from 0 to 1 mg/m^3 up to 0 to 100 mg/m^3. Within a measuring range, the Durag DR 300-40 has three sensitivity levels and automatically moves from one level to the next, where each level is 3 times less sensitive than the previous level. The data acquisition system calculates a "range adjusted" mA value that allows for a continuum in the output as the instrument changes levels. The equations that are used to calculate the range adjusted milliamps are shown below, along with the actual milliamp range and corresponding range adjusted milliamps.

	Equation	Actual mA range	Range adjusted values
Level 1	As read	4.00-20	4-20
Level 2	Range adjusted mA = 3(mA-4) +4	9.33-20	20-52
Level 3	Range adjusted mA = 9 (mA-4) +4	9.33-20	52-148

The sample volume for the DR 300-40 is located in an area 3 to 11 inches (centered at 6 inches) from the face of the instrument . Both the light source and the detector are located in a single unit, thus requiring only one point of access (i.e., a 5-inch by 12-inch rectangular flange is welded to the duct wall). The DR 300-40 does automatic zero and upscale drift checks to meet daily QC check requirements and provides automatic compensation for dirt on the optics (although the optics are protected by an air purge system). This instrument was approved by the German TÜV for all source categories, and it was evaluated by EPA/OSW at the long-term field test at the DuPont Experimental Field Station incinerator. Durag has sold over 500 of these instruments worldwide.

1.1.3.3 Durag F904K PM-CEM

The Durag F904K beta gauge type monitor extracts a heated sample from the stack, transports the sample to the instrument, and deposits particulate on a filter tape during user defined sampling periods (e.g., 4 to 8 minutes). Sample is extracted from the stack at a single point under isokinetic conditions at the normal process operating rate (i.e., isokinetic sampling is not maintained as stack flow changes). The probe is inserted into the stack through a 6-inch port and standard flange. The F904K introduces dilution air after the sampling nozzle to (1) minimize particulate loss in the sampling system, (2) handle high dust loadings (> 200 mg/dscm), and (3) sample wet or saturated stack gas. The measuring range is determined by the length of the sampling period and the amount of dilution air introduced in the probe, but the instrument can accommodate a range of up to 6 to 8 mg of particulate deposited on the filter tape during each sampling period.

Before and after each sampling period, the filter tape is moved between a carbon 14 (^{14}C) 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 dirty tape (after sampling) and the clean tape (before sampling). The attenuation of the beta particles is believed to be minimally sensitive to the composition of the particulate. The sampled gas is dried and the flow rate measured, thus allowing reporting of PM concentration on a dry basis. Further, the temperature of the dry sample gas is measured and the sample gas volume is corrected to standard temperature (20°C). The F904K does automatic zero and upscale drift checks to meet daily QC requirements. The zero check is performed by measuring the same location on the filter tape twice in succession with tape transport between measurements, without collecting a sample. The upscale check is done by simulating beta attenuation at an upscale check value (i.e., 50% transmission). The simulation of beta attenuation is done by counting beta particles for 240 seconds and comparing that count to the count from the first 120 second zero measurement of the zero drift check.

A typical sampling cycle requires 120 seconds for zero measurement, 19 seconds of tape transport, sampling period (300 seconds to 570 seconds), 19 seconds of tape transport, 120 seconds for sample measurement, 38 seconds for tape transport and print on tape. The cycle then starts over with a new tape zero measurement.

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

1.1.3.4 Vaisala HMP 235 Moisture CEM

The Vaisala HMP 235 moisture monitor measures the relative humidity (RH) and temperature of the stack gas and calculates the absolute humidity in units of grams per cubic meter (g/m^3). The two outputs from the instrument are absolute humidity (0 to 600 g/m^3) scaled from 0 to 10 Vdc and temperature (–20°C to 180°C) scaled from 0 to 10 Vdc. RH is detected with a HUMICAP® H-sensor, and temperature is measured with a Pt 100 RTD. The HUMICAP® sensor operates on the principal of changes in capacitance between its thin polymer films as they absorb water molecules.

The HMP 235's moisture readings were correlated to the Method 17 moisture results from the initial correlation tests and compared with results from the two RCA tests. Those results are presented in Section 5 of this report.

Note: Vaisala does not market the HMP 235 as a stack gas moisture monitor. The monitor's application is in less harsh environments (e.g., food production processes) than coal-fired boiler exhausts. Therefore, Vaisala would not guarantee the HMP 235's performance for monitoring stack gas moisture. Vaisala indicated that the corrosive nature of stack gas environments might destroy the thin polymer films that detect the amount of water molecules in the air. A Vaisala technical representative estimated that the HUMICAP® sensor would last for two to three months in a 50 ppm SO_2 and 50 ppm NO_x stack gas. At that point, the approximately $250 sensor would have to be replaced. Noting the potential use of this instrument as an accurate and economical stack gas moisture monitor, EPA decided to examine the HMP 235 as a stack gas moisture monitor during this test program. During this test program, the same HUMICAP® H-sensor was used for the entire period.

1.1.4 Emissions Measured

Emissions measured in these tests were particulate and moisture. Particulate emissions determined by the M17 tests were calculated in mg/dscm and then converted to units corresponding to those measured by each of the PM-CEMS (mg/acm for the light scatter CEMS and mg/dscm for the extractive beta gauge PM-CEM). Moisture measured by the dual M17 trains, in percent by volume, was used directly for correlation with the moisture CEM.

1.1.5 Dates of Tests

This report covers operation of the CEMS during the 6-month endurance test (July 20, 1999-February 16, 2000). It also covers the initial correlation tests and the two RCA/ACA tests.

Nine preliminary runs were carried out over the period of July 9-14 which were used only for assessing the range of emissions and setting the measurement range on the PM-CEMS. Thereafter, a total of 15 runs (Runs 10-24) were carried out during the period of July 15-19 for the initial correlation tests. The first RCA/ACA test (12 runs) was carried out on August 26-31, 1999. The second RCA test (12 runs) was done on November 16-20, 1999.

Results presented later in this report are from each of these three sets of tests and refer to the run numbers within each test. The numbering of runs was as follows:

Initial Correlation Tests	Runs 13-24 (See Note)
First RCA	Runs 1-12
Second RCA	Runs 31-42

NOTE— Runs 10, 11, and 12 were originally excluded from the initial correlation results, as explained later in this report.

1.2 Key Personnel

The key personnel who planned and coordinated the test program are:

•	Dan Bivins	EPA Work Assignment Manager	(919) 541-5244
•	Paul Gorman	Work Assignment Leader for Contractor (MRI)	(816) 753-7600 x1281
•	Craig Clapsaddle	CEM Task Leader for Contractor (MRI)	(919) 851-8181 x5342
•	Tracy Patterson	Air Quality Manager—Cogentrix	(804) 541-4246
•	Steve Carter	Plant Manager—Cogentrix	(252) 442-0708
•	Mike Chaffin	I&C Supervisor—Cogentrix	(252) 442-0708

Section 2.
Sampling Location

2.1 Flue Gas Sampling Location

The PM-CEMS and manual particulate sampling (EPA Method 17) locations are in the flue gas duct exiting the fabric filter as shown in Figure 2-1, where it can be seen that the PM-CEMS were located only about 2 diameters downstream from the 90° bend in the baghouse outlet duct. This rectangular duct has inside dimensions of 5′6″ x 4′9″ with the CEMS (and M17 ports) located on the 4′9″ wall, as shown in Figure 2-2 and Figure 2-3. In this rectangular duct, the gas flows downward toward the inlet to the induced draft fan. The duct is under high negative pressure (–20"H_2O). For the second RCA/ACA test, Cogentrix installed one additional M17 sampling port (port F), which was used only for the single point M17 sampling train as shown in Figure 2-3. A schematic diagram of the baghouse outlet duct, showing the location of the perturbing device, is given in Figure 2-4.

The ESC P5B probe extends 10" inside the duct, with the "sample volume" 5" further into the duct. It is 10" from the right side wall and 159" downstream from the 90° duct bend. The Durag DR 300-40 is mounted on the stack wall, extending 2" outside the wall. The "sample volume" covers 3" to 11" from the instrument; thus, the "sample volume" is 1" to 9" inside the wall. It is 13" from the left side wall and 132" downstream from the 90° duct bend.

The Durag F904K probe extends 24" inside the duct wall, and the probe is fitted with a 5-mm nozzle that provides near isokinetic sampling at the duct velocity of 90 ft/sec. However, the sampling rate is not adjusted to maintain isokinetic sampling as velocity in the duct changes. It is 15" from the right side wall and 128" downstream from the 90°duct bend.

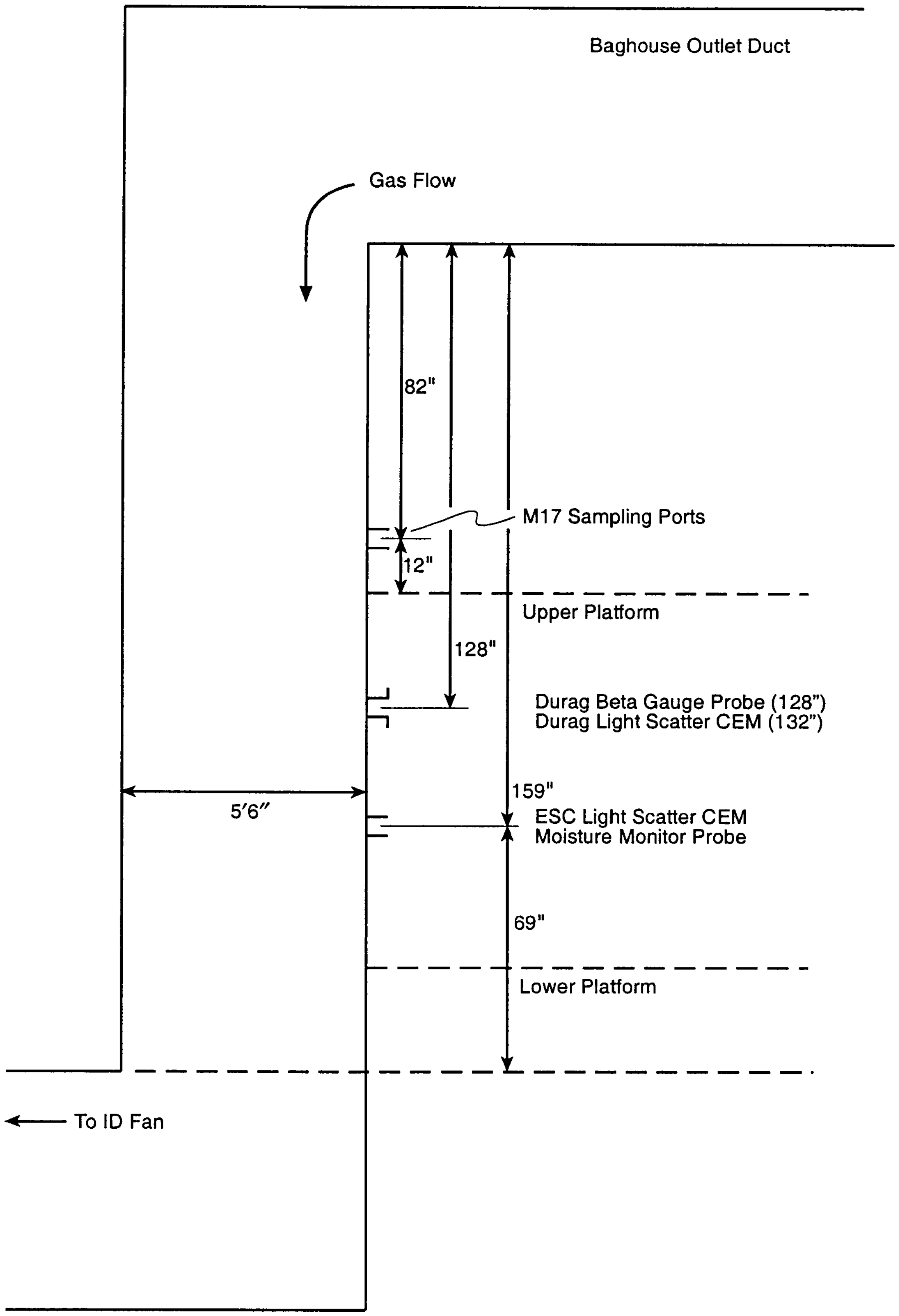


Figure 2-1. Location of CEMS and M17 Test Ports (Elevation Side View)

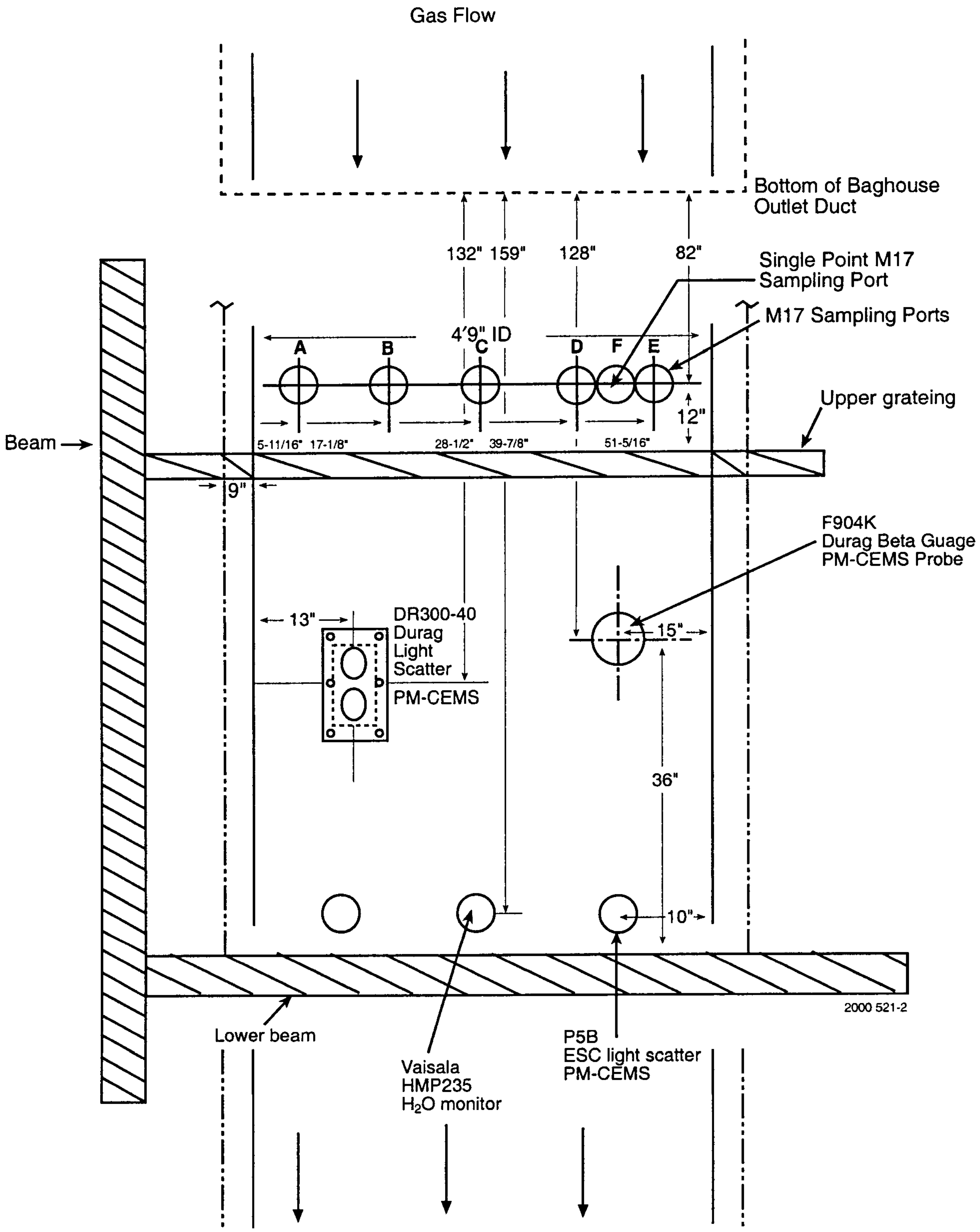
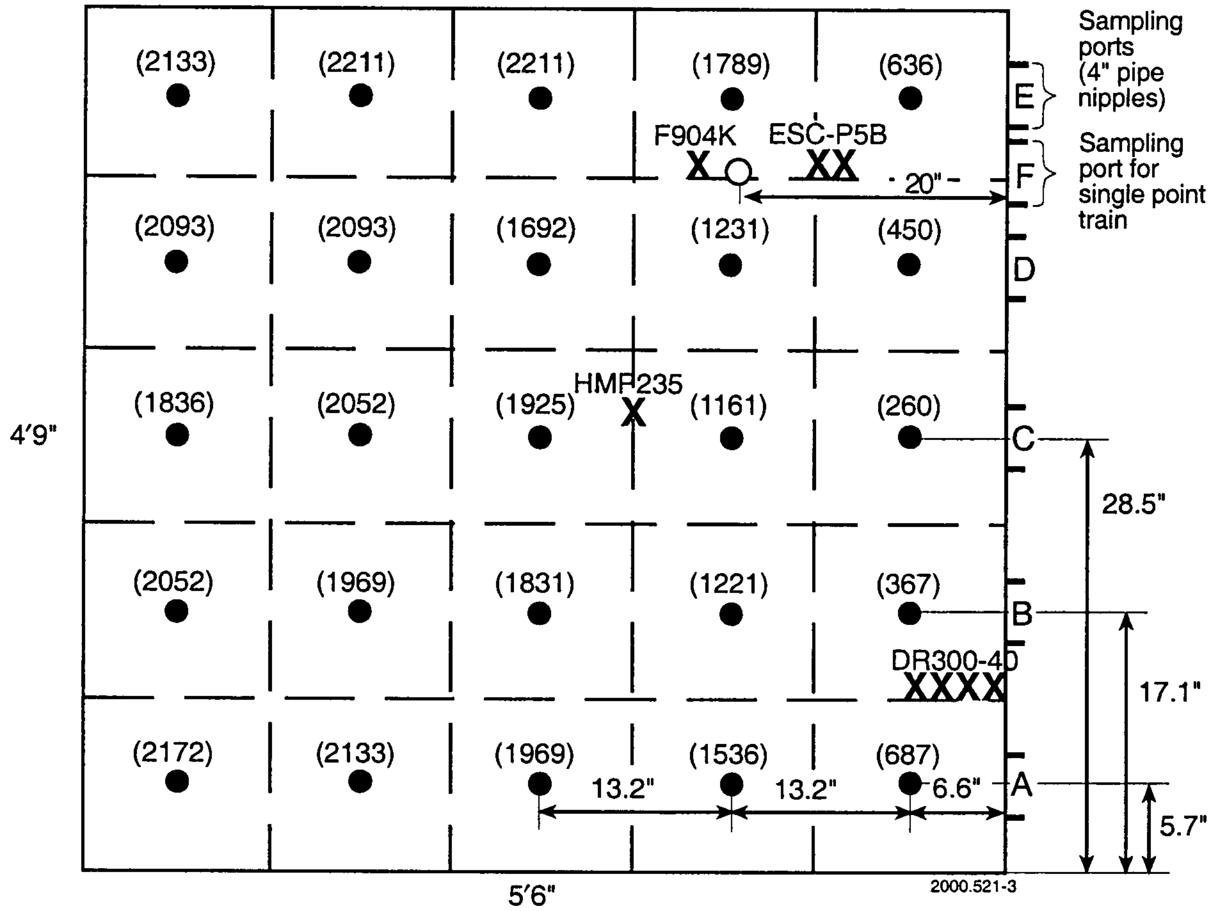


Figure 2-2. Location of CEMS and M17 Test Ports (Elevation Front View)



Note: Values in parenthesis are the average stack velocity at each point, in m/min., as measured during the initial correlation tests.

X depicts the "sampling location" of the CEMS in the duct.
○ depicts the sampling point for the single point M17 train.
● depicts the sampling points for the M17 traversing train.

Figure 2-3. M17 Sampling Points and CEMS Locations

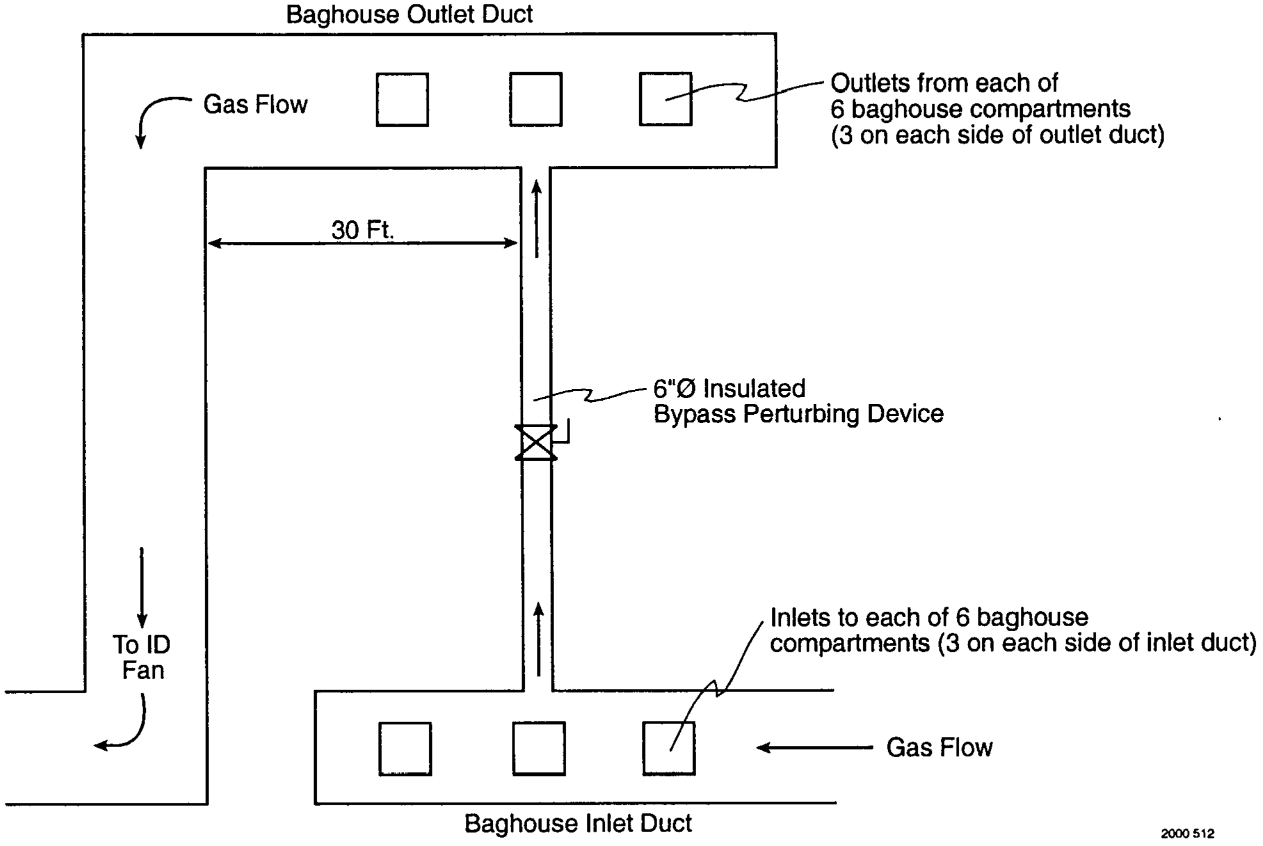


Figure 2-4. Schematic Elevation Side View of Baghouse Inlet/Outlet Ducts and Perturbing Device

The moisture CEM is equipped with a 48" long probe which extends 26" inside the duct wall.

Based on the expectation that the particulate concentration at the sampling location exiting the fabric filter would be quite low, a "perturbing device" was installed by the facility for this project. This perturbing device consisted of an insulated 6" diameter pipe and butterfly valve that allowed a portion of the gas to be diverted from the inlet of the fabric filter to the outlet, thus raising the dust concentration in the outlet duct. This allowed adjustment (increase) of the outlet PM concentration to cover a range of particulate emissions for this project. The 6-inch insulated pipe was installed approximately 30 ft upstream of the 90°bend in the outlet duct (See Figures 2-1 and 2-4). It was discovered during the project that this distance may not have been sufficient to allow complete mixing of the PM from the perturbing device with the baghouse outlet flow prior to the PM-CEMS.

2.2 Sampling and Analytical Procedures

The sampling/analytical procedures used for the initial correlation tests and RCA tests were determination of particulate and moisture concentration per EPA Method 17 (40 *CFR* 60, Appendix A) and associated requirements of draft PS-11 and Procedure 2.

Two EPA Method 17 sampling trains were used in each run. Each train consisted of the following, along with an S-type pitot tube and thermocouple:

- Quartz nozzle
- 47 mm in-stack filter holder with quartz fiber filter
- Teflon ball cone check valve
- 10 ft. stainless steel probe
- 20 ft of thick wall latex tubing
- Impinger box

- Umbilical cord
- Sampling console (dry gas meter and pump)

The two M17 sampling trains were operated simultaneously (except for a 2-minute offset) but were in different ports (i.e., simultaneous traverses were conducted). There were a total of 5 ports (shown in Figure 2-3) with 5 sampling points in each port, for a total of 25 traverse points. There was also a sixth port (port F in Figure 2-3) that was used for a single point sampling train.

However, in the second RCA/ACA tests, one of the two M17 sampling trains was used to sample at a single point (see Figure 2-3) rather than traversing to sample all 25 points. All the M17 tests included determination of particulate and moisture concentration per EPA Method 17 (40 *CFR* 60, Appendix A) and associated requirements of drafts PS-11 and draft Procedure 2 (with the exception that precision was determined in only one run during the second RCA test because one train was used for single point sampling in all other runs).

Analytical procedures for the M17 samples are shown in Figure 2-5.

2.3 Process Sampling Locations

No process samples were collected for this test program, but the facility did provide a computer printout of selected process operating data once every 15 min during each M17 test period.

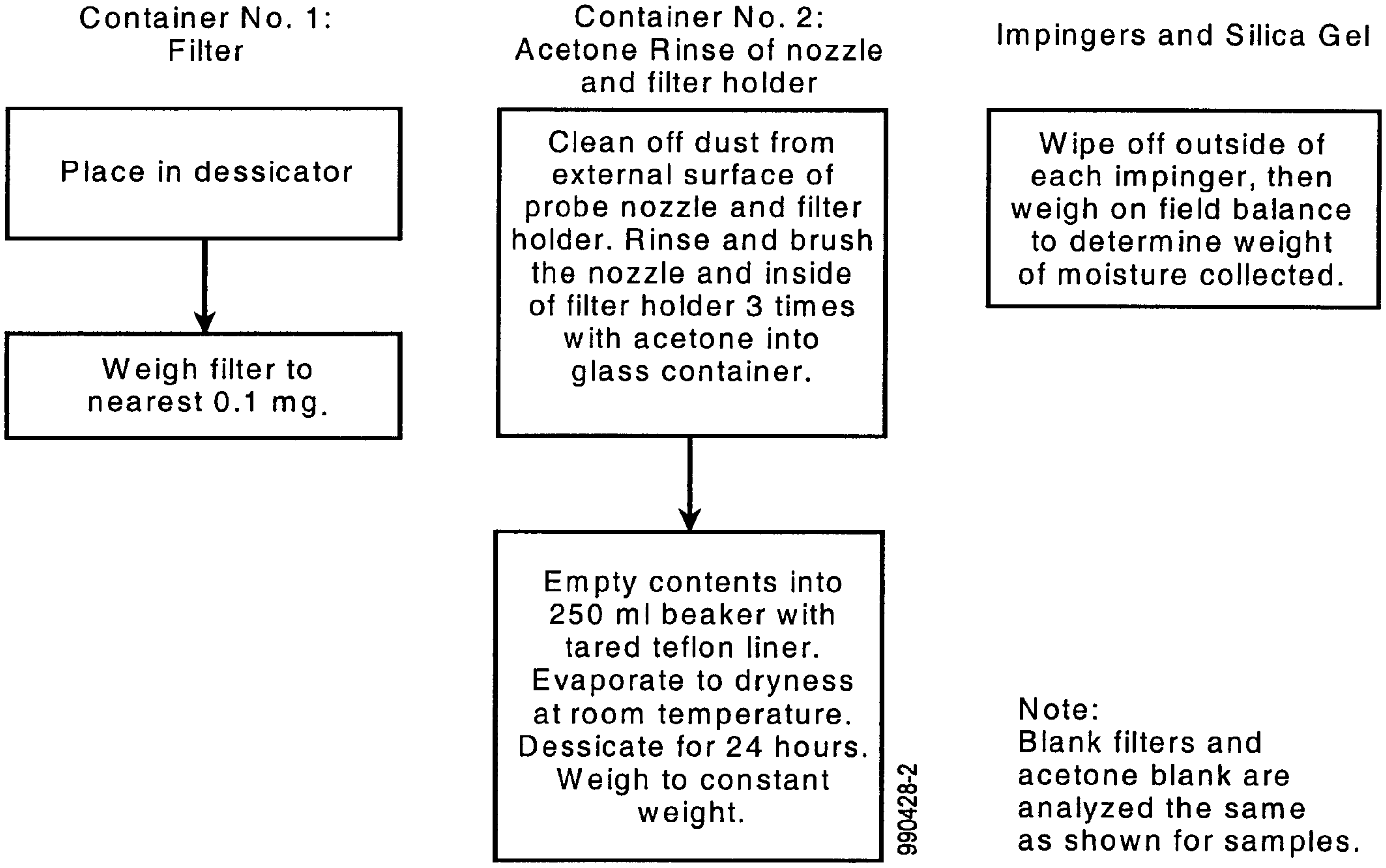


Figure 2-5. Analytical Scheme for M17 Train Components

Section 3.
Installation and Start-up of the CEMS

For the purchase of the three PM-CEMS, a technical specification was written by MRI and sent to the vendors. The vendors responded to the specification with their proposals, and MRI issued purchase orders for the ESC P5B light-scattering PM-CEM, the Durag DR 300-40 light-scattering PM-CEM, and the Durag F904K beta gauge PM-CEM on May 20, 1998. As noted earlier, these PM-CEMS were selected for the following reasons:

1. Each successfully worked on another demonstration test
2. Each does an automatic daily zero and upscale calibration drift check
3. All are commercially available

In addition to the three PM-CEMS, a Vaisala HMP 235 moisture monitor was purchased.

The purchase prices for the CEMS and the data acquisition system are listed in the following table, which includes labor costs for programming the computerized data acquisition system as discussed in Section 3.2.

CEM model	Base price	Additional items
ESC P5B	$12,750	$925 for non-standard 6 foot probe
Durag DR 300-40	$15,500	None
Durag F904K	$36,515	$550 for stainless steel sample line $120/ft for flexible sample line $915 for temperature controller for flexible line $2,375 for reinforced cabinet $4,200 for cabinet air conditioner $1,765 for filter tape printer
Vaisala HMP 235	$2,345	$10 for 6 foot power cord
Fluke Wireless Data Logger 2625 A/WL	$6,100	$500 for two UPS units
Programming of data acquisition system	$12,000	

3.1 CEMS Delivery

In the PM-CEM vendor's proposals, they provided their lead time for delivery of the instruments. Based on each vendor's delivery schedule, MRI requested the following delivery dates:

PM-CEM model	Delivery date
P5B	June 21, 1998
DR 300-40	June 05, 1998
F904K	July 16, 1998

Since the selection of the test site was delayed, the vendors were not strictly required to meet the delivery dates. The P5B was complete and ready for shipping to MRI by mid-June, 1998, but the vendor requested and was given extra time to complete upgrades to the instrument. The P5B was received by MRI on August 19, 1998. The DR 300-40 was received by MRI on July 14, 1998. The F904K arrived in the Durag, USA, office from Germany on July 22, 1998, and Durag personnel completed work on the instrument and finalized the operating manual. The F904K was scheduled for delivery to MRI on October 27, 1998; however, circumstances unrelated to the instrument delayed delivery until December 2, 1998.

3.2 Functional Acceptability Testing

After receiving the instruments at MRI's facility, and before shipping them to the test site, MRI conducted functional acceptability testing (FAT) on each CEM. The FAT consisted of the following:

1. Unpacking and starting up each CEM according to the manufacturer's instructions
2. Wiring the signal and alarm status outputs to the datalogger
3. Logging instrument output by the data acquisition system (DAS)

4. Initiating and recording zero and upscale calibration drift checks
5. Initiating and recording alarms
6. Conducting a 7 day drift test on the PM-CEMS
7. Checking the calibration of the HMP 235 moisture monitor against EPA Method 4
8. Developing a sample volume audit procedure for the F904K

At the conclusion of the FAT, the instruments were repackaged for shipment to the test site. Conducting the FAT led to a much smoother installation and start-up of the PM-CEMS in the field. The FAT of each PM-CEM required approximately the following man-hours to complete:

PM-CEM	FAT Man-hours
P5B	14
DR 300-40	16
F904K	24

The PM-CEMS were connected to the data acquisition system and computer during the FAT period at MRI, and a program was written to provide all the necessary data logging capabilities. They included the following:

- Converting all CEM signals (mA) to computed values (e.g., mg/acm)
- Computing average 1 min values for readings taken every 15 sec
- Logging all 1 min avg values and daily calibration drift values
- Storing all 1 min readings every 24 hrs
- Handling error signals from the PM-CEMS and flagging all associated data

- Providing on-line graphing of PM-CEM readings for any selected time interval, including historic data (i.e., date for days prior to the current day)

- Loading the commercially available program titled "Remotely Possible" so that data could by viewed and/or downloaded from other MRI offices (the test site office trailer containing the computerized data acquisition system was unattended during most of the 6 month test period).

The programming effort involved many details requiring several person-days of effort, at a cost of $12,000. This allowed debugging of the system at MRI, which considerably shortened the start-up time for the system when it was installed on site.

3.3 Installation at the Test Site

The CEMS were shipped via common carrier from MRI in Kansas City, Missouri, to the test site in North Carolina. The boxes were stored at the test site until MRI's installation team arrived. Test site personnel (Cogentrix) made the following site modifications in preparation for the CEMS installation and initial correlation testing:

1. Installed five new ports for the Method 17 testing
2. Installed a new port for the DR 300-40
3. Installed a new port for the F904K
4. Installed an extension to an existing port for the P5B
5. Installed approximately 25 feet of 6-inch pipe and a multi-position butterfly valve to bypass particulate from the inlet duct (dirty-side) to the outlet duct (clean-side) of the baghouse
6. Installed a transformer and 60 amps of electrical power for the CEMS, Method 17 testing, and an office trailer

Preparation effort by the test site personnel required approximately the following man-hours to complete:

Activity	Preparation Man-hours
Install five new ports for the Method 17 testing	12
Install a new port for the DR 300-40	6
Install a new port for the F904K	3
Install an extension to an existing port	2
Install approximately 25 feet of 6-inch pipe and a butterfly valve	10
Install a transformer and 60 amps of electrical power	20

For the installation effort, a crane was used to hoist four large boxes onto a platform about 50 feet above grade. The CEMS and supporting materials (e.g., tools, datalogger, computer, etc.) were unpacked and placed in their installation areas. Approximately 10 man-hours were needed to get the CEMS and supporting materials in place and ready for installation. The CEMS and DAS were installed and started up according to the manufacturer's instructions. The installation and start-up effort required approximately the following man-hours to complete:

PM-CEM	Installation Man-hours
P5B	6
DR 300-40	8
F904K	24[1]
HMP 235	2

[1] Estimate of hours under normal circumstances. See discussion below about start-up issues.

Connecting all of the data communication and alarm wires and starting the datalogger and DAS required an additional 6 man-hours.

3.4 Start-up Issues

Startup of the P5B, DR 300-40, HMP 235, and datalogger/DAS proceeded without incident. As noted above, conducting the FAT before shipping the PM-CEMS to the test site expedited the start-up effort. The following two major problems were experienced during start-up of the F904K:

1. Water passed through the conditioning system and flooded downstream components

2. Sample gas could not be extracted from the extremely negative pressure duct (about –23 inches W.C.) when using dilution air

MRI and Durag personnel expended about 48 man-hours trying to rectify the problems. Eventually, Durag personnel removed the instrument and transported it back to their office to redesign the sampling system and repair the problems. The problems were corrected by:

1. Replacing the leaking moisture condenser
2. Replacing the carbon vane pump that was damaged by the water
3. Moving the dilution air control valve from the exhaust side to the dilution side
4. Replacing the old electronic control system (motherboard with EPROMs programmed in a cryptic language) with a state-of-the-art programmable logic controller (PLC) system

The upgraded instrument was delivered to the test site and reinstalled by Durag personnel. Start-up of the redesigned instrument proceeded without incident and the instrument operated properly. The reinstallation and start-up required about 12 man-hours of effort.

A few other problems with the PM-CEMS and moisture CEM did occur during the subsequent 6-month endurance test period, which are described in the next section.

Section 4.
Durability, Availability, and Maintenance Requirements for CEMS

Data availability and maintenance requirements have been recorded throughout the 6-month endurance test period of July 20, 1999, to February 16, 2000.

During the subject period, operation of the CEMS was interrupted by Hurricane Floyd, which flooded the transformer where Cogentrix ties into the electrical grid system. Therefore, the plant was off-line from September 16 to about October 3, 1999. The CEMS were restarted on October 7, 1999. After the system restart, several CEMS problems occurred. The maintenance and data unavailability for each monitor during the 6-month period are listed below, excluding the hurricane period. Also excluded are the short periods each day (approximately 5-10 min) for the automatic zero and upscale drift checks, and three short periods of data unavailability (30-60 min) when MRI performed an ACA on the ESC-P5B and Durag DR 300-40. (The Durag F904K did not include any reference standards for performing an ACA.)

4.1 ESC-P5B

- Data were unavailable for approximately 30 min on August 23, 1999, while the drift problem was corrected.

- The instrument experienced some upscale drift problems during the 6-month period. The number of daily upscale drift checks that exceeded 2 percent are presented in Table 4-1 and the corrective actions are discussed below.

Table 4-1. Levels of Upscale Calibration Drift for the ESC P5B

Upscale drift exceeded	Number of days
2%	101 days
3%	65 days
4%	24 days
5%	6 days
6%	1 day

- On October 13 and 14, the upscale calibration drift was 6.17% and 5.50%, respectively. Therefore, on October 15, the lenses and purge air filter were cleaned. The reference calibration was reset, and the upscale calibration drift was reduced to 0.75%. During this procedure, 30 min of data were lost.

- Since the filter for the purge air is located inside the instrument's protective housing, ambient air that is used for purge air is drawn into the housing. In the power plant environment, fine particulate in the ambient air collects on all of the instrument's components inside the protective housing. MRI recommends locating the purge air filter separate from the rest of the instrument.

- On October 20, the purge air filter was replaced. No data were lost during this procedure.

- On November 9 and 10, the upscale calibration drift was 5.08% and 4.08%, respectively. Therefore, on November 11, the lenses were cleaned again, and the upscale calibration drift was reduced to 0.92%. During this procedure, 15 min of data were lost.

- On November 20, the lenses and purge air filter were cleaned, resulting in 12 min of lost data.

- On December 1 and 2 a malfunction error occurred because of low battery voltage. The lenses were cleaned and a battery was replaced (39 hr of data were lost). However, it is estimated that no more than 24 hr of data would have been lost if plant personnel were responsible for such instrument problems. The replacement battery was not a spare part and was shipped overnight from ESC.

- December 10 and 30 the lenses were cleaned to correct drift problems. During each cleaning procedure, 14 min and 12 min of data were lost, respectively.

- January 11 and 19 the lenses were cleaned to correct drift problem. During each cleaning procedure, 14 min and 13 min of data were lost, respectively.

- During the period of January 30 through February 6 the upscale daily drift exceeded 4% and thus was out of control for 2 days. As a consequence, 2 days of data were lost. However, this lost time would not have occurred at a permanent installation of the PM-CEMS where plant personnel were responsible for correcting such problems.

4.2 Durag DR 300-40

- Data were unavailable for approximately 60 min on August 26, 1999, while the shutter mechanism was repaired.

- During the calibration drift check, conducted on Saturday, October 16, 1999, the contamination rate value (i.e., dirty window check) exceeded a preset internal limit. This error caused the instrument to actuate the data flag "OFF," and the data were considered suspect. MRI personnel traveled to the site and corrected the error by cleaning the protective lenses and initiating the calibration cycle on Wednesday, October 20. About 4 days of data were lost. By contrast, we estimate that no more than 4 hours of data would have been lost if plant personnel had the responsibility of responding to instrument errors.

- During the February 9 calibration drift check a "dirty window" error occurred. On February 10 the reference filter was cleaned to correct the problem, which took about 1.5 hr. The flag was active for about 29 hr before the reference filter could be cleaned. However, the data were still valid.

4.3 Durag F904K

- The cabinet air conditioner unit was not working when the system was restarted on October 7 (after the hurricane). The air conditioner was removed and sent back to the manufacturer. The problem was the compressor, and repairs, including shipping, cost about $300. Removing and replacing the air conditioner required about 4 man-hours. The air conditioner was out of service for 14 days, but the monitor continued to function without the air conditioner.

- When the system was restarted on October 7, a high pressure air hose inside the cabinet had become disconnected. The hose was reattached using the original hose clamp.

- On October 11, the roll of filter tape was expended, and a new roll was installed on October 12. Approximately 15 hours of data were lost; however, we estimate that no more than 4 hours of data would have been lost if the plant's personnel were responding to instrument errors.

- On October 12, about 9 hours after the filter tape was replaced, the high pressure air hose became disconnected again. This problem caused a vacuum error, and the instrument automatically shut down. MRI responded to this error on October 15 and reconnected the hose. Approximately 3 days of data were lost due to this problem; however, we estimate that at most 4 hours of data would have been lost if the plant's personnel were responding to instrument errors.

- On October 15, about 8 hours after reconnecting the high pressure air hose, it became disconnected again, causing the instrument to shut down. MRI responded to this error on October 20 and installed a second hose clamp along with the original. About 4.5 days of data were lost due to this problem. We estimate that no more than 8 hours of data would have been lost if the plant's personnel were responding to errors. (This estimate is longer than others because the error occurred late at night, just after 2300 hours.)

- On October 22 and 24 and November 8 the boiler went off-line and was then restarted. When the boiler is refired, the baghouse is bypassed, and the PM-CEMS experiences high concentrations of particulate in the duct. Each time the boiler was refired, the F904K would shut down due to high vacuum errors. This type of error occurred on October 22 causing about 3 days of lost data, on October 29 causing about 5 days of lost data, and on November 8 causing about 3 days of lost data. If plant personnel were responding to each of these errors, we estimate that no more than 2 hours of data would have been lost for each occurrence. (To help control the amount of lost data, MRI recommends that Durag design an automatic restart to activate one hour after a vacuum error shutdown.)

- Beginning on November 2, the F904K began to experience filter tear errors. Filter tears occurred on November 2, 9, and 12. Upon close inspection of the filter adapter, it was found that the left side of the adapter was not opening as far as the right side. When the filter tape was moved backward after a zero measurement, sometimes it would become pinched between the top and bottom of the filter adapter and tear down the middle. We found that the mechanism which pulls down the bottom half of the filter adapter had a worn part on the left side which was not allowing the mechanism to move downward as far as required. MRI had a new part made to replace the worn part, and we received a new mechanism as a spare.

Troubleshooting and repair of this problem caused 3 days of lost data. (Since wear on part of the mechanism that opens the filter adapter caused the instrument to malfunction after about 6 months of continuous operation, MRI recommends that Durag redesign the mechanism.)

- During the November 11 maintenance visit, MRI discovered that the automatic and manual blowback of the sample line and probe was not working. During the second RCA, the blowback seemed to work intermittently but not as expected. This problem did not cause any loss of data but has not been solved.

- The F904K's response to particulate concentrations during the first two days of the second RCA test program was not in agreement with the other two PM-CEMS or any of the previous test results. During investigation on November 17, MRI found that the resistance-heated stainless steel tube at the sample line/probe union had melted, and ambient air was leaking into the sample gas. Troubleshooting and repairing this problem required about 8 man-hours. At least 2 days of data were invalid because of this problem, and F904K data from the first four test runs of the second RCA test program were invalid. (Note that this problem would not have been discovered without comparing actual measured PM concentrations to the monitor's results. This finding suggests that some amount of manual field sampling to verify the PM-CEMS values [e.g., 3 test runs done at 6- or 12-month intervals] should be done between full RCAs.)

- A new roll of filter tape was installed on August 31, after the first RCA, and the sample interval was increased from 8 to 9.5 min in order to use less filter tape and still complete a sample and reporting cycle every 15 min. Only 16 operating days had elapsed when the instrument was shut down because of the hurricane-caused flood. The instrument ran for 4 days after restart before the filter tape was depleted (i.e., 20 days of run-time on the roll of filter tape). A new roll of filter tape was installed on October 11, and that roll lasted until November 21.

- The roll of filter tape was replaced again on December 10 and 30, January 19, and February 7.

4.4 HMP 235 Moisture CEMS

The moisture monitor experienced several maintenance issues and was unavailable for an extended period of time while it was sent back to the manufacturer for repair and recalibration. Details are presented below.

- On Friday, September 10, the moisture monitor values were erratic. MRI investigated this on Monday, September 13, and, through communication with the manufacturer, determined the problem was a cold solder junction on the RTD temperature probe. The junction was resoldered, and the monitor returned to proper operation. About 3 man-hours were required to troubleshoot and repair the monitor. About 3 days of data were lost; however, we estimate that no more than 6 hours of data would have been lost if the plant's personnel were responding to instrument errors.

- On Saturday, October 9, the moisture monitor began reporting -440% moisture. MRI responded on Tuesday, October 12, and, with the manufacturer, determined that the best course of action was to send the instrument back for repairs. About 4 man-hours were required to troubleshoot, remove, and ship the monitor. On November 11, the moisture monitor was reinstalled. The manufacturer (Vaisala) could not explain why the monitor did not work properly because it worked fine when they turned it on. The service technician suggested simply disconnecting the electrical power from the unit the next time the problem occurred. Reinstallation effort was about 2 man-hours, and approximately one month of moisture data was lost.

- On November 15, the moisture monitor's temperature values appeared incorrect. The probe was removed and the RTD was repaired. This effort required about 1 man-hour. The following day, the monitor's moisture values were much lower than the moisture values from the Method 17 sampling runs (i.e., about 6% compared to 12%). The probe was removed, and the RTD junction was resoldered. This repair seemed to fix the problem, and the monitor's moisture values returned to normal (12% H_20). This repair effort was about 1 man-hour. In total, approximately 33 hours of moisture data were lost due to these problems.

- Late on November 20 and into November 21, the moisture values gradually increased from 12% to about 36%. The probe was removed, and the relative humidity sensor was examined. A new sensor was installed, but it produced the same readings. The old sensor was reinstalled, and the probe was inserted back into the stack. The moisture values were normal. About 18 hours of moisture data were lost due to this problem.

- Two other periods of obviously erroneous readings occurred on December 7 and December 17, with about 14 hr of data lost.

- More erroneous readings started on December 25 and continued through December 28, 1999. A total of 94 hr of data were lost until a field repair could be made. However, it is estimated that only about 8 hr of data would have been lost if site personnel were responsible for correcting such problems.

- Erroneous readings again occurred on January 3 through January 11 and 192 hr of data were lost. Corrective action on January 11 included bracing the probe to help reduce vibration, which may have been the cause of all the erroneous reading problems. No further problems occurred thereafter (January 11 through February 16).

4.5 Summary

A summary of each monitor's data unavailability is presented in Table 4-2 (not including the period of the hurricane outage or the short periods of daily drift checks or performing the ACAs). Table 4-2 shows actual data unavailability and the estimated data unavailability. The estimated data unavailability is considered more realistic, in that it reflects what would be expected if on-site facility personnel were responsible for responding to problems and/or performing maintenance on the CEMS.

The periods of estimated data unavailability shown in Table 4-2 were used to calculate the percentage of time that data were available for each CEMS, as shown in Table 4-3, for the entire period of July 20, 1999, to February 16, 2000. The total amount of time for that period is 212 days, but when the hurricane period is excluded (21 days), a period of 100% availability would be 191 days (4,584 hr).

As shown in Table 4-3, all three PM-CEMS and the H_2O CEM exhibited data availability of over 80%. The two light scatter type PM-CEMS had on availability of over 99%, and the beta gauge type PM-CEMS had an availability of over 96%. The moisture monitor (HMP-235) had an availability of only 82% primarily because 30 days were lost when it had to be sent back to the manufacturer for repair as discussed in Section 4.4.

Table 4-2. CEMS Data Unavailability

Event	Actual data unavailability	Estimated data unavailability[a]
ESC P5B		
Aug 23—Clean lenses to correct drift problem	0.5 hr	0.5 hr
Oct 15—Lenses and purge air filter cleaned and reference calibration reset	0.5 hr	0.5 hr
Nov 11—Lenses cleaned	0.25 hr	0.25 hr
Nov 20—Lenses and purge air filter cleaned	0.20 hr	0.20 hr
Dec 1 to 2—Malfunction error; cleaned lenses and replaced battery	39 hr	24 hr
Dec 10—Cleaned lenses to correct drift	0.25 hr	0.25 hr
Dec 30—Cleaned lenses to correct drift	0.25 hr	0.25 hr
Jan 11—Cleaned lenses to correct drift and replaced purge air filter	0.25 hr	0.25 hr
Jan 19—Cleaned lenses to correct drift	0.25 hr	0.25 hr
Feb 7—Cleaned lenses to correct drift (drift out of control for 2 days, February 5 and 6, but this would not have occurred if site personnel were available to correct the problem)	48 hr	0.25 hr
		TOTAL = 26.70 hr
Durag DR 300-40		
Aug 26—Repaired shutter	1 hr	1 hr
Oct 17—Contamination rate value over limit	about 4 days	4 hr
Feb 9 to 10—"Dirty Window" error. Cleaned the reference filter	1.5 hr	1.5 hr
		TOTAL = 6.5 hr

Table 4-2 (Continued)

Event	Actual data unavailability	Estimated data unavailability[a]
Durag F904K		
Oct 11—Filter tape replaced	15 hours	4 hr
Oct 12—Vacuum error—high pressure air hose off	about 3 days	4 hr
Oct 15—Vacuum error—high pressure air hose off	about 4.5 days	8 hr
Oct 22—Vacuum error—boiler start-up, high PM	about 3 days	2 hr
Oct 29—Vacuum error—boiler start-up, high PM	about 5 days	2 hr
Nov 8—Vacuum error—boiler start-up, high PM	about 3 days	2 hr
Nov 2, 9, 12—Filter tear error—repaired filter adapter	about 3 days	72 hr
Nov 17—Low response—broken sample line	at least 2 days	48 hr
Nov 21—Changed tape	0.25 hr	0.25 hr
Dec 10—Changed tape	0.25 hr	0.25 hr
Dec 30—Changed tape	0.25 hr	0.25 hr
Jan 19—Changed tape	0.25 hr	0.25 hr
Feb 7—Changed tape	0.25 hr	0.25 hr
		TOTAL = 143.25 hr

Table 4-2 (Continued)

Event	Actual data unavailability	Estimated data unavailability[a]
HMP 235		
Sept 10—Erratic moisture values—cold solder junction problem	about 3 days	6 hr
Oct 9—Erroneous moisture values (–440%)—sent back to manufacturer for repair	about 30 days	720 hr
Nov 15—Erroneous temperatures	33 hr	33 hr
Nov 20—High moisture values	18 hr	18 hr
Dec 7—Erroneous readings*	7 hr	7 hr
Dec 17—Erroneous readings*	7 hr	7 hr
Dec 25—Erroneous readings*	94 hr	8 hr
January 3 to 11—Erroneous readings*	192 hr	8 hr
		TOTAL = 807 hr

* Erroneous readings were likely due to vibration of duct at probe location. Corrective measures were taken (on January 11, 2000) to reduce the vibration by bracing the probe. No erroneous readings occurred thereafter.

[a] Assumes on-site facility personnel would be available to respond to problems.

Table 4-3. Data Availability for Each CEMS

CEMS	Total estimated time of data unavailability, from Table 4-2 (hours)	Total time for period of July 20, 1999, to February 16, 2000, excluding hurricane (hours)	Data availability (%)
ESC P5B	26.70	4,584	99.4
Durag DR300-40	6.5	4,584	99.9
Durag F904K	143.25	4,584	96.9
Vaisala HMP-235	807	4,584	82.4

Section 5.
Presentation and Discussion of Results

5.1 Objectives and Test Matrix

As was noted in Section 1, the primary objectives of this project were to:

- Demonstrate whether the PM-CEMS can provide reliable and accurate information over an extended period of time
- Evaluate the PM-CEMS for durability, data availability, and setup/maintenance requirements
- Determine whether the PM-CEMS satisfy all the requirements of draft PS-11 and QA criteria specified in draft Procedure 2, or determine if changes are needed in the requirements of PS-11 and/or Procedure 2

Other related objectives of the project were to:

- Determine if PM-CEMS exhibit at least 80% data availability (based on number of hours of usable valid results for each month)
- Document PM-CEMS maintenance requirements and operating and maintenance costs
- Evaluate a technique for perturbing (increasing) baghouse PM emissions.
- Determine if PM-CEMS correlation remains true for a long period of time after the initial correlation, per PS-11
- Determine reliability and accuracy of the moisture CEMS

As discussed later, the first RCA tests did not meet all of the criteria in Procedure 2 for any of the three PM-CEMS. It was determined that further testing was necessary to investigate the reason for the difference between the initial correlation test results and the results from the first RCA tests. Thus, the second RCA tests were carried out with two important differences from the first RCA/ACA tests.

In the second RCA tests, two M17 sampling trains were again used in each run, but only one was a traversing train, while the other sampled at a single point. [However, one run (Run 33) was carried out with both trains traversing in order to check precision between the two trains.] The purpose of this was to determine if the concentration measured by the single point train was substantially different from that measured by the traversing train (i.e., particulate stratification) and, if so, determine whether the ratio of the concentrations was constant. If the ratio was not constant, it would indicate that the concentrations at the location of the PM-CEMS (which measure at a single point or small area) would not necessarily be represented by the concentration measured by an M17 traversing train. If the ratio was constant, the stratification would automatically be accounted for in the correlation.

A variable ratio of single point M17 measurements to M17 traversing measurements would provide a plausible explanation for why the results of the first RCA did not meet Procedure 2 criteria for agreement with the initial correlation. A variable ratio would indicate that particulate from the perturbing device (high concentration) is not well mixed with the particulate from the baghouse compartments (low concentration) prior to the location of the PM-CEMS, and the extent of mixing is variable (i.e., shifting stratification).

The initial correlation tests and first RCA tests were carried out with all runs being at or near full boiler load. Full boiler load conditions had a steam flow rate between 268-291 K lb/hr. In the second RCA, some runs were purposely done at reduced boiler load in order to obtain data at lower gas flow rates, which could affect particulate stratification. The reduced boiler load conditions (i.e., low load-LL) had steam flow rates of near

205 K lb/hr. This reduction in boiler load resulted in about an 18% decrease in the average fine gas volumetric flow rate.

5.2 Field Test Changes and Problems

Some field test changes were made to correct problems before and during the initial correlation tests and the RCA tests, as discussed below.

5.2.1 Initial Correlation Test Changes and Issues

There were four field test changes and/or problems in the initial correlation tests as described below.

5.2.1.1 Durag Beta Gauge Changes

Prior to any testing, problems with one of the PM-CEMS (Durag F904K beta gauge) necessitated major changes and repairs by the vendor as discussed previously in Section 4.

5.2.1.2 Re-ranging of PM-CEMS

An issue identified during the initial testing (Runs 1-9) was that the initial ranges of the PM-CEMS were too wide; measuring up to four times the boiler's emission limit of near 17.0 mg/acm. This meant that the PM-CEMS response at the emission limits was only about 6 mA. Therefore, it was necessary to decrease the ranges on the PM-CEMS (i.e., increase sensitivity) in order to expand the response to near 12 mA at the emission limit, but attempting to avoid exceeding the maximum response (20 mA) during momentary spikes in particulate concentration. The range for the ESC P5B was decreased to 0-20 mg. The range for the Durag DR 300-40 was decreased as much as possible by use of the maximum possible aperture (45 mm). The range for the Durag F904K was decreased to 0-20 mg/dm^3 at standard temperature (20°C). After completing this re-ranging, the initial correlation testing (Runs 10-24) was carried out.

5.2.1.3 Moisture Differences in M17 Results

Differences noted in H_2O content determined between the simultaneous dual M17 trains resulted in procedural changes that were implemented to help minimize the difference, as discussed in more detail later in this section.

5.2.1.4 Exclusion of Data for 3 Runs

Preliminary graphing of the PM-CEM initial correlation test results was done in the field as data became available. But, only after results for the last 6 runs (Runs 19-24) were available did it become fairly obvious that there was something different about results for Run 10, 11, and 12. That is, these 3 runs did not appear to correlate well with the other 12 runs (Runs 13-24).

Subsequent inquiries with plant personnel revealed that the facility was burning a different coal during runs 10, 11, and 12, which they referred to as "met coal." This coal caused ash removal problems for the facility in operation of the boilers, but MRI was unaware of these problems at the time. Facility personnel indicated that receipt of "met coal" has occurred less than three times in the past 9 years, and they were considering refusing receipt of coal deliveries that included "met coal." Because operation of the facility was atypical during these three runs it was decided to delete data for Runs 10, 11, and 12 from the PM-CEMS correlations. (However, the results from the subsequent RCA tests indicate that those data probably should not have been deleted, and they have been included in subsequent discussion of results in this report.)

5.2.2 First RCA Test Changes and/or Problems

There were no changes or problems of note. However, discrepancies were found between the initial correlation test results and the first RCA results, as discussed in detail in Section 5.3.

5.2.3 Second RCA Test Changes and/or Problems

There were two changes made in the second RCA tests as described previously in Section 5.1 (i.e., use of a single point train and conducting some runs at reduced boiler load.) In addition, there were two other minor changes.

The first was that the sampling period for the single point train (Train B) was changed slightly after Run 34 so that it sampled continuously, including short periods when the traversing train (Train A) was shut down for port changes.

The second change was that the first run (Run 30) was an experimental run. Data from that run were not valid for use in any evaluation of the data from the second RCA tests. A total of 12 valid runs were carried out (Run 31-42) as planned.

The only other problems were a few mechanical difficulties with the CEMS, as discussed previously in Sections 3 and 4.

5.3 Presentation of Results

This section presents and discusses results from the initial correlation tests, the first RCA test, and the second RCA test, arranged as follows:

5.3.1 Process Data
5.3.2 M17 Test Results and H_20 CEM Results

5.3.3 PM-CEMS Daily Drift Test Data and ACA results
5.3.4 Initial Correlation and RCA Test Results
5.3.5 Investigation of Reasons for Non-agreement of RCA Results

5.3.1 Process Data

Selected process data were printed out by facility personnel every 15 min during each test run. A summary of that data is given in Table 5-1A, B, and C, with more detailed data given in the Appendices. As shown in Table 5-1C, Runs 31-36 of the second RCA tests were carried out at near full boiler load (269-277 K lb/hr steam flow), whereas Runs 37-42 were at reduced boiler load (average steam flow of 199-217 K lb/hr). The reduced boiler load was sometimes steady (Runs 37, 38, 39) with steam flows of 200-210 K lb/hr, and sometimes variable (Runs 40, 41, 42) with increasing or decreasing steam flow during the test runs. (See Volume 4, Appendix A.)

5.3.2 M17 Test Results and H_2O CEMS Results

5.3.2.1 M17 Sampling and Particulate Test Results

Results for the two M17 trains (Train A and Train B) are summarized in Tables 5-2 A, B, C1, and C2 and in Tables 5-3 A, B, C1 and C2. (Tables C1 and C2 for the 2nd RCA tests contain results for the traversing train and single-point train.) Computer printouts of all results are given in Appendix B, and copies of field sampling data sheets are contained in Appendices C and D. Copies of post-test calibrations of the M17 sampling equipment are provided in Appendix E. (See Appendices Volumes 2, 3, and 4 of this report).

It should be noted that the last two columns in Tables 5-3A, B, C1, and C2 are the M17 particulate concentration results that have been converted to units that are consistent with the PM-CEMS measurements, as stipulated in PS-11. It is these particulate

Table 5-1A. Summary of Process Data for Each Run of the Initial Correlation Tests*

Date:	July 15, 1999			July 16, 1999			July 17, 1999			July 18, 1999			July 19, 1999		
Run no.	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Steam Flow (klb/hr)	275.2	274.3	282.2	271.0	281.3	283.3	281.7	279.9	284.0	281.4	280.7	281.0	284.6	268.2	280.7
Steam Temp (deg F)	951	942	957	955	952	951	950	953	951	952	952	950	950	950	950
Coal Flow (lb/hr)	27755	25747	27998	27916	28695	25850	29892	26862	28527	28255	27524	27228	27765	25809	24219
Boiler 0_2 (Avg)	3.5	4.1	3.2	3.5	2.9	2.7	3.2	3.6	3.7	3.1	4.2	3.3	3.2	3.5	3.0
East Undergate Air Flow (lb/hr)	128676	130096	130733	128824	132511	134389	134629	134781	133996	134853	133999	133560	136925	128456	129941
West Undergate Air Flow (lb/hr)	130777	130218	130834	128754	131928	133130	134112	133363	133820	134659	134057	133113	136150	128523	130108
Baghouse Inlet Temp (deg F)	186.8	185.2	191.7	185.1	183.9	184.7	183.1	186.1	183.2	185.2	185	183.7	184.8	189.6	186.1
Baghouse Outlet Temp (deg F)	187.8	184.6	184	180.9	186.9	180.9	179.8	180	180.6	179.7	180.2	180.2	179.3	179.6	179.8
Baghouse DP (in H_2O)	6.9	6.8	8.1	7.4	6.6	6.9	6.7	7.2	7.4	6.3	6.9	6.7	6.8	6.3	7.1
ID Fan Suct. Press. (in H_2O)	–22.5	–23.2	–24.1	–22.9	–22.4	–23.9	–24	–23.4	–23.3	–23	–23.5	–23.8	–23.8	–21.6	–23.4
Stack Opacity	4.79	4.56	5.55	3.72	4.51	5.27	3.71	3.54	3.92	4.01	4.22	4.14	4.25	4.11	5.39

*Based on average of readings taken once every 15 minutes (except opacity which was taken from six-minute averages during each run).

Table 5-1B. Summary of Process Data for Each Run of First RCA Tests*

Date	8/26/99	8/27/99			8/28/99			8/29/99			8/30/99	
Run No.	1	2	3	4	5	6	7	8	9	10	11	12
Steam Flow (klb/hr)	284.9	286.6	286.7	291.2	279.7	285.5	285.3	279.9	267.6	281.3	271.7	278.6
Steam Temp (deg F)	951	949	949	951	949	952	951	951	952	950	952	949
Coal Flow (lb/hr)	NA	NA	NA	30,461	28,493	29,366	28,402	27,208	26,364	27,524	25,803	26,585
Boiler 0_2 (Avg)	3.0	3.4	2.6	2.5	3.1	2.3	2.5	3.0	3.0	2.0	3.9	3.7
East Undergrate Air Flow (lb/hr)	133,132	132,958	131,609	133,930	125,199	127,597	128,255	130,913	124,918	132,169	136,230	139,502
West Undergrate Air Flow (lb/hr)	132,370	131,757	131,202	133,690	127,846	128,703	128,918	131,460	126,814	132,122	135,646	139,180
Baghouse Inlet Temp (deg F)	185.0	186.5	186.8	187.7	185.6	186	188.1	184.7	184.4	185.1	185.1	184.9
Baghouse Outlet Temp (deg F)	179.1	179.4	182.5	180.4	179.5	182.7	190.6	180	181.9	180.2	180.7	177.1
Baghouse DP (in H_2O)	8.2	7.4	8.1	8.6	7.7	8.2	9.1	8	7.4	6.9	7.6	7.3
ID Fan Suct. Press. (in H_2O)	–23.6	–23.1	–23.8	–24.2	–22.4	–22.2	–23.5	–23.2	–21.1	–23.9	–23.8	–24
Stack Opacity	7.26	5.31	4.89	5.09	5.02	6.23	4.75	4.05	5.01	5.82	3.81	3.80

NA—Not available. Monitor not operational.

*Based on average of readings taken once every 15 minutes (except opacity which was taken from six-minute averages during each run).

Table 5-1C. Summary of Process Data for Each Run of Second RCA Tests*

Date	11/16/99	11/17/99			11/18/99			11/19/99		11/20/99		
Run no.	31	32	33	34	35	36	37	38	39	40	41	42
Steam Flow (klb/hr)	269.1	274.6	277.4	276.4	275.4	272.7	205.0	204.3	205.9	199.4	217.9	217.0
Steam Temp (deg F)	945	951	955	954	951	951	951	950	951	953	949	946
Coal Flow (lb/hr)	27,621	28,096	29,286	28,460	28,819	28,028	19,642	19,641	20,261	21,742	21,921	22,029
Boiler O_2 (Avg)	3.0	4.0	2.7	3.4	3.4	3.5	5.0	4.9	5.0	5.5	4.7	4.6
East Undergrate Air Flow (lb/hr)	129,895	125,586	123,375	121,533	119,891	119,534	100,875	100,759	101,711	101,675	101,686	102,958
West Undergrate Air Flow (lb/hr)	130,976	127,925	124,288	120,292	120,611	120,671	99,163	98,441	100,332	99,141	100,244	102,405
Baghouse Inlet Temp (deg F)	185	185	185	185	185	185	185	186	185	185	183	185
Baghouse Outlet Temp (deg F)	174	174	174	175	176	175	173	174	173	176	176	178
Baghouse DP (in H_2O)	10.2	11.5	10.7	10.7	10.9	12.1	6.3	5.5	5.7	5.8	6.8	7.8
ID Fan Suct. Press. (in H_2O)	–25.5	–26.3	–23.1	–25.9	–25.4	–25.7	–16.6	–15.2	–16.4	–-16.0	–17.7	–16.8
2A SDA Outlet Temp (deg F)	188.9	185.0	184.8	184.7	185.1	184.2	184.4	185.6	186.5	186.1	184.8	187.3
2A Atomizer KW (KW)	64.0	66.0	69.5	68.8	63.8	67.0	49.6	49.8	49.2	47.8	55.3	54.6
U2 % Solids (%)	35.0	34.4	34.9	35.4	34.7	34.3	34.8	34.8	34.5	35.0	35.3	35.2
2A Lime Flow (gpm)	4.5	3.8	4.3	5.5	5.6	5.5	5.6	4.8	5.2	6.8	4.6	5.2
Stack Opacity	8.67	9.53	9.74	9.38	8.52	10.49	9.65	7.84	7.76	Opacity data not available		

*Based on average of readings taken once every 15 minutes (except opacity which was taken from six-minute averages during each run).

Table 5-2A. Summary of M17 Sampling Data for Initial Correlation Tests

			Orsat analysis						
Run	Sampling time (min)	Sample gas volume (dscm)	Oxygen (%)	Carbon dioxide (%)	Water (%)	Average stack temperature (F)	Isokinetic (%)	Stack velocity (m/min)	Stack gas flow rate (dscm/min)
10 A	100	1.678	5.0	14.6	12.8	194	100.7	1,430	2,306
10 B	100	1.653	5.0	14.6	13.2	195	101.0	1,445	2,316
11 A	100	1.619	5.0	14.5	12.7	191	100.9	1,405	2,271
11 B	100	1.686	5.0	14.5	13.0	191	101.3	1,447	2,330
12 A	100	1.668	4.5	14.8	14.1	190	102.1	1,423	2,261
12 B	100	1.621	4.5	14.8	14.8	190	102.5	1,421	2,238
13 A	100	1.632	5.8	13.6	11.9	186	99.7	1,413	2,315
13 B	100	1.637	5.8	13.6	11.9	187	99.4	1,409	2,306
14 A	100	1.655	4.7	14.6	13.1	192	100.7	1,415	2,275
14 B	100	1.633	4.7	14.6	13..4	193	100.9	1,431	2,289
15 A	100	1.653	4.7	14.6	13.0	186	100.6	1,437	2,325
15 B	100	1.687	4.7	14.6	13.2	187	100.9	1,451	2,340
16 A	100	1.887	5.1	14.6	13.3	185	100.8	1,444	2,334
16 B	100	1.910	5.1	14.6	13.4	186	101.1	1,460	2,354
17 A	100	1.841	5.0	14.6	12.2	185	99.8	1,444	2,371
17 B	100	1.800	5.0	14.6	14.2	186	101.6	1,420	2,277
18 A	100	1.834	5.1	14.5	12.7	186	99.9	1,413	2,289
18 B	100	1.856	5.1	14.5	14.0	186	101.1	1,435	2,289
19 A	100	1.627	5.2	14.6	13.1	185	99.9	1,419	2,306
19 B	100	1.640	5.2	14.6	13.2	185	100.0	1,416	2,295
20 A	100	1.685	5.2	14.6	15.0	185	101.5	1,445	2,299
20 B	100	1.655	5.2	14.6	15.5	186	102.0	1,452	2,296
21 A	100	1.626	5.4	14.1	13.9	185	100.7	1,428	2,284
21 B	100	1.686	5.4	14.1	14.2	186	101.1	1,467	2,336
22 A	100	1.655	5.0	14.7	13.5	184	99.8	1,428	2,297
22 B	100	1.647	5.0	14.7	13.7	185	99.9	1,455	2,333
23 A	100	1.597	5.0	14.8	12.9	185	99.8	1,390	2,264
23 B	100	1.587	5.0	14.8	13.5	185	100.2	1,372	2,217
24 A	100	1.608	5.0	14.8	13.9	185	100.1	1,392	2,225
24 B	100	1.607	5.0	14.8	14.2	185	100.3	1,422	2,266

Table 5-2B. Summary of M17 Sampling Data for First RCA Tests

Run	Sampling time (min)	Sample gas volume (dscm)	Orsat analysis Oxygen (%)	Orsat analysis Carbon dioxide (%)	Water (%)	Average stack temperature (F)	Isokinetic (%)	Stack velocity (m/min)	Stack gas flow rate (dscm/min)
1 A	100	1.610	4.2	15.0	14.3	184	101.2	1,405	2,225
1 B	100	1.634	4.2	15.0	14.3	185	104.1	1,405	2,222
2 A	100	1.773	4.2	15.0	14.1	185	101.3	1,434	2,274
2 B	100	1.802	4.2	15.0	14.2	185	101.4	1,443	2,285
3 A	100	1.812	4.2	15.0	14.3	188	101.5	1,411	2,227
3 B	100	1.820	4.2	15.0	14.8	189	102	1,421	2,225
4 A	100	1.746	4.2	15.1	14.3	185	101.6	1,415	2,233
4 B	100	1.790	4.2	15.1	14.8	186	102.1	1,437	2,255
5 A	100	1.538	4.2	15.0	14.1	185	99.5	1,348	2,163
5 B	100	1.551	4.2	15.0	13.7	186	99.2	1,374	2,212
6 A	100	1.550	4.1	15.2	13.8	188	99.7	1,351	2,152
6 B	100	1.549	4.1	15.2	13.9	188	99.8	1,381	2,195
7 A	100	1.544	4.2	15.0	13.7	195	99.5	1,376	2,172
7 B	100	1.560	4.2	15.0	14.0	197	99.8	1,411	2,212
8 A	100	1.593	4.0	15.2	13.8	185	99.9	1,383	2,209
8 B	100	1.581	4.0	15.2	13.7	186	99.8	1,404	2,242
9 A	100	1.539	4.2	15.0	13.9	186	99.7	1,355	2,161
9 B	100	1.490	4.2	15.0	13.7	187	99.6	1,324	2,116
10 A	100	1.598	4.0	15.2	14.2	185	100.4	1,393	2,204
10 B	100	1.552	4.0	15.2	14.7	186	100.8	1,386	2,177
11 A	100	1.622	4.8	14.0	11.9	186	97.9	1,430	2,318
11 B	100	1.575	4.8	14.0	12.1	186	98.1	1,406	2,272
12 A	100	1.653	5.1	14.3	12.6	182	98.7	1,432	2,319
12 B	100	1.629	5.1	14.3	12.3	183	98.4	1,444	2,341

Table 5-2C1. Summary of M17 Sampling Data for Traversing Train A (Second RCA Test)

			Orsat analysis						
Run	Sampling time (min)	Sample gas volume (dscm)	Oxygen (%)	Carbon dioxide (%)	Water (%)	Average stack temperature (F)	Isokinetic (%)	Stack velocity (m/min)	Stack gas flow rate (dscm/min)
31 A	75	0.776	4.5	14.6	12.2	177	101.5	1,402	2,291
32 A	75	0.748	4.8	14.7	11.3	177	100.0	1,343	2,242
33 A[a]	100	0.987	3.3	15.4	12.3	178	101.4	1,325	2,187
33 B[a]	100	1.001	3.3	15.4	11.6	180	100.5	1,350	2,237
34 A	75	0.757	4.2	14.6	13.0	179	101.7	1,368	2,230
35 A	75	0.729	3.8	15.0	12.0	179	100.7	1,299	2,170
36 A	75	0.703	3.8	14.9	11.6	179	100.3	1,255	2,101
37 A[b]	75	0.638	6.1	13.5	10.5	177	99.7	1,100	1,917
38 A[b]	75	0.640	5.7	13.0	11.4	177	101.6	1,096	1,890
39 A[b]	75	0.629	5.3	13.3	10.4	177	100.3	1,075	1,878
40 A[b]	75	0.611	6.3	12.5	12.4	179	99.4	1,089	1,843
41 A[b]	75	0.642	5.9	13.3	12.4	180	99.9	1,144	1,927
42 A[b]	75	0.625	5.1	14.1	12.4	181	99.6	1,120	1,880

[a] Run 33 was a test for precision of the Method 17 sampling.

[b] Runs 37-42 were reduced load tests.

Table 5-2C2. Summary of M17 Sampling Data (Train B—Single Point) (Second RCA Test)

			Orsat analysis						
Run	Sampling time (min)	Sample gas volume (dscm)	Oxygen (%)	Carbon dioxide (%)	Water (%)	Average stack temperature (F)	Isokinetic (%)	Stack velocity (m/min)	Stack gas flow rate (dscm/min)
31 B	75	0.794	4.5	14.6	11.0	180	100.8	1,430	2,359
32 B	80	0.812	4.8	14.7	11.9	180	100.7	1,372	2,265
33 B			No single point train used in Run 33 (precision run).						
34 B	85	0.818	4.2	14.6	12.5	182	101.4	1,307	2,134
35 B	80	0.786	3.8	15.0	11.4	181	100.3	1,312	2,201
36 B	80	0.758	3.8	14.9	12.5	182	101.2	1,274	2,104
37 B[a]	80	0.652	6.1	13.5	9.8	179	100.6	1,041	1,821
38 B[a]	80	0.662	5.7	13.0	10.1	180	100.4	1,062	1,852
39 B[a]	80	0.668	5.3	13.3	10.3	179	100.0	1,076	1,876
40 B[a]	80	0.607	6.3	12.5	12.4	181	99.3	1,018	1,716
41 B[a]	80	0.681	5.9	13.3	12.4	182	99.4	1,146	1,924
42 B[a]	80	0.641	5.1	14.1	11.2	184	98.9	1,076	1,821

[a] Runs 37-42 were reduced load tests.

Table 5-3A. M17 Particulate Test Results for Initial Correlation Tests

						M17 Particulate concentration converted to units corresponding to PM CEMs	
Run	Amount found in probe rinse (mg)	Amount found on filter (mg)	Total particulate weight (mg)	Gas volume sampled (dscm)	Particulate concentration (mg/dscm)	ESC and Durag light scatter (mg/acm)	Durag beta gauge (mg/dscm)
10A	7.7	57.1	64.8	1.678	38.6	25.6	38.6
10B	12.4	54.3	66.7	1.653	40.4	26.6	40.4
11A	13.9	54.8	68.7	1.619	42.4	28.2	42.4
11 B	13.0	56.4	69.4	1.686	41.2	27.3	41.2
12 A	11.9	69.1	81.0	1.668	48.6	31.8	48.6
12 B	8.9	73.0	81.9	1.621	50.5	32.8	50.5
13 A	4.8	23.6	28.4	1.632	17.4	11.7	17.4
13 B	4.0	23.9	27.9	1.637	17	11.5	17
14 A	4.3	29.4	33.7	1.655	20.4	13.5	20.4
14 B	4.7	30.9	35.6	1.633	21.8	14.4	21.8
15 A	7.4	29.5	36.9	1.653	22.3	14.9	22.3
15 B	3.4	32.3	35.7	1.687	21.2	14.1	21.2
16 A	2.4	6.2	8.6	1.887	4.6	3.0	4.6
16 B	1.8	6.9	8.7	1.91	4.6	3.0	4.6
17 A	1.4	6.0	7.4	1.841	4.0	2.7	4.0
17 B	1.6	5.6	7.2	1.8	4.0	2.6	4.0
18 A	2.3	6.7	9.0	1.834	4.9	3.3	4.9
18 B	1.7	7.1	8.8	1.856	4.7	3.1	4.7
19 A	5.2	35.2	40.4	1.627	24.8	16.6	24.8
19 B	4.6	34.8	39.4	1.64	24.0	16.1	24.0
20 A	3.9	22.4	26.3	1.685	15.6	10.2	15.6
20 B	3.6	23.9	27.5	1.655	16.6	10.8	16.6
21 A	4.0	19.8	23.8	1.626	14.6	9.7	14.6
21 B	3.6	20.0	23.6	1.686	14.0	9.2	14.0
22 A	4.7	33	37.7	1.655	22.8	15.1	22.8
22 B	3.1	36.0	39.1	1.647	23.7	15.7	23.7
23 A	2.3	18.7	21	1.597	13.1	8.8	13.1
23 B	2.4	18.3	20.7	1.587	13.0	8.7	13.0
24 A	5.3	40.7	46.0	1.608	28.6	18.8	28.6
24 B	4.5	40.7	45.2	1.607	28.1	18.5	28.1

Table 5-3B. M17 Particulate Test Results for First RCA Test

Run	Amount found in probe rinse (mg)	Amount found on filter (mg)	Total particulate weight (mg)	Gas volume sampled (dscm)	Particulate concentration (mg/dscm)	M17 Particulate concentration converted to units corresponding to PM CEMS	
						ESC and Durag light scatter (mg/acm)	Durag beta gauge (mg/dscm)
1 A	12.4	59.9	72.3	1.610	44.9	29.3	44.9
1 B	12.5	54.9	67.4	1.634	41.2	26.9	41.2
2 A	1.1	4.1	5.2	1.773	2.9	1.9	2.9
2 B	0.4	4.8	5.2	1.802	2.9	1.9	2.9
3 A	0.2	6.7	6.9	1.812	3.8	2.5	3.8
3 B	1.3	6.1	7.4	1.820	4.1	2.6	4.1
4 A	0.8	6.1	6.9	1.746	4.0	2.6	4.0
4 B	0.5	6.7	7.2	1.790	4.0	2.6	4.0
5 A	4.0	18.4	22.4	1.538	14.6	9.6	14.6
5 B	2.6	20.6	23.2	1.551	15.0	9.9	15.0
6 A	1.0	18.5	19.5	1.550	12.6	8.2	12.6
6 B	2.7	17.0	19.7	1.549	12.7	8.3	12.7
7 A	5.3	21.9	27.2	1.544	17.6	11.5	17.6
7 B	6.8	20.1	26.9	1.560	17.2	11.1	17.2
8 A	10.6	42.9	53.5	1.593	33.6	22.1	33.6
8 B	9.4	43.8	53.2	1.581	33.7	22.1	33.7
9 A	14.9	41.7	56.6	1.539	36.8	24.2	36.8
9 B	12.0	42.2	54.2	1.490	36.4	23.9	36.4
10 A	2.1	61.5	63.6	1.598	39.8	25.9	39.8
10 B	9.2	56.3	65.5	1.552	42.2	27.3	42.2
11 A	5.6	24.8	30.4	1.622	18.7	12.5	18.7
11 B	5.6	26.2	31.8	1.575	20.2	13.4	20.2
12 A	11.5	35.4	46.9	1.653	28.4	18.9	28.4
12 B	10.9	36.1	47.0	1.629	28.9	19.3	28.9

Table 5-3C1. M17 Particulate Test Results—Traversing Train (Second RCA Test)

Run	Amount found in probe rinse (mg)	Amount found on filter (mg)	Total particulate weight (mg)	Gas volume sampled (dscm)	Particulate concentration (mg/dscm)	M17 Particulate concentration converted to units corresponding to PM-CEMS	
						ESC and Durag light scatter (mg/acm)	Durag beta gauge (mg/dscm)
31 A	2.8	26.4	29.3	0.776	37.8	25.4	37.8
32 A	2.1	18.7	20.8	0.748	27.8	19.1	27.8
33A[a]	2.4	25.5	27.9	0.987	28.3	19.2	28.3
33B[a]	0.7	25.3	26.0	1.001	26.0	17.7	26.0
34 A	2.8	8.8	11.6	0.757	15.3	10.3	15.3
35 A	1.0	13.4	14.4	0.729	19.7	13.6	19.7
36 A	1.6	25.5	27.1	0.703	38.5	26.6	38.5
37 A	4.4	46.8	51.2	0.638	80.2	57.6	80.2
38 A	4.0	29.1	33.1	0.640	51.7	36.7	51.7
39 A	3.8	27.3	31.1	0.629	49.5	35.6	49.5
40 A	1.0	9.7	10.7	0.611	17.5	12.2	17.5
41 A	2.4	19.9	22.3	0.642	34.7	24.1	34.7
42 A	5.2	29.4	34.6	0.625	55.4	38.3	55.4

[a] Run 33 was a test for precision of the Method 17 sampling.

Table 5-3C2. M17 Particulate Test Results (Train B—Single Point) (Second RCA Test)

Run	Amount found in probe rinse (mg)	Amount found on filter (mg)	Total particulate weight (mg)	Gas volume sampled (dscm)	Particulate concentration (mg/dscm)	M17 Particulate concentration converted to units corresponding to PM-CEMS	
						ESC and Durag light scatter (mg/acm)	Durag beta gauge (mg/dscm)
31 B	0.7	18.1	18.8	0.794	23.7	16.1	23.7
32 B	0.8	13.4	14.2	0.812	17.5	11.9	17.5
33 B	No single point train used in Run 33 (precision run).						
34 B	0.3	13.4	13.7	0.818	16.7	11.3	16.7
35 B	0.0	8.8	8.8	0.786	11.2	7.7	11.2
36 B	0.0	17.1	17.1	0.758	22.6	15.3	22.6
37 B	1.3	32.0	33.3	0.652	51.1	36.8	51.1
38 B	2.3	19.9	22.2	0.662	33.5	24.1	33.5
39 B	2.0	20.8	22.8	0.668	34.1	24.5	34.1
40 B	2.1	6.8	8.9	0.607	14.7	10.2	14.7
41 B	0.5	13.1	13.6	0.681	20.0	13.8	20.0
42 B	1.0	20.0	21.0	0.641	32.8	22.8	32.8

concentration values, and the associated PM-CEMS response, that were used to develop the initial correlation relations and to evaluate results from RCA # 1 and # 2 as discussed later in Section 5.3.4.

During each test run of the initial correlation tests and the first RCA tests, dual M17 trains were operated simultaneously. Each train sampled 4 minutes at each of the 25 traverse points for an elapsed test run time of approximately 110 minutes (100 minutes of actual sample time). To facilitate moving the sampling trains from point to point, Train A was started 2 minutes before Train B.

During each test run of the second RCA tests, two M17 trains were again operated essentially simultaneously. But, one train (Train A) was used to traverse the stack, sampling for 3 min at each of 25 points for a total of 75 min. The other train (Train B) was used to sample at a single point for a total of 80 min. In Run 33, both Train A and Train B were traversing trains, sampling for 4 min at each point to recheck precision of the measurements. Except for Run 33, only the results from Train A were used in evaluating the results relative to correlation with PM-CEMS response discussed later in this report.

The dual train particulate results were used to determine the precision of each test run's M17 data and screen the M17 data for outliers. The precision of the dual trains is presented in Table 5-4 A and B and shows that precision criteria were met in all 15 runs of the initial correlation tests and in all 12 runs of the first RCA test. The precision criteria were also met for the one run (Run 33) in the second RCA test.

In addition to the precision criteria, the dual trains were checked for systematic data bias, according to the equation presented in Section 10.1.2 of draft Procedure 2. If no bias exists, a plot of Train B versus Train A would generate a straight line correlation, passing through the origin, with a slope of 1.0. The criteria in draft Procedure 2 stipulate that the slope calculated in the regression analysis must fall between 0.93 and 1.07. The plots of Train B particulate concentration versus Train A particulate concentration for the initial correlation tests and first RCA test are presented in Figures 5-1A and B. The calculated

Table 5-4A. Precision of Method 17 Dual Trains for Initial Correlation Tests

Run no.	Train A (mg/dscm)	Train B (mg/dscm)	RSD (%)	Criteria (See note)	Pass/Fail
10	38.6	40.4	2.28	RSD < 10%	Pass
11	42.4	41.2	-1.44	RSD < 10%	Pass
12	48.6	50.5	1.92	RSD < 10%	Pass
13	17.4	17.0	1.16	RSD < 10%	Pass
14	20.4	21.8	3.32	RSD < 10%	Pass
15	22.3	21.2	2.53	RSD < 10%	Pass
16	4.6	4.6	0.00	RSD < 19%	Pass
17	4.0	4.0	0.00	RSD < 20%	Pass
18	4.9	4.7	2.08	RSD < 18.7%	Pass
19	20.8	20.0	1.96	RSD < 10%	Pass
20	15.6	16.6	3.11	RSD < 10%	Pass
21	14.6	14.0	2.10	RSD < 10%	Pass
22	13.5	13.7	0.74	RSD < 10%	Pass
23	13.1	13.0	0.38	RSD < 10%	Pass
24	28.6	28.1	0.88	RSD < 10%	Pass

Note:

Acceptance limit for precision of paired trains is:

RSD < 10% if conc is > 10 mg/dscm

RSD < 25% if conc is < 1 mg/dscm.

At between 1 and 10 mg/dscm, the allowable RSD decrease linearly from 25% to 10%.

% RSD is defined as 100 x $(C_A - C_B)/(C_A + C_B)$.

Table 5-4B. Precision of Method 17 Dual Trains for First RCA Tests

Run no.	Train A (mg/dscm)	Train B (mg/dscm)	Avg. (mg/dscm)	RSD (%)	Criteria (See note)	Pass/Fail
1	44.9	41.2	43.05	4.30	RSD < 10%	Pass
2	2.9	2.9	2.9	0.00	RSD < 21.8%	Pass
3	3.8	4.1	3.95	3.80	RSD < 20.0%	Pass
4	4	4	4	0.00	RSD < 20.0%	Pass
5	14.6	15	14.8	1.35	RSD < 10%	Pass
6	12.6	12.7	12.65	0.40	RSD < 10%	Pass
7	17.6	17.2	17.4	1.15	RSD < 10%	Pass
8	33.6	33.7	33.65	0.15	RSD < 10%	Pass
9	36.8	36.4	36.6	0.55	RSD < 10%	Pass
10	39.8	42.2	41	2.93	RSD < 10%	Pass
11	18.7	20.2	19.45	3.86	RSD < 10%	Pass
12	28.4	28.9	28.65	0.87	RSD < 10%	Pass

Note:

Acceptance limit for precision of paired trains is:

RSD < 10% if conc is > 10 mg/dscm

RSD < 25% if conc is < 1 mg/dscm

At between 1 and 10 mg/dscm, the allowable RSD decrease linearly from 25% to 10%.

% RSD is defined as 100 x (C_A - C_B)/(C_A + C_B).

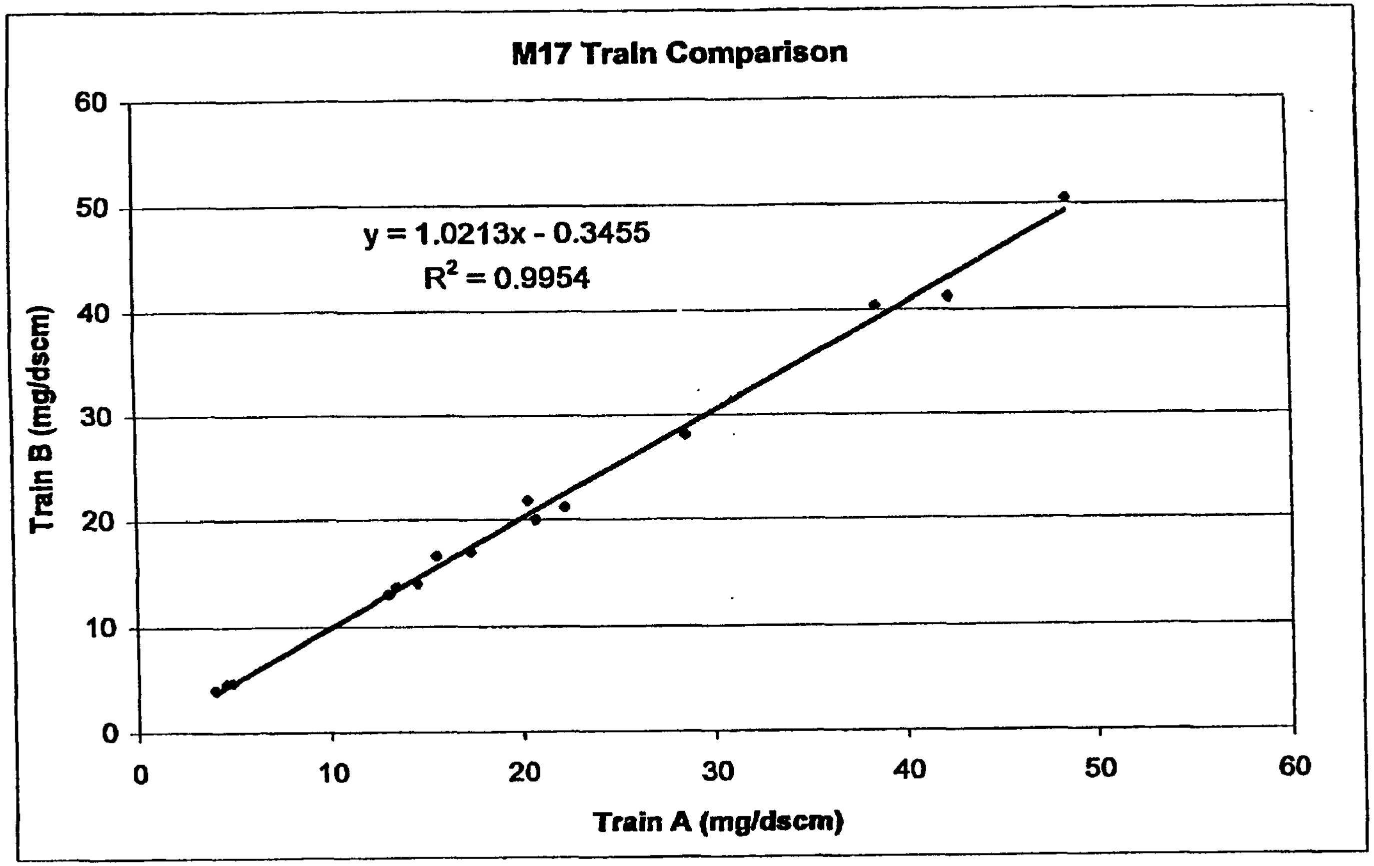


Figure 5-1A. Bias of Train A versus Train B in Initial Correlation Tests

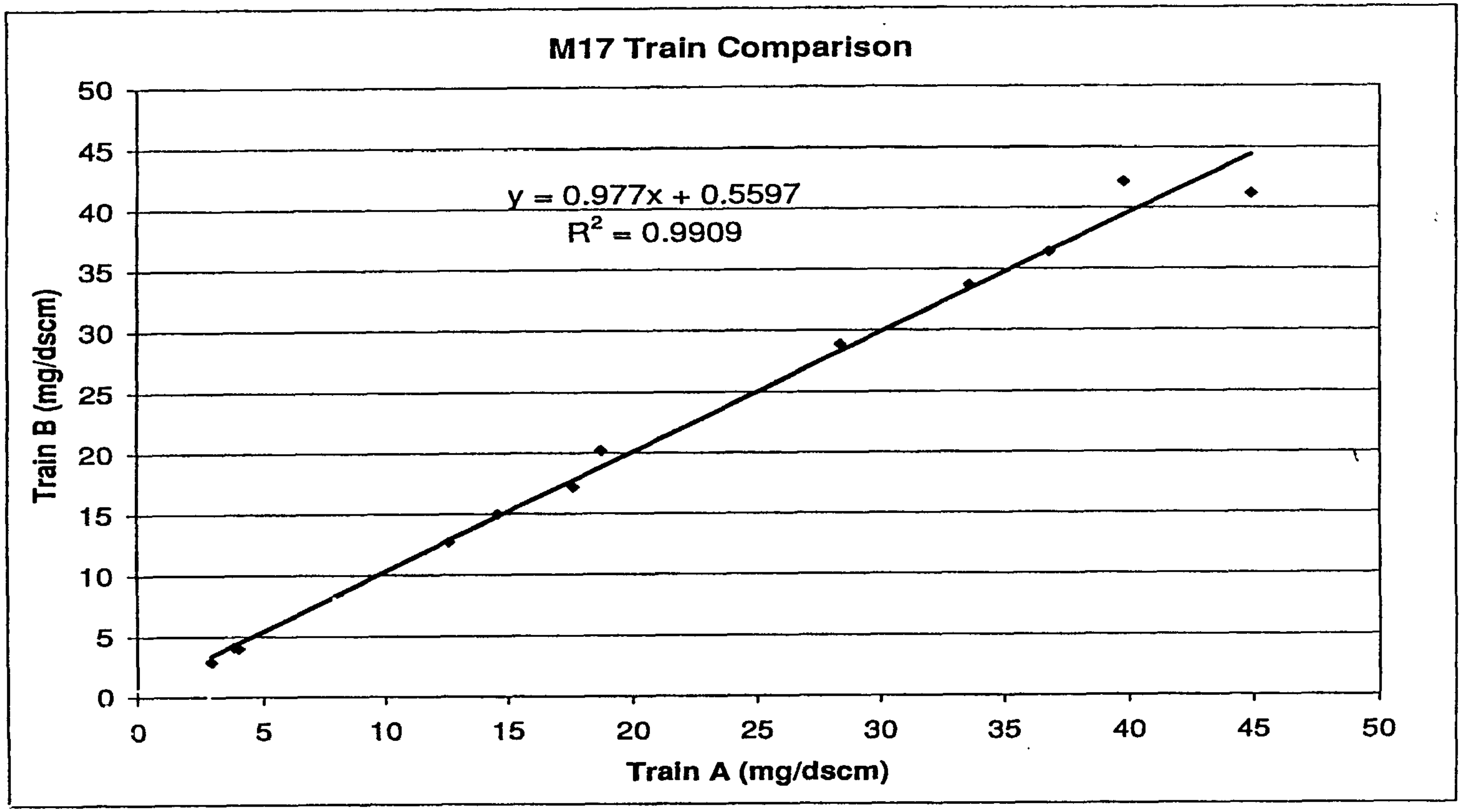


Figure 5-1B. Bias of Train A versus Train B in First RCA Tests slope of 1.02 and 0.977 falls within the Procedure 2 criteria; therefore, the M17 sampling results met the criteria in both sets of tests.

5.3.2.2 M17 H_2O Results

Moisture results for the M17 trains (shown previously in Tables 5-2 A, B, and C) have been retabulated in Table 5-5A, B, and C.

Moisture results for the M17 trains in the initial correlation tests, given in Table 5-5A, show that results for Train B were higher than Train A in almost all runs, with the largest absolute difference occurring in Runs 17 and 18 (2.0 and 1.3% H_2O, respectively). After corrective actions (discussed in Section 6) were implemented for Runs 19-24, the difference ranged from 0.1% H_2O to 0.6% H_2O. The absolute differences in the first RCA tests (Table 5-5B) had a similar range, from 0 to 0.5% H_2O. The absolute differences in the second RCA test (Table 5-5C) had a somewhat higher range of 0 to 1.3% H_2O. In this second RCA test, the trains were not identical (i.e., Train A traversing, Train B single point), but it was expected that the gas sampled by both trains would have the same moisture content. Thus, the reason for the differences is not known.

5.3.2.3 H_2O CEM Results

EPA included testing of the Vaisala HMP 235 moisture CEM in this project to determine if it may be applicable to moisture monitoring in some types of facilities such as the Cogentrix coal fired power plant (with low SO_2 emissions).

Table 5-5A. Comparison of M17 Moisture Results for Initial Correlation Tests

Run no.	Train A (traversing) (% H_2O)	Train B (traversing) (% H_2O)	Average (% H_2O)	Differences A-B (% H_2O)
10	12.8	13.2	13.00	–0.4
11	12.7	13.0	12.85	–0.3
12	14.1	14.8	14.45	–0.7
13	11.9	11.9	11.90	0
14	13.1	13.4	13.25	–0.3
15	13.0	13.2	13.10	–0.2
16	13.3	13.4	13.35	–0.1
17	12.2	14.2	13.20	–2.0
18	12.7	14.0	13.35	–1.3
19	13.1	13.2	13.15	–0.1
20	15.0	15.5	15.25	–0.5
21	13.9	14.2	14.05	–0.3
22	13.5	13.7	13.60	–0.2
23	12.9	13.5	13.20	–0.6
24	13.9	14.2	14.05	–0.3

Table 5-5B. Comparison of M17 Moisture Results for First RCA Test

Run no.	Train A (traversing) (% H_2O)	Train B (traversing) (% H_2O)	Average (% H_2O)	Differences A-B (% H_2O)
1	14.3	14.3	14.30	0
2	14.1	14.2	14.15	–0.1
3	14.3	14.8	14.55	–0.5
4	14.3	14.8	14.55	–0.5
5	14.1	13.7	13.90	+0.4
6	13.8	13.9	13.85	–0.1
7	13.7	14.0	13.85	–0.3
8	13.8	13.7	13.75	+0.1
9	13.9	13.7	13.80	+0.2
10	14.2	14.7	14.45	–0.5
11	11.9	12.1	12.00	–0.2
12	12.6	12.3	12.45	+0.3

Table 5-5C. Comparison of M17 Moisture Results for Second RCA Test

Run no.	Train A (traversing) (% H_2O)	Train B (single point)* (% H_2O)	Differences A-B (% H_2O)
31	12.2	11.0	+1.2
32	11.3	11.9	–0.6
33	12.3	11.6*	+0.7
34	13.0	12.5	+0.5
35	12.0	11.4	+0.6
36	11.6	12.5	–0.9
37	10.5	9.8	+0.7
38	11.4	10.1	+1.3
39	10.4	10.3	+0.1
40	12.4	12.4	0
41	12.4	12.4	0
42	12.4	11.2	+1.2

* Train B was a traversing train in Run 33.

The Vaisala H_2O CEM outputs a 0-10 Vdc signal that is proportional to the moisture content of the gas in terms of absolute humidity (0-600 g/acm). In order to convert the CEM response to $\%H_2O$ by volume, the following equation was used:

$$\%H_2O = (0.029)(Vdc)(t + 273)$$

where t = stack temperature in °C.

NOTE: This equation is based on the assumption of a constant stack pressure of 13.7 psia (i.e., –24" H_2O).

Since the stack gas environment at this specific facility might have an effect on the accuracy of the H_2O CEM, the readings taken during each run of the initial correlation tests were compared with the corresponding average M17 H_2O results. That comparison was used to develop a correction factor that was incorporated into the above equation, as discussed below. Thereafter, the H_2O CEM and average M17 H_2O results obtained for each run in the first and second RCA were used to assess the accuracy of the H_2O CEM.

The data in Table 5-6A show the H_2O results from the initial correlation tests which were used to calculate a correction factor for the moisture monitor as follows:

$$H_2O \text{ Correction Factor} = \frac{\%\ H_2O \text{ by M17}}{\%\ H_2O \text{ reported by CEM}} = \frac{13.45}{11.38} = 1.180$$

This correction factor was applied to the original equation shown above that is used to convert the H_2O CEM response (Vdc) to % H_2O, as follows:

$$\%H_2O = (1.182)\ (0.029)\ (Vdc)(t + 273)$$

$$= (0.034)(Vdc)(t + 273)$$

Table 5-6A. Summary of Moisture Results for Initial Correlation Tests (CEM vs M17, and Calculated Correction Factor)

Run no.		H_2O CEM (% by vol)		M17 (% by vol)*
10		10.95		13.00
11		10.96		12.85
12		11.15		14.45
13		11.10		11.90
14		10.92		13.25
15		11.35		13.10
16		11.72		13.35
17		11.36		13.20
18		11.33		13.35
19		11.71		13.15
20		11.78		15.25
21		11.88		14.05
22		11.56		13.60
23		11.29		13.20
24		11.57		14.05
	Avg	11.38	Avg.	13.45

Calculated Correction Factor = 13.45/11.38 = 1.182.

*Average results for Train A and B.

Using this equation, the H_2O CEM results were recalculated and plotted as shown in Figure 5-2. This figure still shows considerable spread in the data, with differences as wide as 1.3% H_2O. However, an error of 1% H_2O, at a 10% moisture level, (e.g., 10% as 11%) would result in an error of only about 1% in conversion of particulate concentration in mg/dscm to mg/acm.

Since the range of H_2O content measured in these tests had a narrow range of only 11.90% to 15.25%, it was not possible to evaluate accuracy of the H_2O CEM at higher moisture levels (e.g., 30-40%).

The reason for the difference between the H_2O CEM results and the M17 results is not known, but may reflect the fact that the range of the instrument is 600 g/acm, or near 100% H_2O by volume, corresponding to an output signal of 10 Vdc. Thus, a difference of 1% H_2O is a difference of only 0.1 Vdc. It should also be noted that the difference between dual M17 trains may be as much as 1% H_2O, as discussed previously

.

Regardless of the reason for the difference in the H_2O CEM and M17 results, the equation shown above, with the correction factor, was incorporated into the data acquisition system computer program in order to convert the H_2O CEM output to % H_2O. Those values were used in the RCA tests to determine accuracy of the H_2O CEM, by comparison with the M17 H_2O results.

Results for the H_2O CEM in the first RCA tests are tabulated in Table 5-6 B, and show that the CEM met the criteria in the QAPP, with a difference of less than 1% H_2O, and relative accuracy (RA) better than 10%.

A comparison of the M17 H_2O (Train A) test results for the second RCA with the H_2O CEMS data is provided in Table 5-6C and shows that the H_2O CEMS always read lower than the M17 result. The average difference was 2.0% H_2O and an RA of 23%, which did not meet the criteria specified in the QAPP of ±1% H_2O or RA $\leq$ 10%. Also, Section 3 and 4 discussed the fact that there were some operational problems with the H_2O CEMS at

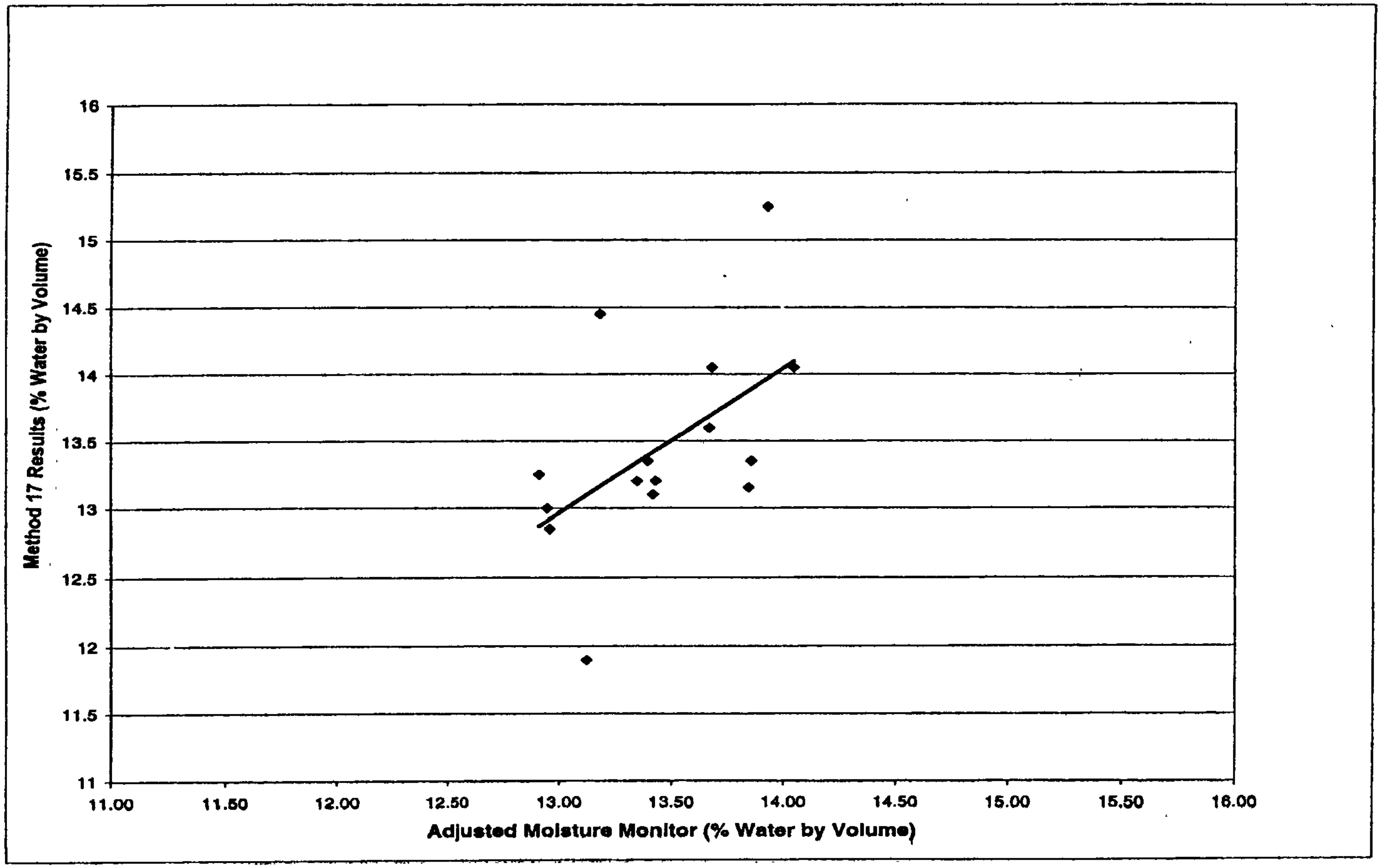


Figure 5-2. Comparison of Adjusted Moisture Monitor Readings with M17 Results, from Initial Correlation Tests

Table 5-6B. Summary of Moisture Results from the first RCA Test (CEM versus M17)

Run no.	H_2O CEM (% by vol)	M17 (% by vol)	Difference (% H_2O by vol)
1	14.69	14.30	–0.39
2	14.28	14.15	–0.14
3	14.24	14.55	+ 0.30
4	14.69	14.55	–0.15
5	14.00	13.90	–0.10
6	13.85	13.85	0
7	13.45	13.85	+ 0.40
8	14.23	13.75	–0.48
9	14.01	13.80	–0.21
10	14.18	14.45	+ 0.27
11	12.17	12.00	–0.17
12	12.50	12.45	–0.05

Note: Relative accuracy of the H_2O CEM was 0.83% and the average difference was < 0.1% H_2O.

Table 5-6C. Summary of Moisture Results for the Second RCA Tests (CEMS versus Method 17)

Run no.	H_2O CEM (% by vol)	M17 Train A (% by vol)	Difference (% by vol)
31	NA*	12.2*	–
32	10.6	11.3	0.7
33	10.7	12.0	1.3
34	10.7	13.0	2.3
35	10.7	12.0	1.3
36	10.5	11.6	1.1
37	9.1	10.5	1.4
38	8.9	11.4	2.5
39	9.0	10.4	1.4
40	9.3	12.4	3.1
41	9.1	12.4	3.3
42	8.5	12.4	3.9

* Moisture CEMS was malfunctioning and was repaired.

Note: Relative accuracy of the H_2O CEM was 23% and the average difference was 2.0% H_2O.

about the time of the second RCA. These problems may have been caused by the constant vibration of the H_2O CEM probe, which may have put severe stresses on the sensor in the CEMS probe. Even so, the H_2O CEMS data were very useful on a day-to-day basis since this data often provided a good indication of plant operational problems or shutdowns. (The PM-CEMS readings were normally quite low and did not show significantly different readings during most plant operational problems or shutdowns.)

The Vaisala HMP 235 moisture CEM also includes a temperature sensor that is used to monitor stack temperature and is also used in the calculation of percent H_2O by volume as discussed in the previous section.

The HMP 235 temperature is output as a 0-10 Vdc signal, with a temperature range of -20° to + 180°C signal. Thus, the equation used to calculate temperature was:

$$\text{Temp in } ^\circ\text{C} = 20\ (\text{Vdc}) - 20$$

In order to evaluate the accuracy of the HMP 235 temperature readings, they were compared with the average M17 stack thermocouple data for each run of the initial correlation tests, as given in Table 5-7A. These results show that the HMP 235 temperatures were an average of 2.0°C lower than the M17 data. Although this met the QA criteria of ±2°C, the equation above was changed slightly in order to improve the accuracy of the temperature readings, as shown in the equation below.

$$\text{Temp in } ^\circ\text{C} = 20\ (\text{Vdc}) - 18$$

The temperature results from the first RCA (which used the modified equation above) are presented in Table 5-7B and show that the CEM met the accuracy criteria of ±2°C. The same comparison for the second RCA tests in Table 5-7C showed that the H_2O CEM reading was always higher than the M17 temperature measurement but did meet the QA criteria of ±2°C.

Table 5-7A. Stack Temperature Comparison for Initial Correlation Tests (M17 Versus H_2O CEM)

Run no.	Stack temperature°C		
	M17	H_2O CEM	Difference
10	90	87.8	–2.2
11	88	85.7	–2.3
12	88	85.5	–2.5
13	85.5	84.1	–1.4
14	89	87.1	–1.9
15	86	83.8	–2.2
16	85	83.0	–2.0
17	85	83.5	–1.5
18	86	83.8	–2.2
19	85	83.1	–1.9
20	85.5	83.7	–1.8
21	85	83.5	–1.5
22	85	82.7	–2.3
23	85	82.9	–2.1
24	85	83.4	–1.6
Average	86.2	84.2	–2.0

Table 5-7B. Stack Temperature Comparison for the First RCA Tests (M17 Versus H_2O CEM)

Run no.	Stack temperature °C		
	M17	H_2O CEM	Difference
1	84.7	84.7	0
2	85.0	84.8	–0.2
3	86.9	86.7	–0.2
4	85.3	85.4	+0.1
5	85.3	85.2	–0.1
6	86.7	87.0	+0.3
7	91.1	90.8	–0.3
8	85.3	85.7	+0.4
9	85.8	86.2	+0.4
10	85.3	85.7	+0.4
11	85.6	85.7	+0.1
12	83.6	84.0	+0.4
Average	85.9	86.0	+0.1

Table 5-7C. Stack Temperature Comparison for Second RCA Test (CEMS versus Method 17)

	Stack temperature (°C)		
Run no.	Method 17	H_2O CEM	Difference
31	80.6	NA	–
32	80.6	82.2	+1.6
33	81.7	83.1	+1.4
34	81.7	83.8	+2.1
35	81.6	84.0	+2.4
36	81.6	83.4	+1.8
37	80.6	82.1	+1.5
38	80.6	82.1	+1.5
39	80.6	82.0	+1.4
40	81.7	83.4	+1.7
41	82.2	83.4	+1.2
42	82.8	84.2	+1.4
Average	81.4	83.1	+1.6

5.3.3 PM-CEMS Drift Test Data and ACA Results

The three PM-CEMS operated since the beginning of the 6-month evaluation period (July 20, 1999) through the end of the 6-month test period (February 16, 2000) except for the downtime of September 15 to October 7 due to Hurricane Floyd. During this period, an initial 7-day drift test was performed, and thereafter the four PM-CEMS have performed automatic daily zero and upscale drift checks. Also, four ACAs were carried out for the two light scatter PM-CEMS as well as sample volume audits (SVA) on the beta gauge CEMS. Results for these tests are presented in the sections below.

5.3.3.1 7-day Zero and Upscale Drift Test Results

Calibration drift data for the 7-day drift test were collected, as prescribed in Section 8.5 of PS-11, beginning after the shakedown period and before the initial correlation test. Calibration drift data for the ESC P5B and Durag DR 300-40 were taken during the period July 1 through July 7, but the Durag F904K had been removed and was at Durag's office undergoing repairs and upgrades.

The 7-day drift test results for the Durag F904K were collected starting July 10, 1999, after the instrument was reinstalled on July 9, 1999. Drift test results are discussed below and are presented in Table 5-8.

- ESC P5B. The zero reference value for the ESC P5B was 4.05 mA, and the upscale reference value was 12 mA. The largest zero drift was 0.25% of the upscale reference value. The largest upscale drift was 1.33% of the upscale reference value. These results show that the ESC P5B met the 7-day zero and upscale drift criteria of ≤ 2% of the upscale reference value.

Table 5-8. 7-Day Calibration Drift Results for the Three PM-CEMS

ESC P5B 7-Day Calibration Drift Test Results

Date	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)
7/1/99	4.02	0.25	11.90	0.83
7/2/99	4.02	0.25	11.85	1.25
7/3/99	4.02	0.25	11.91	0.75
7/4/99	4.02	0.25	11.93	0.58
7/5/99	4.02	0.25	11.93	0.58
7/6/99	4.02	0.25	11.89	0.92
7/7/99	4.02	0.25	11.84	1.33

Durag DR 300-40 7-Day Calibration Drift Test Results

Date	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)
7/1/99	4.03	0.20	15.06	0.40
7/2/99	4.03	0.20	15.06	0.40
7/3/99	4.03	0.20	15.07	0.47
7/4/99	4.03	0.20	15.06	0.40
7/5/99	4.03	0.20	15.13	0.87
7/6/99	4.03	0.20	15.07	0.47
7/7/99	4.03	0.20	15.06	0.47

Durag F904K 7-Day Calibration Drift Test Results

Date	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)
7/10/99	4.10	0.69	14.48	0.55
7/11/99	4.17	1.17	14.40	1.10
7/12/99	4.10	0.69	14.56	0.00
7/13/99	4.02	0.14	14.56	0.00
7/14/99	4.02	0.14	14.48	0.55
7/15/99	4.17	1.17	14.40	1.10
7/16/99	4.10	0.69	14.48	0.55

- Durag DR 300-40. The zero reference value for the Durag DR 300-40 was 4.0 mA, and the upscale reference value was 15 mA. The largest zero drift was 0.20% of the upscale reference value. The largest upscale drift was 0.87% of the upscale reference value. These results show that the DR 300-40 met the 7-day zero and upscale drift criteria of ≤ 2% of the upscale reference value.
- Durag F904K. The zero reference value for the Durag F904K was 4.0 mA, and the upscale reference value was 14.56 mA. The largest zero drift was 1.17% of the upscale reference value. The largest upscale drift was 1.10% of the upscale reference value. These results show that the F904K met the 7-day zero and upscale drift criteria of ≤ 2% of the upscale reference value.

5.3.3.2 Daily Zero and Upscale Drift Test Results

Daily zero and upscale drift checks, as prescribed in draft Procedure 2, were carried out automatically by all three PM-CEMS. Daily calibration drift data for the 6-month endurance test period was collected in segments corresponding with the RCA tests, as follows:

July 20, 1999, to August 31, 1999	(See Table 5-9A)
September 1, 1999, to November 20, 1999	(See Table 5-9B)
November 21, 1999, to February 16, 2000	(See Table 5-9C)

Daily drift data for the period of July 20 to August 31, 1999, show that all three PM-CEM were within the out-of-control limits. (The drift test criteria in draft Procedure 2 specify that a CEM must be adjusted if the drift exceeds 4% of the upscale value, and that the CEM is out of control if the drift exceeds 4% for five consecutive days or exceeds 8% in any one day.) It was noted that for the ESC-P5B, the upscale drift was progressively increasing and exceeded 4% for three consecutive days (August 21 to August 23, 1999). Therefore, on August 24, 1999, the manufacturer's procedures were used to re-adjust the instrument, which decreased the subsequent upscale drift values.

Table 5-9A. Daily Drift Results (July 20 to August 31, 1999)

	ESC PM CEM Zero = 4.05 mA		Ref. Value = 12 mA		Durag DR 300-40 PM CEM		Ref. Value = 15 mA		Durag F904K PM CEM		Ref. Value =14.56 mA	
Date	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)
7/20/99	4.02	0.25	11.83	1.42	4.02	0.13	15.06	0.40	4.02	0.14	14.56	0.00
7/21/99	4.02	0.25	11.82	1.50	4.02	0.13	15.06	0.40	4.18	1.24	14.48	0.55
7/22/99	4.02	0.25	11.82	1.50	4.02	0.13	15.07	0.47	4.02	0.14	14.48	0.55
7/23/99	4.02	0.25	11.83	1.42	4.03	0.20	15.06	0.40	4.1	0.69	14.48	0.55
7/24/99	4.02	0.25	11.78	1.83	4.03	0.20	15.07	0.47	4.02	0.14	14.48	0.55
7/25/99	4.02	0.25	11.8	1.67	4.03	0.20	15.08	0.53	4.02	0.14	14.48	0.55
7/26/99	4.02	0.25	11.77	1.92	4.02	0.13	15.06	0.40	4.02	0.14	14.63	0.48
7/27/99	4.02	0.25	11.75	2.08	4.03	0.20	15.07	0.47	4.02	0.14	14.48	0.55
7/28/99	4.02	0.25	11.76	2.00	4.02	0.13	15.08	0.53	4.18	1.24	14.56	0.00
7/29/99	4.02	0.25	11.7	2.50	4.03	0.20	15.07	0.47	4.02	0.14	14.56	0.00
7/30/99	4.02	0.25	11.7	2.50	4.03	0.20	15.07	0.47	4.1	0.69	14.48	0.55
7/31/99	4.02	0.25	11.73	2.25	4.03	0.20	15.08	0.53	4.18	1.24	14.41	1.03
8/1/99	4.02	0.25	11.71	2.42	4.03	0.20	15.08	0.53	4.18	1.24	14.48	0.55
8/2/99	4.02	0.25	11.68	2.67	4.03	0.20	15.07	0.47	4.02	0.14	14.48	0.55
8/3/99	4.02	0.25	11.6	3.33	4.02	0.13	15.06	0.40	4.1	0.69	14.48	0.55
8/4/99	4.02	0.25	11.59	3.42	4.02	0.13	15.06	0.40	4.02	0.14	14.56	0.00
8/5/99	4.02	0.25	11.57	3.58	4.02	0.13	15.06	0.40	4.1	0.69	14.56	0.00
8/6/99	4.02	0.25	11.63	3.08	4.03	0.20	15.06	0.40	4.02	0.14	14.56	0.00
8/7/99	4.02	0.25	11.57	3.58	4.03	0.20	15.06	0.40	4.02	0.14	14.56	0.00
8/8/99	4.02	0.25	11.59	3.42	4.03	0.20	15.07	0.47	4.02	0.14	14.48	0.55
8/9/99	4.02	0.25	11.55	3.75	4.03	0.20	15.07	0.47	4.02	0.14	14.48	0.55
8/10/99	4.02	0.25	11.56	3.67	4.02	0.13	15.05	0.33	4.1	0.69	14.48	0.55
8/11/99	4.02	0.25	11.54	3.83	4.02	0.13	15.05	0.33	4.02	0.14	14.48	0.55
8/12/99	4.02	0.25	11.58	3.50	4.03	0.20	15.07	0.47	4.02	0.14	14.56	0.00
8/13/99	4.02	0.25	11.61	3.25	4.02	0.13	14.99	0.07	4.02	0.14	14.48	0.55
8/14/99	4.02	0.25	11.58	3.50	4.03	0.20	15.07	0.47	4.18	1.24	14.72	1.10
8/15/99	4.02	0.25	11.53	3.92	4.02	0.13	15.04	0.27	4.02	0.14	14.56	0.00
8/16/99	4.02	0.25	11.57	3.58	4.02	0.13	15.06	0.40	4.1	0.69	14.48	0.55

Table 5-9A (Continued)

	ESC PM CEM Zero = 4.05 mA		Ref. Value = 12 mA		Durag DR 300-40 PM CEM		Ref. Value = 15 mA		Durag F904K PM CEM		Ref. Value =14.56 mA	
Date	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)
8/17/99	4.02	0.25	11.56	3.67	4.02	0.13	15.06	0.40	4.02	0.14	14.56	0.00
8/18/99	4.02	0.25	11.55	3.75	4.02	0.13	15.06	0.40	4.1	0.69	14.56	0.00
8/19/99	4.02	0.25	11.54	3.83	4.03	0.20	15.06	0.40	4.1	0.69	14.56	0.00
8/20/99	4.02	0.25	11.53	3.92	4.02	0.13	15.06	0.40	4.1	0.69	14.56	0.00
8/21/99	4.02	0.25	11.46	4.50	4.02	0.13	15.07	0.47	4.1	0.69	14.48	0.55
8/22/99	4.02	0.25	11.41	4.92	4.02	0.13	15.06	0.40	4.02	0.14	14.48	0.55
8/23/99	4.02	0.25	11.47	4.42	4.02	0.13	15.06	0.40	4.02	0.14	14.56	0.00
8/24/99	4.03	0.17	11.94	0.50	4.02	0.13	15.05	0.33	4.02	0.14	14.56	0.00
8/25/99	4.02	0.25	11.92	0.67	4.03	0.20	15.07	0.47	4.02	0.14	14.48	0.55
8/26/99	4.02	0.25	11.82	1.50	4.02	0.13	15.05	0.33	4.02	0.14	14.48	0.55
8/27/99	4.03	0.17	11.92	0.67	4.02	0.13	15.05	0.33	4.1	0.69	14.48	0.55
8/28/99	4.03	0.17	11.94	0.50	4.03	0.20	15.06	0.40	4.02	0.14	14.56	0.00
8/29/99	4.05	0.00	11.89	0.92	4.03	0.20	15.06	0.40	4.02	0.14	14.64	0.55
8/30/99	4.09	0.33	11.83	1.42	4.02	0.13	15.06	0.40	4.02	0.14	14.56	0.00
8/31/99	4.02	0.25	11.75	2.08	4.02	0.13	15.05	0.33	4.02	0.14	14.48	0.55

Table 5-9B. Daily Drift Results (September 1 to November 20, 1999)

	ESC PM CEM Zero =4.05 mA		Ref. Value = 12 mA		Durag DR 300-40 PM-CEM		Ref. Value =15 mA		Durag F904K PM-CEM		Ref. Value =14.56 mA	
Date	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)
9/1/99	4.02	0.25	11.76	2.00	4.02	0.13	15.05	0.33	4.1	0.69	14.56	0.00
9/2/99	4.02	0.25	11.76	2.00	4.02	0.13	15.05	0.33	4.02	0.14	14.56	0.00
9/3/99	4.02	0.25	11.82	1.50	4.02	0.13	15.02	0.13	4.18	1.24	14.48	0.55
9/4/99	4.02	0.25	12	0.00	4.02	0.13	15.06	0.40	4.02	0.14	14.56	0.00
9/5/99	4.02	0.25	11.87	1.08	4.02	0.13	15.05	0.33	4.02	0.14	14.48	0.55
9/6/99	4.02	0.25	11.93	0.58	4.03	0.20	15.07	0.47	4.18	1.24	14.64	0.55
9/7/99	4.02	0.25	11.88	1.00	4.02	0.13	15.06	0.40	4.1	0.69	14.41	1.03
9/8/99	4.02	0.25	11.9	0.83	4.02	0.13	15.05	0.33	4.02	0.14	14.64	0.55
9/9/99	4.02	0.25	11.87	1.08	4.02	0.13	15.06	0.40	4.02	0.14	14.56	0.00
9/10/99	4.02	0.25	11.84	1.33	4.03	0.20	15.06	0.40	4.17	1.17	14.56	0.00
9/11/99	4.02	0.25	11.75	2.08	4.02	0.13	15.04	0.27	4.1	0.69	14.56	0.00
9/12/99	4.02	0.25	11.73	2.25	4.02	0.13	15.06	0.40	4.1	0.69	14.56	0.00
9/13/99	4.02	0.25	11.7	2.50	4.02	0.13	15.05	0.33	4.1	0.69	14.56	0.00
9/14/99	4.02	0.25	11.75	2.08	4.02	0.13	15.06	0.40	4.18	1.24	14.56	0.00
9/15/99	4.02	0.25	11.81	1.58	4.02	0.13	15.05	0.33	4.02	0.14	14.56	0.00
System off-line due to Hurricane Floyd												
10/7/99	4.02	0.25	11.91	0.75	4.02	0.13	15.04	0.27	4.02	0.14	14.64	0.55
10/8/99	4.02	0.25	11.62	3.17	4.02	0.13	15.06	0.40	4.03	0.21	14.49	0.48
10/9/99	4.02	0.25	11.46	4.50	4.02	0.13	15.04	0.27	4.1	0.69	14.48	0.55
10/10/99	4.02	0.25	11.56	3.67	4.02	0.13	15.06	0.40	4.02	0.14	14.49	0.48
10/11/99	4.02	0.25	11.61	3.25	4.02	0.13	15.04	0.27	4.02	0.14	14.49	0.48
10/12/99	4.02	0.25	11.5	4.17	4.02	0.13	15.04	0.27	4.1	0.69	14.64	0.55
10/13/99	4.02	0.25	11.26	6.17	4.02	0.13	15.05	0.33	F904K is out-of-service; air conditioner broken;			
10/14/99	4.01	0.33	11.34	5.50	4.02	0.13	15.04	0.27	Pressurized air line came disconnected			
10/15/99	4.02	0.25	11.97	0.25	4.02	0.13	15.04	0.27	4.1	0.69	14.41	1.03
10/16/99	4.02	0.25	11.87	1.08	4.02	0.13	15.06	0.40	F904K is out-of-service; pressurized air line off			
10/17/99	4.01	0.33	11.98	0.17	DR 300-40 is out-of-service, dirty window check too high				"			
10/18/99	4.01	0.33	11.95	0.42					"			
10/19/99	4.02	0.25	11.84	1.33					"			
10/20/99	4.01	0.33	11.92	0.67					4.1	0.69	14.48	0.55
10/21/99	4.01	0.33	11.89	0.92	4.02	0.13	15.04	0.27	4.02	0.14	14.56	0.00

Table 5-9B (Continued)

Date	ESC PM CEM Zero =4.05 mA Ref. Value = 12 mA				Durag DR 300-40 PM-CEM Ref. Value =15 mA				Durag F904K PM-CEM Ref. Value =14.56 mA			
	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)
10/22/99	4.01	0.33	11.84	1.33	4.01	0.07	15.03	0.20	4.02	0.14	14.56	0.00
10/23/99	4.02	0.25	11.65	2.92	4.02	0.13	15.05	0.33	F904K is out-of-service; 3 vacuum errors on 10/22/99			
10/24/99	4.02	0.25	11.58	3.50	4.01	0.07	15.04	0.27	"			
10/25/99	4.01	0.33	11.62	3.17	4.01	0.07	15.03	0.20	"			
10/26/99	4.01	0.33	11.68	2.67	4.02	0.13	15.02	0.13	4.18	1.24	14.41	1.03
10/27/99	4.02	0.25	11.65	2.92	4.02	0.13	15.22	1.47	4.1	0.69	14.56	0.00
10/28/99	4.02	0.25	11.57	3.58	4.02	0.13	15.05	0.33	4.02	0.14	14.56	0.00
10/29/99	4.01	0.33	11.73	2.25	4.02	0.13	15.04	0.27	4.1	0.69	14.56	0.00
10/30/99	4.02	0.25	11.61	3.25	4.02	0.13	15.03	0.20	F904K is out-of-service; 3 vacuum errors on 10/29/99			
10/31/99	4.01	0.33	11.66	2.83	4.02	0.13	15.06	0.40	"			
11/1/99	4.01	0.33	11.66	2.83	4.02	0.13	15.05	0.33	"			
11/2/99	4.01	0.33	11.68	2.67	4.02	0.13	15.06	0.40	F904K is out-of-service; filter tear.			
11/3/99	Data logger off line 11/3 a.m.				Data logger off line 11/3 a.m.				4.02	0.14	14.64	0.55
11/4/99	4.01	0.33	11.43	4.75	4.01	0.07	15.03	0.20	4.1	0.69	14.56	0.00
11/5/99	4.01	0.33	11.34	5.50	4.01	0.07	15.04	0.27	4.02	0.14	14.56	0.00
11/6/99	4.01	0.33	11.45	4.58	4.02	0.13	15.03	0.20	4.02	0.14	14.48	0.55
11/7/99	4.01	0.33	11.51	4.08	4.02	0.13	15.04	0.27	4.1	0.69	14.56	0.00
11/8/99	4.01	0.33	11.61	3.25	4.01	0.07	15.05	0.33	4.02	0.14	14.56	0.00
11/9/99	4.01	0.33	11.39	5.08	4.02	0.13	15.04	0.27	F904K is out-of-service; 3 vacuum errors on 11/8/99			
11/10/99	4.01	0.33	11.51	4.08	4.02	0.13	15.04	0.27	F904K is out-of-service; filter tear.			
11/11/99	4.01	0.33	12.11	0.92	4.02	0.13	15.05	0.33	F904K repaired but no drift check			
11/12/99	4.02	0.25	12.03	0.25	4.02	0.13	15.04	0.27	4.02	0.14	14.49	0.48
11/13/99	4.02	0.25	11.97	0.25	4.02	0.13	15.04	0.27	F904K is out-of-service; filter tear.			
11/14/99	4.01	0.33	12.08	0.67	4.02	0.13	15.03	0.20	"			
11/15/99	4.02	0.25	12.04	0.33	4.02	0.13	15.05	0.33	"			
11/16/99	4.01	0.33	12.06	0.50	4.01	0.07	15.03	0.20	F904K back in service, no calibration			
11/17/99	4.02	0.25	12.03	0.25	4.01	0.07	15.05	0.33	4.1	0.69	14.49	0.48
11/18/99	4.01	0.33	11.88	1.00	4.01	0.07	15.04	0.27	4.1	0.69	14.56	0.00
11/19/99	4.01	0.33	11.8	1.67	4.01	0.07	15.04	0.27	4.1	0.69	14.56	0.00
11/20/99	4.02	0.25	11.89	0.92	4.02	0.13	15.03	0.20	4.1	0.69	14.49	0.48

Table 5-9C. Daily Cal Drift Data (November 21 to February 16)

	ESC PM CEM Zero=4.05 mA		Ref. Value = 12 mA		Durag DR 300-40 PM CEM		Ref. Value = 15 mA		Durag F904K PM CEM		Ref. Value = 14.56 mA	
Date	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)
11/21/99	4.02	0.25	11.8	1.67	4.02	0.13	15.04	0.27	4.02	0.14	14.41	1.03
11/22/99	4.02	0.25	11.8	1.67	4.02	0.13	15.04	0.27	4.18	1.24	14.64	0.55
11/23/99	4.02	0.25	11.62	3.17	4.02	0.13	15.05	0.33	4.02	0.14	14.57	0.07
11/24/99	4.02	0.25	11.64	3.00	4.02	0.13	15.05	0.33	4.18	1.24	14.64	0.55
11/25/99	4.02	0.25	11.64	3.00	4.02	0.13	15.04	0.27	4.1	0.69	14.56	0.00
11/26/99	4.02	0.25	11.66	2.83	4.02	0.13	15.04	0.27	4.02	0.14	14.56	0.00
11/27/99	4.02	0.25	11.6	3.33	4.02	0.13	15.04	0.27	4.02	0.14	14.56	0.00
11/28/99	4.02	0.25	11.61	3.25	4.02	0.13	15.05	0.33	4.02	0.14	14.49	0.48
11/29/99	4.01	0.33	11.57	3.58	4.01	0.07	15.03	0.20	4.02	0.14	14.64	0.55
11/30/99	4.02	0.25	11.49	4.25	4.01	0.07	15.02	0.13	4.1	0.69	14.49	0.48
12/1/99	4.01	0.33	11.41	4.92	4.01	0.07	15.05	0.33	4.1	0.69	14.56	0.00
12/2/99	4.01	0.33	12.09	0.75	4.01	0.07	15.02	0.13	4.1	0.69	14.56	0.00
12/3/99	4.01	0.33	12.24	2.00	4.02	0.13	15.03	0.20	4.02	0.14	14.56	0.00
12/4/99	4.02	0.25	11.73	2.25	4.02	0.13	15.04	0.27	4.02	0.14	14.48	0.55
12/5/99	4.02	0.25	12.03	0.25	4.02	0.13	15.03	0.20	4.1	0.69	14.48	0.55
12/6/99	4.02	0.25	11.78	1.83	4.02	0.13	15.05	0.33	4.02	0.14	14.56	0.00
12/7/99	4.01	0.33	11.67	2.75	4.01	0.07	15.02	0.13	4.02	0.14	14.56	0.00
12/8/99	4.02	0.25	11.62	3.17	4.01	0.07	15.03	0.20	4.02	0.14	14.56	0.00
12/9/99	4.01	0.33	11.62	3.17	4.01	0.07	15.02	0.13	4.1	0.69	14.4	1.10
12/10/99	4.02	0.25	11.76	2.00	4.02	0.13	15.04	0.27	4.1	0.69	14.64	0.55
12/11/99	4.01	0.33	11.99	0.08	4.02	0.13	15.04	0.27	4.02	0.14	14.49	0.48
12/12/99	4.02	0.25	11.83	1.42	4.01	0.07	15.03	0.20	4.1	0.69	14.64	0.55
12/13/99	4.01	0.33	11.97	0.25	4.02	0.13	15.04	0.27	4.1	0.69	14.64	0.55
12/14/99	4.02	0.25	11.96	0.33	4.02	0.13	15.05	0.33	4.02	0.14	14.56	0.00
12/15/99	4.02	0.25	11.85	1.25	4.01	0.07	15.03	0.20	4.02	0.14	14.56	0.00
12/16/99	4.01	0.33	11.85	1.25	4.02	0.13	15.04	0.27	4.02	0.14	14.64	0.55
12/17/99	4.02	0.25	11.72	2.33	4.01	0.07	15.02	0.13	4.02	0.14	14.56	0.00
12/18/99	4.02	0.25	11.7	2.50	4.02	0.13	15.05	0.33	4.02	0.14	14.56	0.00
12/19/99	4.02	0.25	11.7	2.50	4.02	0.13	15.03	0.20	4.02	0.14	14.48	0.55
12/20/99	4.02	0.25	11.81	1.58	4.02	0.13	15.04	0.27	4.02	0.14	14.48	0.55
12/21/99	4.02	0.25	11.76	2.00	4.02	0.13	15.04	0.27	4.02	0.14	14.56	0.00

Table 5-9C (Continued)

Date	ESC PM CEM Zero=4.05 mA		Ref. Value = 12 mA		Durag DR 300-40 PM CEM		Ref. Value = 15 mA		Durag F904K PM CEM		Ref. Value = 14.56 mA	
	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)
12/22/99	4.02	0.25	11.73	2.25	4.01	0.07	15.03	0.20	4.02	0.14	14.56	0.00
12/23/99	4.01	0.33	11.68	2.67	4.01	0.07	15.04	0.27	4.02	0.14	14.49	0.48
12/24/99	4.01	0.33	11.67	2.75	4.01	0.07	15.04	0.27	4.02	0.14	14.56	0.00
12/25/99	4.01	0.33	11.56	3.67	4.01	0.07	15.03	0.20	4.1	0.69	14.49	0.48
12/26/99	4.01	0.33	11.49	4.25	4.01	0.07	15.02	0.13	4.1	0.69	14.56	0.00
12/27/99	4.01	0.33	11.57	3.58	4.01	0.07	15.03	0.20	4.02	0.14	14.56	0.00
12/28/99	4.01	0.33	11.55	3.75	4.02	0.13	15.03	0.20	4.1	0.69	14.56	0.00
12/29/99	4.02	0.25	11.52	4.00	4.01	0.07	15.04	0.27	4.1	0.69	14.56	0.00
12/30/99	4.02	0.25	11.52	4.00	4.02	0.13	15.03	0.20	4.02	0.14	14.56	0.00
12/31/99	4.02	0.25	11.9	0.83	4.02	0.13	15.03	0.20	4.02	0.14	14.49	0.48
1/1/00	4.02	0.25	11.78	1.83	4.02	0.13	15.04	0.27	4.18	1.24	14.33	1.58
1/2/00	4.02	0.25	11.82	1.50	4.02	0.13	15.03	0.20	4.1	0.69	14.49	0.48
1/3/00	4.02	0.25	11.88	1.00	4.02	0.13	15.04	0.27	4.02	0.14	14.56	0.00
1/4/00	4.02	0.25	11.91	0.75	4.02	0.13	15.05	0.33	4.1	0.69	14.4	1.10
1/5/00	4.02	0.25	11.75	2.08	4.02	0.13	15.03	0.20	4.1	0.69	14.49	0.48
1/6/00	4.02	0.25	11.65	2.92	4.01	0.07	15.03	0.20	4.02	0.14	14.56	0.00
1/7/00	4.02	0.25	11.65	2.92	4.02	0.13	15.04	0.27	4.1	0.69	14.56	0.00
1/8/00	4.02	0.25	11.59	3.42	4.01	0.07	15.02	0.13	4.1	0.69	14.64	0.55
1/9/00	4.02	0.25	11.61	3.25	4.02	0.13	15.04	0.27	4.1	0.69	14.56	0.00
1/10/00	Computer problem; no drift data taken											
1/11/00	4.02	0.25	11.65	2.92	4.01	0.07	15.03	0.20	4.02	0.14	14.56	0.00
1/12/00	4.02	0.25	12.01	0.08	4.02	0.13	15.03	0.20	4.1	0.69	14.56	0.00
1/13/00	4.02	0.25	12	0.00	4.02	0.13	15.04	0.27	4.02	0.14	14.56	0.00
1/14/00	4.02	0.25	11.95	0.42	4.01	0.07	15.04	0.27	4.02	0.14	14.56	0.00
1/15/00	4.02	0.25	11.89	0.92	4.02	0.13	15.03	0.20	4.1	0.69	14.57	0.07
1/16/00	4.01	0.33	11.87	1.08	4.01	0.07	15.03	0.20	4.1	0.69	14.56	0.00
1/17/00	4.01	0.33	11.91	0.75	4.02	0.13	15.03	0.20	4.1	0.69	14.49	0.48
1/18/00	4.02	0.25	11.84	1.33	4.01	0.07	15.03	0.20	4.1	0.69	14.49	0.48
1/19/00	4.01	0.33	11.81	1.58	4.01	0.07	15.03	0.20	4.01	0.07	14.56	0.00
1/20/00	4.02	0.25	11.93	0.58	4.01	0.07	15.04	0.27	4.02	0.14	14.56	0.00

Table 5-9C (Continued)

Date	ESC PM CEM Zero=4.05 mA		Ref. Value = 12 mA		Durag DR 300-40 PM CEM		Ref. Value = 15 mA		Durag F904K PM CEM		Ref. Value = 14.56 mA	
	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)	Zero reading (mA)	Zero drift (%)	Upscale reading (mA)	Upscale drift (%)
1/21/00	4.01	0.33	11.93	0.58	4	0.00	15.03	0.20	4.02	0.14	14.49	0.48
1/22/00	4.01	0.33	11.92	0.67	4.01	0.07	15.02	0.13	4.09	0.62	14.56	0.00
1/23/00	4.01	0.33	11.9	0.83	4.01	0.07	15.02	0.13	4.01	0.07	14.56	0.00
1/24/00	4.01	0.33	11.86	1.17	4.01	0.07	15.03	0.20	4.01	0.07	14.49	0.48
1/25/00	4.01	0.33	11.69	2.58	4	0.00	15.02	0.13	4.01	0.07	14.56	0.00
1/26/00	4.01	0.33	11.7	2.50	4.01	0.07	15.03	0.20	4.09	0.62	14.64	0.55
1/27/00	4.01	0.33	11.66	2.83	4	0.00	15.02	0.13	4.01	0.07	14.48	0.55
1/28/00	4.01	0.33	11.59	3.42	4	0.00	15.02	0.13	4.01	0.07	14.56	0.00
1/29/00	4.01	0.33	11.56	3.67	4.01	0.07	15.03	0.20	4.09	0.62	14.48	0.55
1/30/00	4.01	0.33	11.41	4.92	4.01	0.07	15.03	0.20	4.01	0.07	14.56	0.00
1/31/00	4.01	0.33	11.42	4.83	4.01	0.07	15.03	0.20	4.09	0.62	14.56	0.00
2/1/00	4.01	0.33	11.44	4.67	4.01	0.07	15.01	0.07	4.01	0.07	14.56	0.00
2/2/00	4.01	0.33	11.44	4.67	4.01	0.07	15.03	0.20	4.01	0.07	14.56	0.00
2/3/00	4.01	0.33	11.39	5.08	4.01	0.07	15.02	0.13	4.02	0.14	14.56	0.00
2/4/00	4.02	0.25	11.43	4.75	4.01	0.07	15.03	0.20	4.09	0.62	14.41	1.03
2/5/00	4.01	0.33	11.42	4.83	4.01	0.07	15.04	0.27	4.09	0.62	14.48	0.55
2/6/00	4.01	0.33	11.39	5.08	4.01	0.07	15.03	0.20	4.01	0.07	14.56	0.00
2/7/00	4.02	0.25	12.02	0.17	4.01	0.07	15.05	0.33	4.09	0.62	14.48	0.55
2/8/00	4.02	0.25	12.02	0.17	4.01	0.07	15.04	0.27	4.17	1.17	14.48	0.55
2/9/00	4.01	0.33	11.86	1.17	4.01	0.07	15.03	0.20	4.09	0.62	14.56	0.00
2/10/00	No data due to maintenance				4.02	0.13	15.05	0.33	4.09	0.62	14.56	0.00
2/11/00	Operator error caused no calibration drift data to be available for any of the PM CEMSs											
2/12/00	4.02	0.25	11.92	0.67	4.01	0.07	15.04	0.27	4.01	0.07	14.49	0.48
2/13/00	4.01	0.33	11.89	0.92	4.01	0.07	15.03	0.20	4.09	0.62	14.48	0.55
2/14/00	4.01	0.33	12.08	0.67	4.01	0.07	15.04	0.27	4.09	0.62	14.64	0.55
2/15/00	4.02	0.25	11.92	0.67	4.01	0.07	15.04	0.27	4.02	0.14	14.48	0.55
2/16/00	4.02	0.25	11.9	0.83	4.01	0.07	15.04	0.27	4.02	0.14	14.56	0.00

Daily drift results for the period of September 1 to November 20, 1999, are given in Table 5-9B. These data show that none of the three PM-CEMS exceeded the out-of-control limits given above. It was noted that for the ESC P5B, the upscale drift was progressively increasing and exceeded 4% for three consecutive days (October 12-14). Therefore, on October 15, 1999, the manufacturer's procedures were used to clean the lenses and to change the purge air filter, which decreased the subsequent upscale drift values. The upscale drift again exceeded 4% on November 9 and 10, and the above corrective procedure was used on November 11, 1999.

Daily drift results for the period of November 21, 1999, to February 16, 2000, are given in Table 5-9C. These also show that the three PM-CEMS did not exceed the out-of-control limits discussed above, except as noted below. That is, it was necessary to perform corrective action on the ESC-P5B six times during the period, to correct the upscale drift problem as noted previously in Section 4.1. The upscale drift exceeded 4% for 7 consecutive days and therefore was out of control for 2 days (February 5 and 6, 2000). However, this out-of-control period would not have occurred if on-site personnel were responsible for responding to such problems.

5.3.3.3 Absolute Correlation Audit Results

Absolute correlation audits (ACA) were conducted on the ESC-P5B and Durag DR 300-40 according to procedures given in draft Procedure 2. Audit standards (i.e., reference materials) for the ACAs were provided by the two PM-CEM manufacturers. No such reference materials were available from Durag for the F904K beta gauge, so the ACAs for this PM-CEM were limited to performing sample volume audits (SVA).

For the ESC-P5B, the manufacturer provided three "reference tubes" with assigned reference values of 34.6 mg, 57.8 mg, and 105.2 mg. To conduct the ACAs on the ESC P5B, the sensor was removed from the probe and each reference tube was alternately attached to the sensor until each tube had been applied three times. The readings (in mg) were read directly from the instrument display.

For the Durag DR 300-40, the manufacturer used a combination of light filters in a "filter box" to establish the reference standards. The manufacturer initially established the reference values in the field on June 6, 1999. The first ACA was carried out on July 8, 1999, using those initial reference values. However, it later became necessary to change the range on the PM-CEMS (as discussed previously in Section 5.2.1.2), which affected the reference values. Therefore, on July 14, 1999, MRI re-established the reference values, as given below, which were used in all the subsequent ACAs. Since the DR300-40 has three operating ranges (i.e., levels) the reference values are range adjusted milliamps, as was explained in Section 1.1.3.2.

Reference values in Range adjusted milliamps		
Initial values established June 6, 1999	Later values after range change established July 14, 1999	Range
16.39 mA	14.53	Range 1
32.83 mA	28.60	Range 2
67.81 mA	61.42	Range 3
144.76 mA	133.78	Range 3

For each ACA of the Durag DR 300-40, the instrument was removed from the duct and placed on the filter box. Each reference filter was alternately applied to the instrument according to the manufacturer's instructions until each reference was applied three times. The readings, in range adjusted mA, were obtained from the 1 min averages generated by the DAS, which were compared with the reference values.

A total of four ACAs were performed on the ESC-P5B and DR 300-40, as follows:

June 30 and July 8, 1999	Initial ACA	Prior to start of 6-month endurance test period on July 20, 1999
August 26, 1999	2nd ACA	Prior to first RCA on August 27, 1999
November 15, 1999	3rd ACA	Prior to second RCA on November 17, 1999
February 7, 2000	4th ACA	Prior to end of 6-month endurance test on February 16, 2000

Results for all four ACAs are given in Table 5-10A, B, C, and D and show that the ESC-P5B and DR 300-40 met the draft Procedure 2 criteria in all four ACAs.

5.3.3.4 Sample Volume Audit Results

The Durag F904K beta gauge is an extractive PM-CEM, as was explained in Section 1.1.3.3. Particulate matter is collected on a paper tape during each sample cycle. The amount (mg) of particulate matter on the filter is determined by the reduction in transmission of beta particles, before and after sampling. During each sampling period the F904K measures the volumetric flowrate of sample gas in order to determine the total volume of gas sampled during the sampling cycle. Thus, the output signal from the monitor (mA) is proportional to the mass of particulate per unit volume of gas (i.e., mg/dscm).

Since the measurement of the gas volume is a critical parameter in the results, EPA draft Procedure 2 (dated November 1998) specifies that a Sample Volume Audit (SVA) be performed every quarter, and that the PM-CEM be considered out of control if results exceed ±5% of the average sample volume audit value.

The procedure used for the SVAs was to connect the sample gas exhaust from the F904K to the inlet of the dry gas meter (DGM) on one of the calibrated sampling consoles

Table 5-10A. Results for Initial ACA

ESC P5B ACA Result

Test date June 30, 1999	Audit points		
	Low (mg)	Mid (mg)	High (mg)
Challenge 1	35.1	57.2	104.9
Challenge 2	35.0	57.4	105.2
Challenge 3	35.0	57.3	104.4
Average	35.0	57.3	104.8
Reference value (by manf.)	34.6	57.8	105.2
ACA%	1.16	0.87	0.35
Pass/Fail 15% Criteria	Pass	Pass	Pass

Durag DR 300-40 ACA Result

Test date July 8, 1999	Audit points (See note)			
	Range 1 A (ra mA)	Range 2 B (ra mA)	Range 3 C (ra mA)	Range 3 D (ra mA)
Challenge 1	15.42	30.67	63.64	137.86
Challenge 2	15.72	31.25	64.15	138.79
Challenge 3	15.76	31.33	64.57	139.45
Average	15.63	31.08	64.12	138.70
Reference value (by manf. in field)	16.39	32.83	67.81	144.76
ACA%	4.64	5.32	5.44	4.19
Pass/Fail 15% Criteria	Pass	Pass	Pass	Pass

Note: Units shown in columns (ra mA) are range adjusted milliamps.

Table 5-10B. Results for 2nd ACA

ESC P5B ACA Result

Test date August 26, 1999	Audit points Low (mg)	 Mid (mg)	 High (mg)
Challenge 1	35.1	56.9	104.0
Challenge 2	35.3	56.9	105.1
Challenge 3	34.8	56.4	104.2
Average	35.7	56.7	104.4
Reference value (by manf.)	34.6	57.8	105.2
ACA%	1.35	1.85	0.73
Pass/Fail 15% Criteria	Pass	Pass	Pass

Durag DR 300-40 ACA Result

Test date August 26, 1999	Audit points (See note) Range 1 A (ra mA)	 Range 2 B (ra mA)	 Range 3 C (ra mA)	 Range 3 D (ra mA)
Challenge 1	14.64	28.57	61.82	132.90
Challenge 2	14.60	28.66	61.74	133.40
Challenge 3	14.64	28.78	61.93	133.70
Average	14.63	28.67	61.83	133.33
Reference value (by MRI on July 14, 1999)	14.53	28.6	61.42	133.78
ACA%	0.67	0.24	0.67	0.33
Pass/Fail 15% Criteria	Pass	Pass	Pass	Pass

Note: Units shown in columns (ra mA) are ranged adjusted milliamps.

Table 5-10C. Results for 3rd ACA

ESC P5B ACA Result

Test date November 15, 1999	Audit points Low (mg)	 Mid (mg)	 High (mg)
Challenge 1	35.4	57.9	105.8
Challenge 2	34.9	57.4	104.8
Challenge 3	35.2	57.1	105.1
Average	35.17	57.47	105.23
Reference value (by manf.)	34.6	57.8	105.2
ACA%	1.64	0.58	0.03
Pass/Fail 15% Criteria	Pass	Pass	Pass

Durag DR 300-40 ACA Result

Test date November 15, 1999	Audit points (See note) Range 1 A (ra mA)	 Range 2 B (ra mA)	 Range 3 C (ra mA)	 Range 3 D (ra mA)
Challenge 1	15.14	29.95	64.57	140.94
Challenge 2	15.16	29.98	64.66	141.07
Challenge 3	15.15	29.98	64.66	141.16
Average	15.15	29.97	64.63	141.06
Reference value (by MRI on July 14, 1999)	14.53	28.6	61.42	133.78
ACA%	4.27	4.79	5.23	5.44
Pass/Fail 15% Criteria	Pass	Pass	Pass	Pass

Note: Units shown in columns (ra mA) is ranged adjusted milliamps.

Table 5-10D. Results for 4th ACA

ESC P5B ACA Result

Test date February 7, 2000	Audit points		
	Low (mg)	Mid (mg)	High (mg)
Challenge 1	35.0	57.3	103.2
Challenge 2	34.7	57.2	104.0
Challenge 3	34.6	56.8	103.7
Average	34.77	57.10	103.63
Reference value (by manf.)	34.6	57.8	105.2
ACA%	0.48	1.21	1.49
Pass/Fail 15% Criteria	Pass	Pass	Pass

Durag DR 300-40 ACA Result

Test date February 7, 2000	Audit points (See note)			
	Range 1 A (ra mA)	Range 2 B (ra mA)	Range 3 C (ra mA)	Range 3 D (ra mA)
Challenge 1	14.74	25.39	62.23	135.50
Challenge 2	14.72	28.99	62.18	135.10
Challenge 3	14.77	29.00	62.14	136.00
Average	14.74	27.79	62.18	135.53
Reference value (by MRI on July 14, 1999)	14.53	28.6	61.42	133.78
ACA%	1.47	2.82	1.24	1.31
Pass/Fail 15% Criteria	Pass	Pass	Pass	Pass

Note: Units shown in columns (ra mA) are ranged adjusted milliamps.

used in the M17 tests in order to determine the volume of gas exhausted over a sampling cycle. This assumed that the exhaust volume was equal to the sampled volume, which is true as long as there are no leaks in the dilution air line or sample line upstream of the sample pump. The volume measured by the DGM was then compared with the volume reported by the F904K. (The F904K only reported volume to the nearest liter.)

For this project a total of four SVAs were carried out. Each audit consisted of three sampling cycles, but several three-cycle audits were done during some of the SVAs since draft Procedure 2 does not specify how many should be done.

The four SVAs were carried out on the following dates:

Initial SVA	July 12 to 18, 1999	During the initial correlation testing
Second SVA	August 26 to 31, 1999	During first RCA
Third SVA	November 16 to 20, 1999	During second RCA
Fourth SVA	February 7, 2000	Prior to end of 6-month endurance test period

Results for the four SVA are presented in Table 5-11A, B, C, and D, and show that the F904K met the criteria (5%) in all the SVAs.

5.3.4 Initial Correlation and RCA Test Results

Probably the most important objective of this project was to carry out the initial correlation tests to determine if the data met the draft PS-11 criteria, and later to carry out RCA tests to determine if those data met the draft Procedure 2 criteria, which is that 75% of the data points must fall within a ± 25% tolerance interval of the initial correlation relation.

Table 5-11A. Initial SVA Results
Durag F904K

Date	Run no.	Reference F904K volume (N liters)	F904K volume (N liters)	Difference (N liters)	Percent of reference (%)	Criteria 5% Pass/Fail
7/12/99	1	95.3	95	0.3	0.3	
	2	94.9	95	–0.1	–0.1	
	3	95.4	95	0.4	0.4	
				Average	0.2	Pass
7/13/99	1	93.8	95	–1.2	–1.3	
	2	93.5	95	–1.5	–1.6	
	3	93.6	95	–1.4	–1.5	
				Average	–1.5	Pass
7/14/99	1	94.8	95	–.02	–0.2	
	2	93.6	94	–0.4	–0.4	
	3	92.8	94	–1.2	–1.3	
				Average	–0.6	Pass
7/15/99	1	95.8	95	–0.8	0.8	
	2	92.2	93	–0.8	–0.9	
	3	93.0	94	–1.0	–1.1	
				Average	–0.4	Pass
7/16/99	1	93.2	94	–0.8	–0.9	
	2	94.4	95	–0.6	–0.6	
	3	92.3	96	–3.7	–4.0	
				Average	–1.8	Pass
7/17/99	1	93.9	94	–0.1	–0.1	
	2	94.4	95	–0.6	–0.6	
	3	93.6	94	–0.4	–0.4	
				Average	–0.4	Pass
7/18/99	1	94.4	95	–0.6	–0.6	
	2	92.9	93	–0.1	–0.1	
	3	94.7	96	–1.3	–1.4	
				Average	–0.7	Pass

N liters refers to Normal liters (i.e., standard conditions of 20°C and 760 mm Hg).

Table 5-11B. Second SVA Results

Durag F904K

Date	Run no.	Reference F904K volume (N liters)	F904K volume (N liters)	Difference (N liters)	Percent of reference (%)	Criteria 5% Pass/Fail
8/26/99	1	96.4	94	2.4	2.5	
	2	96.6	94	2.6	2.7	
	3	95.4	93	2.4	2.5	
				Average	2.6	Pass
8/27/99	1	96.5	95	1.5	1.6	
	2	97.2	95	2.2	2.3	
	3	96.8	94	2.8	2.9	
				Average	2.2	Pass
8/28/99	1	96.3	93	3.3	3.4	
	2	96	93	3	3.1	
	3	96.5	95	1.5	1.6	
				Average	2.7	Pass
8/29/99	1	99.1	96	3.1	3.1	
	2	99.1	96	3	3.0	
	3	96.9	95	1.9	2.0	
				Average	2.7	Pass
8/30/99	1	98.1	94	4.1	4.2	
	2	98.1	95	3.1	3.2	
	3	96.3	94	2.3	2.4	
				Average	3.2	Pass
8/31/99	1	95.6	93	2.6	2.7	
	2	97.7	94	3.7	3.8	
	3	98.5	95	3.5	3.6	
				Average	3.4	Pass

N liters refers to Normal liters (i.e., standard conditions of 20°C and 760 mm Hg).

Table 5-11C. Third SVA Results
Durag F904K

Date	Test no.	Reference F904K volume (N liters)	F904K volume (N liters)	Difference (N liters)	Percent of reference (%)	Criteria 5% Pass/Fail
11/16/99	1	96.7	93	3.7	3.8	
	2	96.7	94	2.7	2.8	
	3	97	93	4	4.1	
				Average	3.6	Pass
11/17/99	1	99.1	94	5.1	5.1	
	2	94.7	92	2.7	2.9	
	3	95.5	94	1.5	1.6	
				Average	3.2	Pass
11/18/99	1	94.2	93	1.2	1.3	
	2	95.1	94	1.1	1.2	
	3	92.8	92	0.8	0.9	
				Average	1.1	Pass
11/19/99	1	94.2	93	1.2	1.3	
	2	93.8	92	1.8	1.9	
	3	93.8	93	0.8	0.9	
				Average	1.3	Pass
11/20/99	1	94.1	91	3.1	3.3	
	2	96.6	95	1.6	1.7	
	3	96.8	94	2.8	2.9	
				Average	2.6	Pass

N liters refers to Normal liters (i.e., standard conditions of 20°C and 760 mm Hg).

Table 5-11D. Fourth SVA Results

Durag F904K

Date	Test no.	Reference F904K volume (N liters)	F904K volume (N liters)	Difference (N liters)	Percent of reference (%)	Criteria 5% Pass/Fail
2/7/00	1	113.9	112	1.9	1.7	
	2	112.6	112	0.6	0.5	
	3	114.2	113	1.2	1.1	
				Average	1.1	Pass

N liters refers to Normal liters (i.e., standard conditions of 20°C and 760 mm Hg).

The initial correlation tests were carried out on July 15-19, 1999, just prior to the start of the 6-month endurance test period on July 20, 1999. The first RCA was carried out August 27 to August 30, 1999. The second RCA was carried out on November 17 to 20, 1999. Results for each of these tests are described in the following three sections:

5.3.4.1	Initial Correlation Test Results and Correlation Relations
5.3.4.2	First RCA Test Results and Comparison with Initial Correlation Relations
5.3.4.3	Second RCA Test Results and Comparison with Initial Correlation Relations

5.3.4.1 Initial Correlation Test Results and Correlation Relations

The initial correlation tests consisted of 15 runs, but only 12 runs were used for determining the initial correlation relations because 3 of the runs (Run 10, 11 and 12) appeared to be outliers. It was discovered that the facility was burning a very unusual coal ("met coal") during these 3 runs, as was explained in Section 5.2.1.4. These runs were therefore not included in the statistical calculations specified in draft PS-11. (However, the later results from the RCA tests indicated that these three data points probably should not have been excluded, and they have been included in the later discussion of the results and graphs from the first and second RCA.)

The start of each test run was coordinated with the beginning of a sampling period for the F904K. Since the time required for M17 port changes was short (2-3 min), port change times were not removed from the PM CEMS test run averages. The average of the PM-CEM readings was computed after each run for comparison with the average of M17 results for each run. Those data are shown in Table 5-12 and were used to develop the correlation relations, as prescribed in draft PS-11, Section 12.3.

Table 5-12. Tabulation of Data from Initial Correlation Tests

Tabulation of Data for ESC P5B and Durag 300-40

Run no.	Concentration* (mg/acm)	ESC P5B response (ma)	DR300-400 response (Range Adj: ma)	
10	26.13	11.40	20.06	Not included in initial correlation relations
11	27.75	11.76	21.62	
12	32.28	13.88	27.83	
13	11.61	9.60	15.45	
14	13.92	10.01	17.22	
15	14.46	10.54	19.36	
16	3.03	5.87	6.42	
17	2.68	5.78	6.44	
18	3.20	6.00	7.28	
19	16.33	12.00	20.93	
20	10.52	9.45	15.80	
21	9.42	8.97	14.32	
22	15.38	13.16	24.54	
23	8.75	9.57	15.68	
24	18.65	14.50	30.88	

*Average particulate concentration measured by M17, converted to units consistent with PM-CEMS (See Table 5-3A)

Table 5-12 (Continued)

Tabulation of Data for Durag F904K

Run no.	Concentration* (mg/dscm)	F904K Response (ma)
10	39.5	11.74
11	41.8	11.71
12	49.5	14.49
13	17.2	8.58
14	21.1	9.24
15	21.8	9.98
16	4.6	5.04
17	4.0	5.09
18	4.8	5.21
19	24.4	10.48
20	16.1	8.07
21	14.3	8.05
22	23.3	10.95
23	13.1	8.08
24	28.4	12.27

} Not included in initial correlation relations (runs 10–12)

*Average particulate concentration measured by M17, converted to units consistent with PM-CEMS (See Table 5-3A)

Polynomial and linear correlation equations were generated for each PM-CEM. The correlation for each PM-CEM was done in units consistent with the results of the PM-CEM's measurements. The ESC P5B and Durag DR 300-40 correlations were done in units of mg/acm, while the Durag F904K correlation was done in units of mg/dscm. The regression equations and corresponding correlation coefficients (r) are listed below. The graphs for the linear correlations are shown in Figures 5-3A, B, and C. (All the CEM data for each run are tabulated in Volume 2, Appendix F, and statistical results are shown in Volume 2, Appendix G.) Emission limits for the facility are shown on the Figures 5-3A, B, and C, in units consistent with those measured by the PM-CEMS, as a horizontal dashed line (i.e., 17 mg/acm or 25.5 mg/dscm).

ESC P5B:

Polynomial Equation ($r = 0.970$)

$$mg/acm = -0.098 * mA^2 + mA - 16.06$$

Linear Equation ($r = 0.964$)

$$mg/acm = 1.89 * mA - 7.50$$

(See Figure 5-3A)

Durag DR 300-40:

Polynomial Equation ($r = 0.972$)

$$mg/acm = -0.018 * mA^2 + 1.33 * mA - 5.29$$

Linear Equation ($r = 0.955$)

$$mg/acm = 0.71 * mA - 0.82$$

(See Figure 5-3B)

Durag F904K:

Polynomial Equation ($r = 0.988$)

$$mg/dscm = -0.11 * mA^2 + 5.12 * mA - 19.13$$

Linear Equation ($r = 0.988$)

$$mg/dscm = 3.37 * mA - 12.38$$

(See Figure 5-3C)

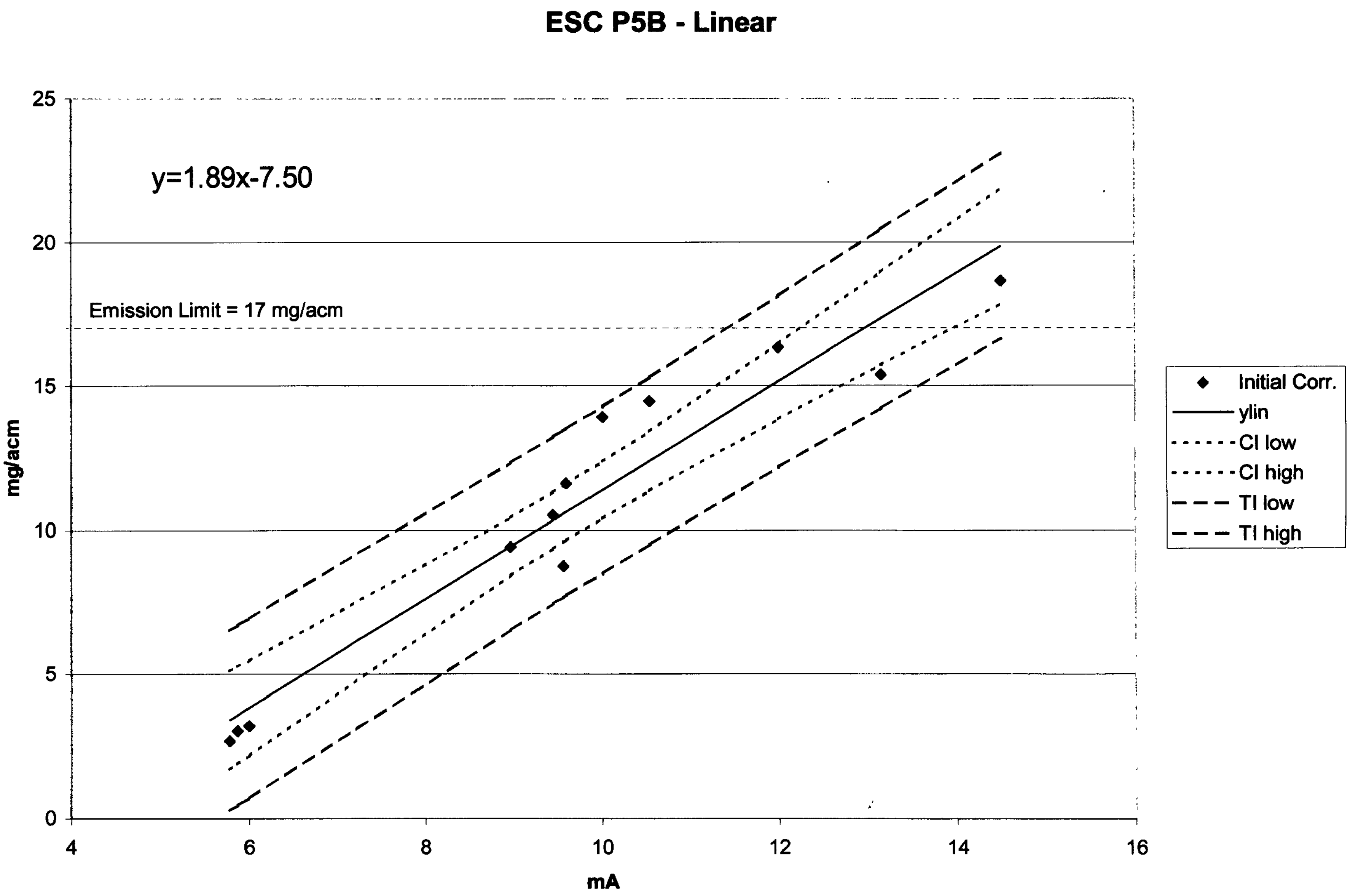


Figure 5-3A. Linear Regression for ESC Light Scatter—P5B

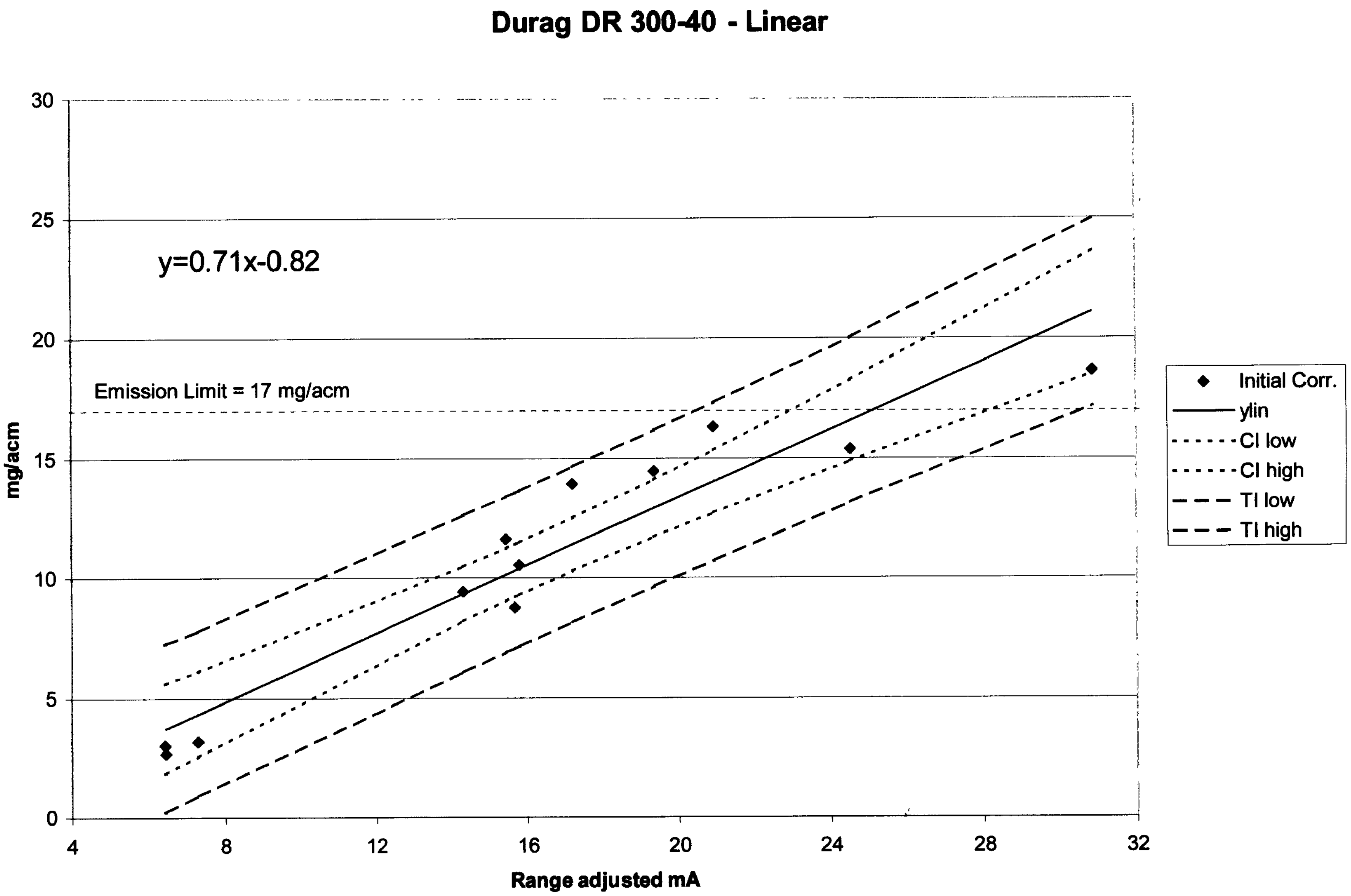


Figure 5-3B. Linear Regression for Durag Light Scatter—DR 300-40

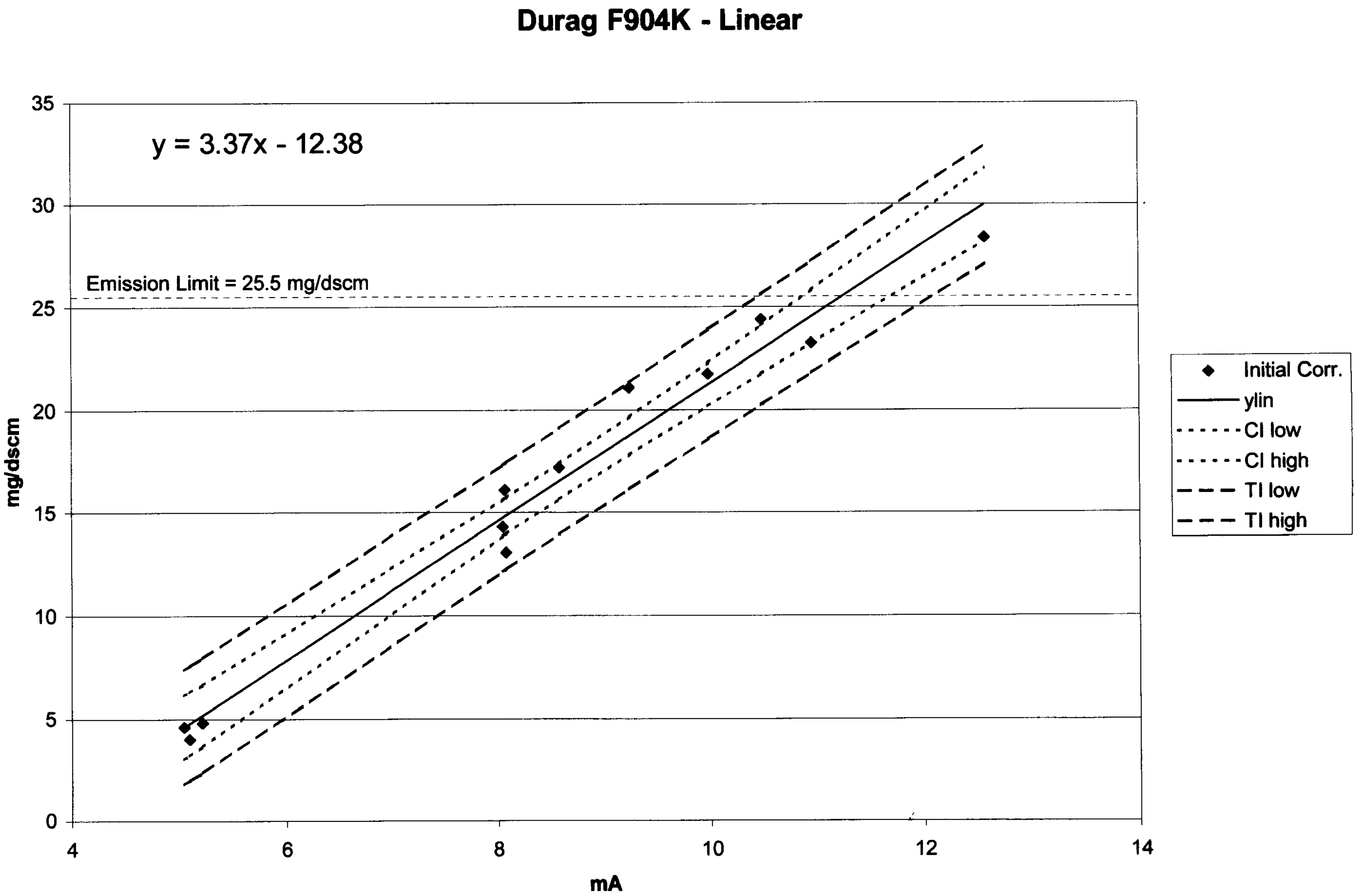


Figure 5-3C. Linear Regression for Durag Beta Gauge—F904K

The test (specified in Section 18.2.3 of draft PS-11) to determine the best correlation fit at the 95% confidence level revealed: (1) for the ESC P5B the linear regression gave the best fit, (2) for the Durag DR 300-40 the polynomial regression gave the best fit, and (3) for the Durag F904K the linear regression gave the best fit. (Details of these calculations are presented in Appendix G.)

Since the polynomial equation gave the best fit for the DR 300-40, a check to determine the location of the maxima was done. This check was carried out by taking the derivative of the equation, setting it equal to zero, and solving for mA. The maxima check showed that the maxima occurred at a range adjusted mA value of 36.9. Although the highest average mA reading obtained during the initial correlation test was only 31, 1-min average readings of greater than 36.9 did occur during the testing. Therefore, the polynomial equation for the DR 300-40 was not appropriate, so the linear regression equation was used.

The PS-11 performance criteria for the selected correlation equations are presented in Table 5-13 and show that (1) the ESC P5B met all three correlation test performance specifications, (2) the Durag DR 300-40 met two of the three correlation test performance specifications, and (3) the Durag F904K met all three correlation test performance specifications.

The Durag DR 300-40 PM-CEM had a confidence interval at the emission limit (10.4%) that was just outside the performance specification (10%). However, if the polynomial equation had been used, which gave the better fit but contained a maxima, the DR 300-40 would also have met all three performance specifications. Therefore, all three PM-CEMS were considered to have met all three performance specifications.

Although the initial correlation data met the criteria for confidence interval (CI) percentage (< 10%) and tolerance interval (TI) percentage (< 25%), the same was not true for the first RCA data, as discussed in the next section. It is important to point out that these percentages are calculated using the emission limit; therefore a facility's emission limit has a direct impact on the TI % and CI % and, thus, a direct impact on whether or not the criteria are met.

Table 5-13. Selected Correlation Equation Values Versus Performance Criteria

Criterion	ESC P5B	Durag DR 300-40	Durag F904K	Criteria limit
Correlation Coefficient (r)	0.964	0.955	0.988	> 0.85
Confidence Interval (CI) at Emission Limit (See note)	9.20%	10.42%	5.37%	< 10%
Tolerance Interval (TI) at Emission Limit	17.94%	20.20%	10.73%	< 25%

Note: This facility's emission limit is 0.02 lb/10^6 BTU. This limit was converted to concentration units of 17.0 mg/acm and 25.5 mg/dscm in order to determine the confidence interval and tolerance interval at the emission limit. However, the conversion to concentration units is not exact since the calculation is dependent on percent O_2 and percent H_2O, as well as temperature and pressure, which are variable.

5.3.4.2 First RCA Test Results and Comparison with Initial Correlations

The primary purpose of the first RCA/ACA test was to compare the RCA test results with the initial correlations discussed above. That is, the initial correlation tests were used to develop graphs (and confidence/tolerance intervals) which relate instrument response (e.g., ma) to particulate concentration (e.g., mg/acm). For the RCA tests, the instrument response and the measured particulate concentration can be plotted on the initial correlation graphs. Ideally, all of the RCA data would fall within the tolerance interval of the initial correlation graph. However, EPA's draft Procedure 2 specifies that at least 75% of the RCA data (i.e., 9 of 12 runs) must fall within a tolerance interval of ± 25% of the emission limit value, drawn as two lines parallel with the initial correlation line.

The data from the first RCA test are presented in Table 5-14, and these data have been plotted on the graphs developed from the initial correlation tests as shown in Figures 5-4A, B, and C (the 12 RCA runs are shown as triangles). Examination of Figures 5-4A, B, and C clearly shows that for each of the three PM-CEMS, no more than 7 of the 12 RCA tests fell within the ± 25% tolerance interval.

These results were unexpected, especially since it occurred for all three PM-CEMS. Preliminary review of all the procedures and data did not provide an explanation for these results and the failure to meet the RCA criteria in draft Procedure 2.

Draft Procedure 2 does provide procedures to follow if a PM-CEMS correlation fails to meet the RCA criteria. The first step is to combine the RCA data with the initial correlation data, and the combined data are then used to perform the mathematical calculations defined in PS-11 for development of a new PM-CEMS correlation, including examination of alternate forms of the correlation relation (e.g., polynomial). If results for the combined data meet the PS-11 criteria, the revised correlation is to be used. This combining of the data was investigated for this project, with results for the best-fit equation shown in Table 5-15.

Table 5-14. Tabulation of Data from First RCA Test

Tabulation of First RCA Data for ESC P5B and Durag 300-40

Run no.	Concentration (mg/acm)	ESC P5B response (ma)	DR300-40 response (Range Adj: ma)
1	28.09	14.66	28.77
2	1.90	6.38	6.11
3	2.54	6.41	6.59
4	2.59	6.40	6.75
5	9.77	8.51	11.72
6	8.29	8.35	11.92
7	11.30	7.70	10.80
8	22.12	10.34	16.22
9	24.05	11.23	18.60
10	26.62	11.92	21.53
11	12.97	9.07	12.62
12	19.10	10.17	14.59

Tabulation of First RCA Data for Durag F904K

Run no.	Concentration (mg/dscm)	F904K response (ma)
1	43.05	14.20
2	2.90	5.04
3	3.95	5.07
4	4.00	4.99
5	14.80	7.30
6	12.65	6.99
7	17.40	6.88
8	33.65	9.71
9	36.60	10.71
10	41.00	11.65
11	19.45	7.57
12	28.65	8.42

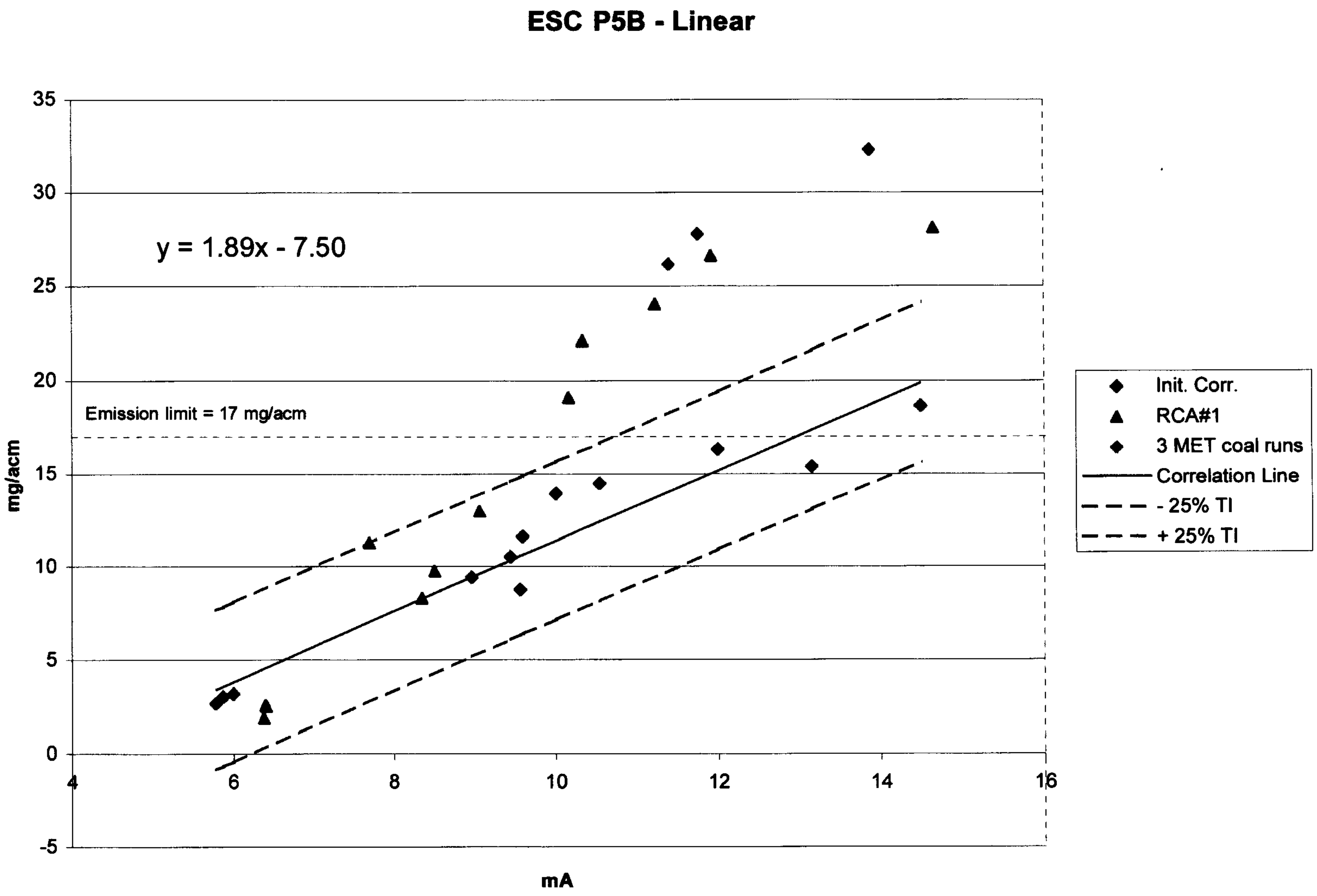


Figure 5-4A. Comparison of Initial Correlation Equation with the First RCA Test Data for ESC-P5B

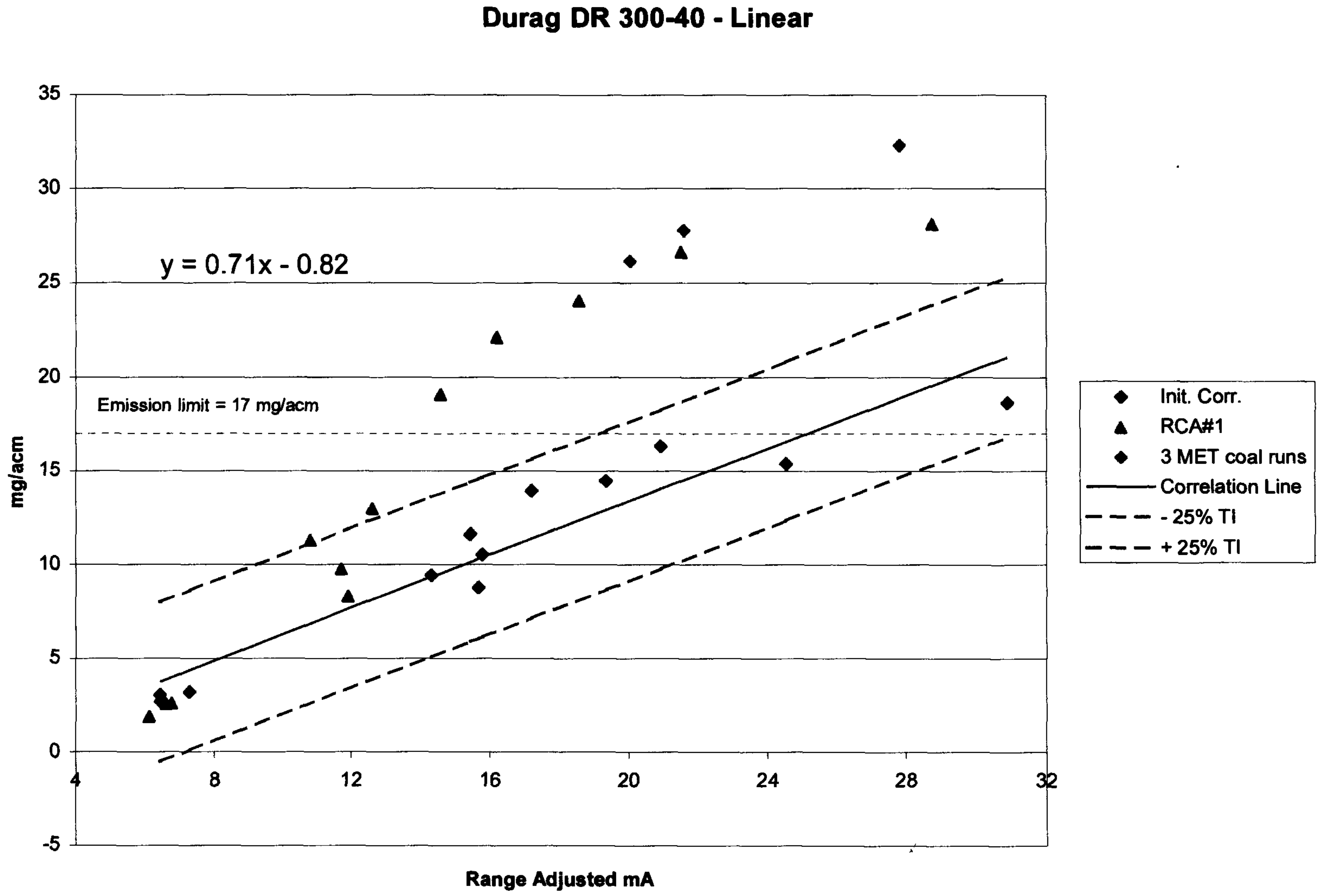


Figure 5-4B. Comparison of Initial Correlation Equation with First RCA Test Data for DR300-40

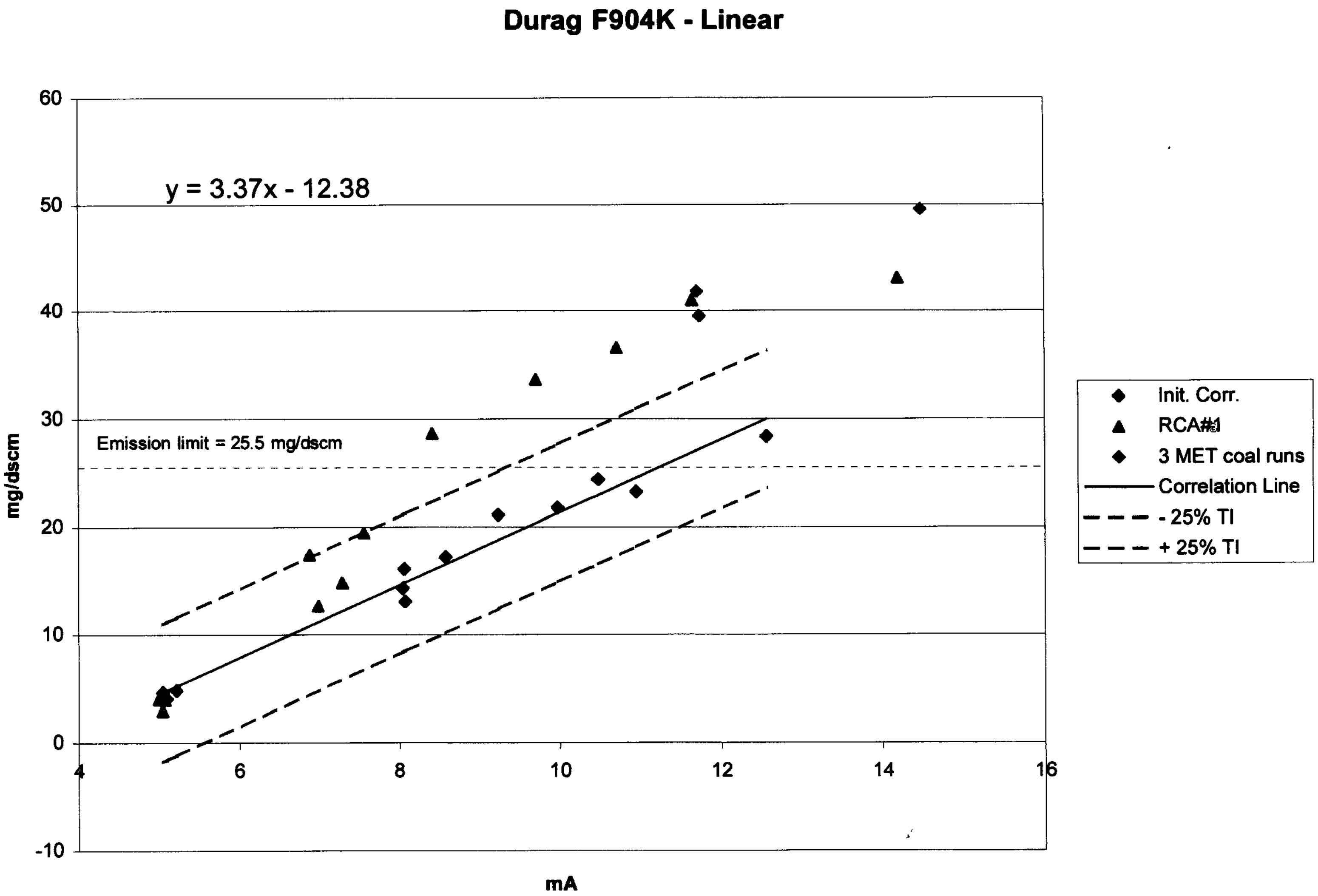


Figure 5-4C. Comparison of Initial Correlation Equation with First RCA Test Data for F904K

Table 5-15. Correlation Equation Results Using Combined Data from Initial Correlation Tests and First RCA Tests (24 Total Data Points)

Criterion	ESC P5B	Durag DR 300-40	Durag F904K	Criteria limit
Correlation Coefficient (r)	(Linear) 0.87	(Polynomial) 0.85	(Linear) 0.92	> 0.85
Confidence Interval (CI) at Emission Limit (See note)	12.0%	14.8%	9.6%	< 10%
Tolerance Interval (TI) at Emission Limit	36.9%	39.8%	30.5%	< 25%

Note: This facility's emission limit is 0.02 lb/10^6 BTU. This limit was converted to concentration units of 17.0 mg/acm and 25.5 mg/dscm in order to determine the confidence interval and tolerance interval at the emission limit. However, the conversion to concentration units is not exact since the calculation is dependent on percent O_2 and percent H_2O, as well as temperature and pressure, all of which are variable.

None of the three PM-CEMS met all of the draft PS-11 criteria for the combined data. Although all three PM-CEMS met the correlation coefficient criterion (> 0.85), only one met the confidence interval criterion (< 10%), and none met the tolerance interval criterion (< 25%). (More details on these calculations and associated graphs are given in Volume 2, Appendix G-2.)

In circumstances where combined data, as discussed above, do not meet the PS-11 criteria, Procedure 2 specifies that a new PM-CEM correlation must be developed based on revised data, which may include the RCA test results but not include the original correlation data.

Therefore, the first RCA test data were evaluated per the calculation procedures in PS-11. The results for the best-fit equations (polynomial) are given in Table 5-16, which shows that only the Durag beta gauge (F904K) met all three criteria. The other two PM-CEMS met the correlation coefficient criterion but did not meet the confidence interval and tolerance interval criteria. (More details on these calculations and associated graphs for the first RCA are given in Volume 3, Appendix G-3). Again, it should be noted that meeting these criteria is a function of the facility's emission limit.

As mentioned earlier, the fact that the results from the first RCA were considerably different from the initial correlation data and did not meet the draft Procedure 2 criteria, was unexpected and caused considerable concern, especially in view of the fact that the initial correlation relation met all the draft PS-11 criteria and all three PM-CEMS had been maintained in proper working order (e.g., the two light scatter PM-CEMS passed ACA criteria and the beta gauge passed the sample volume audits). Therefore, the test scenario for the planned second RCA was modified in an effort to obtain additional data that might explain the reason(s) for the non-agreement between the initial correlation and the first RCA, as described in the next section.

Table 5-16. Correlation Equation Results Using First RCA Test Data Only (12 Data Points)

Criterion	ESC P5B	Durag DR 300-40	Durag F904K	Criteria limit
Correlation Coefficient (r)	(Polynomial) 0.97	(Polynomial) 0.97	(Polynomial) 0.98	> 0.85
Confidence Interval (CI) at Emission Limit	11.6%	11.5%	9.3%	< 10%
Tolerance Interval (TI) at Emission Limit	26.5%	26.6%	21.2%	< 25%

Note: This facility's emission limit is 0.02 lb/10^6 BTU. This limit was converted to concentration units of 17.0 mg/acm and 25.5 mg/dscm in order to determine the confidence interval and tolerance interval at the emission limit. However, the conversion to concentration units is not exact since the calculation is dependent on percent O_2 and percent H_2O as well as temperature and pressure, all of which are variable.

5.3.4.3 Second RCA Test Results and Comparison with Initial Correlations and First RCA Test Results

The primary goal of the second RCA was to obtain data for direct comparison with the initial correlations and the first RCA test results. However, it was decided to replace one of the dual traversing trains (previously used in the initial correlation and first RCA tests) with a single-point train. Only the traversing train data (referred to as Train A) were used for comparison with the initial correlation relations and first RCA test results.

A second change in the test plan for the second RCA was that some runs would purposely be carried out at reduced boiler load. All the runs in the initial correlation tests and first RCA tests had been done at near full boiler load with a steam production rate of 268-291 K lb/hr. In RCA #2, the low load (LL) runs had steam production rates of 200-210 K lb/hr. Some runs were done at variable load (VL) where steam production was increasing or decreasing between the low load and full load steam rates.

As stated above, the primary purposes of the second RCA test was to compare the test results with the initial correlations developed previously from the initial correlation testing and with the first RCA test results. Results from the second RCA test (traversing Train A) are tabulated in Table 5-17 and have been plotted (red dots) on the graphs of the initial correlation results (black diamonds) along with results from the first RCA (blue triangles), as shown in Figure 5-5 A, B, and C and discussed below. (Detailed data for the second RCA test are contained in Volume 4, Appendices F and G.)

Figures 5-5A, B, and C show the initial correlation data (black diamonds) and the best fit equation (linear) along with a ± 25% tolerance interval, and also show the data points from both the first and second RCA. The initial correlation data met all the draft PS-11 criteria as discussed previously. However, data for three runs of the initial correlation were excluded since those runs appeared to be outliers, as was discussed in Section 5.3.4.1. Those 3 data points are included in Figures 5-5A, B, and C (green diamonds).

Table 5-17. Tabulation of Data from Second RCA Test

Tabulation of Second RCA Data for ESC P5B and Durag 300-40

Run no.	Concentration (mg/acm)	ESC P5B response (ma)	DR300-40 response (Range Adj: ma)
31	25.4	11.69	22.41
32	19.1	10.06	18.64
33	18.4	9.60	17.77
34	10.3	9.42	17.32
35	13.6	7.95	13.31
36	26.6	11.00	22.72
37	57.6	13.44	23.69
38	36.7	10.53	16.92
39	35.6	11.08	17.76
40	12.2	7.54	11.07
41	24.1	8.87	14.90
42	38.3	12.74	28.30

* Concentration measured by M17 Traversing Train (Train A) except Run 33 used average for the two traversing trains.

Tabulation of Second RCA Data for Durag F904K

Run no.	Concentration* (mg/dscm)	F904K Response (ma)
31	37.8	NA-probe broken
32	27.8	NA-probe broken
33	27.2	NA-probe broken
34	15.3	NA-probe broken
35	19.7	7.14
36	38.5	10.28
37	80.2	14.80
38	51.7	11.15
39	49.5	11.34
40	17.5	6.35
41	34.7	7.86
42	55.4	10.92

* Concentration measured by M17 Traversing Train (Train A) except Run 33 used average for the two traversing trains.

Figures 5-5A, B, and C include the results from the first RCA tests (blue triangles) and show that no more than 7 of the 12 runs in the first RCA test fell within the ± 25% tolerance interval of the initial correlation (EPA draft Procedure 2 specifies that 9 of 12 runs (75%) must fall within a ± 25% tolerance interval of the initial correlation). Only 1 of the 12 runs in the second RCA test fell within this ± 25% tolerance interval.

Therefore, the results from the second RCA were compared with results from the first RCA alone. That is, the first RCA data had been used for development of separate new correlations as discussed previously in Section 5.3.4.2. Even though these correlations did not meet the confidence interval and tolerance interval criteria for two of the PM-CEMS, they were used to evaluate the data from the second RCA.

As shown in Figures 5-6A, B, and C, no more than 6 of the 12 runs from the second RCA fell within a ± 25% tolerance interval of the first RCA correlation relation. The next section of this report presents an investigation of possible reasons for the non-agreement of the results from both the first and the second RCA.

5.3.5 Investigation of Reason(s) for Non-agreement of RCA Results

It was originally recognized that the location of the PM-CEMS very near the outlet of the baghouse compartments was not the most desirable location since it only minimally met the PS-11 guidance (i.e., only two duct diameters downstream of a 90° bend). However, it was the only possible location at this facility to install three PM-CEMS and a moisture monitor. The location had a potential for particulate stratification, but this was not thought to be a serious problem since much of the large particulate would have been removed from the flue gas by the mechanical dust collector and dry SO_2 absorber upstream of the baghouse. It was also thought that if particulate stratification existed it would be constant.

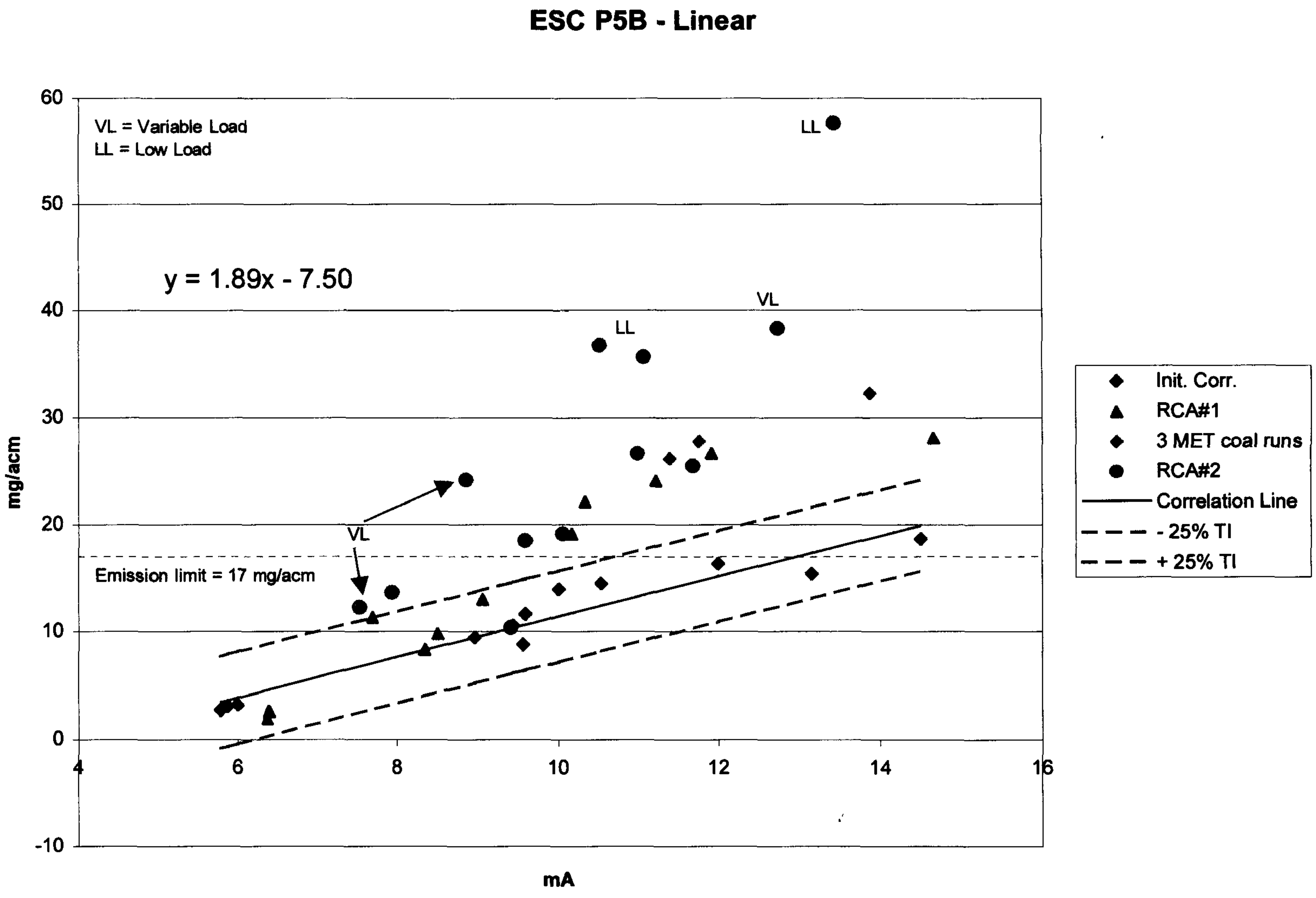


Figure 5-5A. ESC-P5B Initial Correlation and all RCA Data

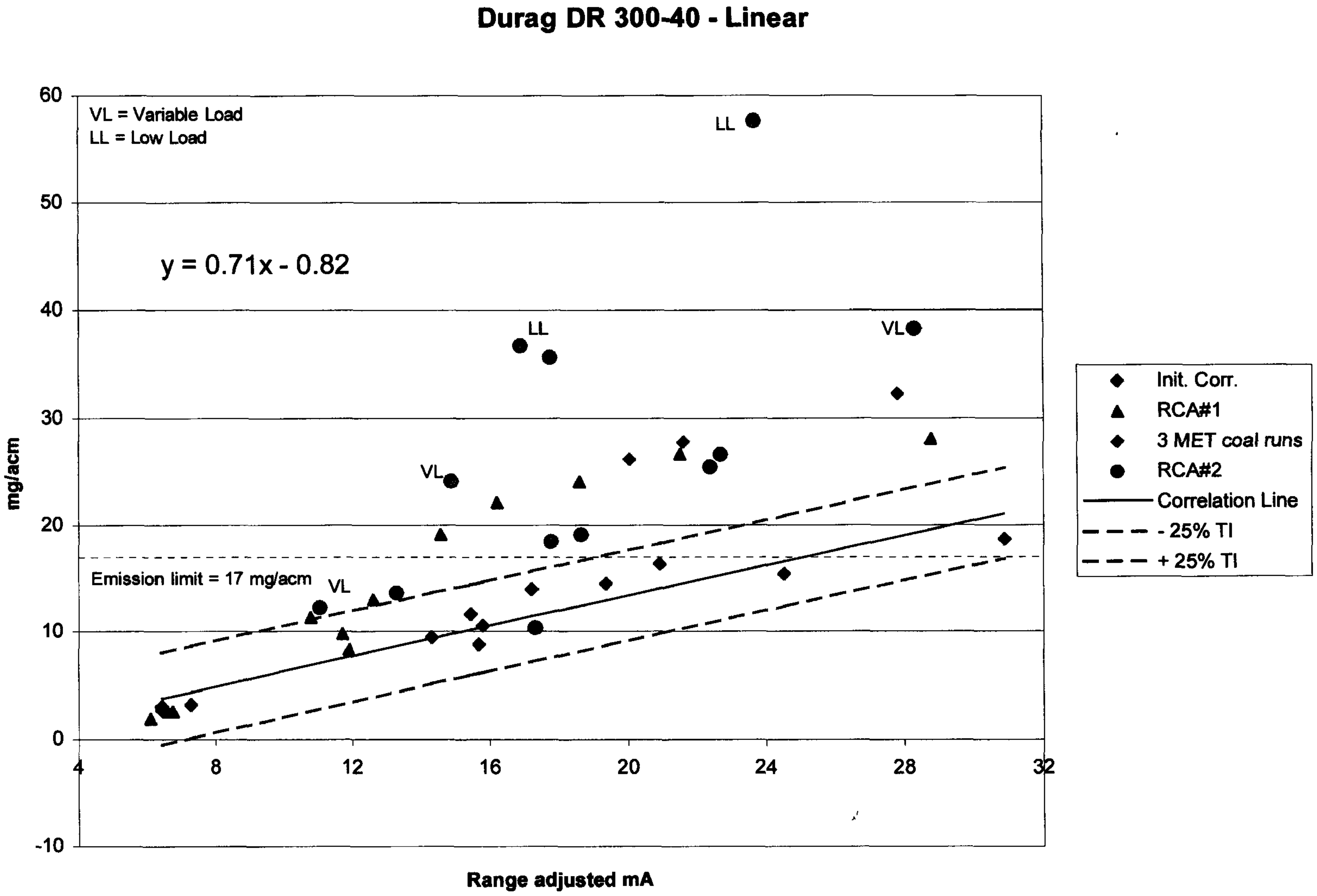


Figure 5-5B. DR300-40 Initial Correlation and all RCA Data

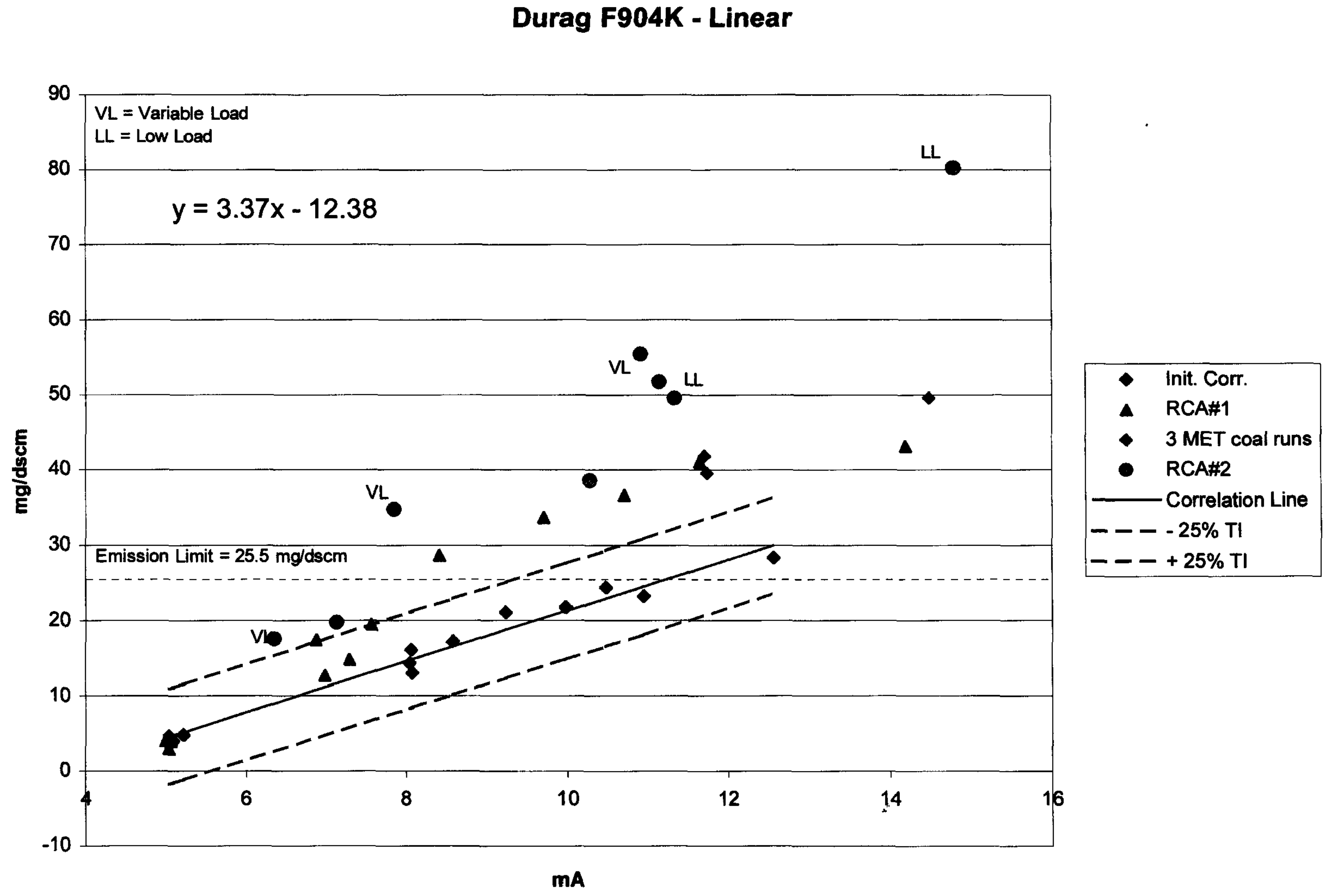


Figure 5-5C. F904K Initial Correlation and all RCA Data

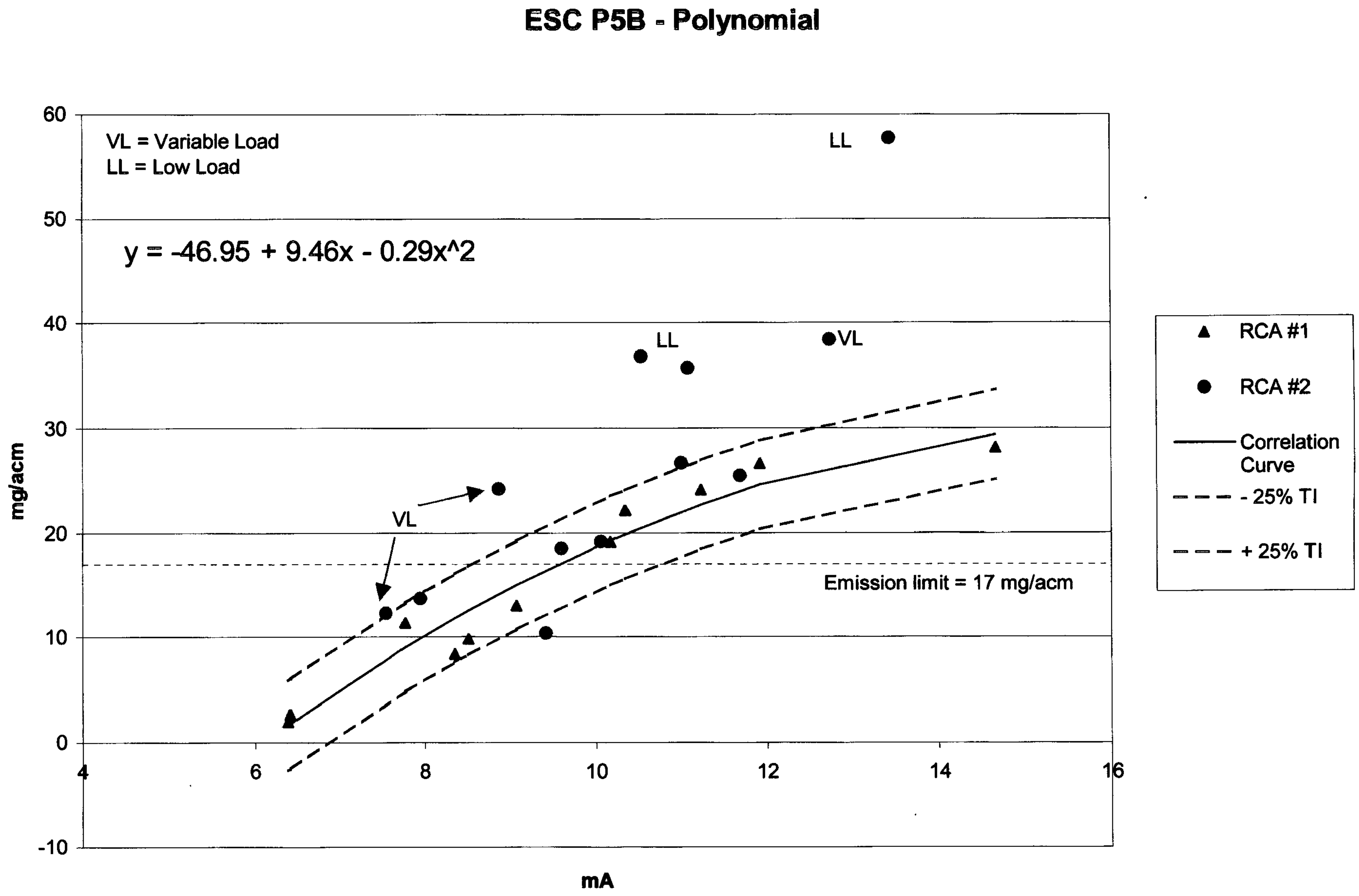


Figure 5-6A. ESC-P5B Correlation for First RCA, and Comparison with Data from Second RCA

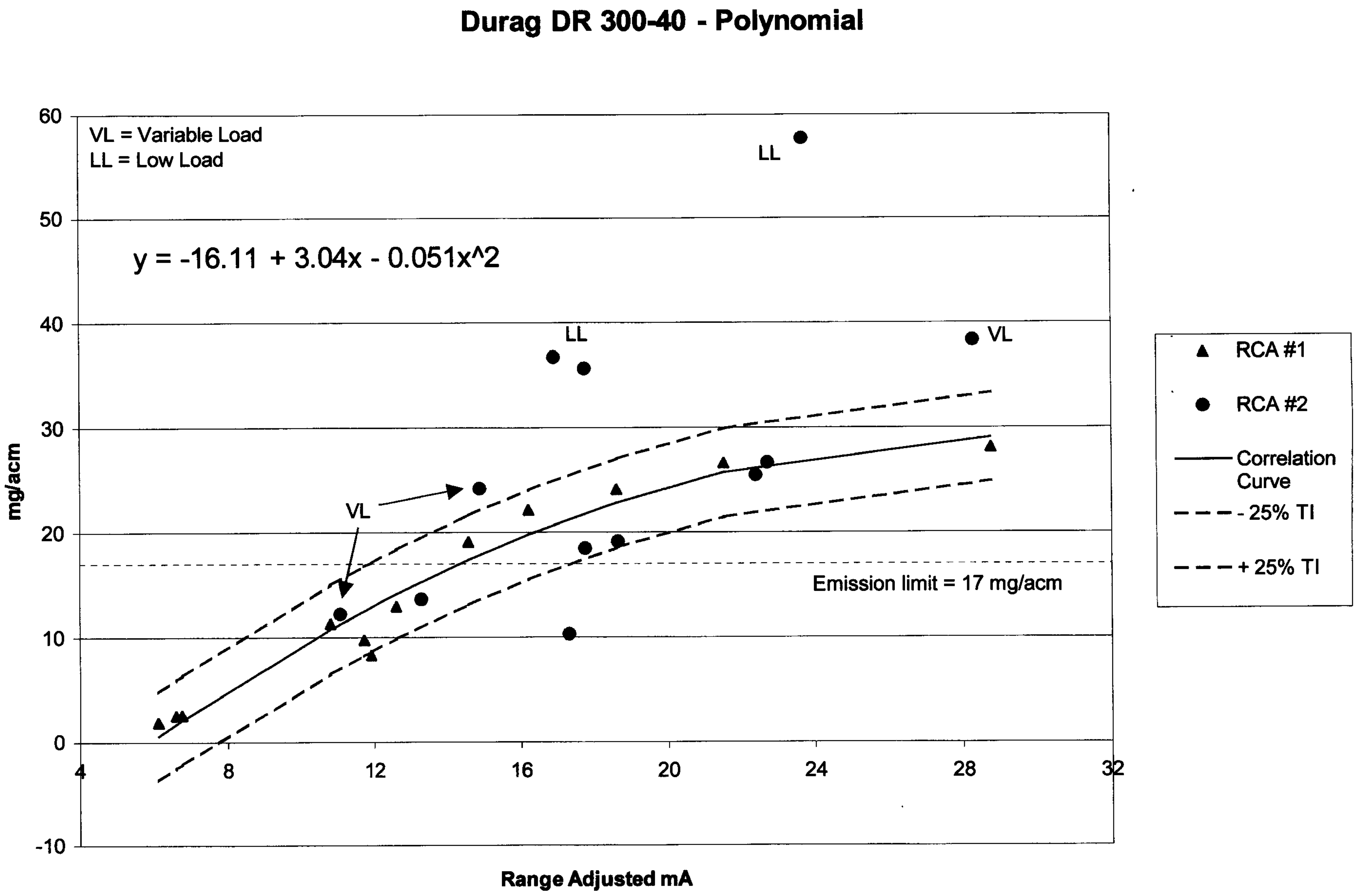


Figure 5-6B. DR300-40 Correlation for First RCA, and Comparison with Data from Second RCA

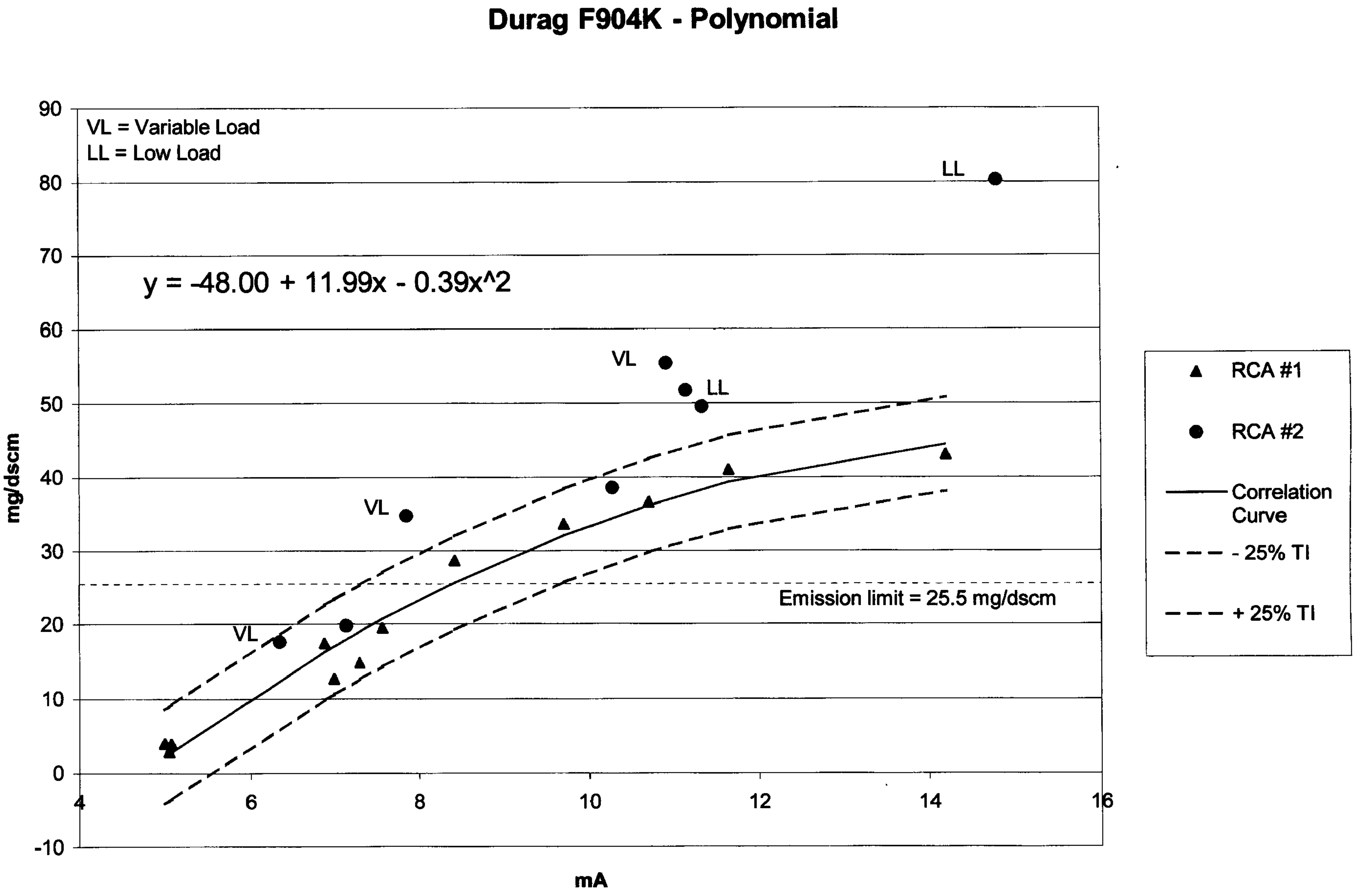


Figure 5-6C. F904K Correlation for First RCA, and Comparison with Data from Second RCA

That is, stratification would not be a problem if the ratio of the particulate concentration at any single point in the duct was constant, relative to the average concentration in the duct. If this ratio was constant, the concentration that existed at any single point (i.e., PM-CEMS location) would be proportional to the average concentration as measured by a traversing train.

Investigation of possible reasons for why the RCA results did not meet the draft Procedure 2 criteria relative to the initial correlation test results is discussed in the following subsections and included the investigation of:

- Differences in velocity distribution
- Spikes in PM-CEMS response and causal relation between baghouse cleaning cycle and operation/location of perturbing device
- Particulate concentration ratio for single point train versus traversing train

It should be noted that the results from each RCA showed similar patterns for all three PM-CEMS (i.e., higher emissions relative to PM-CEMS response). This indicated that changes in particulate characteristics (e.g., size distribution, etc.) probably were not the cause of non-agreement of RCA results, since beta-gauges are not believed to be affected by such changes.

5.3.5.1 Velocity Distribution

The initial correlation test data showed that the velocity distribution across the duct was highly skewed, with the highest velocity toward the duct wall opposite the M17 test ports and the PM-CEMS (see Figure 2-1). An example of this skewed velocity distribution is shown in Figure 5-7. Velocity measurements (made through the middle sampling port C) show that the velocity ranges from nearly 1800 meters/minutes (m/min) down to only 200-300 m/min nearest the M17 sampling ports (i.e., Point C1).

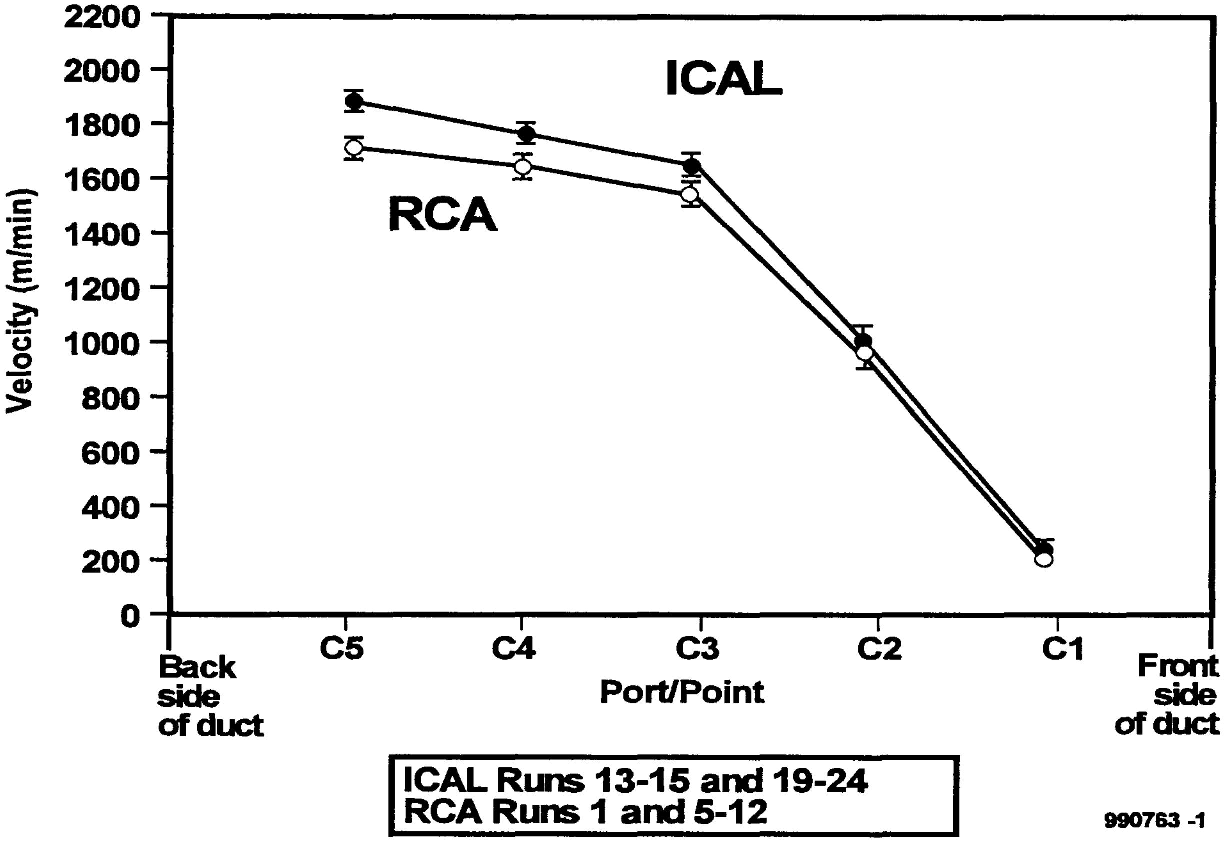


Figure 5-7. Velocity at Traverse Points through Port C—ICAL vs. First RCA

Data like those in Figure 5-7 also show that at the points of highest velocity (C5-C3) the velocity measured during the initial correlation tests was somewhat higher than that measured during the first RCA. This led to a suspicion that the lower velocity in the first RCA test might also be associated with a change in particulate stratification. If so, this might be the reason why the results from the first RCA did not fall within the tolerance interval of the initial correlation data. This was investigated further in the second RCA test, where particulate stratification was measured with a single point and traversing trains, at different velocities (i.e., different loads) as discussed in Section 5.3.5.4.

5.3.5.2 Spikes in PM-CEMS Response

It had been observed during all of the tests that there were spikes in the response of the two light scatter PM-CEMS (ESC-P5B and Durag DR300-40). It was also observed that the spikes were much larger when the perturbing device was open in order to obtain higher concentrations. Moreover, the spikes occurred every 24 minutes with a 4 minute offset between the spike for the ESC-P5B and the DR-300-40. This phenomenon is shown in Figures 5-8A and 5-8B.

Figure 5-8A for November 15 shows the response for the two PM-CEMS over time, when the perturbing device was closed so particulate concentration was low (about 2 mg/acm). The peaks from both monitors occur at the same time and represent relatively small changes in particulate concentration (approx. 0.20 mg/acm). These peaks are likely caused by the brief puff of particulate when a cleaned compartment is first opened. Figure 5-8B for November 17 shows the response of the two PM-CEMS when the perturbing device was open so particulate concentration was high (about 12 mg/acm). The peaks are much greater (about 4-6 mg/acm) and occur every 24 minutes, with the peak for the ESC-P5B occurring 4 minutes after the peak for the DR300-40.

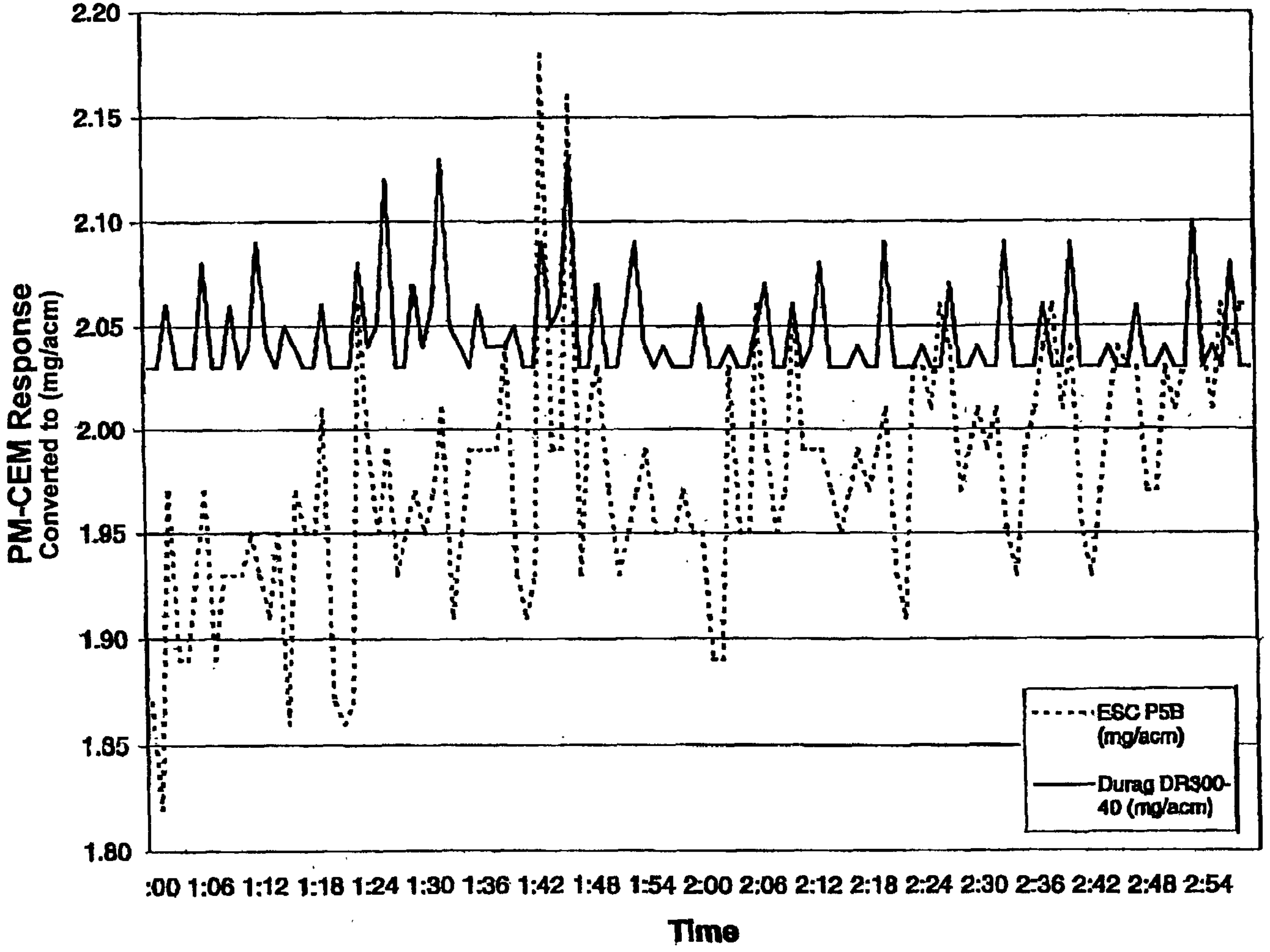


Figure 5-8A. November 15, 1999: Perturbing Device Closed

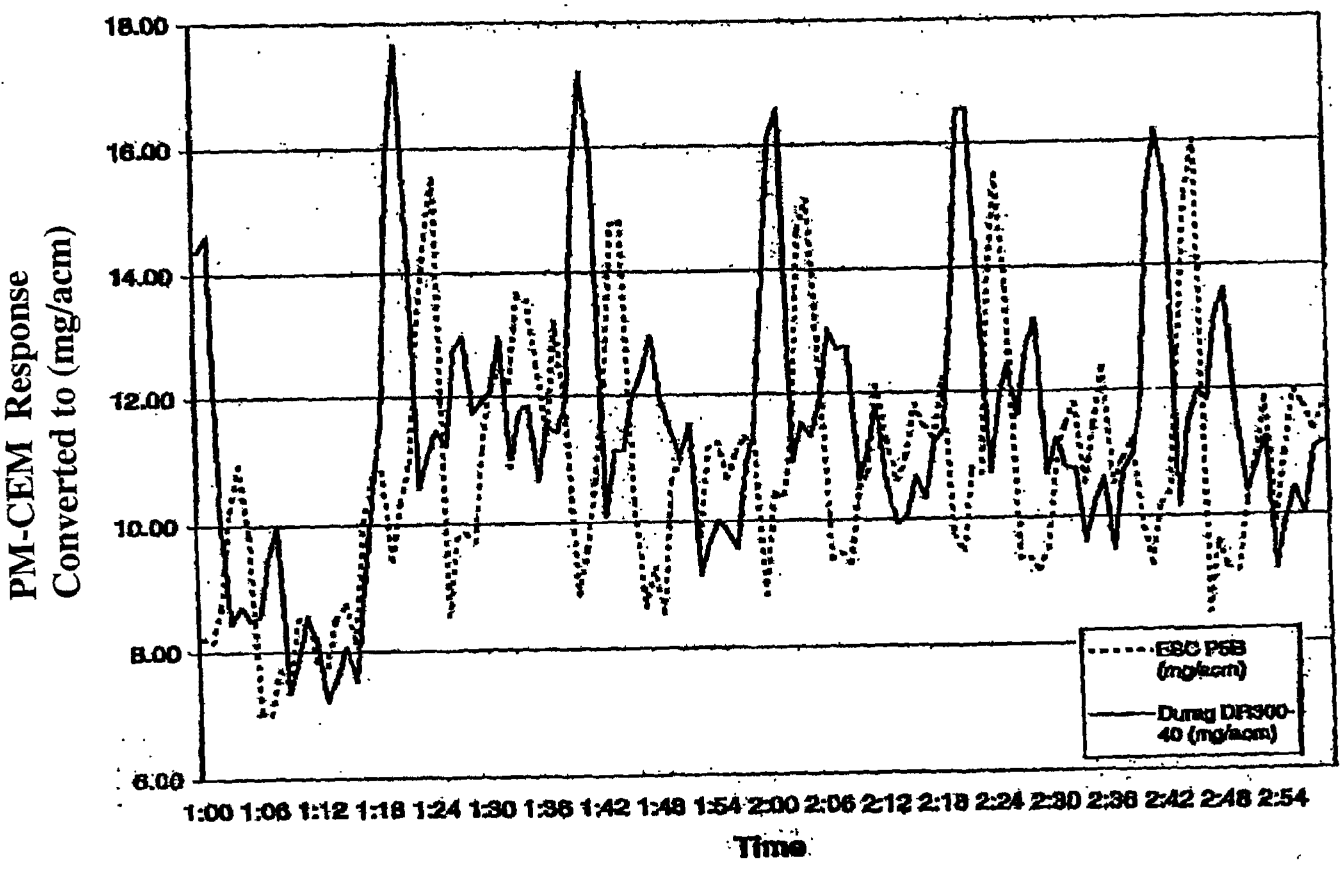


Figure 5-8B. November 17, 1999: Perturbing Device Open

The normal behavior of a baghouse is that there is a PM spike from a freshly cleaned compartment for a brief time until the dust cake on the compartment bags is re-established. However, this is not consistent with what is shown in Figure 5-8B. Moreover, the spike is too large to be attributed to the brief spike that occurs after a compartment cleaning. Rather, the phenomena is caused by the baghouse cleaning cycle and its effect on the particulate from the perturbing device, as explained below.

5.3.5.3 Effect of Baghouse Cleaning Cycle on Spikes in PM-CEMS Response

In order to understand the cause of the peaks in the response of the two light-scatter type PM-CEMS, it is necessary to understand the baghouse geometry, the cleaning cycle, and the location of the perturbing device.

Figure 5-9 is a schematic top view of the baghouse outlet duct and outlet ducts from each baghouse compartment. There are six baghouse compartments, and the outlet from each is connected to the common outlet duct. The ducts from each compartment contain a damper (valve) that closes whenever that compartment undergoes a cleaning cycle. Each compartment is cleaned for 4 minutes, so the cycle for all six compartments is 24 minutes.

Figure 5-9 also shows the location of the perturbing device, a 6-in. diameter pipe which is connected into the bottom of the baghouse outlet duct. The other end of this pipe is connected to the inlet duct to the baghouse. There is a butterfly valve in the 6-in. diameter pipe which provides a means of regulating the amount of particulate that bypasses the baghouse, flowing directly from the inlet duct to the outlet duct. The purpose of this bypass was to increase the PM concentration, simulating a broken bag. However, as mentioned in Section 2.1, the location of the perturbing device may not have been sufficient to allow complete mixing with the baghouse effluent prior to the location of the PM-CEMS.

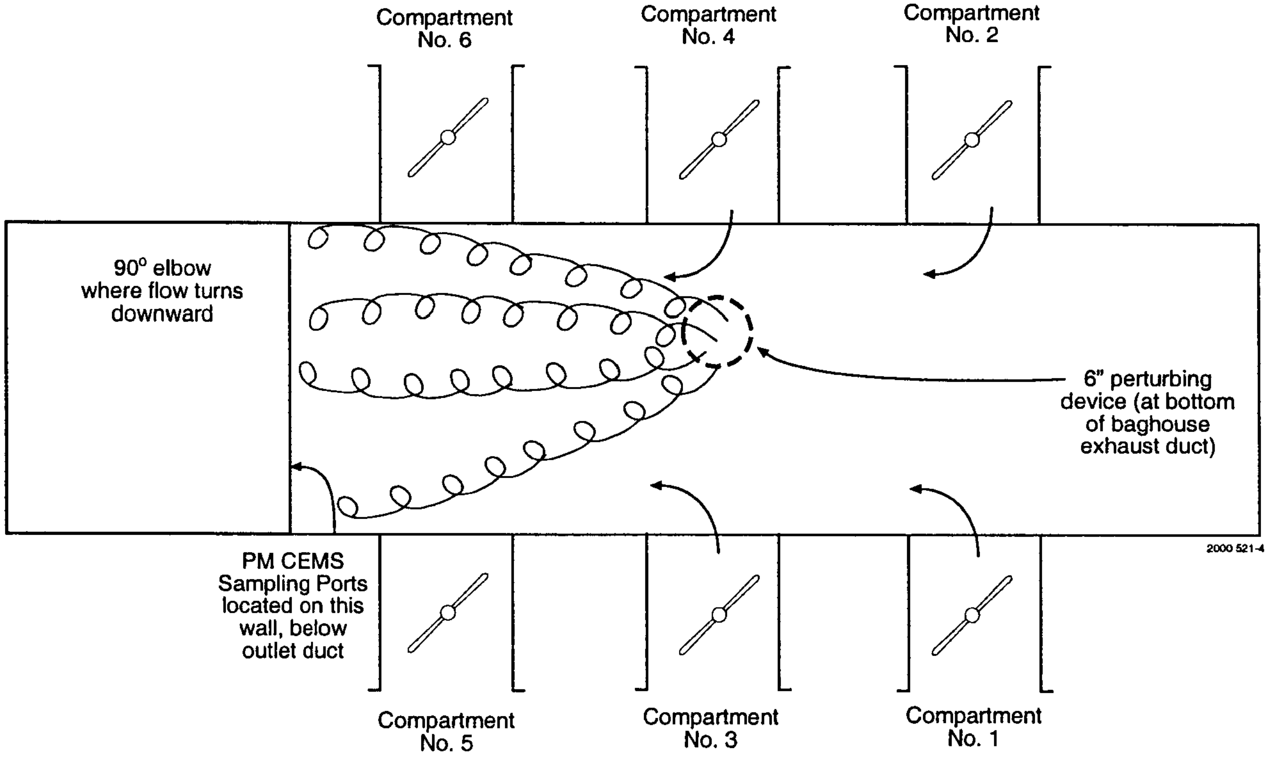


Figure 5-9. Top View of Baghouse Outlet Duct

"Dirty" gas passing through the perturbing device has a very high particulate concentration, probably 100 to 1,000 times the concentration in the baghouse outlet ducts. The intent is for this dirty gas to mix thoroughly with the clean gas in the baghouse outlet duct prior to the location of the PM-CEMS. This is most difficult to achieve when compartment 5 or 6 undergoes cleaning. When the compartment 5 damper closes at the beginning of its cleaning cycle, the clean gas from the open compartment 6 pushes the higher particulate gas in the common outlet duct toward the compartment that is closed (No. 5), causing a sudden rise in response of the Durag DR 300-40 located in the same side of the duct until the air flow pattern becomes stable. Four minutes later, the No. 5 damper reopens and the opposite damper (No. 6) closes, pushing the higher particulate gas in the opposite direction, toward compartment 6, and causing a peak in the response of the ESC P5B located on the other side of the duct until the air flow pattern becomes stable again.

This phenomenon was observed during all the tests when the bypass was open and helped to explain the peaks in the PM-CEMS response and the offset between those peaks.

This analysis shows that the location of the PM-CEMS relative to the location of the perturbing device is just as important as their location relative to the outlet of the control device. That is, if a perturbing device is used to bypass gas around a control device in order to increase outlet particulate concentration, then the PM-CEMS must be located far enough downstream of the point where the low and high concentration gases come together for them to become well mixed before the gas reaches the PM-CEMS (and the M17 sampling points). Also, devices which can introduce dilution air or otherwise disturb the air flow pattern must be well upstream of the PM-CEMS sampling location.

5.3.5.4 Particulate Concentration Ratio for Single Point Train versus Traversing Train

Data for the single point train (B) and traversing train (A) used in the second RCA tests are presented in Table 5-18, including the calculated ratio for the two trains in each

Table 5-18. Tabulation of Data for Single Point Train Versus Traversing Train

Run no.	Load	B-Single point (mg/dscm)	A-Traversing (mg/dscm)	Ratio (B/A)
31	High	23.7	37.8	0.627
32	High	17.5	27.8	0.630
33	Precision run	NA	NA	—
34	High	16.7	15.3	1.092
35	High	11.2	19.7	0.569
36	High	22.6	38.5	0.587
37	Low	51.1	80.2	0.637
38	Low	33.5	51.7	0.648
39	Low	34.1	49.5	0.689
40	Variable	14.7	17.5	0.840
41	Low—High	20.0	34.7	0.576
42	Variable	32.8	55.4	0.592

run. These data are also presented graphically in Figure 5-10, and show that the ratio was essentially constant, covering a narrow range of ratios from 0.569 to 0.689 over a wide range of particulate concentration, except for 2 of the 11 runs (Runs 34 and 40). It can be concluded from these results that the particulate is stratified (i.e., single point values are different from the traversing train values), but that the stratification was essentially constant except in 2 runs (Runs 34 and 40) (i.e., the ratio varies over a narrow range in most runs, even for a wide range in particulate concentration). This indicates that a change in boiler load did not have much effect on particulate stratification.

All of the initial correlation tests and first RCA tests were done at full load (steam flowrates of 268-291 K lb/hr). In the second RCA, six of the tests were done at full load while the other six were done at reduced or variable load (see Volume 4, Appendix A). Results for five of the six full load tests done in RCA #2 fell within the ± 25% tolerance interval of the RCA #1 correlation relation, with stratification ratios varying over a narrow range of 0.57 to 0.63. The other high load test (Run 34) had a higher ratio of 1.09, and the results for that run fell within the ± 25% tolerance interval of the initial correlation relation. Thus, a change in the stratification ratio may be a possible explanation for why the RCA #1 correlation was different than the initial correlation.

Five of the six reduced load tests had stratification ratios about the same as the full load tests, but fell outside (above) the ± 25% tolerance interval of both the initial correlation relation and RCA #1 correlation relation. This suggests that the two light scatter monitors responded differently to the particulate at reduced load as compared to high load. If this was due to changes in the light scatter characteristics of the particulate (e.g., different particle size distribution), then light scatter type PM-CEMS may not be appropriate for sources that change load or otherwise make changes that affect light scatter characteristics of the particulate.

The above represents a possible explanation for why the data for the light scatter monitors at the five reduced load tests did not match either of the two tolerance intervals, but it does not explain why the results for the F904K beta gauge also did not fall within

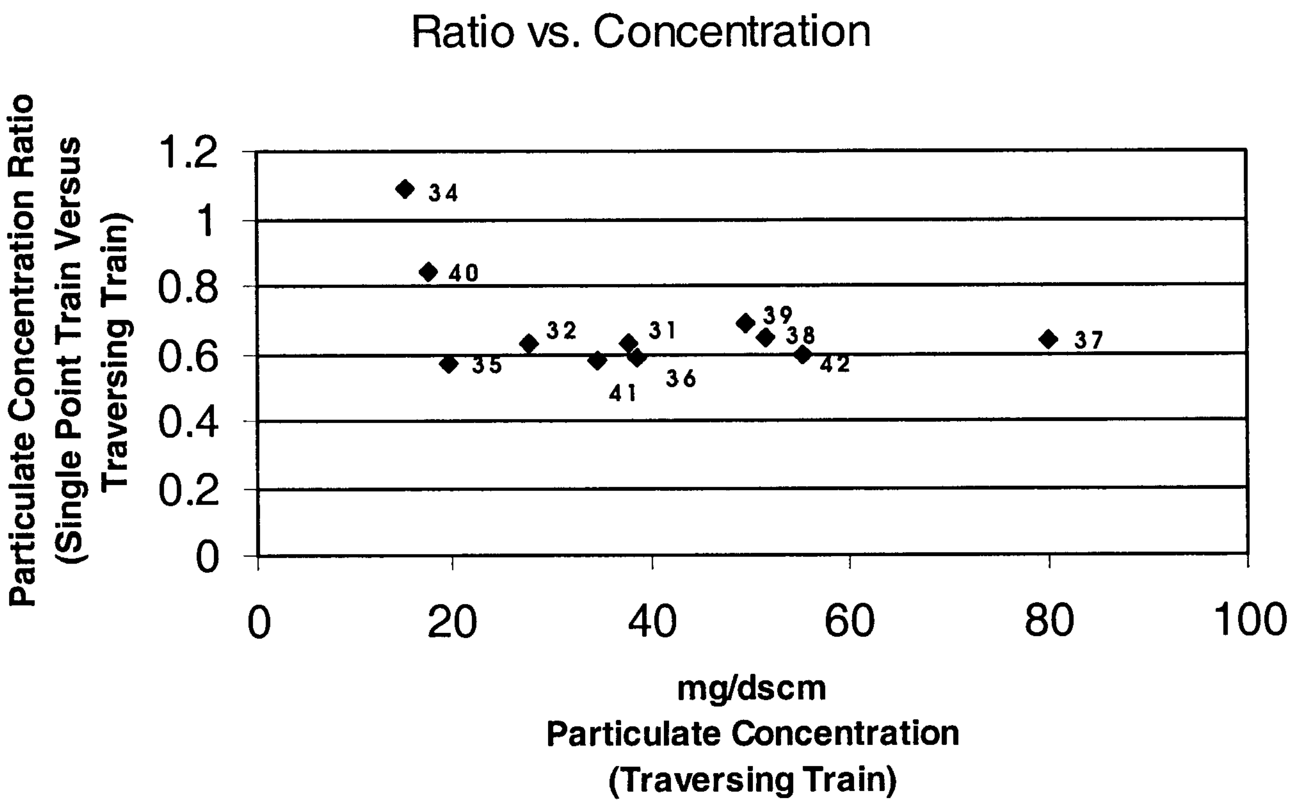


Figure 5-10. Particulate Ratio vs. Concentration

either tolerance interval since beta-gauges are not supposed to be susceptible to changes in particle characteristics. However, the reduced load tests did involve lower duct velocities, which affect the isokinetic sampling rate of the beta gauge. The beta gauge samples at a constant rate and was installed to sample near isokinetically at full load (i.e., the normal operating condition). Therefore, at reduced load it samples at a rate higher than isokinetic, which could produce a low bias in the concentration of particulate sampled by the beta gauge, and thus a lower than expected response.

It should be noted that a difference in the particle size distribution between the full load and low load tests may have been caused by the perturbing device rather than an actual change in the process. That is, the gas in the baghouse inlet duct must make a 90° change in direction in order to enter the perturbing device (6" pipe). At full load (high duct velocity), it is more difficult for larger particles to make this change in direction; but at low load (lower duct velocity), more of the larger particles could enter the perturbing device (i.e., the particulate size distribution at low load would shift to more large particles). This is consistent with the discussion in the above two paragraphs, but no particle size measurements were done in any of the tests.

5.3.5.5 Summary

Results from the second RCA confirmed that the velocity distribution is highly skewed, and that the particulate concentration was stratified but was relatively constant over 9 of 11 runs done in RCA #2. Investigation of spikes in the response of the two light-scatter PM-CEMS certainly indicated that there is short-term variability in the particulate stratification, but such variability is apparently dampened out over the M17 sampling periods of 75 to 100 min. This dampening of short-term variability is evidenced by the narrow range of stratification ratios measured during 9 of the 11 runs in RCA #2 and by the fact that the dual M17 trains used in the initial correlation tests and RCA #1 tests met all of the precision and bias criteria per draft Procedure 2.

The primary purpose of the RCA #2 tests was to obtain data on particulate stratification at full load and reduced load in order to try to determine why the RCA #1 results did not meet the draft Procedure 2 criteria relative to the initial correlation relation. The discussion in Section 5.3.5.4 provides a possible explanation for that finding, but it does not change the fact that the RCA #1 and RCA #2 test results did not meet the draft Procedure 2 criteria.

It is clear that the location of the PM-CEMS was less than ideal, but the location selected was the only suitable location available at this facility. This location minimally met the guidance in draft PS-11. Thus, the inability to meet the draft Procedure 2 criteria in the two RCA tests may have been due, at least in part, to the location of the PM-CEMS rather than the PM-CEMS themselves.

The low load tests done in RCA #2 do indicate possible limitations in the PM-CEMS. That is, if changes in process operating conditions cause changes in particle size distribution, the light scatter PM-CEMS may respond differently to the same particulate concentration. Further, if changes in process operating conditions cause changes in flue gas flowrate, then extractive PM-CEMS, that do not maintain isokinetic sampling, may also respond differently to the same particulate concentration.

One peer reviewer of the report commented that the data suggest that several different correlations exist, but except for the 3 "met coal" runs, there was no indication of changes in the coal or process operating conditions between the 3 sets of tests that would produce different correlations.

One peer reviewer seemed convinced that the non-agreement of the two RCA results with the initial correlation was entirely due to the location of the PM-CEMS relative to the baghouse outlet and perturbing device (i.e., stratification). But, conversely, another reviewer stated that he did not think, based on the information shown, that stratification at the PM-CEMS location could be the cause of the non-agreement. These peer review comments and the discussion presented above demonstrate that no definite conclusion can be made as to the cause of the non-agreement of the results from the RCA tests with the initial correlation, and thus, inability to demonstrate long-term stability of the initial correlation. But, this finding and many other results from the project have been very useful in enabling recommendations for several changes in draft PS-11 and draft Procedure 2, which should be published as a supplementary proposal in the Federal Register in the near future.

Section 6.
Internal QA/QC Activities

6.1 QA/QC Issues

The QA/QC issues are discussed below for the initial correlation tests, first RCA, second RCA, and final ACA.

6.1.1 Initial Correlation Test

Two QA/QC issues occurred during the initial correlation testing as described below:

6.1.1.1 Re-ranging of PM-CEMS

After the first 9 runs it was clear that the range on the three PM-CEMS was too broad, considering the facility's particulate emission limit (~ 17 mg/acm). It was therefore necessary to change (decrease) the range on the CEMS. This necessitated performing the entire set of 15 runs after the range on the PM-CEMS had been changed.

6.1.1.2 Difference in M17 Moisture Contents

It was observed that the moisture content determined in the dual M17 trains sometimes differed by as much as 2.0% H_2O (e.g., 12.2% vs. 14.2% in Run 17). This might have been caused by using an H_2O squirt bottle to identify sources of leaks in an impinger train that did not pass initial leak check. However, even when that had not been done, the difference in some runs was higher than expected.

Investigation of the problem revealed that additional water flowed into the first impinger if the latex transfer line was elevated to help draw water out of the line, while maintaining flow of air through the sampling system using the sampling console pump. (This was done after the end of a run and after completing all leak checks.) This procedure was used in all runs after Run 18, and in the later RCA tests, as well as eliminating the use of water in troubleshooting any leak check problems.

It should be noted that investigation of two sets of similar multiple train data from other stack tests revealed that moisture differences of at least 1% H_2O have occurred for a moisture level of 10-15%, and differences of at least 2% for a moisture level of ~ 50%. In both sets of data the filter/impinger box was directly connected to the probe, or a heated Teflon transfer line was used to connect the probe to the filter/impinger box.

In many emission tests, the moisture content is of minimal importance when particulate emissions are in terms of mg/dscm. However, moisture content does affect conversion to other units (e.g. mg/acm).

An error of 1% H_2O causes a similar error (1%) in converting mg/dscm to mg/acm, for a moisture level of 10% in the gas. However, an error of 1% H_2O causes an error of about 2% in the conversion to mg/acm, for a moisture level of 50% in the gas. Moreover, examination of other test data indicated that in high moisture stack gas, the difference in H_2O measured by dual trains can exceed 1% H_2O (up to as much as 2.3% H_2O).

6.1.2 First RCA Test

No QA/QC problems or issues occurred during the first RCA tests.

6.1.3 Second RCA Test

There were some operational and maintenance problems with the CEMS during the second RCA, primarily the H_2O CEMS and the F904K PM-CEMS, as discussed earlier in this report. No other QA/QC problems occurred during the second RCA/ACA testing.

6.1.4 Final ACA

After the second RCA (November 16 to November 20, 1999) the logging of data from all the PM-CEMS continued to the end of the 6-month endurance test period (February 16, 2000). Near the end of that period (February 7, 2000) a final ACA and SVA was carried out. Although there was some maintenance performed to correct operational problems on some of the CEMS during this period (as discussed previously), there were no QA/QC problems.

6.2 QA Audits

Absolute correlation audits of the two light scatter PM-CEMS were performed four times during the 6-month endurance test, as discussed previously in Section 5, using audit materials supplied by the vendors (no audit materials were available for the Durag F904K). In addition, all three PM-CEMS automatically perform a daily calibration drift check. The ESC P5B was the only one that sometimes exceeded the drift criteria of ≤ 4% of the upscale value, but corrective action prevented it from exceeding the 4% criteria for 5 consecutive days (i.e. the out-of-control criteria). Also, four sets of sample volume audits were performed on the Durag F904K, which met the criteria of ±5% of the audit value (i.e., volume measured by the calibrated dry gas meter).

For all the M17 sampling, the crew chief reviewed all of the raw data sheets, and these were also spot checked by the WAL. Post-test calibration checks of the sampling meter boxes were performed using calibrated critical orifices after the initial correlation and the two RCA tests. Results for both meter boxes were within the acceptable range of 5% after each set of tests. These QA checks, as well as those for thermocouples, barometer, and pitot tubes are contained in Appendix E.

An audit of the initial correlation relationship was also carried out. This consisted of an independent calculation of all statistical results for one PM-CEMS by an MRI statistician. That is, the M17 results and the average response for the Durag beta gauge, for all 12 runs, were used to carry out all the statistical calculations per PS-11. These independently determined results were then compared with those computed for the initial correlation relations. Some minor discrepancies were identified and corrected, including any that affected results for the other two PM-CEMS.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

This final report describes an extended field demonstration of three particulate matter (PM) continuous emission monitoring systems (CEMS) at a coal-fired boiler equipped with a lime slurry scrubber and baghouse for air pollution control. The primary objectives of the field study were to: (1) demonstrate whether the PM CEMS could provide reliable and accurate data over an extended period, (2) evaluate the PM CEMS for durability, data availability, and setup/maintenance requirements, and (3) determine whether the PM CEMS satisfy all the requirements of draft PS-11 and the quality assurance (QA) criteria specified in draft Procedure 2, or determine if changes are needed in the requirements of PS-11 and/or Procedure 2. This report presents the results of the study involving two different PM CEMS technologies (light scatter and beta gauge) at the coal-fired boiler. The report consists of five separate volumes.

7. KEY WORDS AND DOCUMENT ANALYSIS

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