PROPOSED

COMPLIANCE ASSURANCE MONITORING (CAM) PROTOCOL
FOR AN ELECTROSTATIC PRECIPITATOR (ESP) CONTROLLING
PARTICULATE MATTER (PM) EMISSIONS FROM A COAL-FIRED BOILER

I. Introduction

The purpose of this protocol is to outline procedures for the development, verification, operation, and ongoing maintenance of a continuous monitoring approach sufficient to demonstrate a reasonable assurance that an ESP used to control the PM emissions from a coal-fired electric utility facility operates in compliance with the applicable PM emission limits. The protocol is not intended to address the monitoring of compliance with other applicable emissions limits, such as for opacity, SO_2, NO_x, or CO. Other monitoring approaches are necessary to address compliance demonstrations for pollutants other than PM from these facilities.

This protocol provides a monitoring approach that you may use to comply with the Compliance Assurance Monitoring (CAM) Rule (40 CFR Part 64) or with 40 CFR Part 70 or 71 periodic monitoring requirements for PM. Monitoring designed and operated in accordance with this protocol is "presumptively acceptable" monitoring for an ESP controlling PM emissions from a coal-fired boiler with an exhaust stack equipped with a continuous opacity monitoring system (COMS). Monitoring identified by EPA as presumptively acceptable monitoring satisfies the requirements of the CAM Rule's monitoring design criteria. These requirements include both general criteria and performance criteria. The general criteria set guidelines for:

(a) Designing an appropriate monitoring system; and

(b) Setting the appropriate indicator range(s).

The performance criteria require:

(a) Data representativeness;

(b) A method to confirm the operational status of the equipment (for new or modified equipment only);

(c) Quality assurance and quality control procedures; and

(d) Specifications for the monitoring frequency and data collection procedures.

If this protocol is applicable to your facility's type of emissions unit and add-on control device, you may propose presumptively acceptable monitoring without additional justification, referring instead to the EPA CAM Technical Guidance Document[1] and related publications for justification, provided you design and operate your monitoring according to the protocol. For new or modified monitoring systems, you also must submit information on the method to be used to confirm the operational status of the monitoring equipment when it is put into service.

Use of this protocol is not required; you as source owners and operators may propose other PM monitoring approaches for ESP's controlling coal-fired boilers. Presumptively acceptable monitoring is not prescriptive. You may choose to modify the protocol; however, you must submit a rationale for the modification along with your permit application and the modification must be accepted by the permitting authority. For example, if you wanted to use an averaging period other than 1 hour for the opacity indicator range, you would have to submit data supporting the use of a different averaging period to the permitting authority for approval.

II. Applicability

This presumptively acceptable CAM protocol is applicable to monitoring of ESPs controlling PM emissions from coal-fired boilers. The ESP exhaust stack must be equipped with a COMS for this protocol to apply. This protocol assumes that you are familiar with the setup and use of an ESP computer model and does not go into details that are covered by the individual models' user manuals.

III. Monitoring Approach

The key elements of the monitoring approach, including the indicators to be monitored, indicator ranges, and performance criteria, are presented in Table 1. The CAM performance indicator is the output of a calibrated ESP computer model that calculates a site-specific ESP performance indicator related to PM emissions control levels (e.g., PM control efficiency) from measured ESP operating parameters (e.g., voltage and current for each field) and other ESP-specific "fitting factors" (e.g., velocity standard deviation, sneakage fraction, and rapping reentrainment fraction). Sneakage is the fraction of gas that bypasses the collection zone; that fraction experiences no collection. The rapping reentrainment fraction is the fraction of material that is reentrained into the gas flow with each rap. There are three available models that are acceptable for use with this monitoring protocol.[2-4] Application of the ESP computer model is initiated by COMS measurements in excess of the opacity indicator range.

The output of the ESP performance model may be shown as a computer display or printout. For purposes of this protocol, the output may be converted to and reported as an ESP control efficiency. The ESP performance model output is compared with a preestablished indicator range (e.g., minimum acceptable control efficiency) that, based on site-specific testing and ESP equipment evaluation, provides a reasonable assurance of compliance with the applicable PM emissions limit. Findings of ESP performance model indicator values beyond the specified indicator range trigger corrective action and reporting obligations.

IV. Rationale for Selection of Performance Indicators[5,6]

There are several ESP parameters that can be used as indicators of ESP performance; however, the relationship between these parameters and actual PM emissions is subject to considerable variability. For example, opacity, a commonly used parameter, can indicate ESP performance. If the opacity is increasing, you can reasonably assume that PM emissions are increasing. What generally is not known on a quantitative basis is the magnitude of the mass emissions relative to any one opacity value or the increase in mass emissions relative to the increase in opacity. In addition, and perhaps most importantly, the relationship between opacity and mass emissions can vary significantly with the particle size distribution and refractive index of the ash particles. The properties of the particulate matter can be influenced by fuel changes and the number and location of ESP electrical sections in service. However, for any given ESP and boiler, opacity can serve as a very useful indicator to initiate additional action on your part.

The ESP power is another indicator of ESP performance. Lower power generally indicates poorer performance; however, total ESP power is not necessarily a reliable indicator because most ESPs are segmented into many electrical sections. The overall ESP performance depends on which electrical sections are in service and the power consumption of each section relative to its physical position in the ESP.

TABLE 1. MONITORING APPROACH

I. Indicator	Opacity of ESP exhaust.	Output of ESP computer model.
Measurement Approach	COMS in ESP exhaust.	When the opacity is outside the indicator range, enter ESP operating parameters (e.g., voltage, current for each field) into a calibrated ESP computer model to calculate ESP control efficiency.
II. Indicator Range	Establish the opacity indicator range at or below an opacity level where the ESP has demonstrated at least a 10 percent margin of compliance with the PM limit. Select an hourly average opacity value to prevent momentary process perturbations from causing an excursion (other averaging times may be selected if justified). When the average opacity is outside the indicator range, no reporting or corrective action is required for the PM limit, but the ESP computer model must be run.	The indicator range is a model output (ESP control efficiency) that provides a reasonable assurance of compliance with the PM emissions limit, taking into account the quality and quantity of data used to calibrate the model. When an excursion occurs (ESP efficiency lower than the chosen indicator range), corrective action is initiated to bring the unit back within the opacity indicator range. ESP model excursions also trigger a reporting requirement.
III. Performance Criteria A. Data Representativeness	Install the COMS at a representative location in the ESP exhaust per 40 CFR 60, Appendix B, Performance Specification 1 (PS-1) [note that the revised version of PS-1 applies only to new or relocated opacity monitors].	The model is calibrated using PM emissions testing performed on the ESP and operating data collected during testing. A minimum of 3 test runs are conducted at each of 3 opacity/PM levels.
B. Verification of Operational Status	Results of initial COMS performance evaluation conducted per PS-1.	Results of PM emissions tests conducted to calibrate the model.
C. QA/QC Practices/Criteria	Install and evaluate the COMS per PS-1. Check the zero and span drift daily and perform a quarterly filter audit.	Reverify the model calibration if operating conditions (e.g., coal rank) change. Calibrate voltmeters and ammeters at least annually.
D. Monitoring Frequency	Monitor the opacity of the ESP exhaust continuously (every 10 seconds).	Run the model when the hourly average opacity is outside the indicator range. If corrective action does not return the hourly average opacity to a level within the opacity indicator range, run the model every 3 hours to evaluate ESP control efficiency.
Data Collection Procedures	Set up the data acquisition system (DAS) to retain all 6-minute and hourly average opacity data.	Retain all records of ESP, boiler, and coal parameters collected for model runs. Retain all printouts or electronic copies of the results of all model runs. Report the results of the model runs that exceed the ESP efficiency indicator range.
Averaging period	Use the 10-second opacity data to calculate 6-minute averages. Use the 6-minute averages to calculate the hourly block average opacity.	None.

An approach that has been demonstrated to provide a reliable indication of ESP performance is the use of an ESP performance computer model calibrated using site-specific emissions and other data in conjunction with continuous opacity data. The three currently available ESP models calculate ESP control efficiency using first principles approaches and, therefore, have the capability to account for power variations in the various ESP electrical sections in service.[2-4] If calibrated properly, the models inherently compensate for minor fuel changes that influence the ash resistivity, which affects the voltage and current relationships. The models predict the outlet particle size distribution and may enable fine-tuning of the opacity to mass emissions relationship for a given ESP. Another advantage of the ESP models is that they can be used for planning purposes. For example, you could examine the potential impact of a minor fuel change or evaluate the effect of additional ESP electrical sections being out of service recognizing that coal rank changes require recalibration of the model.

Like other parametric tools, any ESP model has limitations in its ability to calculate indicators of ESP performance and the resulting error can be reduced by calibration of the model to a specific ESP. Recent research has shown that these ESP models can be calibrated with as few as three particulate test runs under each of three ESP operating conditions.[6] Research also has shown the calibrated models can accurately calculate indicators of ESP performance.

Because the currently available ESP models do not operate on a real-time basis, this CAM protocol uses continuous monitoring of opacity to indicate when to initiate use of the computer model. In other words, you will use a less accurate indicator of ESP performance (opacity) to warn you that the ESP performance has deteriorated to a level that requires you to run the computer model to confirm that you have a reasonable assurance of compliance with the emissions limit. The CAM indicator is the output of the model that you run in response to an average (e.g., 1-hour) opacity value in excess of the established indicator range.

V. Selection of Indicator Ranges[5, 6]

You will use the results of the model calibration test program to select indicator ranges for opacity and the ESP model output. A measured opacity level greater than the selected indicator range will trigger execution of the ESP computer model but will not trigger a reporting requirement relative to the PM limit. The indicator range for the ESP computer model will be established based on calibration testing and will correspond to a reasonable assurance of compliance with the PM emission limit.

You will establish the indicator range for opacity based on the concurrent PM measurements and COMS opacity measurements obtained during the ESP model calibration testing. You may supplement these data with other available historical concurrent opacity and PM emissions data. You likely will want to set the opacity indicator range based on hourly average opacity values to prevent momentary process perturbations from requiring unnecessary execution of the ESP computer model. You may use a different averaging period, but you must justify a longer averaging time with additional supporting information. Such information will include data showing low emissions and opacity variability and a large margin of compliance under almost all operating conditions. In no case should you select an opacity averaging time longer than 3 hours. An average opacity outside the indicator range will trigger execution of the ESP computer model, but alone will not trigger a reporting requirement or corrective action relative to the PM limit.

You will establish the opacity indicator range at a level equal to or less than an opacity at which the source has demonstrated a margin of compliance with the PM emissions limit of at least 10 percent at normal operating conditions. In other words, an opacity level at which, based on the available data, the ESP computer model's efficiency output represents a reasonable assurance of compliance with the PM emissions limit. For example, you may select the opacity indicator range based on the average of all of the 6-minute average opacity values measured during the ESP model calibration testing (using only the opacity data from test runs for which the PM emissions were less than the PM emissions limit). Alternatively, you could select the opacity indicator range as an hourly average opacity less than or equal to the highest opacity value observed during emissions testing that showed a margin of compliance with the PM limit of at least 10 percent. You should not select an opacity higher than the maximum opacity you observed during the calibration test program.

The indicator range for the ESP computer model output is a range of ESP control efficiencies that represents normal ESP operation and compliance with the PM emissions limit. You should select the indicator range as follows:

PROPOSED

1. Use the measured ESP outlet PM emissions and the average measured ESP inlet PM value to calculate the ESP efficiency for each test run.
2. Establish the "perfect fit" line through the two points that represent: 1) zero emissions and 100 percent efficiency, and 2) the efficiency at the emission limit (calculated based on the average measured ESP inlet PM value).
3. Use the model to calculate the outlet concentration and ESP efficiency for each test run using various rapping reentrainment or other fitting factors.
4. For each of the model runs conducted using the various rapping reentrainment or other fitting factors, use linear regression techniques to define the relationship of the calculated ESP efficiency to the actual measured emissions (i.e., determine the best fit regression line for the data).
5. Use the "perfect fit" line to help you select the appropriate model data. Select the model that has a regression line with a good fit to the actual measured data and provides conservative estimates of ESP efficiency (i.e., the calculated efficiency does not overstate the ESP efficiency at points in the range of the emissions limit).

1. If you collected emissions test data at conditions less than 80 percent of the PM emissions limit, use the regression line for the selected model output to determine the ESP efficiency at a PM emissions level equal to 1.25 times the maximum PM outlet emissions experienced during testing. Establish the indicator range at an ESP efficiency equal to or greater than that ESP efficiency value. For example, if the emissions limit is 0.20 lb/mmBtu and the highest PM emissions measured during testing were 0.08 lb/mmBtu, the outlet emissions level corresponding to 1.25 times the measured value is 0.10 lb/mmBtu. You would use the model regression line to determine the ESP efficiency corresponding to an emission level of 0.10 lb/mmBtu and you would set the indicator range at a level equal to or greater than this ESP efficiency value.
2. If you collected emissions test data at conditions at 80 percent of the PM emissions limit or greater, use the regression line for the selected model output to determine the ESP efficiency at

the PM emissions limit and establish the indicator range at an ESP efficiency equal to or greater than that ESP efficiency value.

A model output outside the established indicator range (i.e., a calculated ESP efficiency value less than the established indicator range) is considered an excursion relative to compliance with the PM emissions limit and will trigger corrective action. You also must report the time, date, duration, and response to excursions outside the ESP model indicator range in accordance with Part 64 and the title V permitting rules. In addition, you must run the computer model every 3 hours and record the results until the hourly average opacity is within the opacity indicator range. Section VI below describes the procedures for calibrating the ESP model and obtaining the data used to develop the ESP efficiency indicator range.

VI. ESP Model Calibration Test Program[5,6]

The following sections outline the test program that you must conduct to calibrate the ESP computer model to your ESP.

A. Model Inputs

The specific inputs to the ESP computer model depend on the model selected, although the inputs to each model are similar (e.g., boiler, coal, flue gas, fly ash, particle, and ESP characteristics). Each model has ESP-specific "fitting factors." You will determine the specific values of these factors during the performance test program you conduct to calibrate the model. Each model's user manual provides guidance for setting the values of these factors. You should perform independent calibrations if your boiler burns both Eastern and Western coal, because the ash characteristics of these two types of coal are different.

B. Design of the Test Program

First, you must determine the primary performance reduction mode of the ESP. The two most likely performance reduction modes are: (1) completely shorted electrical sections, and (2) low power consumption across sections. You also may evaluate some combination of the two.

Then, you must design the ESP test program to address the primary performance reduction mode of the ESP and to provide the data suitable for calibrating the ESP performance model. The test program should consist of at least three ESP outlet PM measurements under each of at least three ESP operating conditions (a minimum of 9 runs total) spanning a range of opacity from the best the ESP can achieve to an opacity value close to the opacity limit (or the PM emissions limit, whichever is the more stringent control level), and a single series of at least three ESP inlet particulate mass loading measurements. ESP inlet particle size distribution measurements are optional.

(Note: To best validate any ESP model, it is desirable to test as close to the highest particulate emission or opacity level that the unit might be expected to operate. You should speak with your permitting authority about the possibility that, during these tests, the emission limit may be exceeded for short periods and arrange that they allow such exceedances without enforcement action. You and your permitting authority may consider including conditions in your permit to allow such short-term exceedances during the conduct of ESP model calibration testing to clarify the enforcement status further.)

C. Conduct of the Test Program

1. Conduct at least three PM emissions tests for each of three ESP operating conditions using the applicable compliance method (e.g., EPA Method 5 or 17, as appropriate). The emissions value used in the final analysis will be the average of the three individual test run values obtained for each ESP operating condition. The three test conditions should simulate the most common ESP performance reduction mode. For example, if the primary performance reduction mode is shorted electrical sections, you should create the test conditions by removing sections from service. You can fine-tune the test conditions by reducing the power to the fields in service. Some field judgement will be necessary to set the test conditions, and opacity can be a good guide. If, for example, the normal opacity is 5 percent and the opacity limit is 20 percent, you could perform testing at 5, 10, and 15 percent opacity.
2. At some point during the test program, conduct three PM emissions tests at the ESP inlet to verify the PM mass loading entering the ESP. These runs do not have to be concurrent with the ESP outlet mass tests. Alternatively, you can use the computer model to estimate the ESP inlet PM mass loading from the fuel ash content.

3. Unless special conditions exist that are expected to skew the ESP inlet fly ash particle size distribution, use the model's default particle size distribution. If special conditions exist, conduct at least two particle size distribution tests at the ESP inlet and average the results. (ESP inlet particle size distribution measurements are difficult to make. Use the procedures and equipment described in "Procedures Manual for the Recommended ARB Particle Size Distribution Method (Cascade Impactors), California Air Resources Board Report, ARB Contract A3-092-32, Southern Research Institute - Contractor, May 1986.)
4. Collect the ESP electrical parameters (secondary voltage and current), opacity, flue gas flow, flue gas constituent, and boiler operations data at least twice during each PM emissions test. Secondary voltage and current data are very important in the operation of the model. In most cases, the secondary current meters on ESP controls maintain their accuracy very well while the secondary voltage meters are not as reliable. Therefore, you should use calibrated voltage dividers to develop calibration curves for the individual secondary voltage meters.

D. <u>Calibrating the ESP Model</u>

The ESP computer models require you to enter information about the boiler, coal, flue gas, and fly ash. You may enter particle data if you have ESP inlet particle sizing measurements, or use the defaults provided by the model. You also must enter mechanical and electrical information about the ESP.

Use the emissions test condition with the highest particulate emissions to calibrate the model. Use the actual voltages and currents of each ESP section for the model runs. Use the model "fitting factors" (e.g., velocity standard deviation, rapping reentrainment fraction, sneakage fraction) to fit the model's calculated ESP control efficiency to the measured control efficiency at the highest emission condition. (The user manual for your ESP model will contain starting points and the normal range of values for these factors.) You should compare the measured (actual) PM control efficiency to the model's output and adjust the fitting factors until the model is in good agreement with the actual values. Then, model lower emissions test conditions, changing only the test-specific parameters (ESP voltage and current for each field) to evaluate the fit of the model to all test conditions. Include details on how the model was calibrated, data obtained during testing, and the selected opacity and ESP model indicator ranges in the CAM monitoring approach submittal.

VIII. Example Compliance Assurance Monitoring Submittal

This section presents an example CAM approach using this protocol. The example is based on data obtained from an actual facility during an evaluation of the three ESP computer models.

PROPOSED

EXAMPLE COMPLIANCE ASSURANCE MONITORING

ELECTROSTATIC PRECIPITATOR FOR PM CONTROL: FACILITY CC

A. Background

1. Emissions Unit:

Description:	Coal-fired boiler
Identification:	BLR 1
APCD ID:	ESP 1
Facility:	Facility CC
	Anytown, USA

2. Applicable Regulation, Emissions Limit, and Monitoring Requirements:

Regulation:	Permit, State regulation
Emissions Limits:	
PM:	0.24 lb/mmBtu
Opacity:	40 percent (6-minute average)
	34 percent (4-hour average)
Monitoring Requirements:	Continuous opacity monitoring system (COMS)

3. Control Technology: Electrostatic precipitator (ESP)

B. Monitoring Approach

The key elements of the monitoring approach, including the indicators to be monitored, indicator ranges, and performance criteria are presented in Table 2. The CAM performance indicators are the opacity of the ESP exhaust and the results of an ESP computer model (the Electric Power Research Institute's [EPRI] ESPM) that uses ESP operating parameters (voltage and current in each field) as its inputs. The model was calibrated based on boiler, coal, flue gas, and fly ash characteristics, ESP inlet particle data, performance test data, operating data, and other ESP-specific "fitting factors" (velocity standard deviation, sneakage fraction, and rapping reentrainment fraction).

TABLE 2. MONITORING APPROACH

I.	Indicator	Opacity of ESP exhaust.	Calculated ESP control efficiency from EPRI's ESPM computer model.
	Measurement Approach	COMS in ESP exhaust.	When the hourly average opacity is outside the indicator range, ESP operating parameters and other boiler and coal parameters are entered into the calibrated ESPM computer model to calculate ESP control efficiency.
II.	Indicator Range	The opacity indicator range is an hourly average opacity less than 20 percent. When the hourly average opacity is outside the indicator range, there is no reporting or corrective action requirement relative to the PM limit, but the operator must run the EPRI ESPM computer model.	The indicator range is a model output (ESP control efficiency) greater than or equal to 96.1 percent. Excursions outside the ESP efficiency indicator range trigger an inspection, corrective action, and a reporting requirement.
III.	Performance Criteria A. Data Representativeness	The COMS was installed at a representative location in the ESP exhaust per 40 CFR 60, Appendix B, PS-1.	The model was calibrated based on PM emissions testing performed on the ESP and operating data collected during testing. Parameter information for model runs is obtained from the ESP and boiler control panels.
	B. Verification of Operational Status	Results of initial COMS performance evaluation conducted per PS-1.	Results of PM emissions tests conducted to calibrate the model.
	C. QA/QC Practices and Criteria	The COMS was initially installed and evaluated per PS-1. Zero and span drift are checked daily and a quarterly filter audit is performed.	Model calibration will be reverified if operating conditions (e.g., fuel rank) change. Calibration of voltmeters and ammeters is checked annually.
	D. Monitoring Frequency	The opacity of the ESP exhaust is monitored continuously (every 10 seconds).	The model is run when the hourly average opacity is outside the indicator range. If the hourly average opacity does not return to a level within the indicator range, the model is run every 3 hours to evaluate ESP performance.
	Data Collection Procedures	The DAS retains all 6-minute and hourly average opacity data.	All records of ESP, boiler, and coal parameters collected for model runs and printouts or electronic copies of all model runs performed are retained.
	Averaging period	The 10-second opacity data are used to calculate 6-minute averages. The 6-minute averages are used to calculate the hourly block average opacity.	None.

PROPOSED

C. Monitoring Approach Justification

1. Background

The pollutant-specific emissions unit (PSEU) is an ESP controlling a tangentially-fired boiler with a rated capacity of 360 MW. The boiler was put into service in 1974 and burns Eastern bituminous coal. It is outfitted with low-NO_x burners with separate over-fire air. The ESP is comprised of two side-by-side boxes, each with ten electrical and mechanical fields in the direction of gas flow. The first two fields are 6 feet long and the remaining fields are 3 feet long (36 feet total plate length) in the direction of gas flow. The plates are 30 feet high.

2. Rationale for Selection of Performance Indicators

The CAM indicators selected are the opacity of the ESP exhaust in combination with the output of the EPRI ESPM computer model. Opacity was selected as the first performance indicator because, as the opacity of the ESP emissions increases, it can be reasonably assumed that PM emissions increase. However, as the ESP's performance deteriorates, rapping reentrainment of large particles becomes a factor and the relationship between opacity and PM deteriorates because these particles contribute a significant amount to the mass loading, but not to the opacity.

Because the relationship between PM and opacity is not robust over all operating conditions, the second CAM indicator is the output of the computer model calibrated to better calculate ESP performance. When the hourly average opacity falls outside the selected indicator range, the ESP operating parameters (voltage and current in each field) and other required boiler and coal parameters will be input to the computer model and the results used to assess the operation of the ESP relative to past model calibration tests. Because the voltages and number of fields in service typically will be different for each side of the ESP, the model is run for both sides and the results are averaged. Because the model does not operate on a real-time basis and performance test data show the unit has a large margin of compliance with the PM emissions limit at normal operating conditions, the model is executed only when the hourly average opacity is outside the selected indicator range. The ESP model results are reported and corrective action is initiated if the model results fall outside the selected ESP control efficiency indicator range.

3. Rationale for Selection of Indicator Ranges

The indicator range selected for opacity is an hourly average opacity less than 20 percent. When the hourly average opacity is outside the indicator range, the EPRI ESPM computer model will be executed to calculate ESP control efficiency. The ESPM model will be executed and the results recorded at 3-hour intervals to assess ESP performance for as long as the opacity continues to exceed the indicator range. All hourly average opacities outside the opacity indicator range will be documented, along with the results of model runs performed due to these events. No reporting requirement or corrective action relative to the PM limit is triggered by an opacity outside the indicator range if the ESP model efficiency results are within their selected indicator range.

Test data show that at full power, when the ESP is fully operational, PM emissions typically are less than 0.03 lb/mmBtu and have less than 5 percent opacity. When ESP fields are taken out of service and the power is reduced on other fields, PM emissions approach the emissions limit when the average hourly opacity exceeds 20 percent. For example, one test showed PM emissions of 0.236 lb/mmBtu when the average hourly opacity was 25.5 percent. Figure 1 shows how the opacity indicator range was selected. The figure presents the actual opacity and PM emission rate data. The opacity indicator range was selected based on the highest observed opacity during testing that showed a margin of compliance with the PM limit of at least 10 percent.

The indicator range for the ESPM computer model output is an ESP control efficiency greater than or equal to 96.1 percent. When the model results indicate an excursion (ESPM efficiency output less than 96.1 percent), corrective action will be initiated, beginning with an evaluation of the occurrence to determine the action required to correct the situation. All ESP model excursions will be documented and reported. The value of 96.1 percent was selected as the indicator range by determining the point on the 0.15 rap regression line that represents the PM emissions limit (0.24 lb/mmBtu); the corresponding calculated ESP efficiency is 96.1 percent.

4. Model Calibration

The model was calibrated based on the boiler, coal, and ESP characteristics and the performance test data. Table 3 presents general ESP, gas, boiler, and coal characteristics, and Table 4 presents the performance test data. Inlet particle size data also were gathered to further refine the model, instead of using the ESP model defaults (see Table 5). The average particle size (mass median diameter) was 21.55 microns, with a geometric standard deviation of 2.5 microns. The ESP inlet mass loading averaged 2.1 gr/acf.

A velocity standard deviation of 0.15 and a sneakage fraction of 0.10 were used (sneakage is the fraction of gas that bypasses the collection zone). The model was run with a rap of 0.10 and a rap of 0.15. Figure 2 presents the model's output of calculated ESP efficiency for rap values of 0.15 and 0.10 versus actual PM emissions. The linear regressions for these data also are shown. The R^2 value for the 0.15 rap linear regression is 0.96; the R^2 value for the 0.10 rap linear regression is 0.95. The perfect fit line (calculated efficiency based on actual measured PM emissions data) also is presented in Figure 2. As shown in Figure 2, the ESP efficiency calculated by the model using a rap of 0.10 overstates the ESP efficiency (understates PM emissions) at the levels of interest; i.e, emission levels between 0.15 lb/mmBtu (which roughly corresponds to the emissions at the 20 percent opacity indicator range) and the emission limit of 0.24 lb/mmBtu. The ESP efficiency calculated by the model using a rap of 0.15 fits the data well, although it understates ESP efficiency (overstates PM emissions) across the entire emissions range. Because the model will be used to evaluate performance when the hourly average opacity is greater than 20 percent, the model will be run with a rap of 0.15. As indicated by the regression line, use of a rap value of 0.15 is a conservative approach because it is likely to result in underestimating ESP control efficiency at levels approaching the emissions limit. Consequently, the indicator range is based on the model using the 0.15 rap.

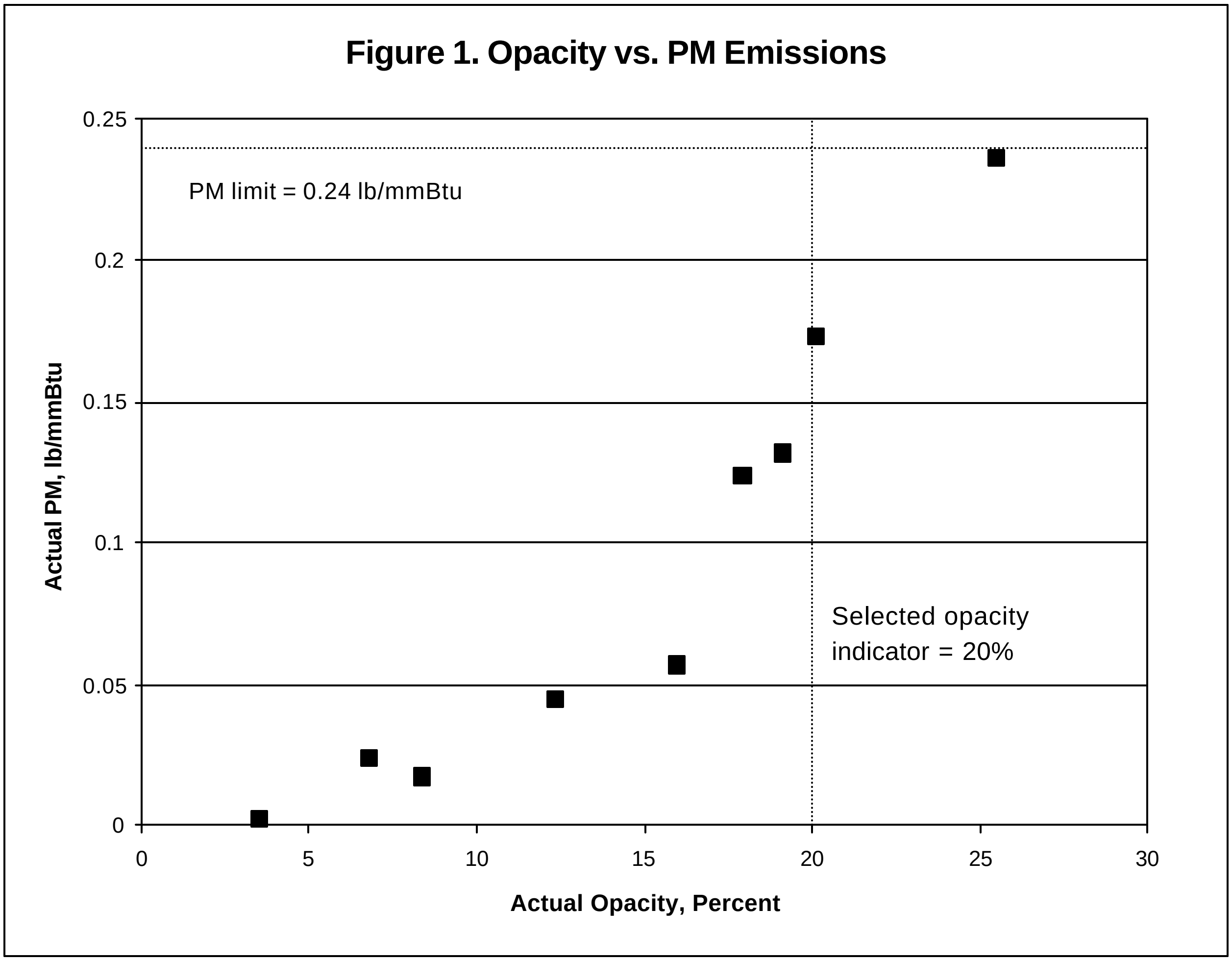
Figure 1. Opacity vs. PM Emissions
PM limit = 0.24 lb/mmBtu
Selected opacity indicator = 20%
Actual PM, lb/mmBtu
Actual Opacity, Percent
0
0.05
0.1
0.15
0.2
0.25
0
5
10
15
20
25
30

PROPOSED

TABLE 3. ESP MODEL PARAMETERS

Parameter	Value
ESP PARAMETERS	
Total specific collector area	125 ft^2/kacfm
Total plate area	147,600 ft^2
Number of sections	5
Total length	15 ft
Height	30 ft
Width	150.3 ft
Stack diameter	16.3 ft
Resistivity	$1.00x10^{11}$ ohm-cm
ESP SECTION PARAMETERS	
Specific collector area	25 ft^2/kacfm
Area	29,520 ft^2
Length	3 ft
Wire-plate spacing	5.5 in
Wire-wire spacing	9.0 in
Wire diameter	0.109 in
Reynolds number	11,100
GAS PARAMETERS	
Gas velocity	4.4 ft/s
Volumetric flow	1,181,000 acfm
Temperature	282.5 /F
Pressure	1 atm
Viscosity	$2.86x10^{-4}$
BOILER AND COAL PARAMETERS	
Megawatts	360
Coal grind diameter	50 :m
Grind exponent	1.2
Heat rate	9,300 Btu/kwh
Coal burning rate	165 ton/hr
Coal heating value	10,500 Btu/lb

TABLE 4. ACTUAL MEASURED AND CALCULATED PM EMISSIONS DATA.

Test	Actual measured opacity, percent	Actual measured PM, lb/mmBtu	ESP efficiency[a]	Model with 0.10 rap, calculated ESP efficiency	Model with 0.15 rap, calculated ESP efficiency
1	3.5	0.002	99.97	99.99	99.99
6	8.4	0.017	99.75	99.73	99.58
5	6.8	0.024	99.64	99.75	99.58
2	12.3	0.045	99.33	99.24	98.76
4	16	0.057	99.15	98.95	98.40
7	17.9	0.124	98.14	98.40	97.54
9	19.1	0.132	98.02	97.78	96.96
8	20.1	0.173	97.41	98.34	97.54
3	25.5	0.236	96.46	97.56	96.43

[a] Based on average measured ESP inlet PM concentration of 2.1 gr/acf.

TABLE 5. PARTICLE SIZE DATA

Diameter, μm	Cumulative fraction	Diameter, μm	Cumulative fraction	Diameter, μm	Cumulative fraction	Diameter, μm	Cumulative fraction
0.08	0.0000	0.59	0.0006	3.67	0.0286	16.73	0.3998
0.12	0.0000	0.84	0.0008	5.20	0.0633	24.49	0.5640
0.18	0.0006	1.22	0.0015	6.93	0.1121	36.74	0.7270
0.27	0.0006	1.73	0.0037	9.38	0.1880	51.96	0.8372
0.41	0.0006	2.45	0.0099	12.41	0.2810	69.28	0.9023

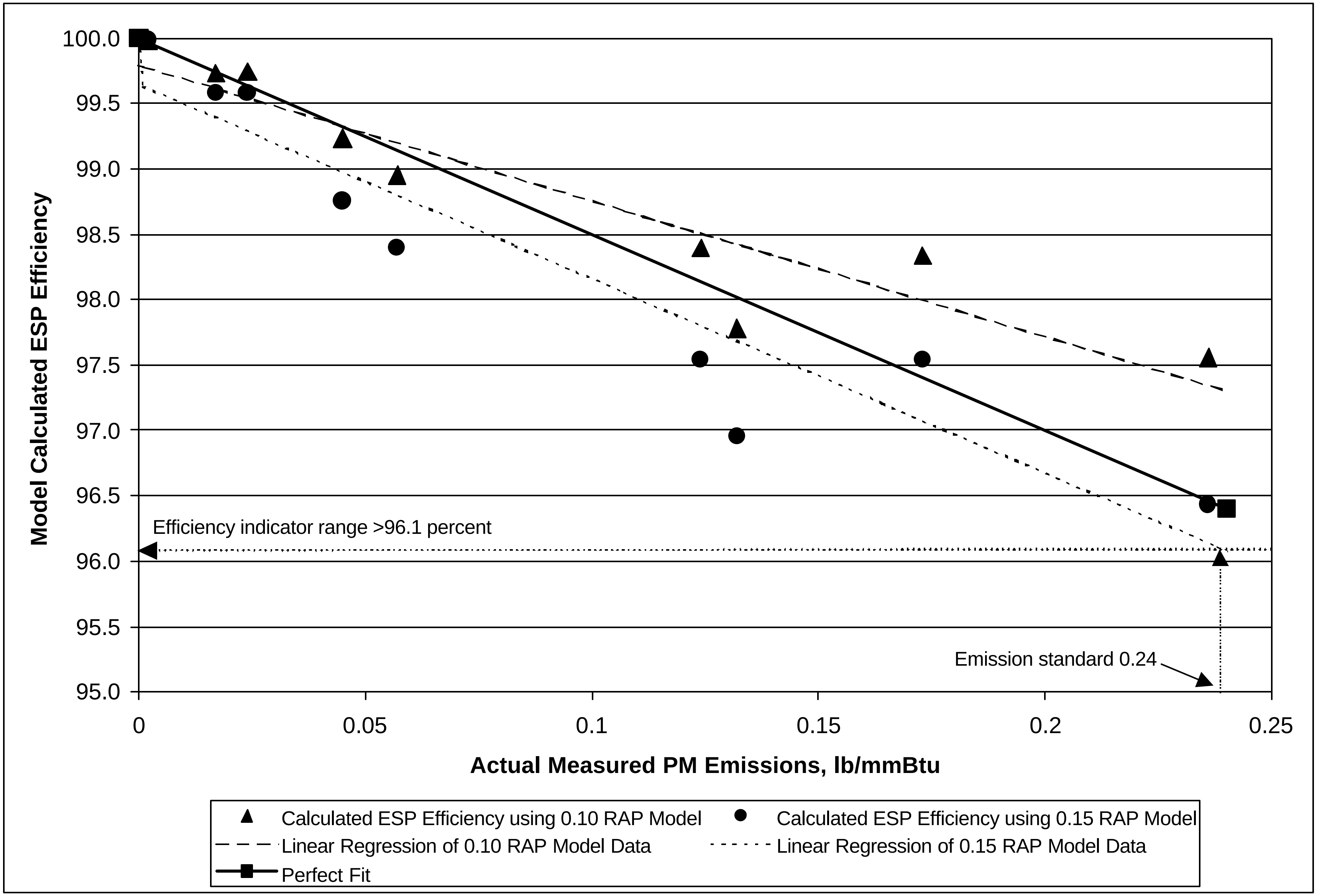

Figure 2. Calculated ESP Efficiency vs. Actual Measured PM Emissions

REVIEW DRAFT

IX. References

1. U.S. Environmental Protection Agency. Technical Guidance Document: Compliance Assurance Monitoring. Office of Air Quality Planning and Standards, Research Triangle Park, NC. August 1998. http://www.epa.gov/ttn/emc/cam.html.

2. U.S. Environmental Protection Agency. ESPVI 4.0 Electrostatic Precipitator V-I and Performance Model (EPA-600/SR-92/104). Air and Energy Engineering Research Laboratory, Research Triangle Park, NC. August 1992.

3. Southern Research Institute. A Mathematical Model of Electrostatic Precipitation (Revision 3): Volume I, Modeling and Programming. Birmingham, AL. 1993.

4. Electric Power Research Institute. Electrostatic Precipitator Performance Model (ESPM). Palo Alto, CA.

5. McRanie, R. Electrostatic Precipitator Compliance Assurance Monitoring Protocol. RMB Consulting and Research, Inc., Raleigh, NC. March 2000.

6. Electric Power Research Institute. Compliance Assurance Monitoring Field Test Program (TE-114178). Palo Alto, CA. November 1999.