U.S. DEPARTMENT OF ENERGY
INNOVATIVE CLEAN COAL TECHNOLOGY II
DEMONSTRATION PROJECT

ADVANCED TANGENTIALLY FIRED LOW-NOx COMBUSTION DEMONSTRATION

PHASE II LNCFS LEVEL II TESTS

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ETEC would like to acknowledge Mr. J. D. McDonald of Plant Smith for his efforts in ensuring that the testing progressed with the maximum level of efficiency.

EXECUTIVE SUMMARY

This report summarizes the activities and results for the second testing phase (Phase II) of an Innovative Clean Coal Technology (ICCT) demonstration of advanced tangentially fired combustion techniques for the reduction of nitrogen oxide (NOx) emissions from coal-fired boilers. All three levels of Asea Brown Boveri Combustion Engineering Service's (ABB CE's) Low-NOx Concentric Firing System (LNCFS) are being demonstrated during this project. The primary goal of this project is to determine the NOx emissions characteristics of these technologies when operated under normal load dispatched conditions. The equipment is being tested at Gulf Power Company's Plant Lansing Smith Unit 2 in Lynn Haven, Florida.

In Phase II, Level II of the LNCFS and a simulated version of Low-NOx Bulk Furnace Staging (LNBFS) were demonstrated. Following equipment optimization by ABB CE, the condition of LNCFS Level II hardware was documented by establishing the NOx emissions characteristics of the equipment under short-term, well-controlled conditions. Results from 138 short-term tests indicate fairly constant NOx emissions of about 0.35 lb/MBtu from 115 to 180 MW, with slightly higher NOx emissions at maximum loads (200 MW), and significantly higher emissions (up to 0.43 lb/MBtu) at minimum loads (75 MW). Loss-on-ignition (LOI) ranged from 3.8 to 5.4 percent for loads of 115 and 200 MW respectively.

The long-term NOx emission trends were documented while the unit was operating under normal load dispatch conditions with the LNCFS Level II equipment. Fifty-five days of long-term data were collected. The data included the effects of mill patterns, unit load, mill outages, weather, fuel variability, and load swings. Test results indicated full-load (180 MW) NOx emissions of 0.39 lb/MBtu, which is about equal to the short-term test results. At 110 MW, long-term NOx emissions increased to 0.42 lb/MBtu, which are slightly higher than the short-term data. At 75 MW, NOx emissions were 0.51 lb/MBtu, which is significantly higher than the short-term data. The annual and 30-day average achievable NOx emissions were determined to be 0.41 and 0.45 lb/MBtu, respectively, for long-term testing load scenarios.

NOx emissions were reduced by a maximum of 40 percent when compared to the baseline data collected in the previous phase. The long-term NOx reduction at full load (180 MW) was 37 percent while NOx reduction at low load was minimal.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ABB CE	Asea Brown Boveri Combustion Engineering Services, Inc.
AMIS	all mills in service
APH	air preheater
BOD	boiler operating days
CCOFA	close-coupled overfire air
CCTFS	Concentric Clustered Tangential Firing System
CE	combustion engineering
CEM	continuous emission monitor
CO	carbon monoxide
DAS	data acquisition system
DOE	Department of Energy
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ESP	electrostatic precipitator
ETEC	Energy Technology Consultants, Inc.
Gulf	Gulf Power Company
ICCT	Innovative Clean Coal Technology
LNBFS	Low-NOx Bulk Furnace Staging
LNCFS	Low-NOx Concentric Firing System

LIST OF ABBREVIATIONS AND ACRONYMS (continued)

LOI	loss-on-ignition
MBtu	million Btu
MOOS	mills-out-of-service
MW	megawatt
NOx	nitrogen oxides
NSPS	new source performance standards
ppm	parts per million
PTC	performance test codes
SCS	Southern Company Services, Inc.
SOFA	separated overfire air
SoRI	Southern Research Institute
THC	total hydrocarbons
WSPC	W.S. Pitts Consulting, Inc.

1.0 INTRODUCTION

This Innovative Clean Coal Technology (ICCT) project to evaluate nitrogen oxide (NOx) control techniques on a 180-MW utility boiler is funded by the U.S. Department of Energy (DOE), Southern Company Services, Inc., (SCS), and the Electric Power Research Institute (EPRI). Through its cost sharing in the installed low-NOx retrofit technology, Asea Brown Boveri Combustion Engineering Services, Inc., (ABB CE) is also participating as a project cofunder. Gulf Power Company (Gulf) is providing Plant Lansing Smith as the host site in addition to onsite assistance and coordination for the project.

This report documents the testing performed and the results achieved during testing of Level II of the Low-NOx Concentric Firing System (LNCFS Level II). This effort began in May 1991, following completion of baseline testing, and after installation of the LNCFS Level II. Phase I activities and results were documented in a previous report[1].

While this report provides sufficient background material for a general understanding of the program scope, test procedures, and the relationship of the Phase II testing to the overall program, the Phase I topical report should be referred to for more detailed descriptions of the test program, test methods, instrumentation, and unit configuration.

1.1 Project Description

On September 19, 1990, SCS was awarded a DOE ICCT Round II contract for the "180-MW Demonstration of Advanced Tangentially Fired Combustion Techniques for the Reduction of Nitrogen Oxide (NOx) Emissions from Coal-Fired Boilers." The primary objective of the project is to investigate the long-term effects of commercially available, tangentially fired low-NOx combustion technologies on NOx emissions and boiler performance. The technologies are being demonstrated on Unit 2 at Gulf's Plant Lansing Smith located in Lynn Haven, Florida. The project will characterize emissions and performance of a tangentially fired boiler operating in the following configurations during the three phases of the program.

1.	Phase I		- Baseline "as-found" configuration.
2.	Phase II	LNCFS	- Retrofitted LNCFS Level II.
		LNBFS	- Simulated Low-NOx Bulk Furnace Staging (LNBFS).
3.	Phase III	LNCFS	- Retrofitted LNCFS Level III.
		LNCFS	- Simulated LNCFS Level I.

The objectives of the project are

- Demonstrate (in a logical stepwise fashion) the short-term NOx reduction capabilities of the following four low-NOx combustion technologies:

    1. LNBFS.
    2. LNCFS Level I.
    3. LNCFS Level II.
    4. LNCFS Level III.

- Determine the dynamic long-term NOx emission characteristics of the three levels of LNCFS using sophisticated statistical techniques.

- Evaluate progressive cost-effectiveness (i.e., dollars per ton of NOx removed) of the low-NOx combustion technologies tested.

- Determine the effects on other combustion parameters [e.g., carbon monoxide (CO) production, carbon carry-over, particulate characteristics related to electrostatic precipitators (ESPs)] due to applying the low-NOx combustion technologies.

Each of the three phases of the project involves three distinct testing periods:

1. Short-Term Characterization (consisting of diagnostic and performance testing) - establishes the NOx emissions trends as a function of various parameters and the influence of the operating mode on other combustion parameters.

2. Long-Term Characterization - establishes the dynamic response of the NOx emissions over 2 - 3 months and includes the influencing parameters encountered during routine unit operations.

3. Short-Term Verification - documents fundamental changes in NOx emission characteristics that may have occurred during long-term testing.

1.2 Lansing Smith Unit 2 Description

Plant Lansing Smith Unit 2 is a combustion engineering (CE), tangentially fired (T-fired) boiler originally rated at 180 MW but capable of firing at 200 MW with design steam conditions of 1875 psig and 1000/1000°F superheat/reheat temperatures, respectively. Five CE mills provide pulverized eastern bituminous coal for delivery to five burner elevations. Individual windboxes are located at the four corners of the furnace, and each windbox contains the five burner elevations.

Unit 2 is a balanced draft unit using two forced-draft and three induced-draft fans. The unit has both hot-side and cold-side ESPs and two Ljungstrom air preheaters (APH).

At the beginning of Phase II, the boiler was retrofitted with the LNCFS Level II, consisting of new coal nozzle assemblies, nozzles, auxiliary air buckets, and offset air yaw assemblies. The LNCFS Level II also included a separated overfire air (SOFA) system consisting of air conduits, flow control dampers, venturi flow sensing elements, SOFA registers, waterwall tube panels for the overfire air registers, and instrumentation for sensing and controlling the SOFA air flowrates. The SOFA ports are located in the corners of the boiler above each burner column. Each of the three levels of SOFA ports has separate horizontal adjustment capabilities (yaw) to optimize the mixing for completing combustion. All three levels are on a common tilt mechanism, with the SOFA tilt angle proportionally related to the burner tilt angle. The SOFA is extracted from the two main secondary air ducts on the sides of the furnace, is metered by the venturis, and is then split to the associated front and rear corners of the boiler.

The flow of SOFA as a percentage of the total air is controlled by two mechanisms - the furnace-to-windbox pressure differential and the SOFA dampers. The three levels of SOFA dampers in each corner are separately varied with load by an automatic controller. Figure 1-1 shows the original and revised controller output signals to the three levels of SOFA dampers. The long-term testing was performed using the original vendor recommended settings which were subsequently revised by ABB CE following review of the long-term NOx data. Adjustments were made to the control scheme to improve NOx emissions during low load operation. The split between the secondary and SOFA flows is also affected by the pressure difference between the main burner windbox and the furnace. The windbox-to-furnace pressure differential is controlled by the operators through manual adjustments on the controllers for the auxiliary air dampers. Figure 1-2 shows the recommended windbox-to-furnace differential pressure with load. The excess oxygen level with load is also manually set according to the discretion of the control board operators. The recommended excess oxygen level is shown in Figure 1-3.

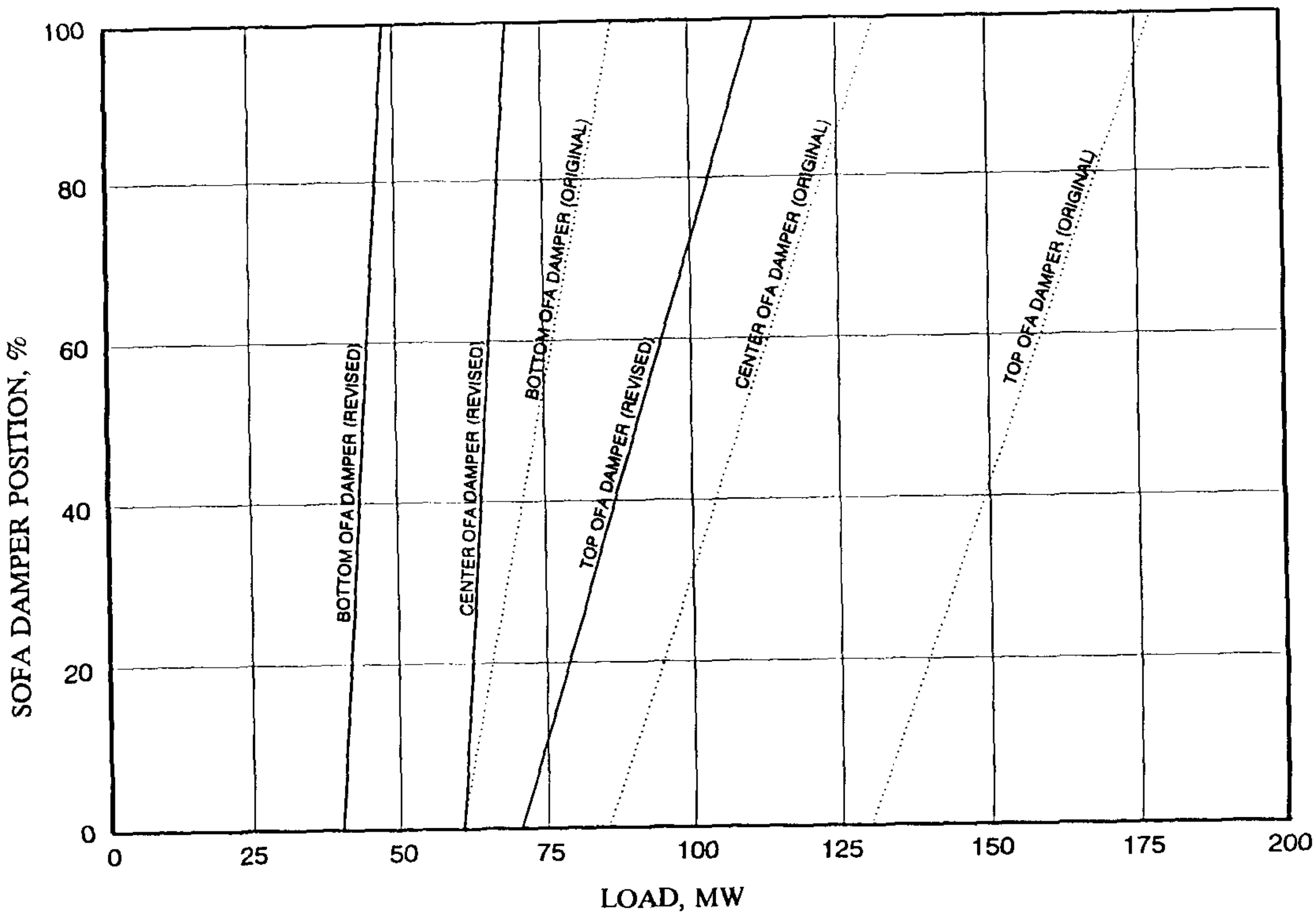

Figure 1-1. Phase II LNCFS Level II SOFA Damper Settings

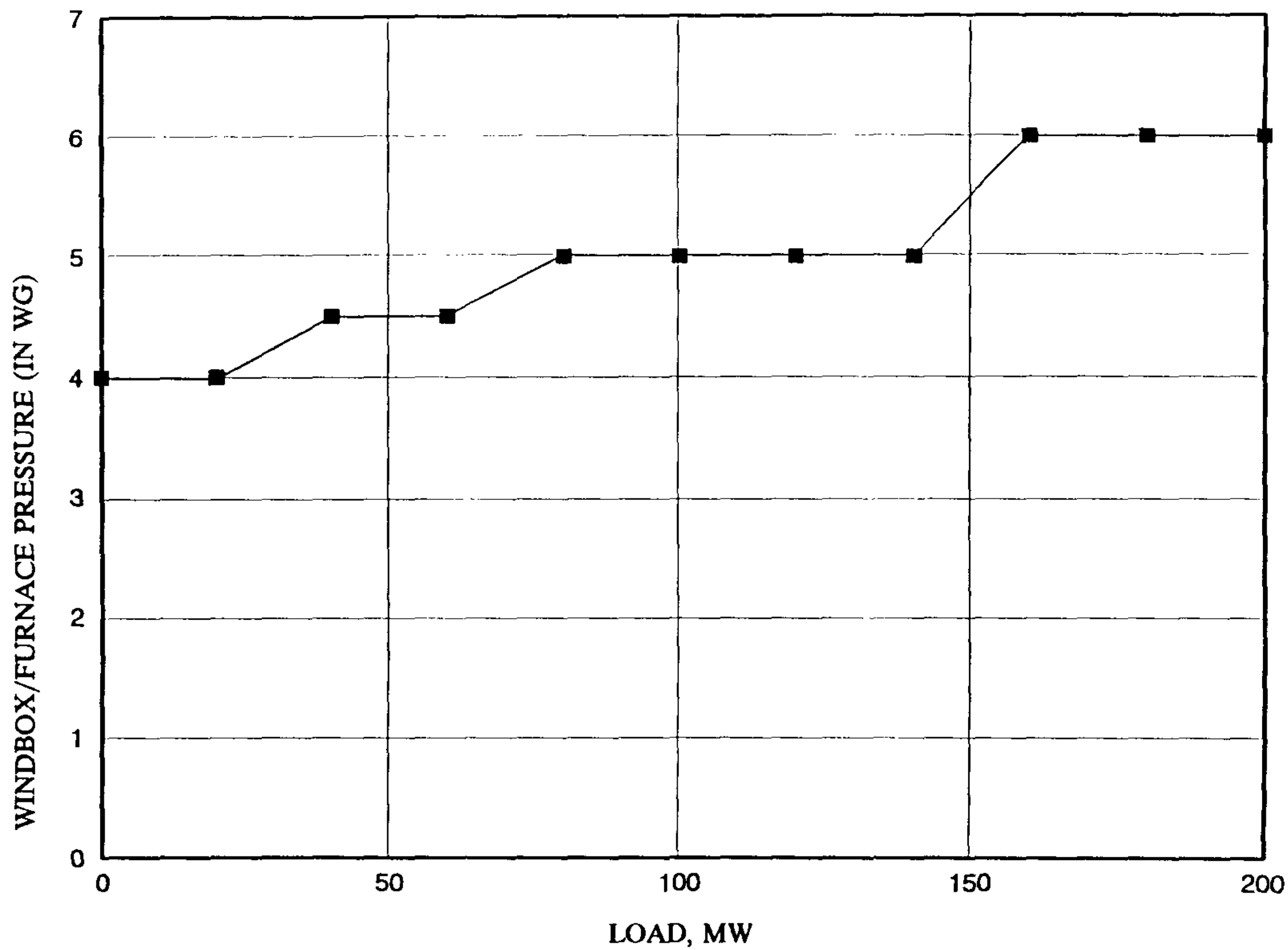

Figure 1-2. Phase II LNCFS Level II Recommended Windbox-to-Furnace Pressure Differential

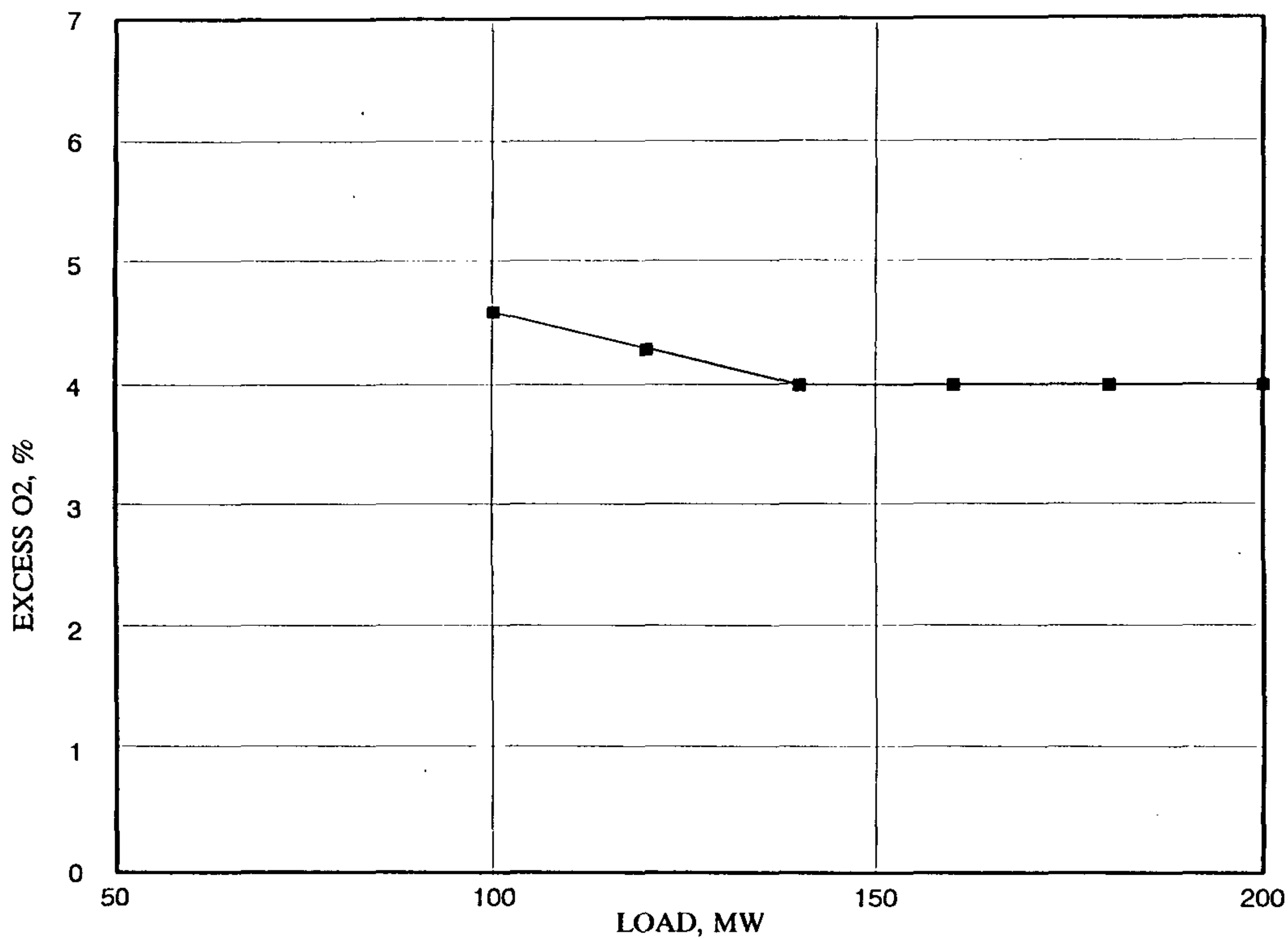

Figure 1-3. Phase II LNCFS Level II Recommended Operating Excess Oxygen Level

2.0 TEST PROGRAM DESCRIPTION

In the past, there have been many demonstration programs by various burner manufacturers to evaluate the NOx reduction potential of their equipment. However, very few of these demonstrations have provided long-term data (i.e., months of continuous data) in the pre- or postretrofit configuration. This DOE ICCT II program provides short- and long-term, pre- and postretrofit emission data on three of low-NOx combustion technologies.

2.1 Technology Background

Four different low-NOx combustion technologies offered by ABB CE for tangentially fired boilers are planned for this demonstration. The demonstration of these technologies progresses in the most logical manner from an engineering and construction viewpoint. During Phase I, the baseline conditions of the unit were studied. During Phase II, the LNBFS and the LNCFS Level II were demonstrated. During Phase III, the LNCFS Levels I and III will be demonstrated.

The concept of overfire air is demonstrated in all of these systems. In LNCFS Level I, a close-coupled overfire air (CCOFA) system is integrated directly into the windbox. Compared to the baseline configuration, LNCFS Level I is arranged by exchanging the highest coal nozzle with the air nozzle immediately below it. This configuration provides the NOx reducing advantages of an overfire air system without pressure part modifications to the boiler.

In LNBFS and LNCFS Level II, a SOFA system is used. This is an advanced overfire air system having backpressuring and flow measurement capabilities. The air supply ductwork for the SOFA is taken from the secondary air duct and routed to the corners of the furnace above the existing windbox. The inlet pressure to the SOFA system can be increased above windbox pressure using dampers downstream of the takeoff in the secondary air duct. The intent of operating at a higher pressure is to increase the quantity and injection velocity of the overfire air into the furnace. A multicell venturi is used to measure the amount of air flow through the SOFA system.

LNCFS Level III uses both CCOFA and SOFA.

In addition to overfire air, the LNCFS incorporates other NOx reducing techniques into the combustion process. Using offset air, two concentric circular combustion regions are formed. The inner region contains the majority of the coal thereby being fuel rich. This region is surrounded by a fuel lean zone containing combustion air. For this demonstration, the size of this outer circle of combustion air will be varied using adjustable offset air nozzles. The separation of air and coal at the burner level further reduces the production of NOx.

The LNBFS consists of a standard tangentially fired windbox with a SOFA system. This technology will be demonstrated by repositioning the offset air nozzles in the main windbox to be in line with the fuel nozzles. No other modifications to the windbox will be required. LNBFS will be demonstrated using short-term diagnostic tests only.

When the statement of work for this project was prepared in June 1990, ABB CE offered the following low-NOx combustion systems:

- LNCFS.
- Concentric Clustered Tangential Firing System (CCTFS).

Since that time, the technologies which ABB CE offers to the public have evolved to reflect the results of its most recent knowledge. The equipment that is presently offered comprises a family of technologies called the LNCFS Levels I, II, and III as discussed previously. ABB CE developed this family of systems to provide a stepwise reduction in NOx emissions with LNCFS Level III providing the greatest reduction.

Although the names of these technologies have changed, the basic concepts for the reduction of NOx emissions have remained constant. LNCFS included the NOx reduction techniques of overfire air and adjustable offset air nozzles as part of its design. These features are now incorporated into the design of LNCFS Level II.

The CCTFS included two sets of overfire air and clustered coal nozzles. Both LNCFS Levels I and III utilize clustered coal nozzles and overfire air in their design. Research by ABB CE has shown that the use of clustered coal nozzles does not positively or negatively affect the production of nitrogen oxide emissions in a coal-fired boiler. As a result, one set of coal nozzles at the top of the main windbox is clustered to facilitate the addition of the CCOFA system discussed in the section above. This modification allows the low pressure overfire air system (now designated the CCOFA) to be integrated directly into the windbox. This design change reduced the number of pressure part modifications required to install this low-NOx combustion technology. No significant design changes to the high pressure overfire air system (now designated the SOFA) were made.

2.2 Program Test Elements

One of the underlying premises for testing efforts in all of the phases is that short-term tests cannot adequately characterize the true emissions of a utility boiler. As a consequence, the focal point during all phases is long-term testing. Short-term testing establishes trends that may be used to extrapolate the results of this project to other similar boilers. The short-term test results are not intended to determine the relative effectiveness of the retrofitted NOx control technologies. The determination of relative effectiveness will be accomplished by statistical analyses of the long-term data. The following paragraphs describe the purpose and sequence for each of the three types of testing.

2.2.1 Short-Term Characterization

Short-term testing establishes the trends of NOx emissions under the common operating configurations. It also establishes the performance of the boiler in these normal operational modes. The short-term characterization testing has two parts:

1. Diagnostic tests which establish the gaseous emission trends.

2. Performance tests which establish boiler efficiency and ability to meet design steam temperatures as well as gaseous and particulate emissions characteristics.

Both sets of tests are conducted under controlled conditions and with the unit off of automatic system load dispatch to maintain steady control of the boiler operation.

Diagnostic testing, which lasts from 1-3 hours each, involves characterizing the gaseous emissions at three to four load conditions over the range of operating parameters normally encountered on the unit. The primary variables for the gas emission characterization are excess oxygen, mill pattern, mill bias, burner tilt, burner yaw, fuel/air damper settings, and SOFA flow. Loss-on-ignition (LOI) tests of the flyash collected at the economizer outlet were conducted during some of the diagnostic conditions, primarily to determine sensitivity to the excess oxygen level.

Performance testing, which lasts from 10-12 hours each, is accomplished at steady loads under operating configurations recommended by plant engineering and from recommendations based on the results of the diagnostic tests. The performance configurations represent one of the normal (usually the most frequent) modes of operation for each load condition.

2.2.2 Long-Term Characterization

Long-term tests are conducted under normal automatic load dispatch conditions. No intervention with respect to specifying the operating configuration or conditions are imposed by project test personnel. The long-term testing provides emission and operational results that include most, if not all, of the possible influencing parameters that can affect boiler NOx emissions. These parameters include coal variability, mill patterns, mill bias ranges, excess oxygen excursions, burner tilts, unit operation preferences, equipment conditions, and weather related factors. Long-term testing results provide a true representation of the unit emissions. Data during long-term tests are recorded continuously (5-minute averages) for periods in excess of 50 days.

2.2.3 Short-Term Verification

Over the 50- to 80-day test period required for the long-term characterization, changes in the unit condition and coal can occur. Verification testing is conducted at the end of each phase to quantify the impacts of changes in some of the identifiable parameters on the long-term emission characterization. This testing assists in explaining anomalies in the long-term data statistical analysis. The tests are conducted similar to the short-term characterization tests. Four to five basic test configurations (e.g., load, mill pattern, excess air) are tested during this effort.

2.3 Phase II Test Plan

Phase II testing began May 7, 1991, and was completed on October 20, 1991. All test objectives were met.

Table 2-1 shows the initial test plan for the Phase II short-term characterization. The table includes conditions for diagnostic, performance, and verification tests with the LNCFS Level II, and diagnostic tests with LNBFS. The following paragraphs describe the Phase II test strategies.

2.3.1 Short-Term Characterization Testing (LNCFS Level II)

The short-term characterization tests were conducted at five loads ranging from 75 to 200 MW; three of these were identified and tested in Phase I. The 200-MW test load was added to the test plan since the unit operated much of the time at that load during the baseline long-term testing. The lowest load tested was 75 MW, rather than the 95-MW minimum load tested during Phase I due to the observed occurrences of the lower loads during baseline long-term operation. The intermediate load points tested were representative of normal operating points.

A total of 69 diagnostic tests of LNCFS Level II were performed. The performance portion of the short-term characterization was executed as planned (see Table 2-1), with 15 tests being conducted over a 7-day period. No performance make-up tests were necessary.

2.3.2 Long-Term Characterization Testing (LNCFS Level II)

During the long-term characterization testing period, 55 days of validated continuous emission data were collected. A total of 120 days were potentially available for data collection during the 5-month period. The unit was online during the entire period except for 11 days of unscheduled outages due to difficulties with the CEM system (44 days of data were invalidated). Ten other days were invalidated due to plant substitution of a different coal from the test coal and/or testing conducted by ABB CE outside of the present program. These losses did not impact the proper analysis of the data.

2.3.3 Verification Testing (LNCFS Level II)

A total of 15 verification tests were planned and 29 were performed for LNCFS Level II. The trends exhibited by these data indicated that no significant changes occurred during the long-term testing.

2.3.4 Diagnostic Testing (LNBFS)

The LNBFS diagnostic tests were concluded at the end of the LNCFS Level II verification tests. Twenty-five LNBFS diagnostic tests were performed.

Table 2-1
Preliminary Phase II Test Matrix

Phase II LNCFS Level II

PURPOSE	DAY	TEST CONDITIONS	LOAD MW	MILL PATTERN	O2 LEVEL	BURNER TILT	SOFA
DETERMINE PARAMETRIC EFFECTS OF SOFA AND INTERACTION WITH OPERATING PARAMETERS. DEFINE OPERATING POINTS	1	NORMAL	180	ABCDE	MH	AUTO	AUTO
	2	TILT IMPACT	180	ABCDE	MH	HORIZ	AUTO
	3	TILT IMPACT	180	ABCDE	M	HORIZ	AUTO
	4	HIGH LOAD	200	ABCDE	L	HORIZ	AUTO
CHARACTERIZE EFFECTS OF VARIOUS PARAMETERS ON EMISSIONS AND OPERATION WITH SOFA. COMPARE WITH BASELINE.	5	HIGH LOAD	200	BCDE	L	AUTO	0
	6	HIGH LOAD	200	BCDE	L	AUTO	100
	7	VARY OFA	140	BCDE	LMH	AUTO	VARIOUS
	8	MILL EFFECTS	140	CDE	LMH	AUTO	AUTO
	9	BURNER DAMPERS	140	BCDE	LM	AUTO	AUTO
	10	LOW LOAD	115	CDE	LMH	AUTO	AUTO
	11	MILL EFFECT	115	BCDE	M	AUTO	100
	12	VARY OFA	115	CDE	LM	AUTO	VARIOUS
	13	LOW LOAD	70	DE	M	AUTO	0
	14	LOW LOAD	70	DE	LMH	AUTO	AUTO
	15	VARY BURNER DAMPERS	180	ABCDE	LMH	AUTO	100
REPEAT TESTS TO CONFIRM AND SUPPLEMENT DATA.	16	VARY OFA	180	ABCDE	LMH	AUTO	VARIOUS
	17	VARY BURNER DAMPERS	180	ABCDE	LMH	AUTO	AUTO
	18	MILL VARIATION	180	BCDE	LMH	AUTO	AUTO
DOCUMENT EMISSIONS AND PERFORMANCE WITH LNCFS LEVEL 2	19	ENVIR & PERF CHARACT	180	ABCDE	M	AUTO	AUTO
	20	ENVIR & PERF CHARACT	180	ABCDE	M	AUTO	AUTO
	21	ENVIR & PERF CHARACT	200	ABCDE	M	AUTO	AUTO
	22	ENVIR & PERF CHARACT	115	CDE	M	AUTO	AUTO
	23	ENVIR & PERF CHARACT	115	CDE	M	AUTO	AUTO
	24	ENVIR & PERF CHARACT	135	BCDE	M	AUTO	AUTO
	25	ENVIR & PERF CHARACT	135	BCDE	M	AUTO	AUTO
VERIFY SHORT-TERM EMISSIONS CHARACTERISTICS AFTER LONG-TERM TESTS	26	LOW LOAD	115	CDE	HML	OPT	AUTO
	27	LOW LOAD	115	BCD	HL	OPT	AUTO
	28	MED LOAD	136	BCDE	HML	OPT	AUTO
	29	HIGH LOAD	180	ABCDE	LM	OPT	AUTO
	30	HIGH LOAD	180	ABCDE	HML	OPT	AUTO
	31	HIGH LOAD	180	ABCDE	M	OPT	AUTO
	32	HIGH LOAD	180	ABCDE	M	OPT	AUTO

Phase II LNBFS

PURPOSE	TEST DAY	TEST CONDITIONS	LOAD MW	MILL PATTERN	O2 LEVEL	BURNER TILT	SOFA
DETERMINE PARAMETRIC EFFECTS OF BURNER YAW ANGLE AND SOFA, AND INTERACTION WITH OPERATING PARAMETERS	33	VARY BURNER YAW	180	ABCDE	M	AUTO	0
	34	VARY BURNER YAW	180	ABCDE	M	AUTO	AUTO
	35	VARY BURNER YAW	180	ABCDE	M	AUTO	0
	36	ZERO YAW	140	BCDE	M	AUTO	VARIOUS
	37	VARY BURNER YAW	115	CDE	LMH	AUTO	VARIOUS

3.0 TEST PROCEDURES AND MEASUREMENTS

A wide variety of measurement apparatuses and procedures were used during the test program. The collection of data can be grouped into four broad categories relating to the equipment and procedures used. The following paragraphs provide a brief description of each data category. A more complete description of each category is contained in the Phase I baseline test report.

3.1 Manual Boiler Data Collection

Boiler data were recorded manually on forms from visual readings of existing plant instruments and controls. The data were subsequently entered into the computer data management program. Coal, bottom ash, and ESP hopper ash samples were collected regularly for laboratory analysis. In addition to the readings taken during Phase I tests, data characterizing the SOFA system were also recorded.

3.2 Automated Boiler Data Collection

Two scanning data loggers were used to record the signals from preexisting plant instrumentation and instruments installed specifically for this test program. The data loggers were monitored by a central computer which maintained permanent records of the data and also allowed instantaneous, real-time interface with the data.

Specialized instrumentation was also installed to measure specific parameters related to the combustion and thermal performance of the boiler, as well as selected gaseous emissions. These instruments included combustion gas analyzers, an acoustic pyrometer system, fluxdomes, and continuous ash samplers. During Phase II, SOFA flowrates, SOFA damper positions, SOFA tilts, and burner tilts were added to the measurements provided in Phase I. The combustion gas emissions analyzers, fluxdomes, and the acoustic pyrometer system were linked to the central computer for automated data recording.

3.3 Combustion System Tests

During performance tests, combustion system tests were performed by a team from Flame Refractories, Inc. Specialized apparatuses and procedures were used to measure variables related to combustion and thermal performance of the boiler at several specific operating conditions. The measurements included the following variables:

- Primary Air/Fuel Supply

  - Primary air velocity to each burner.
  - Coal flowrate to each burner.
  - Coal particle size distribution to each burner.

- Secondary Air Supply

  - Secondary air flow, left/right windbox.
  - Secondary air flow, front/rear windbox.

- SOFA Supply

  - SOFA flow to each corner of the boiler.

- Furnace Combustion Gases

  - Gas temperatures near furnace exit.
  - Gas species near furnace exit.

3.4 Solid/Sulfur Emissions Tests

During the performance tests, a team from Southern Research Institute (SoRI) made measurements of particulate and gaseous emissions exiting the boiler using specialized equipment and procedures. These particulate characteristic measurements included:

- Total particulate mass emissions.
- Flyash resistivity at the ESP inlet.
- Flyash particulate size distributions.
- SO_2 and SO_3 concentrations.
- *Unburned carbon losses in flyash.*

The results of the solid particulate and sulfur emissions tests will be used to estimate the effect of NOx reduction technologies on the performance of a generic ESP which is representative of large utility installations.

4.0 DATA ANALYSES METHODOLOGY

Two different types of data analyses were used to characterize test data:

1. Discrete analyses for short-term data - established emission trends, provided information for engineering assessments, and provided data for evaluating commercial guarantees or goals established with the equipment vendors

2. Statistical analyses for long-term data - established the long-term emission trends and regulatory assessments when the unit was operated in a normal system load dispatch mode.

4.1 Short-Term Characterization Data Analysis

The short-term data collection was divided into two test efforts:

1. Diagnostic - established the sensitivities of NOx with the variables of load, mill patterns, excess oxygen, SOFA flows, burner tilts, auxiliary air yaws, and SOFA yaws.

2. Performance - established input/output characterizations of fuel, air, flue gas emissions, and boiler efficiency.

Both the diagnostic and performance efforts were performed under controlled conditions with the unit off of system load dispatch. Each data point is for a single operating condition. Unlike the data collected in the long-term effort, these data are generally not of sufficient quantity to apply advanced statistical analyses. Most of the short-term emission data were evaluated using comparative graphics.

4.1.1 Diagnostic Data

The emphasis of the diagnostic testing was to collect NOx characteristics data to determine the effects of various operational parameters on NOx emissions. Emissions of NOx, O_2, CO, total hydrocarbons (THC), and SO_2 were automatically recorded every 5 seconds and stored in computer files. The NOx measurements were obtained via a sample flow distribution manifold connected to individual probes or combinations of probes located in the economizer exit.

A single data point was determined by selecting a probe group and obtaining numerous 1-minute averages of the 5-second data over the 1- to 3-hour period for each test condition. Sampling on one of the groupings was made for a sufficient time to ensure that the readings were steady. The data acquisition system (DAS) was then prompted to gather data for 1 minute (twelve 5-second readings) and to obtain the statistics for that period. If the standard deviation was large, the reading was discarded. The average of all of the 1-minute average measurements during the test constituted a single data point for the condition under which the test was performed.

A preliminary matrix of tests was established to allow trending and engineering evaluations of the short-term NOx emissions data. During the diagnostic testing, attempts were made to gather three sequential data points (either increasing or decreasing excess oxygen level) at each load level (or mill pattern). With three data points on 1 day with a minimum variation of the other influencing parameters, the general trend of NOx versus load, or against any of the other tested variables, could be determined. Test points which were not sequential (e.g., different loads or mill patterns on the same day) were used to indicate the potential variability about the trend lines. It was assumed that the trends for these single, non-sequential data points were similar to those determined for sequential data and that families of curves exist. This assumption was tested and found to be true by obtaining several days of sequential data at the same operating conditions. Where possible, general equations that represent the trend were developed. In most cases, only three points were available to describe the trend.

4.1.2 Performance Data

The performance tests were designed to:

- Establish the evaluation criteria for the low-NOx combustion equipment, i.e., the impacts of the retrofits on the boiler efficiency, particulate matter changes (size, amount, carbon content, and resistivity), and the retrofit NOx reduction effectiveness.

- Quantify the boiler characteristics for comparison with other program phases.

During performance tests, the boiler condition was fixed at one load with a specified mill pattern and excess oxygen level that was most representative of the normal operating configuration. One repetition of each condition was made to provide data for one configuration per load. Consequently, the emphasis for the performance tests was on the analysis of the flows, solids, and boiler efficiency rather than the NOx trends. During performance tests, data on coal flows, coal fineness, primary air flows, secondary air flows, total particulate mass, particulate sizing, and SO_3 emissions were obtained.

The boiler efficiency was determined using the short form performance test codes (PTC) 4.1 methodology described in the "ASME Power Test Codes for Steam Generators." Data for these calculations were obtained using the gaseous samples from the sample flow distribution manifold and Yokagawa in-situ O_2 analyzers along with other logged information on the DAS. Air preheater leakage was also calculated using these data. The performance tests were segregated into inlet (fuel and air) and outlet (solids and gaseous) measurements. Generally, two sets of solid emission tests were performed for the test configuration while only one fuel/air test was performed during the 10- to 12-hour test period for each configuration. While gaseous measurements (NOx, CO, O_2, etc.) could be made more frequently than inlet and solids matter measurements, the outlet gaseous test duration was arbitrarily made equivalent to the duration for the solids emission tests. Consequently, for each performance configuration, two boiler efficiency calculation determinations were made. Data from the following sources were used to calculate the American Society of Mechanical Engineers (ASME) PTC 4.1 boiler efficiency and air preheater leakage:

- Air preheater inlet gas temperatures, CO emissions, and O_2 level.
- Air preheater outlet gas temperatures and CO emissions.
- ESP inlet LOI using Environmental Protection Agency (EPA) Method 17.
- Fuel ultimate analyses from grab samples.
- Ambient moisture content.

For each performance configuration (2-test days), the following data were obtained:

- Two gaseous emission measurements of NOx, O_2, SO_2, CO, and THC each composed of at least ten 1-minute sample distribution manifold composite flue gas measurements.

- Two PTC 4.1 boiler efficiency determinations and two air preheater leakage determinations.

- A minimum of three repetitions of each of the specific flue gas solids emission parameters (total particulate mass emissions, SO_3, resistivity, LOI, and particle size).

- A minimum of one repetition of inlet fuel and air measurements (primary air distribution, secondary air distribution, coal particle size, or coal mill pipe distribution), or furnace combustion gas temperature and species.

4.2 Long-Term Characterization Data Analysis

During long-term testing, emission and plant operating data inputs were automatically recorded on the DAS and archived. The emission inputs were handled automatically by the CEM. A single emission measurement point in the ductwork just prior to the stack inlet was monitored 24 hours per day during the entire testing. The emission sample was delivered to the CEM through heated lines to preclude scrubbing of SO_2 in the lines.

The primary focus of long-term testing was to capture the natural variation of the data in the normal mode of operation. To ensure long-term data were not biased, no operational intervention by the test team members occurred. For all practical purposes, the boiler was operated in its normal day-to-day configuration under control of the load dispatcher.

The long-term data were interpreted primarily by statistical methods. The specific types of analyses used were:

- Related to regulatory issues, i.e., those associated with the determination of the 30-day rolling average emissions and the estimation of an achievable emission level that the data support.

- The engineering interpretation of long-term results compared to short-term diagnostic results, i.e., those associated with the determination of the best statistical estimates of the operating characteristics (e.g., NOx versus load, mill pattern, etc.).

The following two subsections provide information on 1) the manner in which the raw long-term data were processed to produce a valid emission data set, and 2) the fundamentals of the data specific analytic techniques.

4.2.1 Data Set Construction

4.2.1.1 5-Minute Average Emissions - Data collected during the long-term test period consisted of 5-minute averages of boiler operating conditions and emissions. Since the intent of analyses conducted on long-term test data is to understand boiler operation during normal operating conditions, data collected during boiler startup, shutdown, or unit trips were excluded from the analyses.

4.2.1.2 Hourly Average Emissions - The amount of 5-minute data sufficient to compute an hourly average for emissions monitoring purposes was based on an adaptation of the EPA New Source Performance Standards (NSPS) guidelines. For an hourly average to be considered valid, one of two things has to occur. If 12, 5-minute periods in an hour were available, then at least 6 of the periods had to contain complete load and emissions data. If 11 or less 5-minute periods were available, then that hour had to contain 5 or more periods of complete load and emissions data.

4.1.2.3 Daily Average Emissions - The daily averages were used to determine the achievable NOx emission limit. At least 18 hours of valid hourly data had to be collected for emission monitoring purposes.

4.2.2 Data Analyses Procedures

4.2.2.1 5-Minute Average Emission Data - The edited 5-minute average data were used to 1) determine the NOx versus load relationship, and 2) the NOx versus O_2 response for various load levels. These graphical and analytical data were used to make engineering assessments and comparisons with the short-term data.

4.2.2.2 Hourly Average Emission Data - The hourly average emission analyses were used to assess the hour-to-hour and within-day variations in NOx, O_2, and load during long-term testing. The hour-to-hour variations in NOx, O_2, and load were time-ordered graphical presentations of the hourly averages and were used to establish general trends. The within-day data analyses were performed by sorting the hourly averages by hour of the day and computing the average NOx, O_2, and load for these periods. The statistical properties for these hourly periods and the 95-percentile uncertainty band were computed for each hourly data subset. These data were used to compare the effectiveness of the technologies.

4.2.2.3 Daily Average Emission Data - The daily average emission data were used to establish the trends in NOx, O_2, and load, and to calculate the 30-day rolling NOx emission levels for the entire long-term period. The daily average emissions data were analyzed both graphically and statistically. The graphical analyses consisted of a series of plots to depict the daily variations in NOx, O_2, and load to establish trends. The statistical analyses determined the population mean, variability (standard deviation), distributional form (normal, lognormal), and time series (autocorrelation) properties of the 24-hour average NOx emissions. The SAS Institute statistical analysis package (UNIVARIATE and AUTOREG) procedures were used to perform the statistical analyses.

4.2.2.4 Achievable Emission Rate - The results of the UNIVARIATE and AUTOREG analyses were used to determine the achievable emission level on a 30-day rolling average basis. The achievable emission limit is defined as the value that will be exceeded, on average, no more than one time per 10 years on a 30-day rolling average basis. This compliance level is consistent with the level used by EPA NSPS Subpart Da and Db rulemakings.

The achievable emission limit can be computed using the following relationship if the emissions data are normally distributed:

$$Z = \frac{L - X}{S30} \tag{4-1}$$

where: Z = the standard normal deviate
L = the emission limit
X = the long-term mean
S30 = the standard deviation of 30-day averages.

S30 is computed using the estimated standard deviation (S24) and autocorrelation (ρ) level for daily averages.

$$S30 = \frac{S24}{\sqrt{30}} \left(\frac{1 + \rho}{1 - \rho} - \frac{(2)(\rho)(1 - \rho^{30})}{30\ (1 - \rho)^2} \right)^{1/2} \tag{4-2}$$

Since there are 3,650 30-day rolling averages in 10 years, one exceedence per 10 years is equivalent to a compliance level of 0.999726 (3649/3650). For a compliance level of one violation in 10 years, Z is determined to be 3.46 (based upon the cumulative area under the normal curve).

5.0 SHORT-TERM TEST RESULTS

Most tests during the diagnostic and performance portions of the short-term test were conducted within the normal limits of operating parameters for the unit, with the exception of excess oxygen. Excess oxygen was purposely varied well above and below the recommended levels to the potential levels that might be encountered during transients in the long-term test phase. With the exception of a short period when A-mill was unavailable due to forced maintenance, all major boiler components and ancillary equipment were in their normal operating conditions. The fuel burned throughout the short-term testing was from the normal supply source and was handled according to common plant practice.

The Phase II short-term characterization testing began on May 7, 1991, shortly after ABB CE completed their optimization process. The tests were completed on October 20, 1991. A total of 138 short-term characterization tests were performed. The tests are summarized in Table 5-1.

5.1 Diagnostic Tests (LNCFS Level II)

The LNCFS Level II diagnostic effort consisted of characterizing gas emissions and flyash LOI using the recommended operating configurations established by ABB CE. Diagnostic tests were performed at nominal loads of 200, 180, 140, 115, and 75 MW with the following mill patterns:

Load (MW)	Mill Pattern	Number of Tests
200	Primary (AMIS)	6
180	Primary (AMIS)	56
180	Alternate (A-MOOS)	4
140	Primary (A-MOOS)	29
140	Alternate (AB-MOOS)	11
115	Primary (AB-MOOS)	27
75	Primary (ABC-MOOS)	5

AMIS = All-Mills-In-Service
MOOS = Mills-Out-Of-Service

5.1.1 Unit Operating Condition

During the diagnostic tests, no unusual operating conditions were encountered that placed restrictions on the effort. As a result, more tests were accomplished than originally planned. Table 5-2 presents the as-tested conditions during the diagnostic portion of the testing. Eighteen days of testing were planned and executed, comprising the 69 individual tests at various excess oxygen, mill pattern, SOFA, and load conditions. Twelve of the diagnostic tests were performed after the performance testing. When specified test loads or mills were unavailable on a given day, tests were conducted at the available loads provided by system dispatch, thereby achieving the

Table 5-1
Short-Term Characterization Tests

Test Type	Start-End Dates	Number of Tests
LNCFS Level II		
Diagnostic	May 7, 1991 - June 6, 1991	69
Performance	May 29, 1991 - June 4, 1992	15
Verification	September 12, 1991 - October 1, 1991	29
LNBFS		
Diagnostic	October 2, 1992 - October 6, 1992	25

desired number of tests at each of the test loads. While it was planned to test with no more than four test conditions per test day, it was possible to complete as many as eight test conditions on some days, which accounted for the large number of diagnostic tests performed.

5.1.2 Gaseous Emissions

Table 5-3 presents a summary of important emission and operating parameters recorded during the diagnostic tests. The table provides information on the steam conditions (temperatures and pressures) and the fuel flows supplied from each mill.

The ranges of excess oxygen and SOFA flows and the resulting NOx emissions for the five nominal load levels tested during the diagnostic and performance portions are shown in Figures 5-1 and 5-2. The conditions shown in these figures include variations in excess oxygen, mills-out-of-service, mills biasing, SOFA flows, burner dampers, and tilts. Performance test conditions are also included since they are used for comparison with diagnostic tests. Note that all NOx data reported in parts per million are corrected to 3-percent excess oxygen.

Figure 5-1 shows that the testing was performed over a wide range of excess oxygen levels. The solid curve represents the O_2 level recommended by ABB CE for operation of the LNCFS Level II. During system dispatch control of the unit, excursions to the upper and lower limits of the O_2 levels may be commonly experienced during transient load conditions. In order to properly compare the short-term and long-term characteristics, O_2 excursion testing during the short-term diagnostic effort was conducted.

Figure 5-2 is a summary of the NOx emission data that were collected for the LNCFS Level II configuration. The conditions in the figure represent the range of normal configurations that might be experienced during the system load dispatch mode of operation during long-term testing. The data scatter is because different configurations and excess oxygen levels are represented. The solid curve shown in Figure 5-2 indicates the NOx emissions at the recommended operating conditions. At the lowest load tested, the NOx emissions increase sharply due to the higher excess O_2 level and the SOFA flow as a percentage of the total air flow diminishes.

Table 5-2
Summary of Lansing Smith Unit 2 Phase II LNCFS Level II
Diagnostic Testing (Sheet 1 of 2)

TEST NO.	DATE	TEST CONDITIONS	LOAD MW	MOOS	SOFA DAMPER TOP/MID/BOT % OPEN	O2 %	NOx ppm
25-1	05-07-91	LOI VERSUS O2 VARIATION	181	NONE	101/100/100	3.9	296
25-2	05-07-91	"	180	NONE	101/100/100	3.6	246
25-3	05-07-91	"	181	NONE	101/100/100	4.3	288
26-1	05-08-91	HIGH LOAD, O2 VARIATION	180	NONE	101/100/100	5.2	288
26-2	05-08-91	"	180	NONE	101/100/100	4.3	274
27-1	05-09-91	HIGH LOAD, TILT VARIATION	180	NONE	100/100/100	3.8	264
27-2	05-09-91	"	180	NONE	100/100/100	3.8	262
27-3	05-09-91	INCOMPLETE DUE TO LOAD CHANGE	180	NONE	– / – / –	–	–
27-4	05-09-91	MAX LOAD, OFA / MILL VARIATION	200	NONE	60/100/100	3.2	260
28-1	05-14-91	"	210	A	0/ 0/ 0	3.4	399
28-2	05-14-91	"	200	A	60/100/100	3.3	282
29-1	05-14-91	MID LOAD, O2 VARIATION	140	A	20/101/100	2.4	245
29-2	05-15-91	"	140	A	20/101/100	3.7	278
29-3	05-15-91	"	140	A	20/101/100	5.3	318
29-4	05-15-91	MID LOAD, OFA VARIATION	140	A	0/ 0/100	3.9	298
29-5	05-15-91	"	140	A	0/ 0/100	4.1	379
30-1	05-16-91	MID LOAD, O2 / MILL VARIATION	141	AB	20/100/100	2.4	251
30-2	05-16-91	"	142	AB	20/100/100	3.0	230
30-3	05-16-91	"	143	AB	20/100/100	4.2	265
30-4	05-16-91	"	142	AB	20/100/100	5.4	292
30-5	05-16-91	"	142	A	20/100/100	4.7	293
30-6	05-16-91	"	142	A	20/100/100	3.2	248
31-1	05-16-91	LOW LOAD, O2 / OFA VARIATION	115	AB	0/ 0/ 0	2.4	282
31-2	05-17-91	"	117	AB	0/ 60/100	2.4	250
31-3	05-17-91	"	117	AB	0/ 60/100	3.9	266
31-4	05-17-91	"	114	AB	0/ 60/100	4.7	286
31-5	05-17-91	HIGH LOAD, NORMAL OFA	181	A	100/100/100	3.2	257
32-1	05-17-91	LOW LOAD, O2 / OFA VARIATION	115	AB	0/ 60/100	2.4	250
32-2	05-18-91	"	116	AB	0/ 60/100	3.7	283
32-3	05-18-91	"	116	AB	0/ 60/100	4.8	288
33-1	05-18-91	MIN LOAD, O2 / OFA VARIATION	75	ABC	0/ 0/ 0	5.4	330
33-2	05-19-91	"	76	ABC	0/ 0/ 50	4.8	269
33-3	05-19-91	"	76	ABC	0/ 0/ 50	6.5	311
33-4	05-19-91	"	76	ABC	0/ 0/ 50	7.7	338
33-5	05-19-91	"	76	ABC	0/ 0/ 0	7.8	398
34-1	05-28-91	HIGH LOAD, 02 / FUEL AIR VARIATION	181	NONE	100/100/100	3.7	252
34-2	05-28-91	"	181	NONE	100/100/100	2.7	204
34-3	05-28-91	"	181	NONE	100/100/100	3.0	221
34-4	05-28-91	"	181	NONE	100/100/100	3.5	249
34-5	05-28-91	"	181	NONE	100/100/100	4.1	276
34-6	05-28-91	"	181	NONE	100/100/100	3.7	252
36-1	05-30-91	HIGH LOAD, O2 VARIATION	181	NONE	100/114/114	3.4	229
37-3	05-31-91	MAX LOAD, O2 VARIATION	200	NONE	114/114/114	4.7	351
38-1	06-01-91	LOW LOAD, O2 VARIATION	115	AB	0/ 53/114	3.7	251
38-4	06-01-91	"	115	AB	0/ 57/114	5.3	265
39-3	06-02-91	"	115	AB	0/ 56/114	3.7	239
39-4	06-02-91	"	115	AB	0/ 56/114	5.4	279

Table 5-2
Summary of Lansing Smith Unit 2 Phase II LNCFS Level II
Diagnostic Testing (Sheet 2 of 2)

TEST NO.	DATE	TEST CONDITIONS	LOAD MW	MOOS	SOFA DAMPER TOP/MID/BOT % OPEN	O2 %	NOx ppm
40-3	06-03-91	MID LOAD, O2 VARIATION	137	A	15/104/114	3.0	242
40-4	06-03-91	"	137	A	15/104/114	5.0	272
41-1	06-04-91	MID LOAD, O2 / OFA VARIATION	135	A	11/ 97/114	4.9	284
41-4	06-04-91	"	136	A	100/100/114	3.8	245
41-5	06-04-91	MID LOAD, OFA / AIR VARIATION	136	A	100/100/114	3.9	259
41-6	06-04-91	"	136	A	13/100/114	4.2	274
42-1	06-05-91	HIGH LOAD, OFA VARIATION	182	NONE	101/114/114	3.9	253
42-2	06-05-91	"	182	NONE	75/ 75/ 75	3.9	258
42-3	06-05-91	"	181	NONE	50/ 50/ 50	4.0	275
42-4	06-05-91	"	182	NONE	25/ 25/ 25	4.0	321
42-5	06-05-91	"	182	NONE	0/ 0/ 0	4.0	412
42-6	06-05-91	"	181	NONE	100/ 0/ 0	4.2	384
42-7	06-05-91	"	181	NONE	100/100/ 0	4.0	305
42-8	06-05-91	"	182	NONE	100/100/100	4.0	256
43-1	06-06-91	HIGH LOAD, FUEL / AIR VARIATION	182	NONE	100/114/114	4.0	247
43-2	06-06-91	"	181	NONE	100/114/114	3.8	245
43-3	06-06-91	"	182	NONE	100/114/114	4.0	252
43-4	06-06-91	"	182	NONE	100/114/114	4.0	275
43-5	06-06-91	HIGH LOAD, MILL / O2 VARIATION	181	A	100/114/114	4.0	287
43-6	06-06-91	"	182	A	100/114/114	2.9	243
43-7	06-06-91	"	182	A	100/114/114	5.2	323
43-8	06-06-91	HIGH LOAD, MILL / AIR VARIATION	181	A	100/114/114	4.0	285

Table 5-3
Summary of Phase II LNCFS Level II Diagnostic Tests
Operating and Emission Data (Sheet 1 of 2)

TEST NO	DATE	GROSS LOAD (MWe)	PLANT O2 E ECON OUTLET (PCT)	PLANT O2 W ECON OUTLET (PCT)	CEM O2 AVERAGE OUTLET (PCT)	CEM COMPOSITI AVG NO (PPM)	STACK OPACITY (PCT)	CEGRIT LOI	SAPH A OUT TEMP (°F)	SAPH B OUT TEMP (°F)	STEAM FLOW (kLB/HR)	SH TEMP (°F)	SH SPRAY FLOWS LOWER SPRAY (PCT)	SH SPRAY FLOWS UPPER SPRAY (PCT)	HOT RH TEMP (°F)	PULVERIZER FLOW MILL A (kLB/HR)	PULVERIZER FLOW MILL B (kLB/HR)	PULVERIZER FLOW MILL C (kLB/HR)	PULVERIZER FLOW MILL D (kLB/HR)	PULVERIZER FLOW MILL E (kLB/HR)
25-1	05/07/91	181	5.7	4.9	3.9	296	3.4	3.1	306	301	1295	999	43.8	33.7	995	26.3	28.0	26.1	25.8	27.9
25-2	05/07/91	180	5.2	4.1	3.6	246	2.9	4.0	301	304	1300	1001	43.5	32.9	1000	26.2	28.3	26.8	26.7	28.2
25-3	05/07/91	180	5.9	5.2	4.3	288	5.8	2.5	303	307	1300	1000	46.3	57.3	1002	27.0	29.4	28.2	28.3	30.4
26-1	05/08/91	180	5.6	6.7	5.2	288	2.0		294	299	1310	999	16.1	22.4	978	27.6	28.7	27.4	27.9	29.7
26-2	05/08/91	180	4.9	5.8	4.3	274	1.9	2.8	301	304	1305	998	29.8	30.2	982	26.0	27.8	27.0	27.6	29.5
27-1	05/09/91	180	4.3	4.8	3.8	264	2.9		303	307	1305	1001	27.8	19.2	980	27.5	26.4	27.0	26.6	26.5
27-2	05/09/91	180	4.1	5.2	3.8	262	2.9		302	304	1310	999	18.4	22.4	973	27.7	26.5	27.0	26.7	26.7
27-4	05/09/91	200	4.0	3.8	3.2	260	5.8		311	317	1206	1000	33.7	34.8	995	31.0	30.0	31.6	30.3	29.9
28-1	05/14/91	201	4.5	4.4	3.4	399	8.3		304	306	1473	1000	31.4	36.1	1003	0.0	38.7	34.9	34.3	43.9
28-2	05/14/91	200	4.5	5.4	3.3	282	4.8		309	311	1474	1002	28.8	30.2	996	0.0	39.2	32.5	33.4	42.7
29-1	05/14/91	140	3.6	3.1	2.4	245	2.4		299	302	969	1001	32.2	43.9	993	0.0	26.2	23.4	23.0	29.6
29-2	05/15/91	140	4.9	4.3	3.7	278	N/A		288	291	971	1001	78.8	71.8	997	0.0	26.4	24.7	24.0	30.7
29-3	05/15/91	140	6.2	5.7	5.3	318	2.4		289	290	972	1009	98.8	98.8	995	0.0	27.0	24.9	24.2	30.7
29-4	05/15/91	140	4.6	4.4	3.9	298	1.9		287	290	985	1001	49.8	60.0	987	0.0	26.6	24.0	23.2	30.4
29-5	05/15/91	140	4.8	4.4	4.1	379	N/A		285	288	978	1001	98.6	73.3	989	0.0	26.3	24.3	24.3	30.9
30-1	05/16/91	141	3.3	3.3	2.4	251	2.4		285	286	992	1001	35.3	43.1	989	0.0	0.0	34.4	34.5	40.8
30-2	05/16/91	142	4.4	3.2	3.0	230	2.4		283	284	996	1001	47.1	59.2	997	0.0	0.0	35.1	24.6	41.1
30-3	05/16/91	143	5.3	4.3	4.2	265	2.4		282	283	997	1001	98.0	76.1	997	0.0	0.0	33.5	33.5	40.1
30-4	05/16/91	142	6.4	5.8	5.4	292	3.4		285	287	999	1001	59.6	74.1	984	0.0	0.0	34.4	33.5	40.1
30-5	05/16/91	142	5.9	5.1	4.7	293	2.4		292	294	999	998	45.1	63.9	980	0.0	26.7	25.6	25.4	32.3
30-6	05/16/91	142	4.3	3.6	3.2	248	1.9		292	295	993	1005	36.5	47.8	985	0.0	26.2	24.7	24.1	31.0
31-1	05/16/91	115	3.6	3.5	2.4	282	4.4		283	285	808	1001	22.0	27.8	947	0.0	0.0	28.5	28.5	29.5
31-2	05/17/91	117	3.7	3.2	2.4	250	5.4		273	275	802	998	41.2	52.2	980	0.0	0.0	28.8	29.6	30.7
31-3	05/17/91	117	5.0	4.5	3.9	266	4.5		270	271	803	998	47.1	71.8	983	0.0	0.0	28.7	27.0	30.6
31-4	05/17/91	114	6.0	5.6	4.7	286	4.5		271	272	801	1001	45.5	62.4	971	0.0	0.0	29.5	29.5	30.9
31-5	05/17/91	181	4.9	4.8	3.2	257	6.8		296	297	1312	999	31.8	38.8	1001	0.0	33.8	32.3	32.8	36.0
32-1	05/17/91	115	3.8	3.5	2.4	250	6.3		287	290	802	1002	20.8	24.7	962	0.0	0.0	28.9	27.9	31.3
32-2	05/18/91	116	4.9	4.8	3.7	283	6.7		274	277	800	1000	54.9	65.9	979	0.0	0.0	28.9	28.2	30.2
32-3	05/18/91	116	5.8	5.4	4.8	288	4.6		276	276	805	1000	74.9	83.5	977	0.0	0.0	28.8	27.8	31.2
33-1	05/18/91	75	5.8	5.6	5.4	330	5.3		282	286	539	972	2.0	0.0	898	0.0	0.0	0.0	26.0	32.3
33-2	05/19/91	76	5.2	4.8	4.8	269	6.8		261	265	545	975	2.0	0.0	907	0.0	0.0	0.0	26.4	32.9
33-3	05/19/91	76	6.9	6.5	6.5	311	3.3		250	253	534	998	27.1	35.7	938	0.0	0.0	0.0	26.7	33.2
33-4	05/19/91	76	7.5	7.1	7.7	338	3.8		250	253	535	997	40.4	54.5	943	0.0	0.0	0.0	26.9	30.3
33-5	05/19/91	76	7.5	7.5	7.8	398	3.8		252	254	534	1001	47.5	59.6	947	0.0	0.0	0.0	27.5	34.0
34-1	05/28/91	181	5.6	4.0	3.7	252	5.0		318	314	1311	1001	35.7	25.5	997	27.5	27.9	24.7	26.1	31.1
34-2	05/28/91	181	3.8	3.0	2.7	204	3.6		321	318	1304	1000	26.7	25.5	1002	26.6	27.1	23.3	26.4	30.3
34-3	05/28/91	181	4.7	3.2	3.0	221	4.1		320	317	1302	999	34.9	27.1	1003	25.8	26.8	23.9	25.8	30.6
34-4	05/28/91	181	5.1	3.7	3.5	249	5.3		319	317	1304	1000	43.4	30.6	999	27.7	28.3	24.2	26.1	31.1
34-5	05/28/91	181	5.8	4.4	4.1	276	9.1		322	319	1307	1000	54.1	40.4	1002	27.9	28.6	24.5	26.4	31.3
34-6	05/28/91	181	5.1	4.5	3.7	252	7.7		325	323	1302	1002	52.2	41.6	1001	27.8	28.9	25.1	26.6	31.7
36-1	05/30/91	182	5.3	3.7	3.4	229	N/A		316	314	1304	998	33.7	23.1	1005	26.8	27.8	26.1	25.5	29.7
37-3	05/31/91	200	6.5	4.9	4.7	351	7.3	2.0	330	332	N/A	993	32.9	36.5	993	30.1	29.9	29.7	28.0	31.4

Table 5-3
Summary of Phase II LNCFS Level II Diagnostic Tests Operating and Emission Data (Sheet 2 of 2)

TEST NO	DATE	GROSS LOAD (MWe)	PLANT 02		CEM 02	CEM	STACK OPACITY (PCT)	CEGRIT LOI	SAPH A OUT TEMP (°F)	SAPH B OUT TEMP (°F)	STEAM FLOW (kLB/HR)	SH TEMP (°F)	SH SPRAY FLOWS		HOT RH TEMP (°F)	PULVERIZER FLOW (kLB/HR)				
			E ECON OUTLET (PCT)	W ECON OUTLET (PCT)	AVERAGE OUTLET (PCT)	COMPOSITI AVG NO (PPM)							LOWER SPRAY (PCT)	UPPER SPRAY (PCT)		MILL A	MILL B	MILL C	MILL D	MILL E
38-1	06/01/91	115	4.8	4.0	3.7	251	3.3	2.5	298	295	797	1005	61.2	48.6	978	0.0	0.0	30.4	26.7	32.4
38-4	06/02/91	115	5.8	5.2	5.3	265	3.3	2.7	284	282	800	989	36.9	58.0	950.2	0.0	0.0	30.1	26.1	32.0
39-3	06/03/91	115	4.6	3.9	3.7	239	8.3		280	277	798	996	27.1	20.4	953	0.0	0.0	29.3	25.5	32.1
39-4	06/03/91	114	6.2	5.3	5.4	279	7.3		277	276	800	993	42.7	55.7	958	0.0	0.0	30.1	26.1	32.7
40-3	06/04/91	139	3.8	3.6	3.0	242	3.3	2.1	293	290	974	995	65.5	47.8	988	0.0	27.1	25.3	21.7	33.5
40-4	06/04/91	137	6.1	4.9	5.0	272	10.0		293	290	982	995	54.9	40.8	959	0.0	66.0	58.0	54.0	78.0
41-1	06/04/91	135	5.9	5.0	4.9	284	5.3		308	305	951	994	53.7	42.4	982	0.0	27.6	26.2	23.8	28.8
41-4	06/05/91	136	5.6	5.9	3.8	245	4.4		297	293	957	988	57.3	43.9	973	0.0	27.3	26.2	23.8	28.7
41-5	06/05/91	136	5.4	4.2	3.9	259	6.8		294	291	956	996	56.1	51.4	977	0.0	27.6	26.2	23.6	28.5
41-6	06/05/91	136	5.1	4.5	4.2	274	5.8		296	291	959	991	62.4	76.5	979	0.0	27.6	26.7	23.9	29.0
42-1	06/05/91	182	6.4	4.8	3.9	253	8.3		324	324	1320	994	39.2	27.5	1000	26.8	27.9	26.4	25.1	27.7
42-2	06/05/91	182	6.5	4.5	3.9	258	7.8		324	323	1325	993	48.6	34.5	1001	26.9	28.5	27.5	25.7	28.6
42-3	06/05/91	181	6.5	4.5	4.0	275	7.8		323	321	1319	994	47.5	35.7	998	27.5	28.9	27.9	26.1	28.9
42-4	06/05/91	182	6.7	4.8	4.0	321	N/A		323	320	1319	994	54.9	41.6	1003	27.6	29.1	28.4	26.4	29.2
42-5	06/05/91	182	5.5	4.4	4.0	412	7.8		323	320	1320	994	62.0	50.2	1004	26.8	28.5	27.0	25.9	28.5
42-6	06/06/91	181	5.6	4.4	4.2	384	12.3		324	322	1324	994	55.3	43.9	996	27.6	29.1	28.1	26.4	29.1
42-7	06/06/91	181	6.0	4.7	4.0	305	10.8		323	320	1315	994	47.1	35.7	992	27.6	29.1	28.0	26.2	29.1
42-8	06/06/91	182	6.4	4.5	4.0	256	7.8		323	319	1315	994	47.5	34.9	995	27.7	28.8	27.7	26.1	28.9
43-1	06/06/91	182	6.5	4.2	4.0	247	13.3		321	320	1313	993	37.3	21.6	999	27.2	27.1	25.5	24.7	29.6
43-2	06/06/91	181	6.6	4.1	3.8	245	9.3		311	319	1317	994	43.1	26.7	1001	27.7	27.5	26.6	25.2	29.9
43-3	06/06/91	182	6.2	4.4	4.0	252	8.3		322	318	1316	994	49.0	33.7	1003	27.9	28.3	27.5	25.4	30.7
43-4	06/06/91	182	6.0	4.4	4.0	275	10.0		322	319	1320	994	41.6	31.0	998	28.1	28.2	27.0	26.1	30.4
43-5	06/06/91	181	6.3	4.5	4.0	287	8.3		317	313	1317	994	45.1	33.7	996	0.0	35.6	34.2	31.4	38.2
43-6	06/06/91	182	4.7	3.3	2.9	243	12.3		317	311	1315	994	38.8	31.8	1000	0.0	35.7	34.3	31.3	38.3
43-7	06/06/91	182	6.9	5.3	5.2	323	17.2		316	313	1316	993	67.5	54.9	996	0.0	36.4	34.8	32.2	38.7
43-8	06/07/91	181	5.8	4.6	4.0	285	7.3		316	312	1313	993	45.1	34.1	994	0.0	36.2	34.8	31.7	39.6

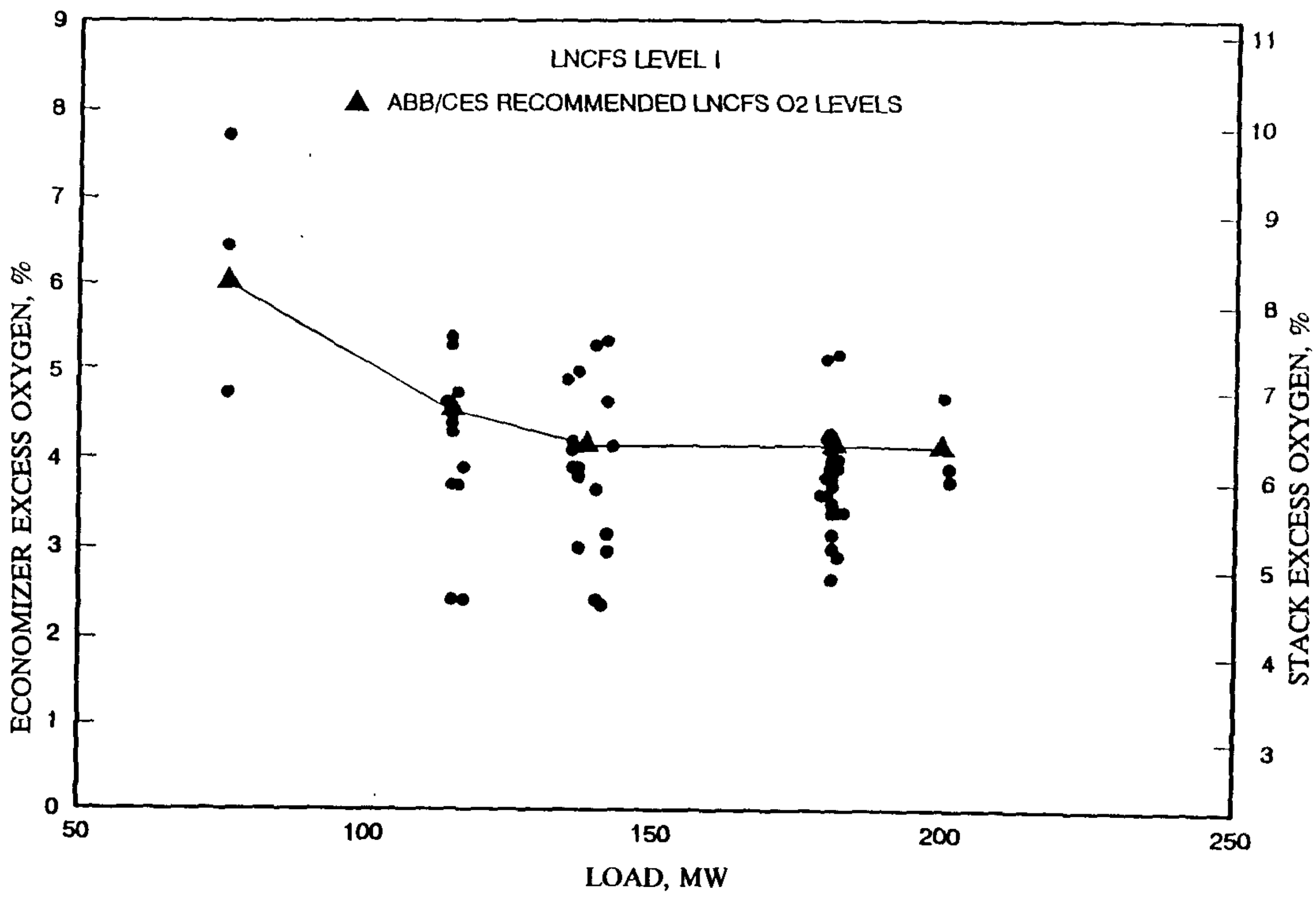

Figure 5-1. Smith Unit 2 Excess Oxygen Levels Tested

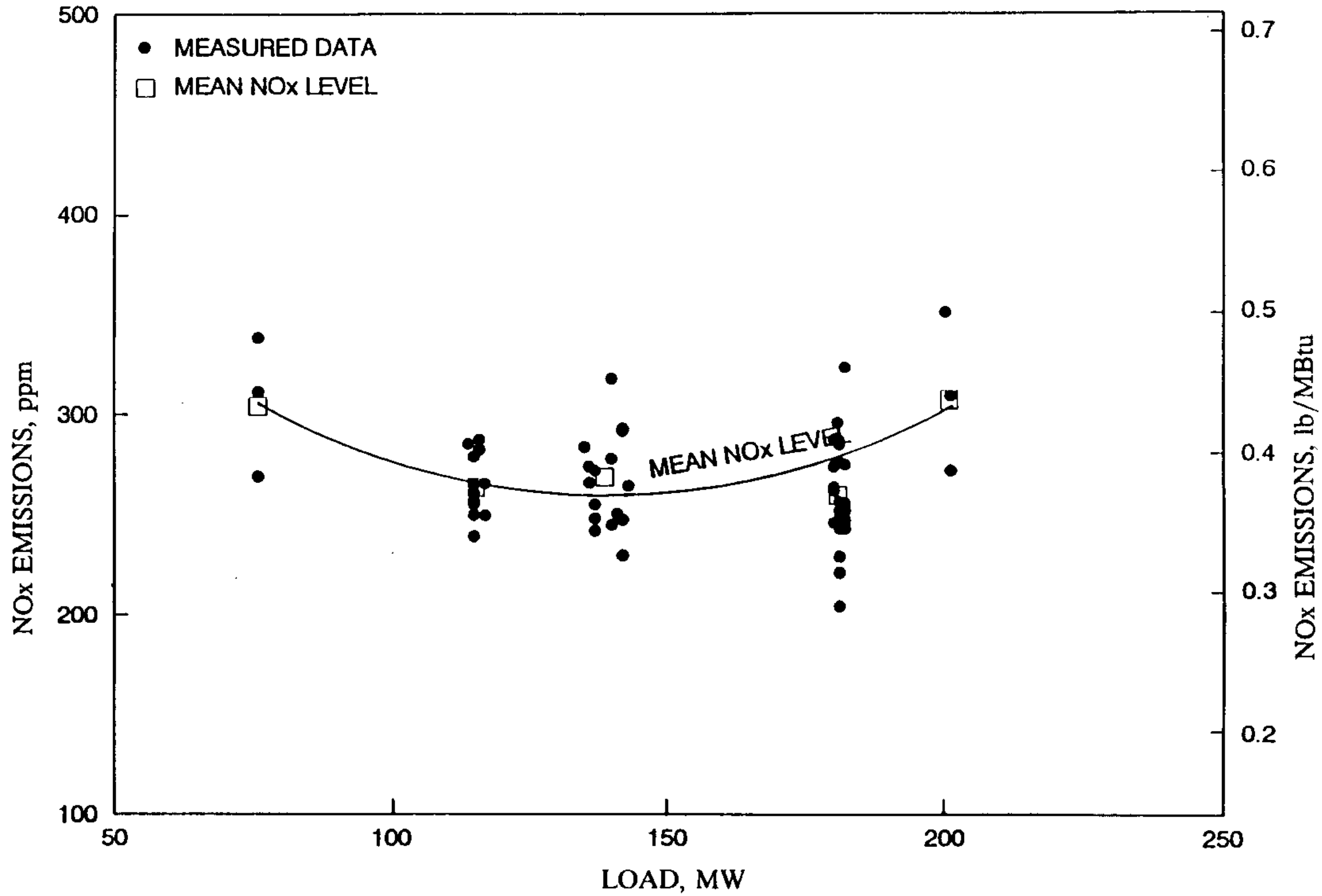

Figure 5-2. Smith Unit 2 Nitric Oxide Measurements

Short-term characterizations of the NOx emissions generally were made for trends determined on the same day of testing for a particular configuration. This process mitigates the influence of uncontrollable parameters. Figures 5-3 through 5-7 show the diagnostic test results for the five nominal loads tested. The legend for each data point indicates the mill configuration (where appropriate) and the test day for that point.

Figure 5-3 illustrates the NOx emission data obtained for the 200 MW test load. The most commonly used mill pattern at this load was all-mills-in-service (AMIS). The A-mill-out-of-service (A-MOOS) test condition occurred due to a broken shaft on A-mill at a time when system dispatch had required the maximum load. These data are not included in Figure 5-3. The NOx increased at a rate of about 52 parts per million/percent O_2 for the pattern at this load.

Figure 5-4 shows the NOx data for the 180-MW test point. At this load, the most commonly used mill pattern was AMIS with the A-MOOS used on occasion when conditions dictated. Over the wide range of achievable excess oxygen levels (2.7 to 5.2 percent), the NOx increased at a rate of change of approximately 35 parts per million/percent O_2 for the two mill patterns tested.

NOx data for the 140 MW test point are shown in Figure 5-5 for two mill patterns - A-MOOS and AB-MOOS. Plant personnel indicated that these were the most commonly used mill patterns at this load. The NOx increased at a rate of approximately 25 parts per million/percent O_2 at this load over an excess oxygen range of 2.4 to 5.4 percent.

At 115 MW, the oxygen range could be tested over the same excursion range as the 140 MW test point, as shown in Figure 5-6. A single mill pattern (AB-MOOS) was tested at this load. The NOx increased at a rate of approximately 18 parts per million/percent O_2.

Figure 5-7 shows the NOx emissions characteristics at 75 MW, one MOOS pattern (ABC-MOOS). This configuration exhibited a nominal 24 parts per million/percent O_2 slope or slightly greater than the slope at the 115-MW load point.

From these figures it is evident that 1) the relative trends of NOx versus O_2 compared at the same load were repeatably similar from day to day, and 2) the influence of excess oxygen levels on NOx emission generally decreased as the load is decreased. It should be noted that it is not possible from the short-term data to detect absolute differences between mill patterns. The utility of these data presented in these figures is that the relative trend (slope) can be discerned.

Figure 5-8 compares the NOx emissions sensitivities to excess oxygen levels for the baseline and LNCFS Level II. In contrast to the straight-line load characteristic for the baseline configuration, the NOx/O_2 sensitivity in the Level II configuration exhibited a parabolic characteristic curve. At loads below 140 MW, the increase in the slope is believed to be due to the use of less SOFA than the system is capable of, as well as the rapidly increasing use of excess oxygen at low loads to maintain reheat temperature. Near 200 MW, the NOx/O_2 also increased more rapidly with load, since the SOFA dampers were fully open at 180 MW, and therefore at 200 MW the SOFA ports could not provide proportionally more SOFA flow without further restricting the burner and

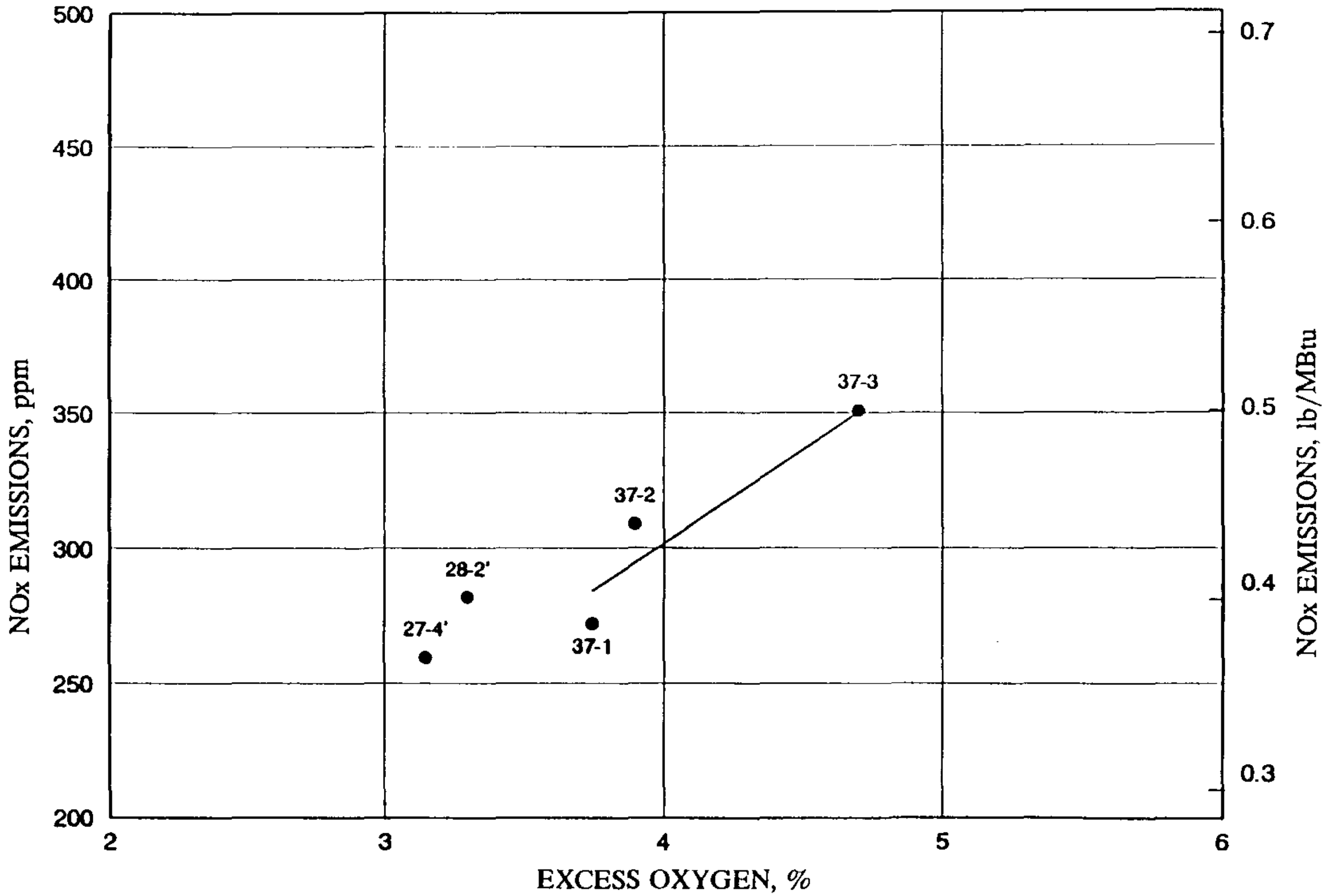

Figure 5-3. 200-MW LNCFS Level II NOx Characteristics

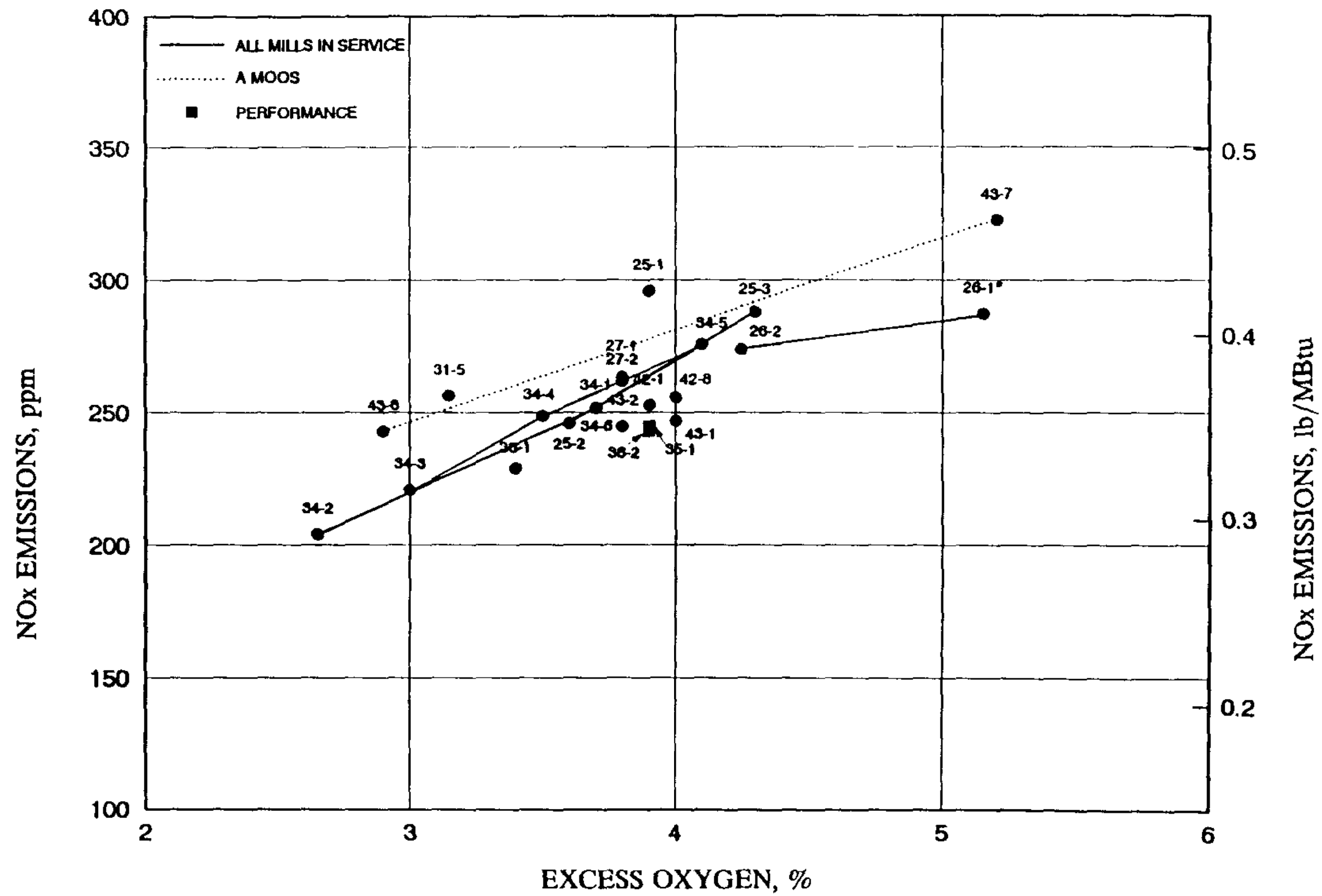

Figure 5-4. 180-MW LNCFS Level II NOx Characteristics

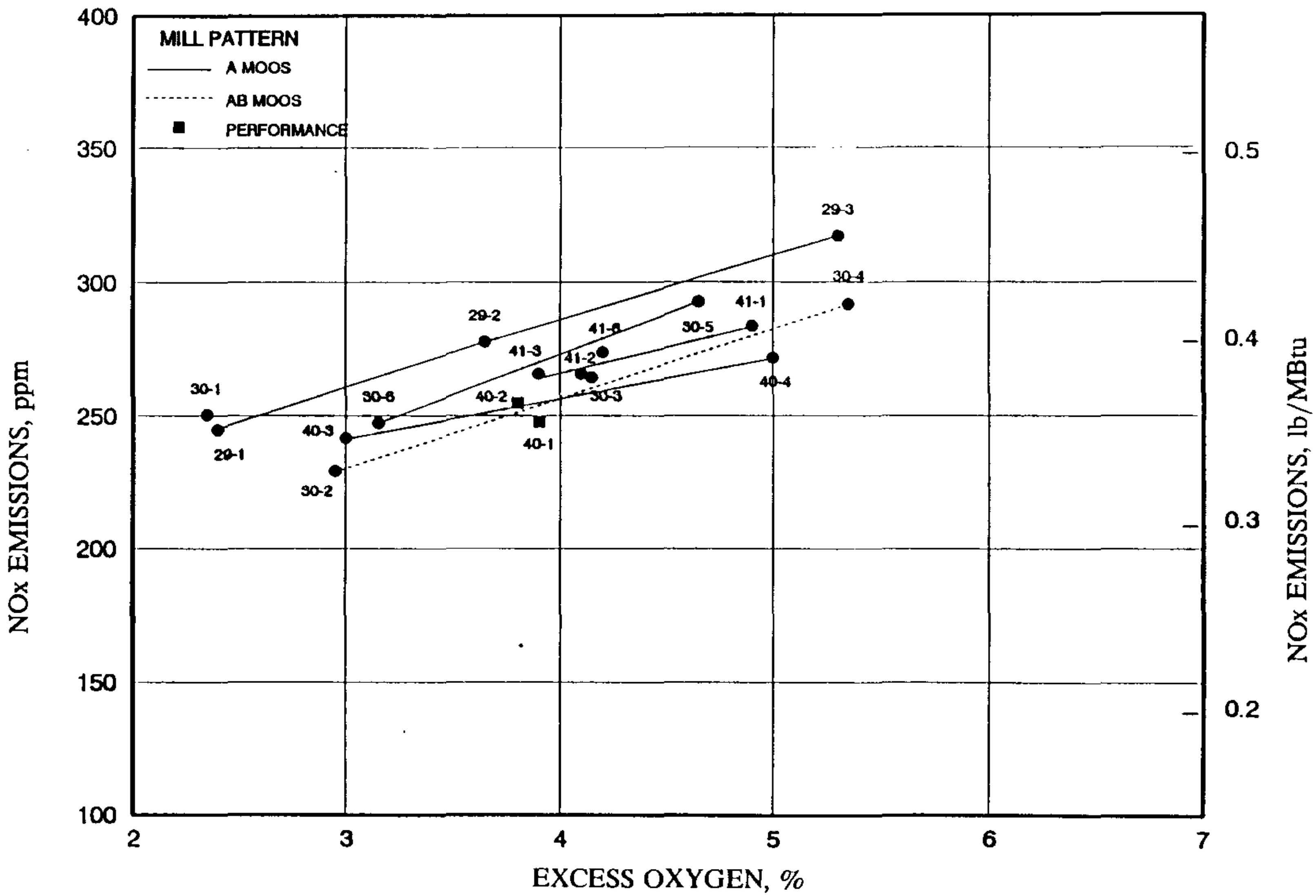

Figure 5-5. 140-MW LNCFS Level II NOx Characteristics

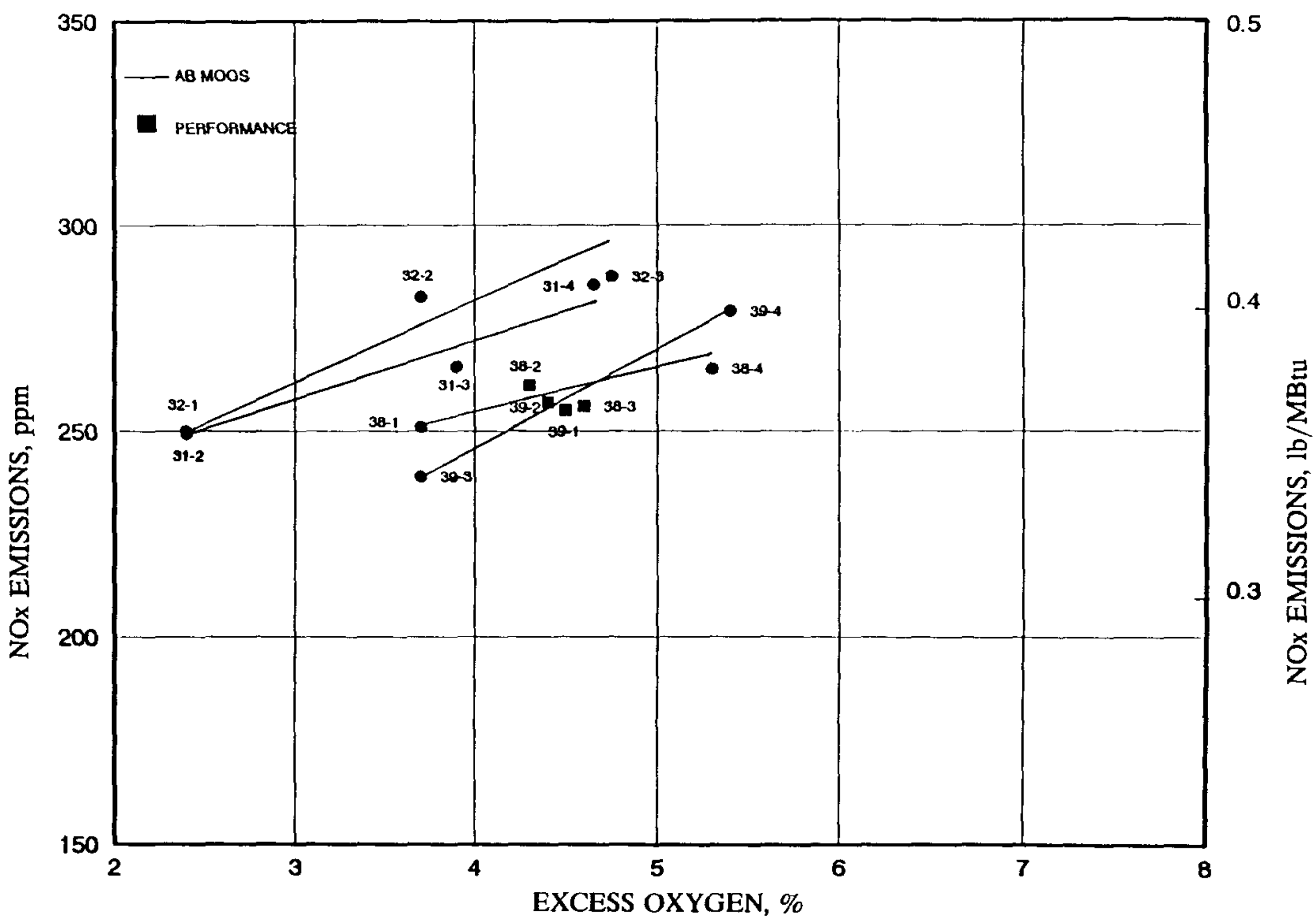

Figure 5-6. 115-MW LNCFS Level II NOx Characteristics

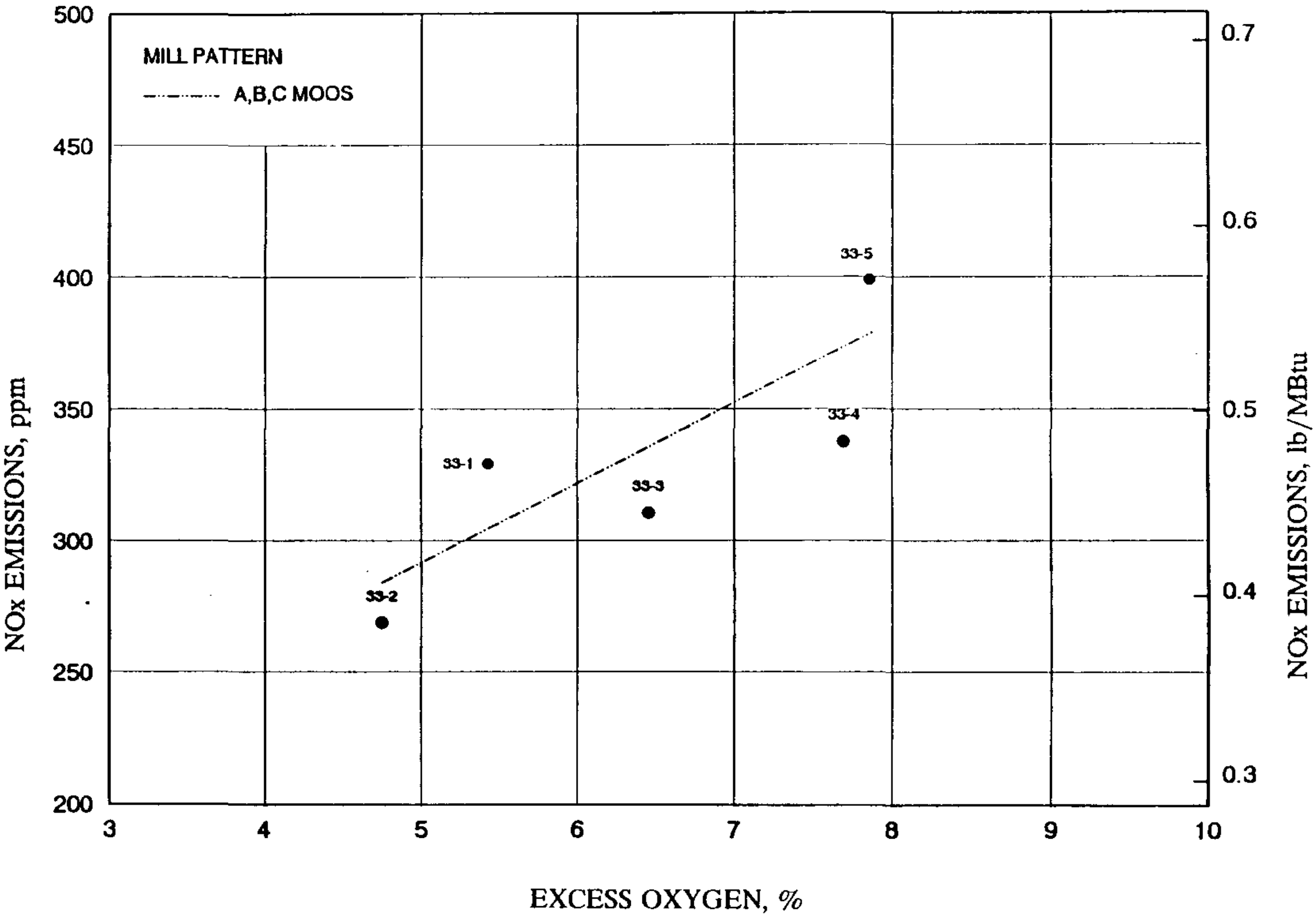

Figure 5-7. 75-MW LNCFS Level II NOx Characteristics

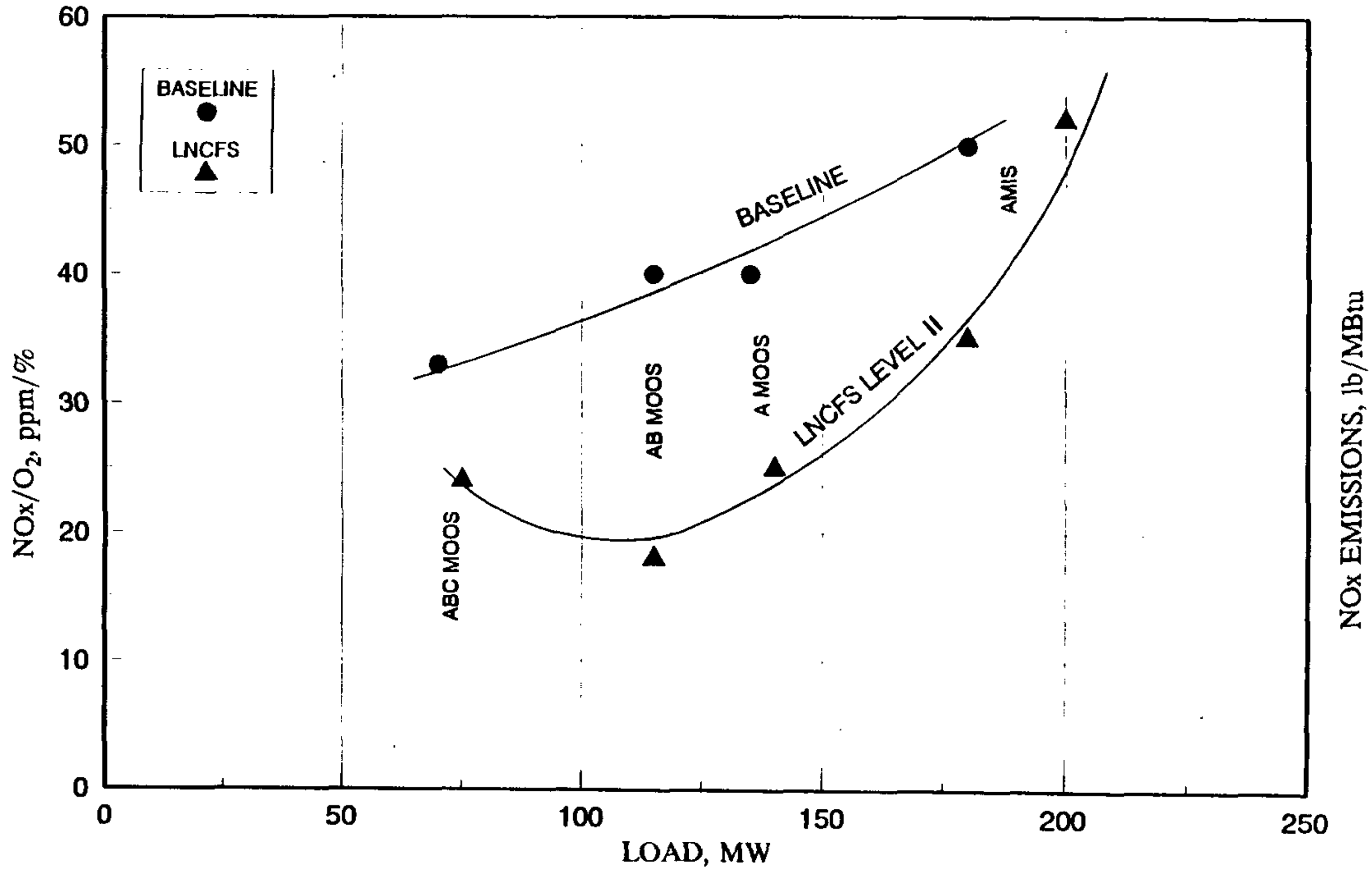

Figure 5-8. Baseline and LNCFS Level II NOx Sensitivity

auxiliary air dampers. The sensitivities of NOx to O_2 across the load range with LNCFS Level II were substantially lower than found with the baseline configuration.

Figure 5-9 shows the effect of SOFA as a percent of total air on NOx emissions at 180 MW with the LNCFS Level II configuration. The amount of SOFA was varied by two methods at 180 MW. First, the SOFA was reduced by closing all three levels of SOFA dampers uniformly from 100 percent open to completely closed. Second, the top, center, and bottom SOFA levels were completely opened in sequence as illustrated in Figure 5-9. This created nominal OFA flows of 33, 67, and 100 percent of the design flow. The two methods of modulating the OFA flow created different characteristic curves. This indicated that the flow to each SOFA section was not equal. Note that the SOFA dampers were completely closed at the minimum SOFA flow shown in the figure.

Figure 5-10 shows the effect of SOFA compared for three load levels. The SOFA dampers for the 140- and 115-MW loads were closed in levels from top to bottom. The start and end points of the 180-MW tests are shown for comparison.

5.1.3 Coal and Ash Analyses

Coal samples were taken periodically during the diagnostic testing. The results of these analyses are shown in Table 5-4. These data show that the coal properties were relatively constant during the Phase II diagnostic tests.

Flyash samples were collected by the CEGRIT samplers located in the economizer outlet duct. The data collected with these samplers are listed in Table 5-3.

5.2 Performance Tests (LNCFS Level II)

Performance tests were conducted at loads of 200, 180, 140 and 115 MW. With the exception of the 1-day 200-MW test, testing at each load condition required 2-consecutive days to complete sampling of all of the parameters included in the performance test matrix. At each nominal load, the coal firing rate was maintained as constant as possible, and the load was allowed to swing slightly as affected by coal variations, boiler ash deposits, and ambient temperature. Each day of performance testing covered from 10 to 12 hours, during which manual and automated boiler operational data were recorded, fuel and ash samples collected, gaseous and solid emissions measurements made, and the engineering performance tests conducted.

5.2.1 Unit Operating Data

For each performance test, the desired test conditions were established and allowed to stabilize at least 1 hour prior to beginning that test. To the extent possible, the active coal mills were balanced with respect to coal feed rate. Normal primary air/coal ratios and mill outlet temperatures were maintained within the capacity of the existing primary

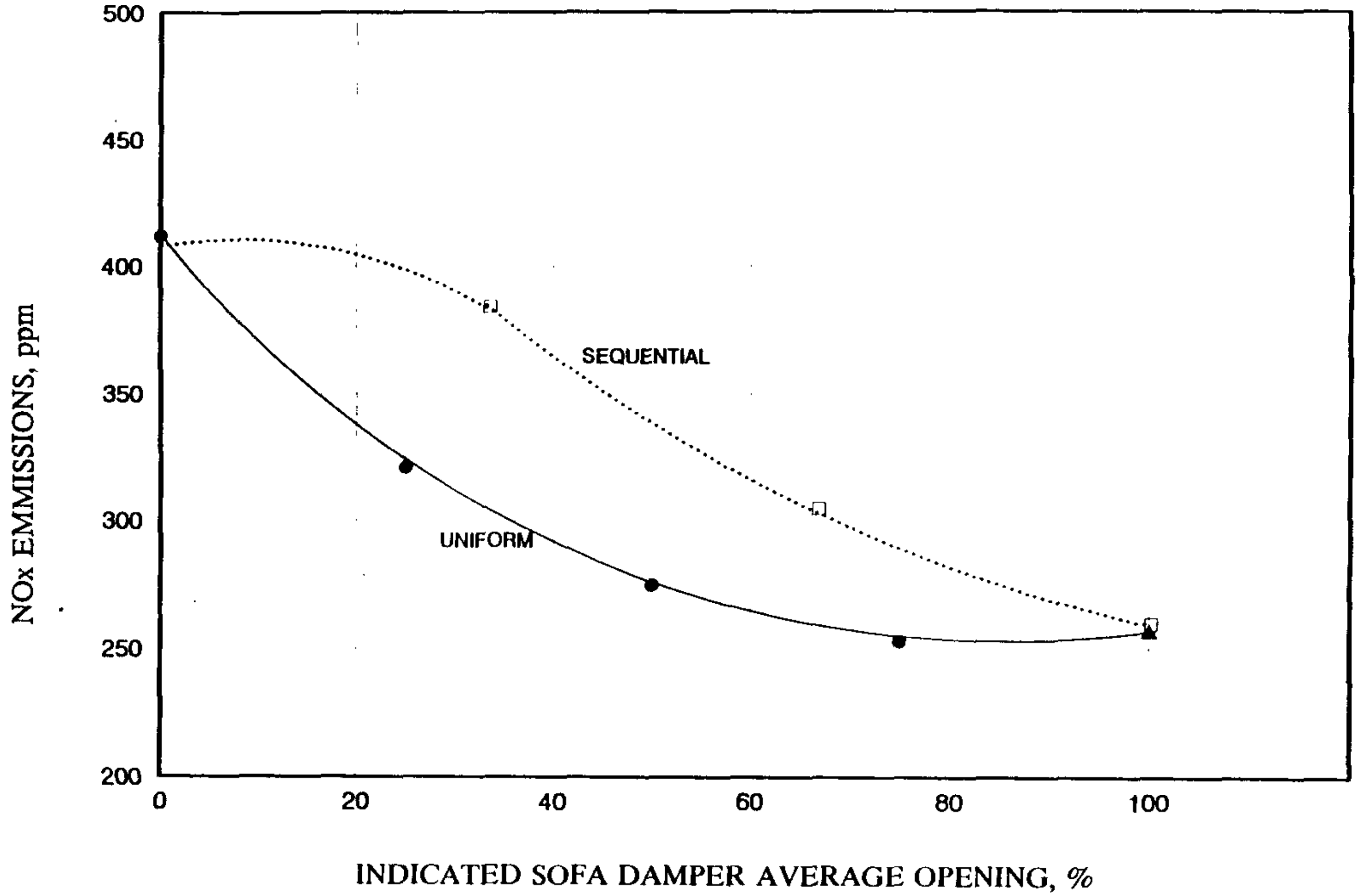

Figure 5-9. Effect of SOFA Damper Opening (Lansing Smith Phase II, 180 MW, 4% O_2)

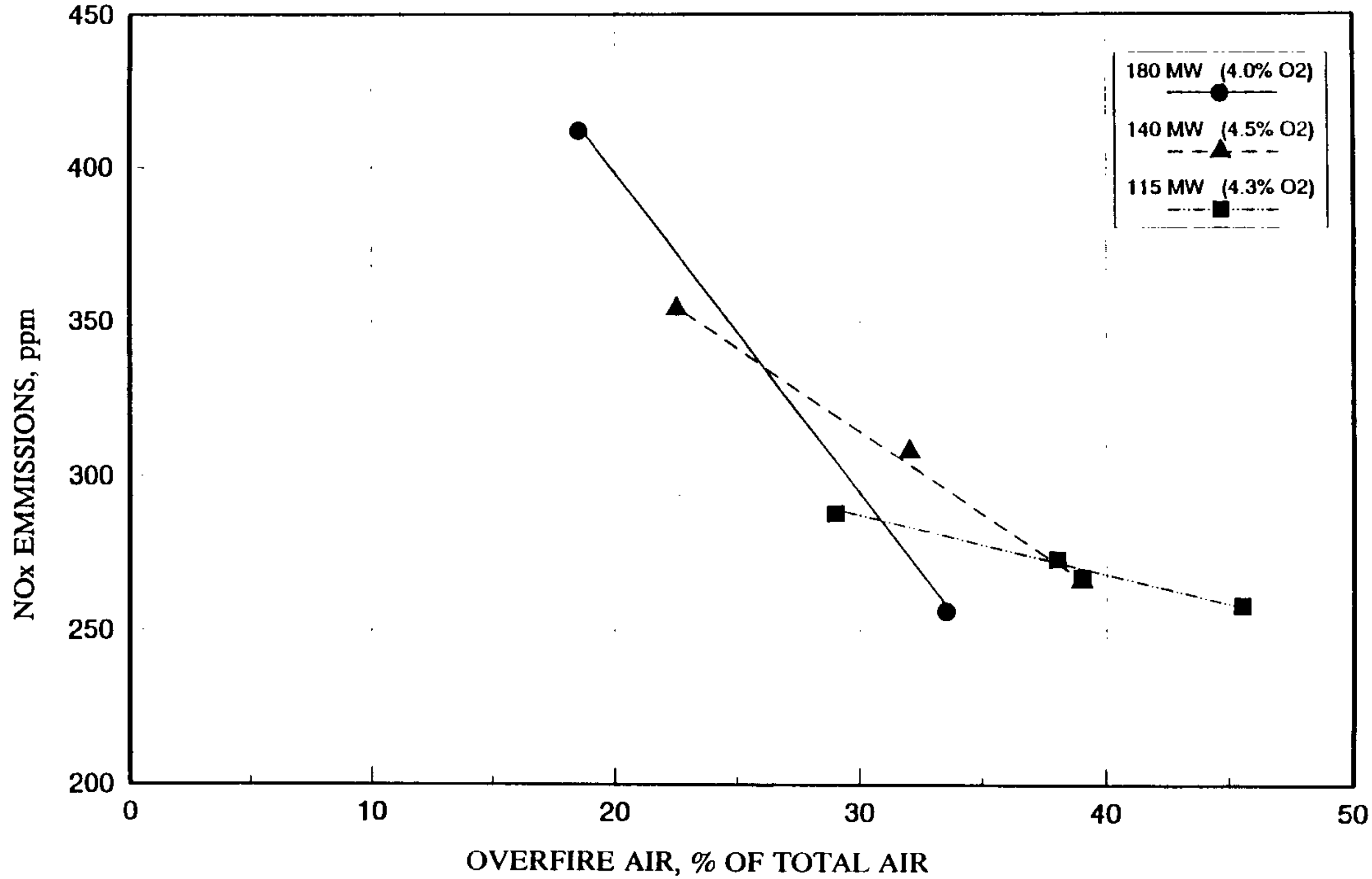

Figure 5-10. LNCFS Level II SOFA Damper Position NOx Sensivity

Table 5-4
Phase II LNCFS Level I Diagnostic Tests Coal Analyses

Test Number	Date	Time	Ultimate Analyses (%)									HHV BTU/lb	VM %	Fixed Carbon %
			H2O	C	H	N	Cl	S	Ash	O	TOTAL			
42-2	06/05/91	1840	9.86	66.86	4.61	1.39	0.08	2.89	9.00	5.41	100.10	11892	36.59	44.56
42-2	06/05/91	1840	9.49	66.20	4.42	1.41	0.15	2.84	9.12	6.52	100.15	11902	35.40	45.99
43-2	06/05/91	1915	10.64	66.24	4.59	1.39	0.13	2.81	8.74	5.59	100.13	11862	36.38	44.24

air system. When the desired operating conditions were established, some controls were placed in manual mode to minimize fluctuations in the fuel or air firing rate. This technique resulted in extremely stable operating conditions requiring only minor adjustments to the unit air flow over the day.

Because a portion of the testing was concerned with measurement of particulate emission characteristics, soot blowing of the furnace and air preheaters was suspended during the particulate sampling periods. As a result, the test measurements included only the particulate matter generated by the coal combustion process at the time of testing (plus any normal attrition of wall or air preheater deposits). When necessary for control of final steam temperatures, the furnace walls or tube surfaces (superheater or reheater) were blown in between repetitions of the solids emissions testing. It was not necessary to sootblow the air preheaters.

Table 5-5 summarizes the conditions during each performance test and Table 5-6 presents a summary of important operating parameters recorded during these tests. The values shown in these tables represent averages over the duration of the test segment during the day.

5.2.2 Gaseous Emissions

During the performance tests, gaseous emissions were measured with the extractive CEM operating in the manual mode. At various times, flue gases were sampled from selected probes or probe groups in the primary and secondary air preheater inlet and outlet ducts. These groupings consisted of composites of each of the east and west economizer exit ducts and individual measurements from each probe in these ducts. Composite grouping was used to establish the overall emission characteristics, while the individual probe measurements were used to establish spatial distributions of emission species. The composite average values of O_2 and NOx measured for each test segment are shown in Table 5-5.

5.2.3 Particulate Emissions

Particulate emission characteristics which relate to the ability to collect flyash within an ESP were measured. The measurements included:

- Total mass emissions.
- Particle size.
- Chemical composition.
- Ash resistivity.
- SO_2/SO_3 concentrations.

These measurements were made immediately before the air preheater. The following paragraphs describe the results of these measurements.

Table 5-5
Summary of Lansing Smith Unit 2 Phase II LNCFS Level II Performance Testing

TEST NO.	DATE	TEST CONDITIONS	LOAD MW	MOOS	SOFA DAMPER TOP/MID/BOT	O2 %	NOx ppm	SOFA %
35-1	05-29-91	HIGH LOAD	181	NONE	100/114/114	3.9	245	22.6
35-2	05-29-91	"	181	NONE	100/114/114	3.7	255	–
35-3	05-29-91	"	181	NONE	100/114/114	3.7	255	–
36-2	05-30-91	"	181	NONE	100/114/114	3.9	243	22.6
36-3	05-30-91	"	180	NONE	100/114/114	3.9	243	–
37-1	05-31-91	MAX LOAD	201	NONE	114/114/114	3.8	272	–
37-2	05-31-91	"	201	NONE	114/114/114	3.9	309	–
38-2	06-01-91	LOW LOAD	115	AB	0/54/114	4.3	261	23.9
38-3	06-01-91	"	115	AB	0/54/114	4.6	256	–
39-1	06-02-91	"	115	AB	0/54/114	4.5	255	24.3
39-2	06-02-91	"	115	AB	0/55/114	4.4	257	–
40-1	06-03-91	MID LOAD	137	A	15/104/114	3.9	248	23.7
40-2	06-03-91	"	137	A	15/104/114	3.8	255	–
41-2	06-04-91	"	136	A	11/100/114	4.1	266	–
41-3	06-04-91	"	136	A	12/100/114	3.9	266	–

Table 5-6
Summary of Phase II Performance Tests Operating and Emission Data

TEST NO	DATE	GROSS LOAD (MWe)	PLANT O2 E ECON OUTLET (PCT)	PLANT O2 W ECON OUTLET (PCT)	CEM O2 AVERAGE OUTLET (PCT)	CEM COMPOSITE AVG NO (PPM)	STACK OPACITY (PCT)	CEGRIT LOI	SAPH A OUT TEMP (°F)	SAPH B OUT TEMP (°F)	STEAM FLOW (kLB/HR)	SH TEMP (°F)	SH SPRAY FLOWS LOWER SPRAY (PCT)	SH SPRAY FLOWS UPPER SPRAY (PCT)	HOT RH TEMP (°F)	PULVERIZER FLOW MILL A (kLB/HR)	MILL B	MILL C	MILL D	MILL E
35-1	05/29/91	181	6.4	3.9	3.9	245	5.3	2.8	316	312	1299	1000	41.0	27.5	1001	27.7	28.2	27.7	25.9	30.9
35-2	05/29/91	182	5.6	4.1	3.7	255	4.3	2.4	323	319	1312	1000	45.5	34.9	1001	28.2	28.6	28.1	26.4	31.1
35-3	05/29/91	181	5.5	4.3	3.7	255	4.3	1.8	323	322	1307	1000	45.1	35.7	1003	27.6	27.7	27.5	25.7	30.5
36-2	05/30/91	181	6.0	4.6	3.9	243	4.9	2.7	317	314	1312	1000	36.1	25.5	1003	27.6	28.5	26.7	26.0	30.0
36-3	05/30/91	180	5.9	4.2	3.9	243	4.4	2.0	324	321	1305	1001	43.5	31.4	1002	26.3	27.6	25.9	26.1	29.5
37-1	05/31/91	201	6.1	4.5	3.8	272	6.3		321	316	1477	1002	42.7	32.5	1001	30.5	30.7	30.1	28.0	31.4
37-2	05/31/91	201	5.0	4.0	3.9	309	5.3	2.3	328	328	1478	1004	43.5	31.8	1004	31.5	31.2	31.0	29.0	32.4
38-2	06/01/91	116	5.3	4.4	4.3	261	3.3	2.7	289	286	795	997	98.0	98.0	985.3	0.0	0.0	30.4	26.8	32.2
38-3	06/02/91	115	5.2	4.6	4.6	256	3.3	2.9	281	277	800	993	87.1	73.3	970.4	0.0	0.0	30.4	26.9	32.4
39-1	06/02/91	116	5.2	4.5	4.5	255	3.3	2.5	283	280	800	994	34.1	42.7	962	0.0	0.0	29.6	25.9	32.5
39-2	06/02/91	115	5.5	4.4	4.4	257	3.3	3.2	278	275	799	993	25.5	18.0	953	0.0	0.0	30.1	26.0	32.6
40-1	06/03/91	137	4.8	4.2	3.9	248	4.3		298	296	974	994	28.6	19.6	966	0.0	26.6	24.7	21.2	32.9
40-2	06/04/91	138	4.4	4.0	3.8	255	4.3	2.6	292	290	970	994	66.3	48.6	982	0.0	27.5	26.7	22.2	33.6
41-2	06/04/91	136	5.3	3.9	4.1	266	4.3	2.0	299	295	948	995	92.5	77.6	992	0.0	27.3	26.3	23.9	28.9
41-3	06/05/91	136	5.4	3.9	3.9	266	6.8	2.1	297	294	953	995	75.7	60.4	982	0.0	27.4	26.1	23.3	28.3

*5.2.3.1 **Total Mass Emissions*** - Total mass emissions reflect both a fraction of the total ash in the coal that is injected into the furnace (100 percent minus the ash which drops into the furnace bottom hopper or the economizer hopper), plus most of the unburned carbon leaving the flame zone. Table 5-7 presents the results of the Method 17 tests performed at each test condition. The results shown for each load level represent the average of three replicate tests. For all tests, the data were remarkably consistent. The agreement between different test conditions was also surprisingly good during this performance series.

Table 5-7
Summary of Solid Mass Emissions Tests

			Particulate Massloading				
Test	**Load MW**	**Mass Train O_2,%**	**gr/dscf**	**lb/MBtu**	**Gas Flow dscfm**	**Carbon %**	**LOI %**
35	181	5.3	2.61	4.91	395,200	3.8	4.2
37	201	4.5	2.49	4.45	435,000	4.8	5.4
38	115	5.0	2.57	4.74	276,400	3.4	3.8
40	137	4.6	2.66	4.78	317,400	3.3	3.9

As a measure of the degree of completeness of combustion, the ash collected in the cyclone portion of the Method 17 train for each test was analyzed to determine its carbon content and LOI. The LOI is considered to represent carbon content along with volatile solids (sulfates, chlorides, etc.) driven off in the analysis procedure. The correlation between the carbon and LOI analyses for all samples provided a measure of confidence in the reliability of the results. The principal use of the carbon and LOI analyses provided a reference for comparison with ash samples acquired during other phases of the program. Based on these results, carbon constitutes roughly 90 percent of the combustibles in the LOI analysis.

*5.2.3.2 **Particle Size*** - The particle size distribution of ash exiting the outlet of the hot-side ESP was determined using a cascade impactor. Three samples were obtained for each test condition. Figure 5-11 shows the particle size distributions for all test conditions as the total percentage of cumulative mass of particles smaller than the 50-micron aerodynamic diameter. The vertical bars visible to the upper right show the 90-percent confidence level for the mass values determined at the indicated particle diameter while the symbols show the average of the replicate samples for each load. For most of the data, the 90-percent confidence interval is smaller than the plotting symbol. For large particle sizes, the confidence band is exaggerated due to the exponential scale. The confidence interval for these points is in the 1-percent range.

The close agreement of all the data points indicates the relatively minor effect of load on the ash-particle size distribution. The small range of the confidence intervals indicates excellent replication of results under common test conditions.

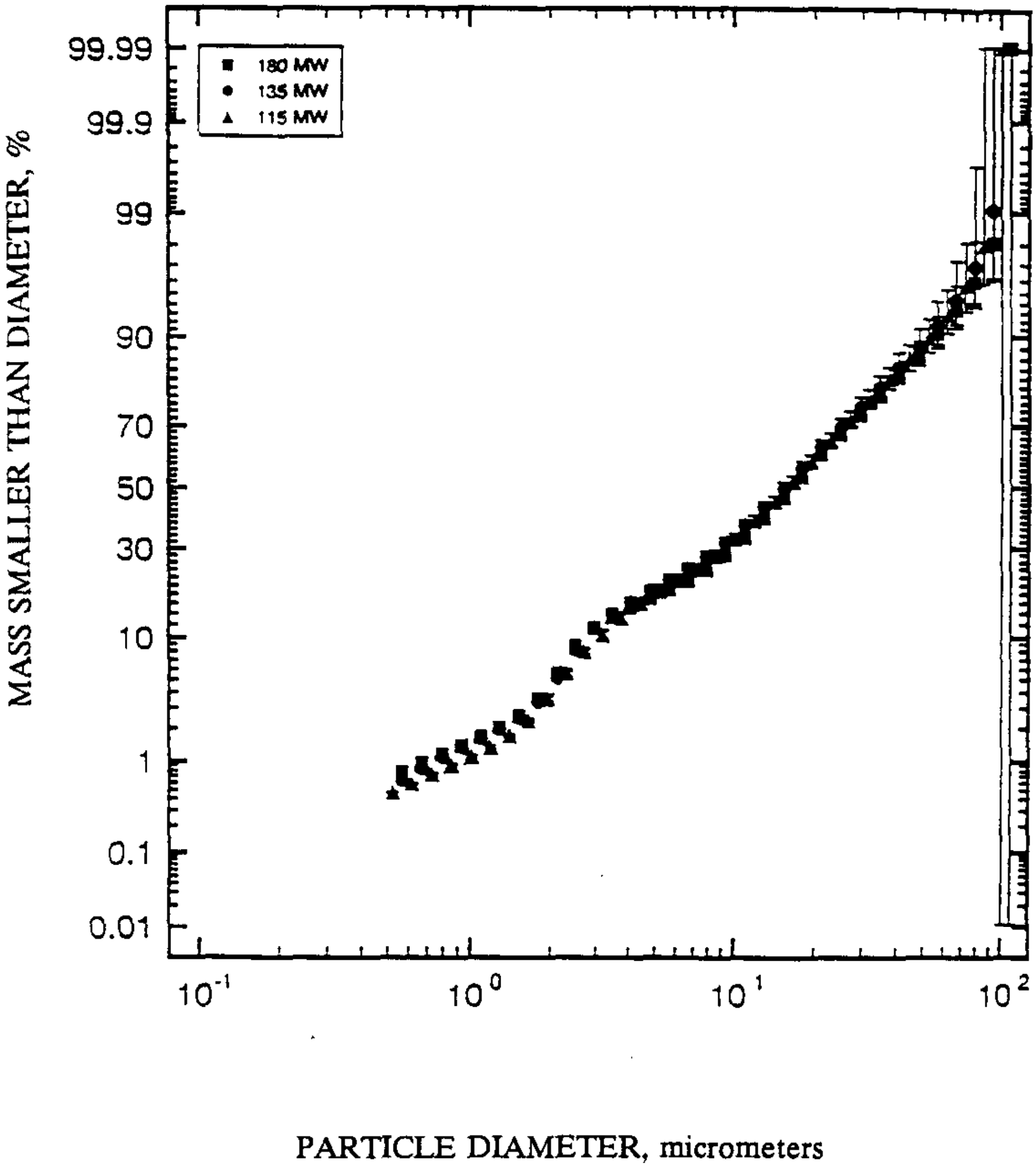

Figure 5-11. Inlet Percent Mass Distribution

5.2.3.3 ***Chemical Composition*** - Samples of flyash collected from the economizer exit by Method 17 and selected ESP hoppers were analyzed for LOI and separately for carbon content. The ESP hopper samples (north and south composites) were analyzed for mineral composition. Table 5-8 presents these data, providing a comparison of the LOI measured levels for the economizer exit using Method 17 and the ESP hopper using grab samples. Relatively poor agreement exists between the LOI values from the ESP hopper and the Method 17 results. The ESP samples were collected by dumping selected hoppers while the Method 17 samples were collected isokinetically from the economizer exit. The poor agreement indicates that stratification exists within the furnace. For the purpose of further comparisons, the Method 17 results will be used to eliminate potential bias caused by the stratification in the hopper sample data.

5.2.3.4 ***Ash Resistivity*** - One of the most important properties affecting ESP performance is the resistivity of the ash particles. Ash resistivity is a measure of the ash's ability to retain an electrical charge which allows it to migrate and adhere to the ESP plates. Since the unit is equipped with a hot-side ESP, in-situ resistivity measurements could not be made. The laboratory resistivity measurements are presented in Table 5-9. Laboratory measurements of the resistivity of ESP hopper samples from the different test conditions are shown in Figures 5-12 and 5-13.

The resistivity of the ESP hopper samples was calculated using their chemical compositions (Table 5-9) and a mathematical model of flyash resistivity[1]. Figures 5-12 and 5-13 show these calculated resistivities for typical ash compositions are for assumed SO_3 levels of approximately 4 percent.

Because the laboratory measurement of resistivity with acid vapor was run for an extended period of time to reach an equilibrium condition, the resulting values of resistivity with some ashes could be lower than could realistically be achieved at a power plant. This over-conditioning effect does not appear to be related to ash compositions similar to that at Lansing Smith, but the lack of a developed correlation for the effect suggests caution in the interpretation of laboratory data. However, even if the actual resistivity were more than an order of magnitude higher than the laboratory data, the actual resistivity would still be low enough not to impede ESP operation.

5.2.3.5 ***SO_2/SO_3 Tests*** - The concentrations of SO_2 and SO_3 (as separate species) were measured in both the north and south ducts at the air preheater exit for every performance test load condition. Table 5-10 presents the results of the tests for each load point. The table highlights some important observations related to the SO_2. First, the SO_2 values are relatively constant for any particular test sequence, indicating good repeatability. Second, the SO_2 varied only slightly between sampling periods. Since Unit 2 uses a hot-side ESP, the SO_3 data are not considered relevant for the more common cold-side ESP applications. The SO_3 levels at the exit of a hot-side ESP are expected to be higher than for those normally measured at the entrance of a cold-side ESP.

Table 5-8
Chemical Analyses of LNCFS Level II Hopper Samples in Weight Percent

Oxide	TEST 35 180 MW 05/29/91 NORTH DUCT	TEST 35 SOUTH DUCT	TEST 37 200 MW 05/31/91 NORTH DUCT	TEST 37 SOUTH DUCT	TEST 38 115 MW 06/1-2/91 NORTH DUCT	TEST 38 SOUTH DUCT	TEST 40 135 MW 06/4-5/91 NORTH DUCT	TEST 40 SOUTH DUCT
Li_2O	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Na_2O	0.64	0.61	0.56	0.56	0.62	0.64	0.59	0.57
K_2O	1.9	1.9	1.7	1.8	1.9	1.9	2.2	2.2
MgO	0.91	0.89	0.87	0.87	0.89	0.89	0.91	0.91
CaO	7.5	7.5	8.6	8.4	7.5	7.5	7.3	8.0
Fe_2O_3	18.2	18.9	18.9	18.5	17.5	17.1	17.5	17.5
Al_2O_3	18.7	18.5	18.4	18.5	19.0	18.8	18.6	18.7
SiO_2	49.4	48.8	48.5	48.5	50.2	49.9	49.8	49.4
TiO_2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.1
P_2O_5	0.22	0.19	0.19	0.21	0.18	0.18	0.25	0.23
SO_3	0.89	0.94	0.84	0.81	0.79	0.71	0.67	0.80
LOI	7.7	6.3	6.8	8.1	3.1	4.6	4.8	7.4
AVERAGE LOI's								
ESP Hopper	7.0		7.5		3.9		6.1	
Mass Train	4.2		5.4		3.8		3.9	
CEGRIT	2.3		3.0		2.7		2.5	

Table 5-9
Laboratory and Model Resistivity for Hot-Side ESP

Test Series	Date	Load	Duct	Temp (F)	RESISTIVITY (ohm-cm) Laboratory Measurement	Inherent Prediction	Sodium Depleted Prediction
35	05/29/91	180 MW	North	677	$2x10^9$	$2x10^9$	$8x10^9$
			South		$5x10^9$	$2x10^9$	$8x10^9$
37	05/31/91	200 MW	North	698	$2x10^9$	$2x10^9$	$8x10^9$
			South		$2x10^9$	$2x10^9$	$8x10^9$
38	06/01/91	115 MW	North	588	$1x10^{11}$	$7x10^9$	$4x10^{10}$
			South		$1x10^{10}$	$7x10^9$	$4x10^{10}$
40	06/03/91	135 MW	North	617	$7x10^9$	$5x10^9$	$3x10^{10}$
			South		$1x10^{10}$	$6x10^9$	$3x10^{10}$

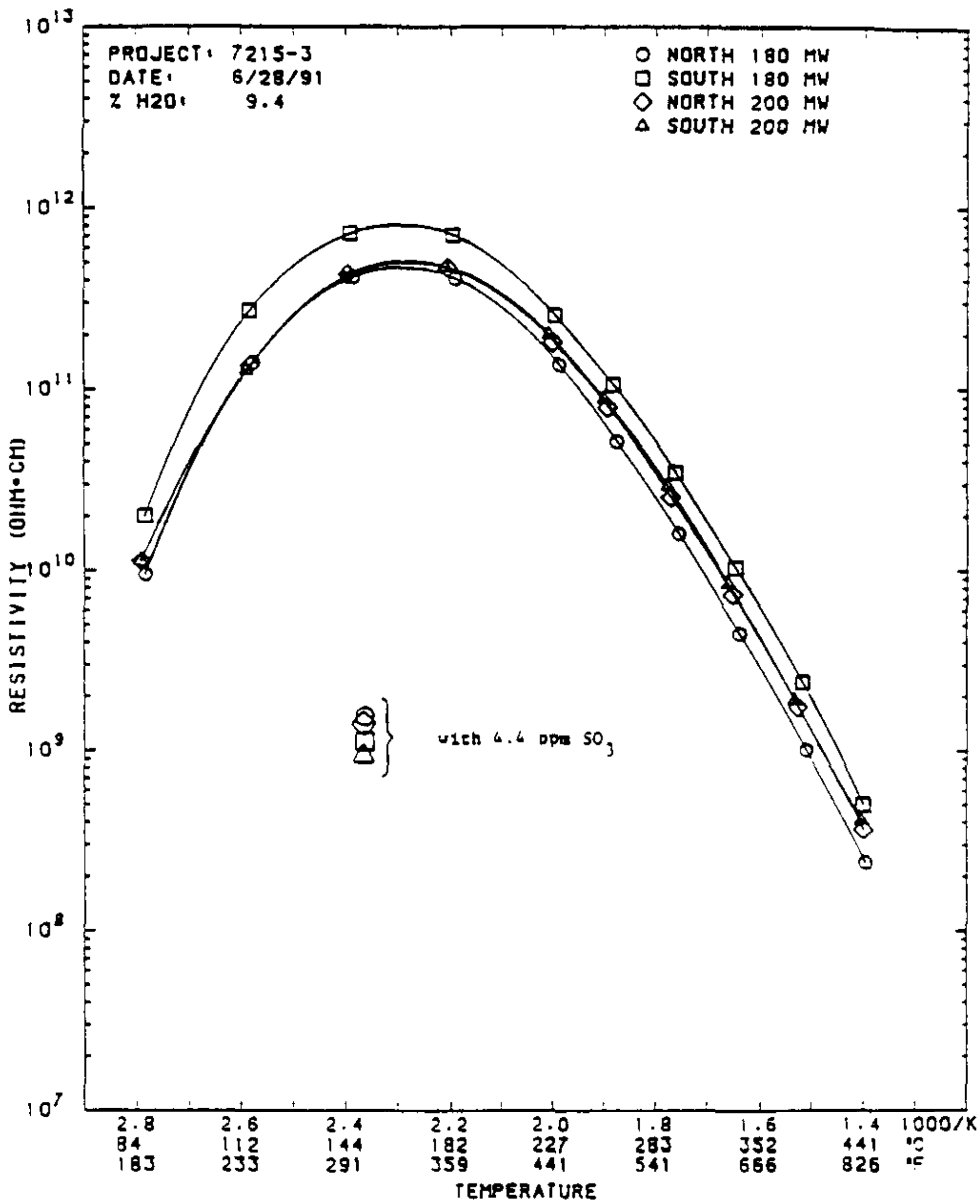

Figure 5-12. High-Load Laboratory Ash Resistivity Measurements

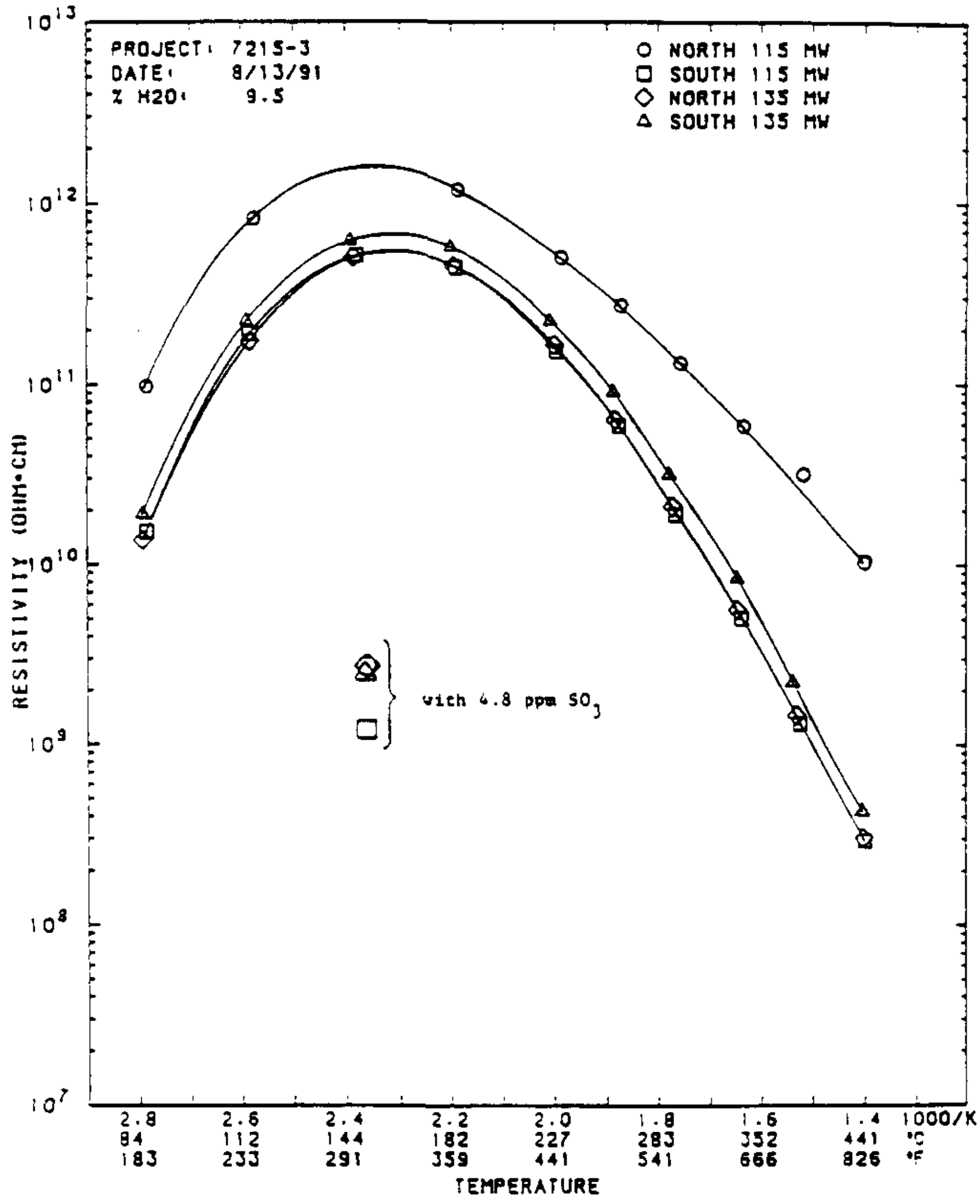

Figure 5-13. Low-Load Laboratory Ash Resistivity Measurements

Table 5-10
Sulfur Oxide Emission Results

Test Series	Load (MW)	Date	Duct	Gas Temperature (F)	Vapor Phase Concentration, ppm SO3	SO2
35	180	05/29/91	North	316	5	2351
				318	8	2342
				320	10	2357
				320	10	2351
36	180	05/30/91	South	341	12	2196
				345	14	2228
				345	15	2211
				348	16	2218
Average +/− 1 sigma				332 +/− 14	11 +/− 4	2282 +/− 74
37	200	05/31/91	South	355	14	2282
				357	16	2392
				358	16	2282
				359	17	2269
Average +/− 1 sigma				357 +/− 2	16 +/− 1	2306 +/− 57
38	115	06/01/91	North	291	3	2146
				290	5	2158
				289	5	2120
				288	6	2147
39	115	06/02/91	South	302	5	2112
				301	7	2124
				299	8	2124
				301	9	2144
Average +/− 1 sigma				295 +/− 6	6 +/− 2	2134 +/− 16
40	135	06/03/91		298	3	2240
				298	5	2247
				298	6	2264
				298	6	2264
41	135	06/04/91		323	7	2222
				323	10	2213
				323	10	2197
				323	11	2208
Average +/− 1 sigma				311 +/− 13	7 +/− 3	2232 +/− 26

5.2.4 Combustion System Tests

Combustion performance tests were performed at each of the four load levels to document the specific performance parameters related to the fuel and air combustion systems.

*5.2.4.1 **Mill Performance*** - The air flow to each mill and the fuel particle size and mass flow distributions of coal to each burner were measured. Duplicate tests were performed for loads of 180, 140, and 115 MW. A single measurement was made at 200 MW. Despite the mills being set to approximately equal coal flows with the boiler controls, the measured coal flows varied considerably from mill to mill (Table 5-11). The measured ratio of primary air-to-coal flow varied from approximately 2.0 to 3.1 over the load range.

The results of the mill performance were obtained by two methods. One method, which was also used during the baseline tests, was to extract coal fineness samples from a straight section of pipe using isokinetic samplers. These locations and methods were different from those normally used by the plant personnel. ABB CE recommends obtaining fineness near the mill outlet, which is the location normally used by the plant. The plant follows a method similar to the ASTM (American Society for Testing and Materials) D197 sampling method.

During these mill tests, the coal fineness was found to be less than 70 percent through 200 mesh on all mills using the isokinetic method. When measurements were taken near the mill outlet with this method, fineness was closer to the 70 percent through 200-mesh range. The low fineness could potentially cause the LOI values to be higher than for a condition with 70 percent or better through a 200-mesh screen.

*5.2.4.2 **Air Flow Measurements*** - Primary, secondary, and SOFA flows were measured using forward-reverse impact Pitot tubes. Based on the test results (Table 5-12), the air flow data were repeatable.

*5.2.4.3 **Furnace Measurements*** - Measurements were made of combustion gas temperatures and O_2 concentrations at eight locations within the boiler furnace at the 7th and 8th floor levels. At each port, approximately 10 measurements were made of temperature and excess oxygen at loads of 180, 140, and 115 MW.

Table 5-13 presents the averages of the temperature and O_2 measurements at the 7th floor. At 180 MW, the temperature averaged about 160°F less than the baseline tests at the same load and O_2 conditions. The temperature reduction at lower loads was considerably less - between 30 and 70 °F.

5.2.5 Coal and Ash Analyses

During each day of LNCFS Level II performance testing, samples of coal entering the active mills, flyash exiting the furnace (east and west sides), and bottom ash in the furnace ash pit were obtained.

Table 5-11
Summary of Mill Performance Tests

PARAMETER	MILLS A	B	C	D	E
TEST 35-1 181 MWe					
MEASURED COAL FLOW, Klb/hr	28.9	29.0	25.9	23.6	23.5
MEASURED PRIMARY AIR FLOW, Klb/hr	70.1	66.3	71.5	68.9	70.0
A/F RATIO, lb/lb	2.42	2.29	2.76	2.92	2.97
AVG. PASSING 200 MESH, PCT	57.1	56.7	63.1	62.9	60.7
AVG. PASSING 50 MESH, PCT	97.7	97.6	98.5	98.5	97.0
AVG. PASSING 200 MESH AT EXHAUSTER, PCT	62.4	59.5	67.7	66.9	58.6
AVG. PASSING 50 MESH AT EXHAUSTER, PCT	98.0	98.0	98.8	98.5	96.5
TEST 36-2 181 MWe					
MEASURED COAL FLOW, Klb/hr	25.7	26.3	31.4	25.0	31.8
MEASURED PRIMARY AIR FLOW, Klb/hr	72.4	69.0	74.0	68.5	70.9
A/F RATIO, lb/lb	2.82	2.62	2.35	2.74	2.23
AVG. PASSING 200 MESH, PCT	58.3	56.4	62.4	62.9	52.7
AVG. PASSING 50 MESH, PCT	97.9	97.8	98.6	98.4	95.8
AVG. PASSING 200 MESH AT EXHAUSTER, PCT	63.6	60.6	70.6	66.5	59.4
AVG. PASSING 50 MESH AT EXHAUSTER, PCT	98.4	98.2	98.1	98.5	96.9
TEST 37-1 201 MWe					
MEASURED COAL FLOW, Klb/hr	31.6	30.2	31.9	27.7	32.6
MEASURED PRIMARY AIR FLOW, Klb/hr	71.8	68.9	74.5	68.4	72.6
A/F RATIO, lb/lb	2.27	2.28	2.34	2.47	2.23
AVG. PASSING 200 MESH, PCT	55.0	55.1	61.1	63.2	53.7
AVG. PASSING 50 MESH, PCT	97.0	97.3	98.1	97.7	95.6
AVG. PASSING 200 MESH AT EXHAUSTER, PCT	60.6	60.5	67.8	65.3	63.5
AVG. PASSING 50 MESH AT EXHAUSTER, PCT	97.8	97.9	98.5	98.0	97.3
TEST 38-2 115 MWe					
MEASURED COAL FLOW, Klb/hr			33.6	26.9	31.5
MEASURED PRIMARY AIR FLOW, Klb/hr			69.0	65.0	66.5
A/F RATIO, lb/lb			2.06	2.42	2.11
AVG. PASSING 200 MESH, PCT			62.4	64.2	54.3
AVG. PASSING 50 MESH, PCT			98.4	98.4	96.2
AVG. PASSING 200 MESH AT EXHAUSTER, PCT			68.2	66.1	61.6
AVG. PASSING 50 MESH AT EXHAUSTER, PCT			98.8	98.3	97.3
TEST 39-1 115 MWe					
MEASURED COAL FLOW, Klb/hr			34.2	25.5	30.0
MEASURED PRIMARY AIR FLOW, Klb/hr			69.5	63.5	67.3
A/F RATIO, lb/lb			2.03	2.49	2.24
AVG. PASSING 200 MESH, PCT			63.8	63.7	55.9
AVG. PASSING 50 MESH, PCT			98.6	98.4	96.2
AVG. PASSING 200 MESH AT EXHAUSTER, PCT			68.9	67.1	60.4
AVG. PASSING 50 MESH AT EXHAUSTER, PCT			98.9	98.4	97.0
TEST 40-1 137 MWe					
MEASURED COAL FLOW, Klb/hr		25.9	25.7	21.9	31.4
MEASURED PRIMARY AIR FLOW, Klb/hr		65.8	71.8	68.0	67.6
A/F RATIO, lb/lb		2.54	2.80	3.11	2.15
AVG. PASSING 200 MESH, PCT		55.7	63.3	64.4	53.1
AVG. PASSING 50 MESH, PCT		97.8	98.6	98.8	95.6
AVG. PASSING 200 MESH AT EXHAUSTER, PCT		58.6	68.4	66.7	58.0
AVG. PASSING 50 MESH AT EXHAUSTER, PCT		97.8	98.8	98.5	96.5
TEST 41-1 136 MWe					
MEASURED COAL FLOW, Klb/hr		24.5	26.7	21.7	26.9
MEASURED PRIMARY AIR FLOW, Klb/hr		67.0	72.1	68.2	68.3
A/F RATIO, lb/lb		2.74	2.70	3.14	2.54
AVG. PASSING 200 MESH, PCT		58.0	62.2	67.7	53.9
AVG. PASSING 50 MESH, PCT		98.0	98.4	98.6	96.1
AVG. PASSING 200 MESH AT EXHAUSTER, PCT		59.0	68.6	68.2	58.4
AVG. PASSING 50 MESH AT EXHAUSTER, PCT		98.1	98.8	98.6	96.8

Table 5-12
Combustion Air Distribution

			Secondary Air		Primary Air (Hot & Tempering)		Separated Overfire Air		
Test	**Load Mw**	**DAS O_2 %**	**Mlb/hr**	**%**	**Mlb/hr**	**%**	**Mlb/hr**	**%**	**Total Sum of Each**
35	181	3.8	0.926	56.6	0.341	20.8	0.370	22.6	1.64
36	181	3.9	0.195	55.5	0.361	21.9	0.373	22.6	1.65
37	201	3.0	*	---	*	---	0.366	22.1	-
38	115	4.5	0.545	50.3	0.280	25.8	0.259	23.9	1.08
39	115	4.5	0.539	51.2	0.258	24.5	0.257	24.3	1.05
40	137	3.9	0.616	50.1	0.322	26.2	0.291	23.7	1.23
41	136	4.0	0.632	51.5	0.311	25.3	0.285	23.2	1.23

*Combined secondary and hot primary air flow for Test 37-1 were 1.29 Mlb/hr.

Table 5-13
Furnace Measurements

		Avg. Temp., °F		Avg. O_2,%	
	Load	7th	8th	7th	8th
Test#	MW	Floor	Floor	Floor	Floor
35	181	2175	1931	2.5	2.6
36	181	2189	2098	0.6	2.7
37	201	N/A	N/A	N/A	N/A
38	115	2224	1986	1.3	3.2
39	115	2071	1927	1.6	3.5
40	137	2157	2018	1.5	2.4
41	139	2247	2007	0.9	2.4

The coal samples were analyzed for proximate and ultimate composition, calorific value, grindability, and ash-fusion properties. The results of these analyses (Table 5-14) show that the coal properties remained very consistent over the duration of the performance testing, and that they were also consistent with the analyses obtained during diagnostic tests (Table 5-4).

In general, the ESP hopper ash samples had higher average LOI values than the Method 17 mass train samples (see Table 5-8).

5.2.6 Boiler Efficiency

During selected performance tests at each load point, heat loss efficiency was calculated by measuring the flue gas temperatures and the gaseous species upstream and downstream of the air preheaters. The excess O_2 probes upstream and downstream of the air preheater were sampled continuously over several hours of each test. In addition, the gas temperatures in each duct were measured continuously (every 5 seconds - compiled into 5-minute averages) over the entire test duration. Measurements for CO were obtained from composite sampling of the CEM at discrete intervals over the test duration.

Heat loss method calculations (ASME PTC 4.1), were made of boiler efficiency losses for dry flue gas, moisture in flue gas (humidity plus moisture in fuel plus hydrogen combustion product), LOI in flyash, LOI in bottom ash (negligible), and radiation loss (standard ASME curves). These calculations used data previously discussed. The results of the efficiency calculations are presented in Table 5-15 for those tests where isokinetic LOI samples were obtained.

The heat loss calculations document the Phase II boiler efficiencies at specific operating conditions for comparison with other phases. The important result is any difference in efficiency which can be attributed to the technology, rather than the absolute value of efficiency. For this reason some efficiency loss components not related to the combustion process (e.g., blowdown, steam properties, etc.) were not included. The heat loss calculations were based on the measured calorific value, moisture, and chemical composition of the as-fired fuel test samples.

Table 5-14
Performance Tests Coal Analyses

Test Number	Date	Time	Ultimate Analyses: H2O	C	H	N	Cl	S	Ash	O	TOTAL	HHV BTU/lb	VM %	Fixed Carbon %
35-1	05/29/91	1036	10.11	66.17	4.58	1.42	0.11	2.91	9.10	5.71	100.11	11834	35.53	45.26
35-2	05/29/91	1340	10.66	66.00	4.51	1.38	0.11	2.80	8.75	5.91	100.12	11806	35.88	44.71
35-2	05/29/91	1503	11.39	65.31	4.42	1.44	0.10	2.79	9.26	5.39	100.10	11578	35.04	44.31
35-2	05/29/91	1503	10.21	64.72	4.17	1.35	0.10	2.81	9.75	6.99	100.10	11698	34.47	45.57
35-3	05/29/91	1908	10.17	66.11	4.50	1.42	0.11	2.92	9.02	5.86	100.11	11765	35.70	45.11
36-2	05/30/91	0850	10.69	65.82	4.50	1.46	0.10	2.88	8.75	5.89	100.09	11739	36.25	44.31
36-2	05/30/91	1135	10.77	65.99	4.51	1.34	0.12	2.78	8.66	5.96	100.13	11781	35.70	44.86
36-3	05/30/91	1451	10.83	65.74	4.54	1.33	0.09	2.76	8.64	6.16	100.09	11770	35.45	45.08
37-1	05/31/91	0930	9.81	66.78	4.57	1.35	0.10	2.87	8.91	5.71	100.10	11921	35.77	45.51
37-2	05/31/91	1207	9.37	67.27	4.60	1.37	0.10	2.90	8.80	5.69	100.10	11930	36.39	45.44
37-2	05/31/91	1540	9.85	66.65	4.60	1.41	0.11	2.93	8.91	5.66	100.12	11881	36.08	45.17
38-2	06/01/91	2315	10.40	66.55	4.57	1.40	0.10	2.85	8.98	5.26	100.11	11813	35.88	44.75
38-3	06/02/91	0245	10.36	66.25	4.60	1.38	0.13	2.90	8.92	5.59	100.13	11814	35.51	45.21
38-3	06/02/91	0400	9.45	66.93	4.63	1.39	0.11	2.87	8.89	5.84	100.11	11954	36.39	45.27
38-3	06/02/91	0400	11.57	63.91	4.23	1.34	0.17	2.74	9.63	6.58	100.17	11502	34.29	44.51
39-1	06/02/91	2230	10.41	66.14	4.60	1.39	0.11	2.80	8.69	5.97	100.11	11739	35.19	45.71
39-2	06/03/91	0100	9.89	66.48	4.62	1.39	0.12	2.88	8.99	5.74	100.11	11870	36.72	44.40
39-3	06/03/91	0415	10.32	66.61	4.64	1.44	0.10	2.77	8.75	5.47	100.10	11855	36.54	44.39
40-1	06/03/91	2200	11.30	65.71	4.52	1.45	0.10	2.78	8.99	5.52	100.37	11699	35.21	44.51
40-3	06/04/91	0100	10.82	65.78	4.55	1.41	0.10	2.88	9.00	5.56	100.10	11728	35.76	44.42
40-3	06/04/91	0400	11.83	65.03	4.52	1.38	0.10	2.89	9.15	5.19	100.09	11600	35.25	43.77
41-2	06/04/91	2300	10.41	65.90	4.55	1.38	0.11	2.84	9.00	5.91	100.10	11787	35.76	44.82
41-2	06/05/91	0100	10.97	66.07	4.56	1.36	0.08	2.91	8.91	5.22	100.08	11772	35.82	44.30
41-2	06/05/91	0500	10.84	65.72	4.56	1.35	0.11	2.78	8.92	5.84	100.12	11750	36.94	43.31
42-2	06/05/91	1840	9.86	66.86	4.61	1.39	0.08	2.89	9.00	5.41	100.10	11892	36.59	44.56
42-2	06/05/91	1840	9.49	66.20	4.42	1.41	0.15	2.84	9.12	6.52	100.15	11902	35.40	45.99
43	06/05/91	1915	10.64	66.24	4.59	1.39	0.13	2.81	8.74	5.59	100.13	11862	36.38	44.24
		AVERAGE	10.46	66.03	4.53	1.39	0.11	2.84	8.97	5.78	100.12	11787	35.77	44.80
		STD DEV	0.62	0.70	0.11	0.03	0.02	0.06	0.25	0.41	0.05	107	0.63	0.60
		VARIANCE	0.39	0.48	0.01	0.00	0.00	0.00	0.06	0.17	0.00	11353	0.40	0.36

Table 5-15
Lansing Smith Unit 2 ASME PTC 4.1 Boiler Efficiency

Test No.	Load (MW)	O_2 (%)	Efficiency As Measured (%)	Efficiency Normalized* (%)
35-1,2,3	181	3.9	89.77	89.13
37-1,2	201	3.8	89.45	88.86
38-2,3	115	4.5	90.57	89.96
41-2,3	138	4.0	90.19	89.59

* Normalized to APH design gas out and air in temperatures.

5.3 Verification Tests (LNCFS Level II)

Following long-term testing, verification tests were performed to determine if significant changes in the NOx characteristics had occurred during the long-term testing. During the verification period, 29 tests were performed from high to medium loads (180, 140, and 115 MW).

Table 5-16 summarizes the data recorded during the verification tests which were conducted at nominal loads of 115, 140, and 180 MW with the following mill patterns:

LOAD	MILL PATTERN	TESTS
180	Primary (AMIS)	10
140	Primary (A-MOOS)	5
140	Alternate (AB-MOOS)	8
115	Primary (AB-MOOS)	6

Figure 5-14 compares the verification test results with the diagnostic tests for the 180-MW load point. The data for the two periods are very similar and exhibit the same trends. The verification data fit within the data scatter envelope for the diagnostic tests. The full load NOx characteristics did not significantly change during the long-term testing.

Figure 5-15 compares the verification and diagnostic test results for the 140-MW load point. Testing at the 140-MW load point was performed with the same two mill patterns used during the diagnostic testing. From Figure 5-15 it is evident that the verification trends and the absolute levels of NOx were remarkably similar to those for the diagnostic test results.

Figure 5-16 compares the results for the 115-MW test point. These data illustrate that the trends were similar and the verification test results were at the lower bounds of the data from the diagnostic tests.

Table 5-16
Summary of Lansing Smith Unit 2 Phase II Verification Testing

TEST NO.	DATE	TEST CONDITIONS	LOAD MW	MOOS	SOFA DAMPER TOP/MID/BOT	O2 %	NOx ppm
44-1	09-12-91	HIGH LOAD, O2 VARIATION	182	NONE	103/108/108	2.2	191
44-2	09-12-91	"	182	NONE	104/108/108	3.4	231
44-3	09-13-91	"	181	NONE	105/108/108	4.3	274
44-4	09-13-91	"	180	NONE	104/108/108	5.3	323
45-1	09-13-91	HIGH LOAD, TILT VARIATION	180	NONE	103/108/108	3.2	201
45-2	09-13-91	"	180	NONE	106/108/108	3.4	224
46-1	09-13-91	MID LOAD, O2 VARIATION	142	A	24/108/108	3.2	244
46-2	09-13-91	"	140	A	21/108/108	4.4	277
46-3	09-14-91	MID LOAD, O2 / MILL VARIATION	139	AB	23/108/108	5.3	303
46-4	09-14-91	"	139	AB	18/106/108	5.1	314
46-5	09-14-91	"	138	AB	15/105/108	4.4	289
46-6	09-14-91	"	138	AB	18/107/108	3.2	256
46-7	09-14-91	MID LOAD, O2 / MILL / dP VARIATION	140	AB	16/104/108	3.3	260
47-1	09-14-91	MID LOAD, O2 / MILL VARIATION	142	AB	22/108/108	3.3	243
47-2	09-14-91	"	140	AB	24/108/108	4.5	264
47-3	09-15-91	"	140	AB	24/108/108	5.4	305
47-4	09-15-91	MID LOAD, OFA VARIATION	141	A	22/108/108	4.4	266
47-5	09-15-91	"	141	A	0/ 0/108	4.4	308
47-6	09-15-91	"	141	A	0/ 0/ 0	4.5	356
48-1	09-15-91	LOW LOAD, O2 VARIATION	116	AB	0/ 61/108	3.8	242
48-2	09-15-91	"	116	AB	0/ 62/108	4.4	258
48-3	09-16-91	"	116	AB	0/ 61/108	5.5	273
48-4	09-16-91	LOW LOAD, OFA VARIATION	117	AB	0/ 0/108	4.4	267
48-5	09-16-91	"	117	AB	0/ 0/ 50	4.2	273
48-6	09-16-91	"	117	AB	0/ 0/ 1	4.2	288
49-1	09-16-91	HIGH LOAD, TILT VARIATION	182	NONE	106/108/108	3.5	227
49-2	09-17-91	"	183	NONE	106/108/108	3.7	215
50-1	10-01-91	"	182	NONE	101/108/108	3.5	235
50-2	10-01-91	"	182	NONE	100/108/108	3.4	224

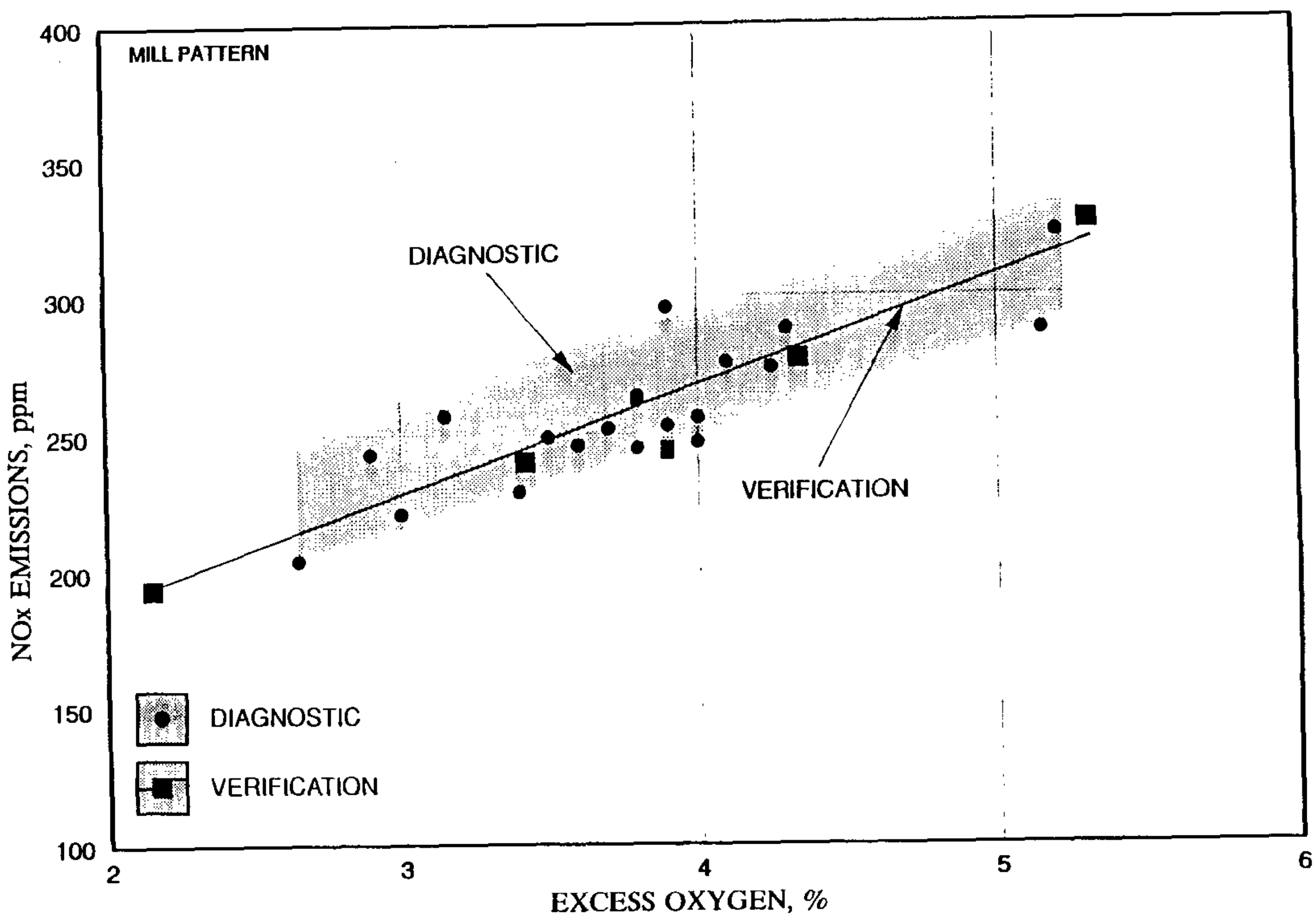

Figure 5-14. 180-MW Verification Test Summary

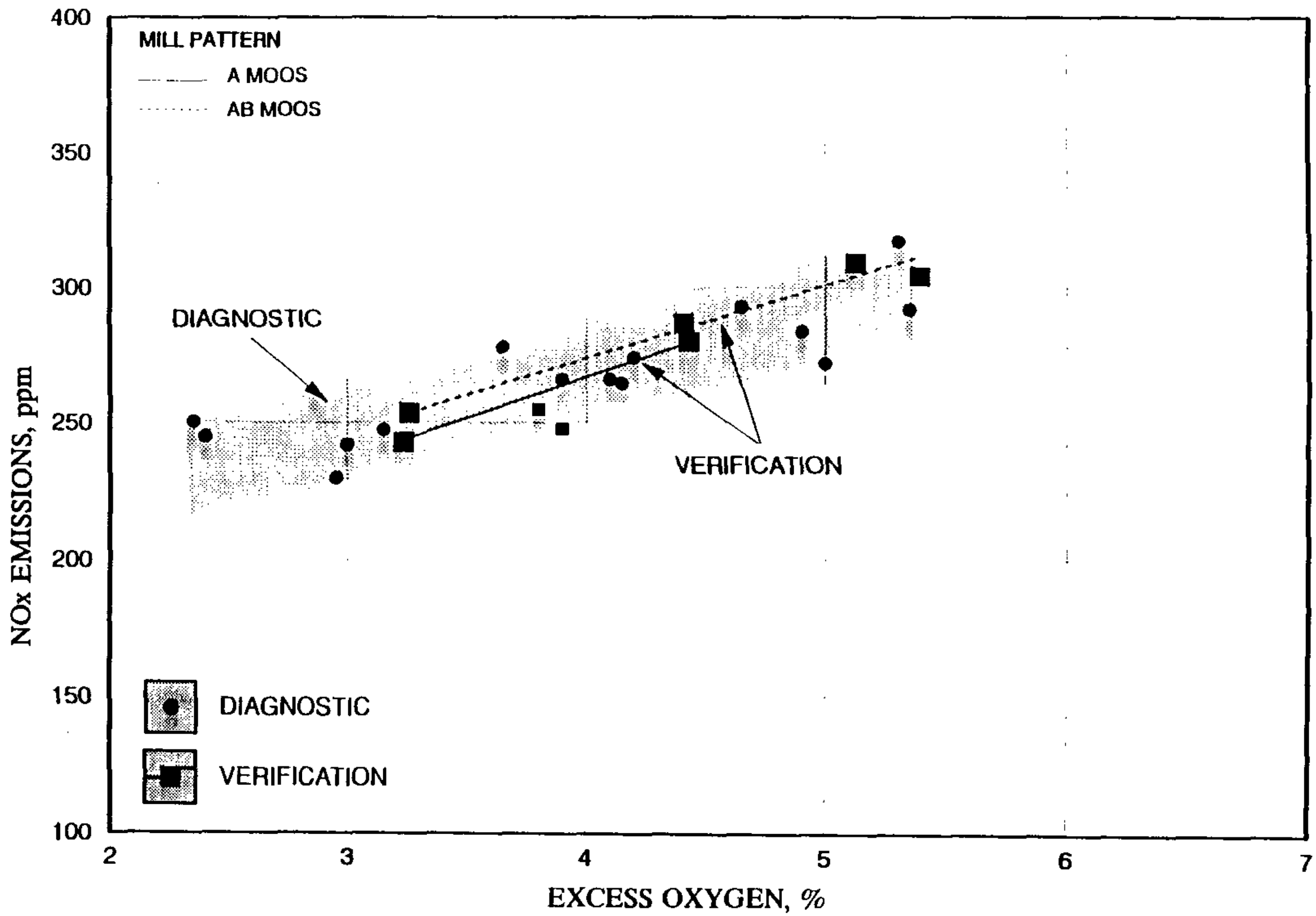

Figure 5-15. 140-MW Verification Test Summary

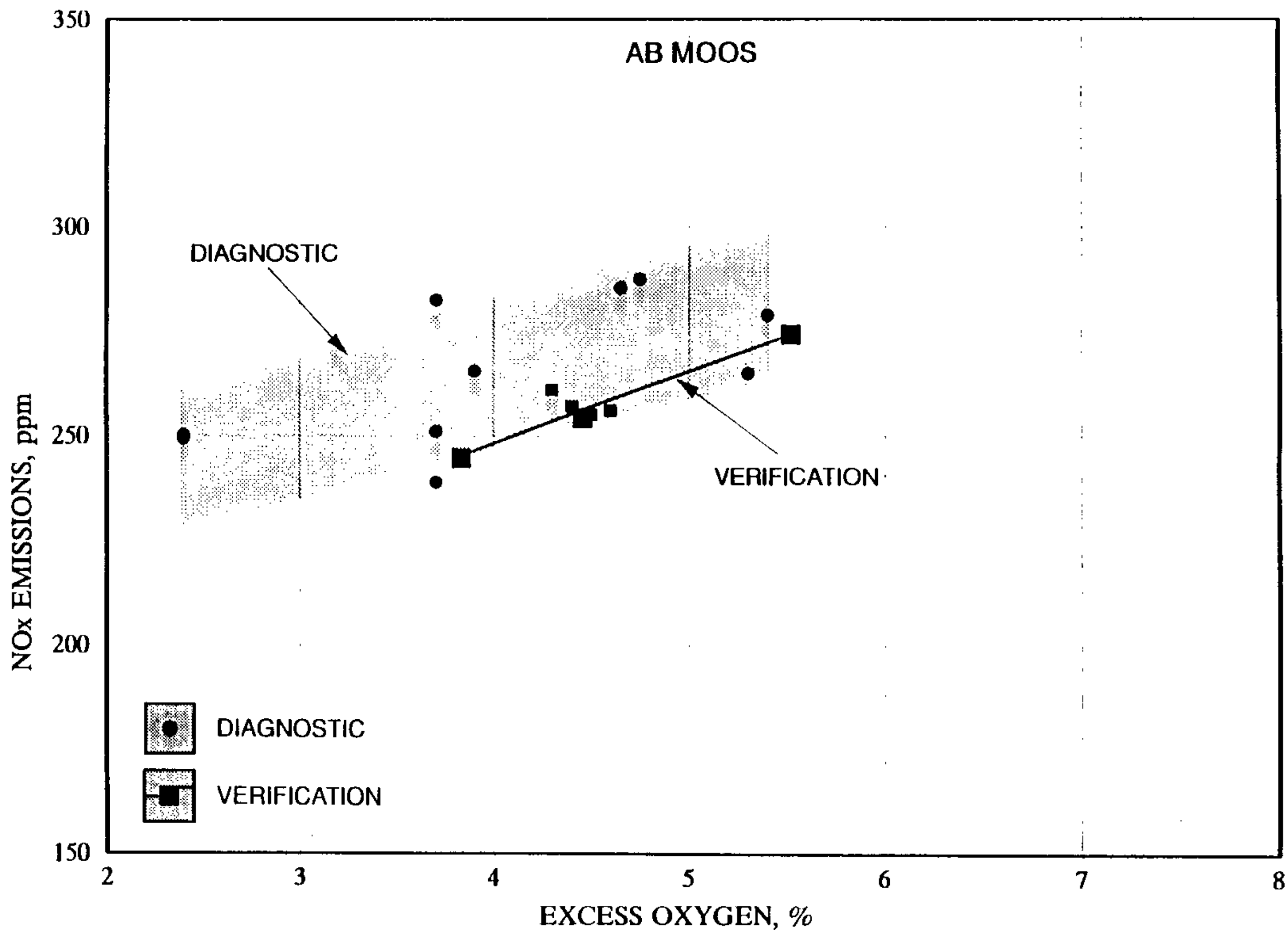

Figure 5-16. 115-MW Verification Test Summary

5.4 Diagnostic Tests (LNBFS)

Low-NOx Bulk Furnace Staging (LNBFS) was simulated with the LNCFS Level II hardware by zeroing the auxiliary air yaws and SOFA yaws, while maintaining the burner dampers, auxiliary air dampers, and SOFA dampers at the LNCFS Level II settings. Yaws refer to the adjustable horizontal offsets of the offset air nozzles from the burners.

Diagnostic tests determined the effects of the auxiliary air yaws, SOFA yaws, and SOFA flowrates on emissions at nominal loads of 115, 140, and 180 MW with the primary mill patterns:

LOAD	MILL PATTERN	TESTS
180	Primary (AMIS)	13
140	Primary (A-MOOS)	6
115	Primary (AB-MOOS)	6

Table 5-17 summarizes the as-tested operating conditions for the simulated LNBFS diagnostic testing. Changes in NOx emissions due to the various components of the low-NOx combustion system hardware were individually evaluated as a function of load by selectively disabling those components from operation.

In the LNCFS Level II configuration, the auxiliary air yaws were normally positioned at 22° to the right of the burners, which is the hardware limitation for offsetting the air. Except for the right rear corner of the boiler, the SOFA yaws were positioned at 15° right for the top level, 0° for the center level, and 15° left for the bottom level. The right rear corner had all three of its SOFA nozzles positioned at 15° to the left. Normally, all of the yaws were pinned at these fixed angles for the LNCFS Level II test conditions. The SOFA damper positions were operated in the manual mode to allow adjustment of SOFA flow.

Figure 5-17 shows the effect of changes in the auxiliary air yaws on NOx emissions with the SOFA dampers closed at 180 MW. By decreasing the yaws from 22° offset (to the right of the burners) to 0° offset, the NOx increased by 29 parts per million. The excess O_2 level and SOFA flows were held constant.

Figure 5-18 shows the trends of NOx increases due to progressive disabling of the burner auxiliary air yaws, followed by the SOFA yaws, and finally the SOFA flows (by closing the dampers as much as possible). As expected, the SOFA flowrates provided the greatest amount of NOx reduction.

5.5 REFERENCE

1. Bickelhaupt, "A Study to Improve a Technique for Predicting Flyash Resistivity with Emphasis on the Effect of Sulfur Trioxide," EPS-600/7-86-010, 1985.

Table 5-17
Summary of Lansing Smith Unit 2 Phase II LNBFS Diagnostic Testing

TEST NO.	DATE	TEST CONDITIONS	LOAD MW	MOOS	AUX YAW	OFA YAW	SOFA DAMPER TOP/MID/BOT	O2 %	NO ppm
51-1	10-02-91	HIGH LOAD, BURNER YAW VARIATION	182	NONE	NORM	NORM	103/108/108	3.5	230
51-2	10-02-91	"	183	NONE	NORM	NORM	0/ 0/ 0	3.4	326
51-3	10-02-91	"	182	NONE	3/4	NORM	0/ 0/ 0	3.4	326
51-4	10-02-91	"	183	NONE	1/2	NORM	0/ 0/ 0	3.4	358
51-5	10-02-91	"	182	NONE	0	NORM	0/ 0/ 0	3.4	356
52-1	10-03-91	HIGH LOAD, BURNER AIR VARIATION	182	NONE	NORM	NORM	100/108/108	3.5	221
52-2	10-03-91	"	181	NONE	NORM	NORM	101/108/108	3.6	226
52-3	10-03-91	HIGH LOAD, BURNER YAW VARIATION	181	NONE	0	NORM	101/108/108	3.5	230
52-4	10-03-91	HIGH LOAD, OFA / YAW VARIATION	179	NONE	0	0	101/108/108	3.6	245
52-5	10-03-91	"	180	NONE	0	0	0/108/108	3.6	267
52-6	10-03-91	"	180	NONE	0	0	0/ 0/108	3.6	314
52-7	10-03-91	"	180	NONE	0	0	0/ 0/ 0	3.6	373
52-8	10-03-91	"	179	NONE	0	0	0/ 0/ 0	3.6	391
53-1	10-04-91	MID LOAD, OFA VARIATION	140	A	NORM	NORM	17/107/108	4.4	272
53-2	10-04-91	"	139	A	NORM	NORM	50/105/108	4.2	247
53-3	10-05-91	MID LOAD, BURNER YAW VARIATION	139	A	0	NORM	17/105/108	4.2	261
53-4	10-05-91	MID LOAD, OFA / YAW VARIATION	138	A	0	0	16/107/108	4.4	265
53-5	10-05-91	"	139	A	0	0	0/ 0/108	4.4	332
53-6	10-05-91	"	140	A	0	0	0/ 0/ 0	4.4	384
54-1	10-05-91	LOW LOAD, BURNER AIR VARIATION	114	AB	NORM	NORM	0/ 56/108	4.3	246
54-2	10-06-91	"	115	AB	NORM	NORM	0/ 55/108	5.3	274
54-3	10-06-91	LOW LOAD, BURNER YAW VARIATION	114	AB	0	NORM	0/ 54/108	5.4	284
54-4	10-06-91	LOW LOAD, OFA / YAW VARIATION	114	AB	0	0	0/ 55/108	5.4	296
54-5	10-06-91	"	113	AB	0	0	0/ 0/ 50	5.4	345
54-6	10-06-91	"	114	AB	0	0	0/ 0/ 0	5.3	383

NORM=NORMAL LNCFS II SETTING

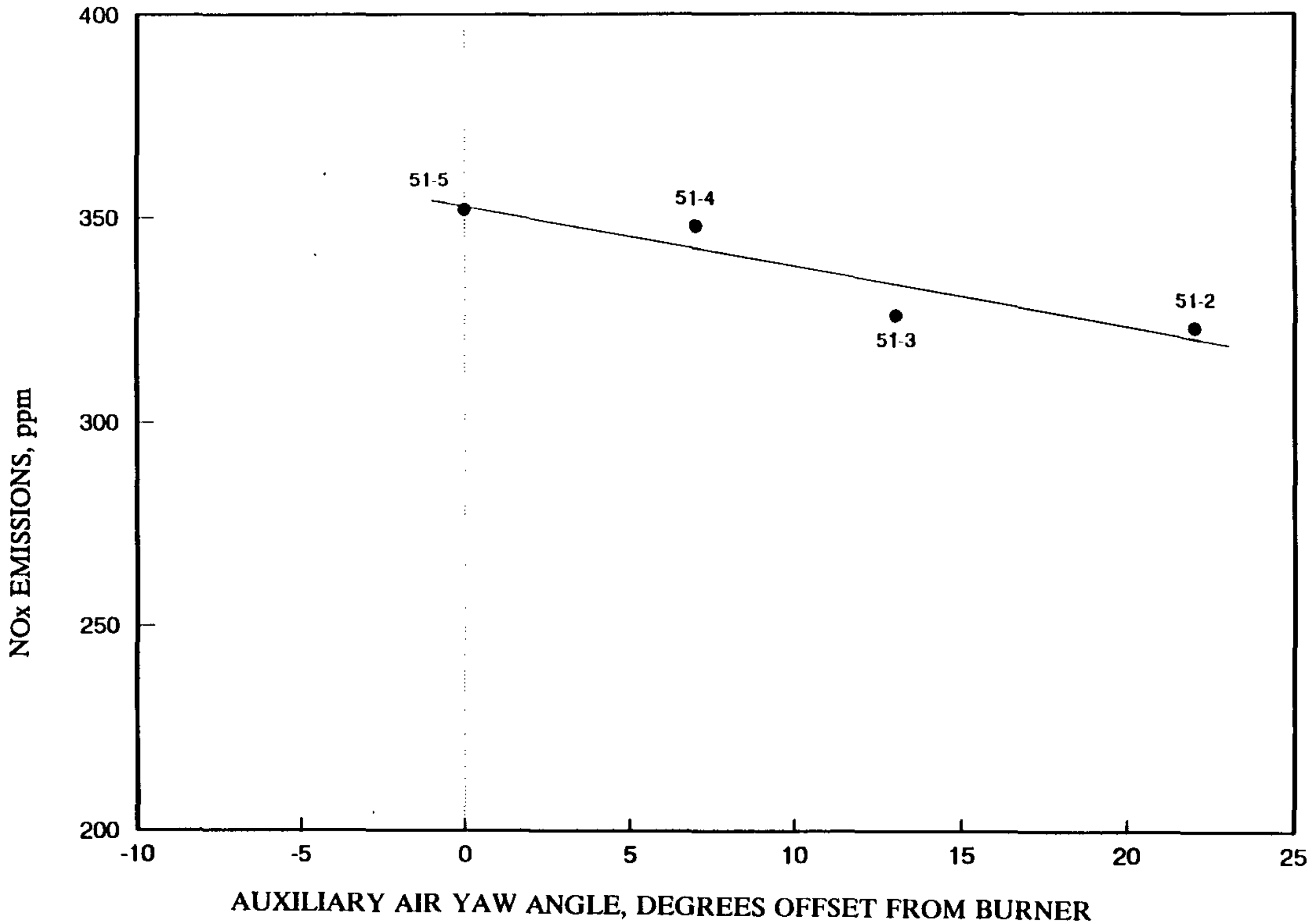

Figure 5-17. Effect of Auxiliary Air Yaw Angle

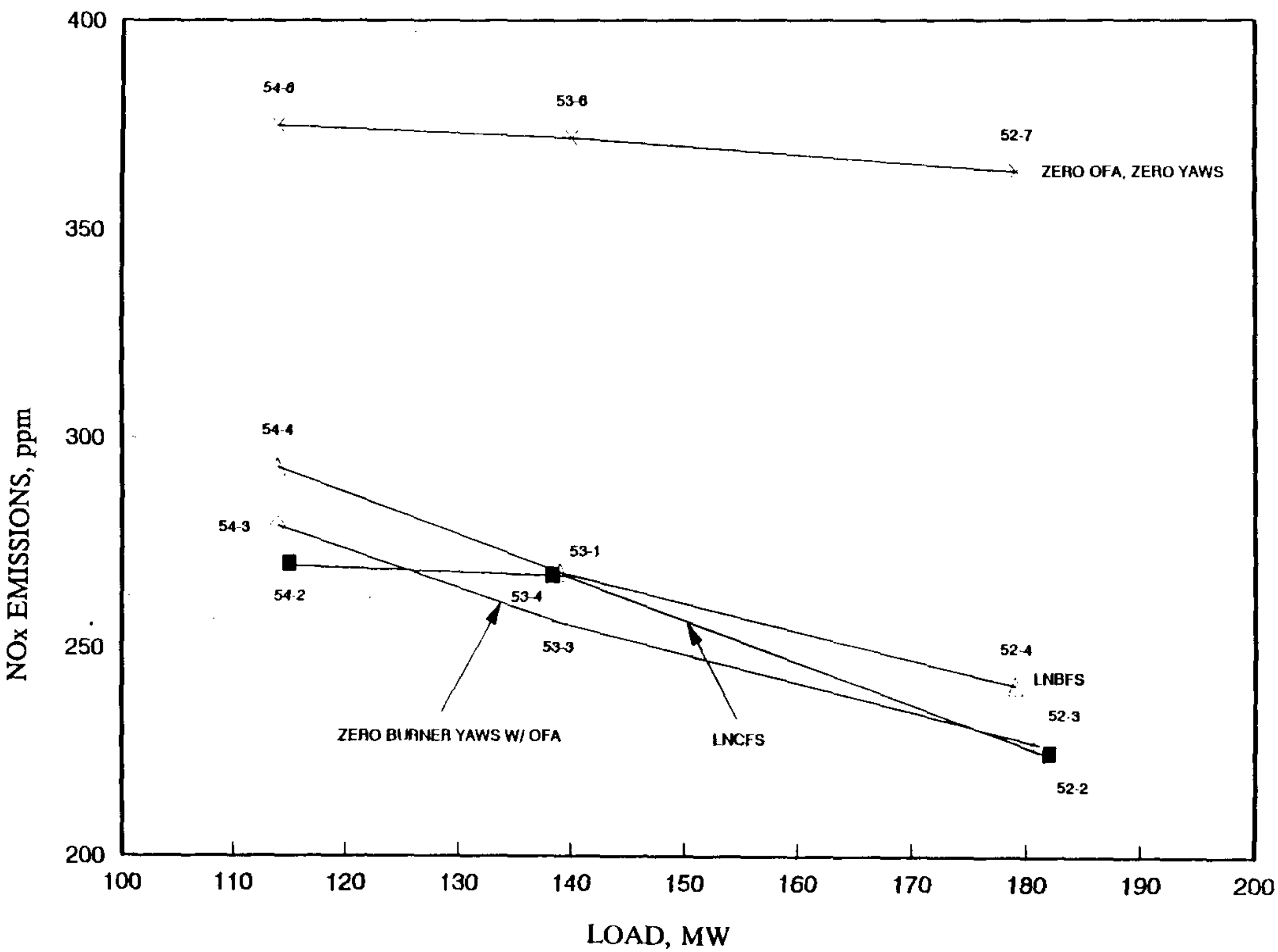

Figure 5-18. Effect of Yaw and SOFA Damper Position

6.0 LONG-TERM DATA ANALYSIS

The long-term testing consisted of continuous monitoring of operating parameters while the unit was under load dispatch control. This testing was performed from late-June through late-October 1991. Sufficient data were collected to fully characterize the unit both from an engineering perspective and a regulatory point of view.

The focus of the long-term data analysis was:

1. Characterization of the daily load, NOx emissions, and the within-day statistics.

2. Characterization of the NOx emissions as a function of the O_2 and mill patterns for all 5-minute CEM data.

3. Determination of the 30-day rolling average NOx emissions based on valid days and hours of CEM data.

4. Determination of the achievable NOx emission level based on valid days of CEM data.

5. Comparison of long-term results to short-term results.

The following paragraphs describe the results of these analyses.

6.1 Unit Operating Characteristics

Figure 6-1 illustrates the NOx emissions and load scenario during the month of July 1991. Other months, which experienced lesser degrees of data capture, exhibited similar characteristics. NOx emissions varied from approximately 0.6- to 0.3-lb NOx/MBtu during the month of July. Similar variations were experienced during the other months of testing. The data illustrate that the unit experienced load changes from the minimum operating load (70 MW) to the maximum continuous operating load (200 MW) during the entire long-term test period.

Figure 6-2 shows the daily averages of load and NOx. These daily averages were determined from the entire long-term data set using the EPA criteria for valid data as explained in Section 4.2.1. Only days with at least 18 hours of data are presented in this figure. The average daily load during the first half of the long-term testing was generally in excess of 150 MW. At the end of long-term testing, the load decreased to below 150 MW.

The boiler operating characteristics were determined by examining the within-day variation of load and NOx. The data were segregated by hour of the day (i.e., 0100, 0200,...2400), and mean load and NOx were computed. In addition, the hourly values representing the lower 5 percent and upper 95 percent of all values were determined. Figure 6-3, which illustrates the daily trend for load and NOx emissions over the entire long-term test period, shows that the unit was

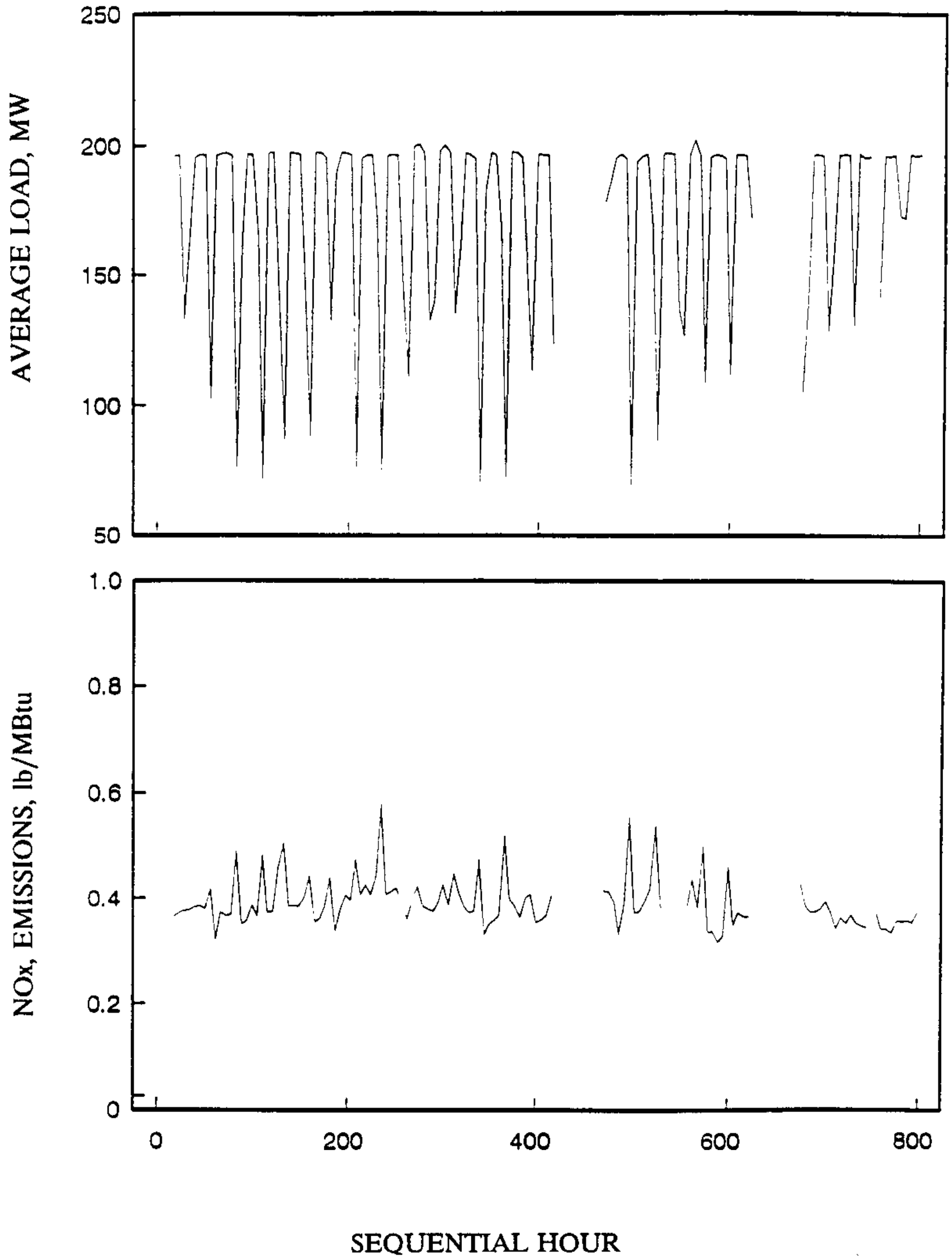

Figure 6-1. Hourly Average Characteristics (Plant Smith Unit 2 July 1991)

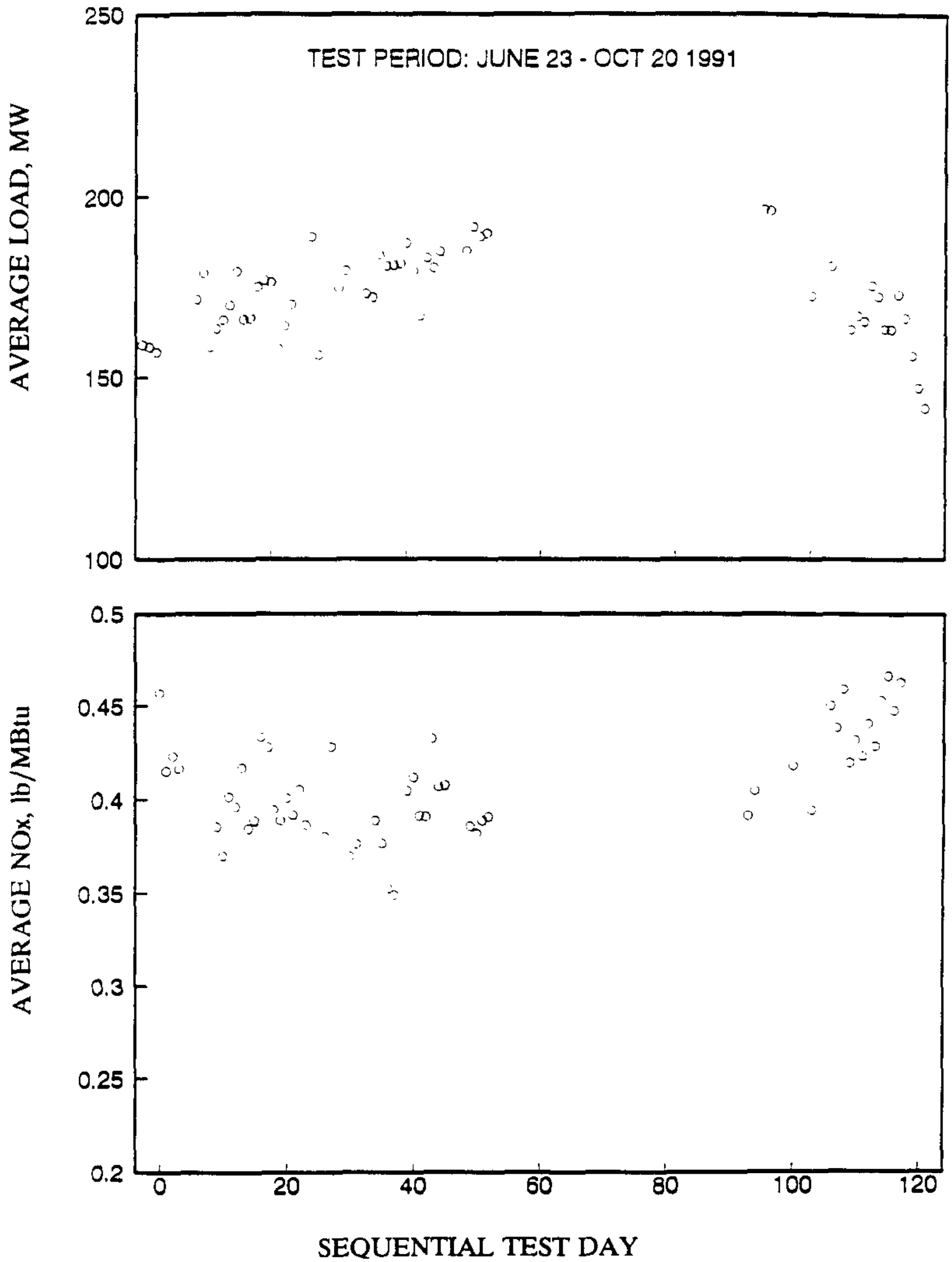

Figure 6-2. Daily Average Characteristics

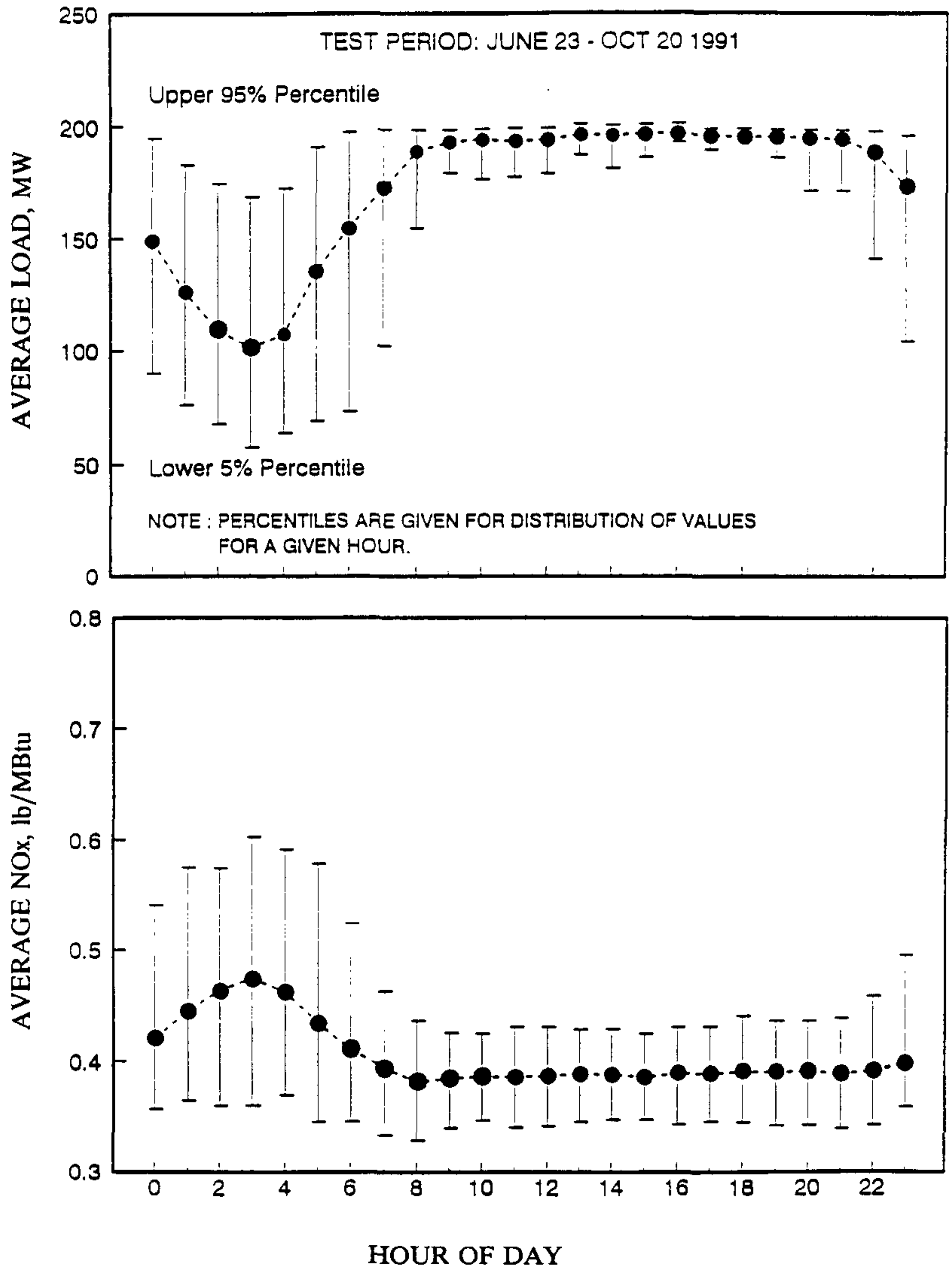

Figure 6-3. Within Day Average Characteristics

operated in a base-loaded condition for most of the day (on average 13 hours were above 150 MW). It is evident that the NOx versus load characteristics are flat with respect to load change at high loads but NOx increases as the load is dropped below 150 MW.

6.2 Parametric Test Results

For the parametric analyses, all of the valid 5-minute data were used. The 5-minute and hourly average emission data were analyzed to determine the overall relationship between NOx and load, and the effect of boiler O_2 on NOx emissions for certain frequently used mill patterns. Since these data were obtained while the unit was under normal load dispatch control, they represent the long-term NOx characteristics.

The NOx versus load relationship was determined by first segregating the 5-minute average load data into 10 MW-wide load ranges (Table 6-1). The number of data points (n) in each load range, as well as the mean lower 5 percentile and upper 95 percentile, are shown for both load and NOx emission values. Figure 6-4 illustrates the NOx versus load trend for these data.

The effect of operating O_2 on NOx emissions for certain mill patterns was examined for load ranges that corresponded to some of those used during the short-term testing and included 65-75, 115-125, 135-145, and 185-200 MW. All of the valid 5-minute data for these load ranges were used to assess the impact of excess oxygen levels for the most commonly used mill patterns. In order to identify the most frequently used patterns, the frequency distribution of the MOOS pattern was determined. Table 6-2 presents the frequency distribution for the two most used mill patterns. It is apparent that there are certain preferred mill patterns for each load range. These patterns are based on the operational requirements of the unit (e.g., slag minimization, steam temperature control, etc.).

Prior to commencing short-term testing, discussions with plant operations personnel indicated that certain mill patterns were preferred. These patterns were then used during the diagnostic and performance testing with the intent of comparing the results with the same patterns during long-term testing. The mill patterns used during the short-term test effort were the A-, A&B-, and A,B&C-MOOS at loads below 150 MW. Table 6-2 shows that these patterns were the most prevalent during this long-term testing.

All of the valid 5-minute load data were analyzed for the most prevalent long-term MOOS patterns for each of the four load ranges to establish the NOx versus O_2 characteristics using statistical regression techniques. The graphical analysis consists of two separate procedures. The data were characterized by first segregating the O_2 into cells that were one O_2 percentage point wide (i.e., 2.5-3.5, 3.5-4.5,...10.5-11.5 percent). Second, the average NOx and O_2 for each O_2 cell was calculated and the best fit regression was computed. For each of the average values, the upper 95 percentile and lower 5 percentile were computed. Since some of the O_2 ranges contained only one value, for it was not possible to compute the lower 5th and upper 95th percentiles. Consequently, neither the average nor the percentiles for these data were included in the analysis.

Table 6-1
Baseline Test Load Segregation

PLANT SMITH BASELINE TESTING PHASE II: JUNE 1991 – OCTOBER 1991
AVERAGE BY LOAD RANGE
5 MINUTE DATA

		LOAD			O_2			NOx		
LOAD RANGE	N	L5% LOAD	AVG LOAD	U95% LOAD	L5% KO2	AVG KO2	U95% KO2	L5% KNOX	AVG KNOX	U95% KNOX
55–65	245	55.50	57.86	61.50	9.15	9.88	11.05	0.286	0.567	0.671
65–75	588	68.50	71.18	74.50	8.45	9.40	10.45	0.385	0.520	0.608
75–85	454	75.50	80.02	84.50	8.15	9.21	10.15	0.401	0.514	0.601
85–95	448	85.50	89.74	94.50	7.55	8.83	9.75	0.412	0.495	0.575
95–105	412	95.50	99.95	104.50	7.05	8.22	9.45	0.316	0.433	0.512
105–115	339	105.50	110.09	114.50	6.65	7.87	9.05	0.350	0.422	0.495
115–125	404	115.50	120.33	124.50	6.25	7.58	8.75	0.372	0.435	0.500
125–135	406	125.50	129.84	134.50	6.25	7.37	8.55	0.363	0.426	0.503
135–145	477	135.50	140.17	144.50	6.05	7.10	8.25	0.335	0.405	0.474
145–155	436	145.50	149.82	154.50	5.85	6.82	7.85	0.348	0.399	0.476
155–165	491	155.50	159.45	164.49	5.85	6.71	7.55	0.346	0.396	0.451
165–175	605	165.49	170.49	174.49	5.65	6.51	7.35	0.337	0.391	0.448
175–185	628	175.49	180.18	184.49	5.65	6.34	7.05	0.339	0.394	0.436
185–195	1154	185.49	192.16	194.49	5.25	5.95	6.65	0.339	0.384	0.430
195–200	10352	195.49	196.91	198.49	5.25	5.87	6.55	0.341	0.387	0.431

* NOTE: THE LOWER 5% AND UPPER 95% REFLECT THE DISTRIBUTION OF THE INDIVIDUAL 5 MINUTE DATA POINTS IN EACH LOAD RANGE

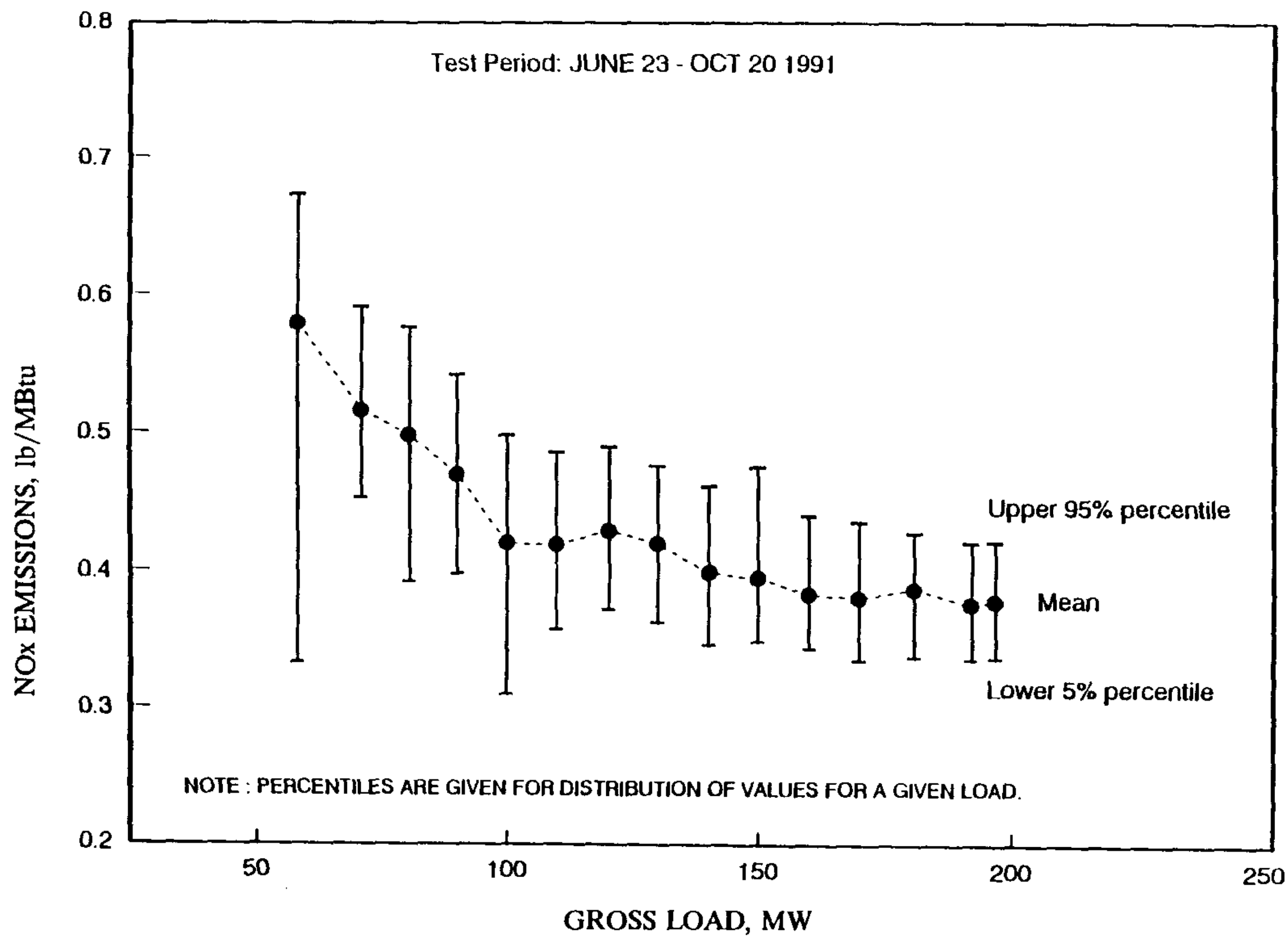

Figure 6-4. Baseline Load Characteristics

Table 6-2
Mill Pattern Use Frequency

MOOS	Sample Size	Average Load (MW)	Average NOx (lb/MBtu)	Average O_2 (%)
NONE	612	180.2	0.39	6.3
A	7	177.8	0.40	6.2
A	352	135.6	0.42	7.1
AB	28	133.5	0.45	7.5
AB	296	114.9	0.43	7.7
A	26	117.3	0.46	7.9
ABC	55	71.2	0.54	9.4
CDE	29	70.2	0.24	10.1

The results of the above analyses are shown in Figures 6-5 through 6-8. With the exception of the CDE-MOOS pattern at the 70-MW load point, NOx emissions increased as the O_2 increased. In addition, there were significant variations in NOx emissions for different emissions MOOS patterns at the same load. At the nominal 70-MW load condition, NOx emissions varied by as much as 50 percent. The amount of variation decreased as load was increased, however, it was as much as 25 percent at the 115-MW load point. These results are compared to the short-term results for the same mill patterns in Section 6.5.

6.3 30-Day Rolling Averages

The NSPS Subpart Da and Db standards are based on compliance on a 30-day rolling average. While this unit is not required to comply with these standards, it is of value to evaluate the data for Phase I on a 30-day rolling average basis and later compare it to the results from subsequent phases. Thirty-day rolling average load, NOx, and O_2 were computed using the valid boiler operating days (BOD) as defined by the EPA criteria. These 30-day rolling averages are shown in Figure 6-9 for the 92 valid BOD (by EPA criteria) of data representing 39 30-day rolling averages.

It should be pointed out that the 30-day rolling average results shown in Figure 6-9 are only representative of the load scenario that was experienced by the unit during long-term testing. During other periods, when the load might be significantly different, the rolling averages would be expected to be somewhat different. For this particular period, there was a slight decrease in the daily load as the testing progressed as evidenced by the declining 30-day rolling average load. Since it was shown in the previous paragraphs that the NOx increases with decreasing load, it is obvious that the rolling average NOx emissions should increase as the testing progressed.

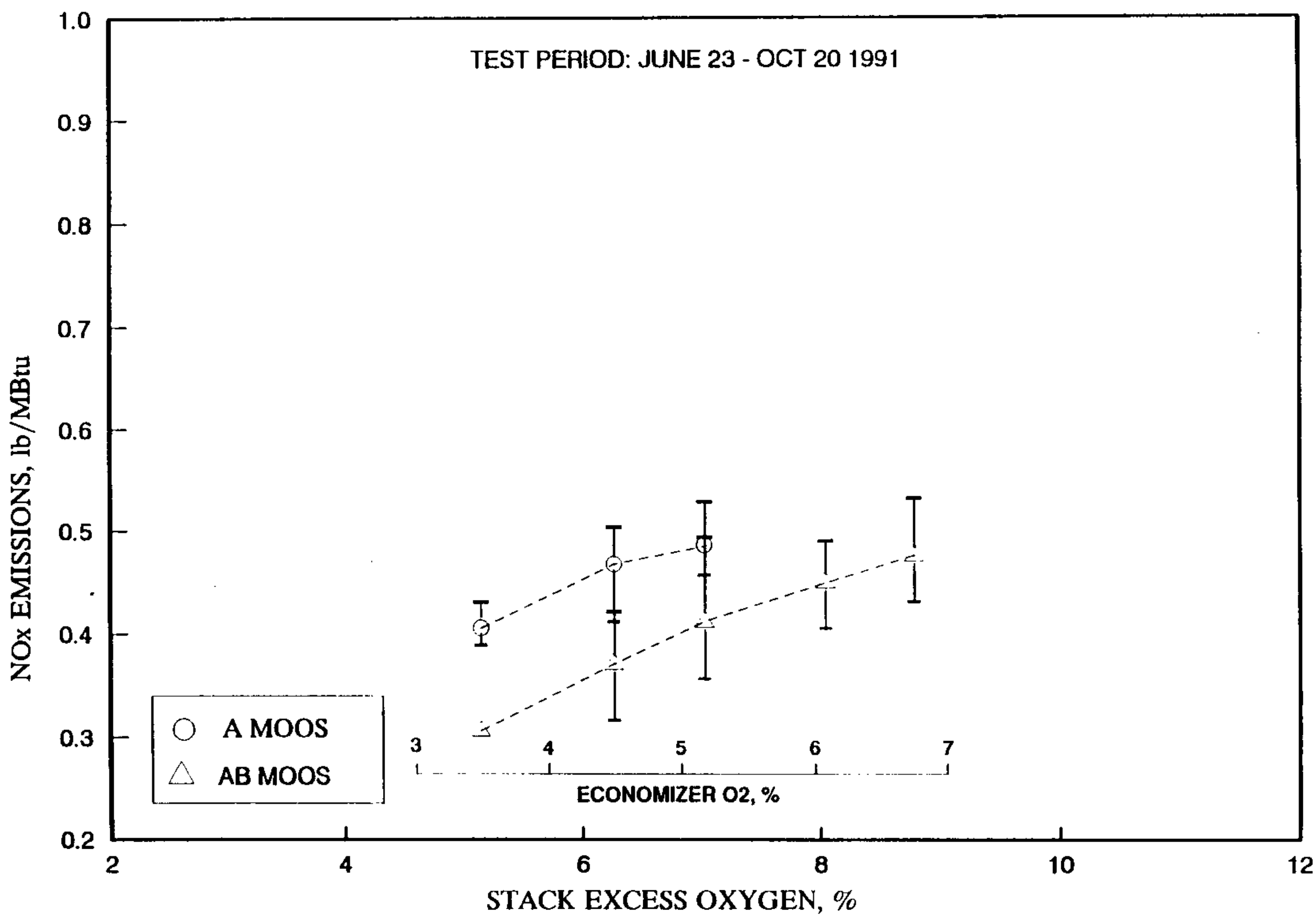

Figure 6-6. 115-MW Excess Oxygen Characteristics

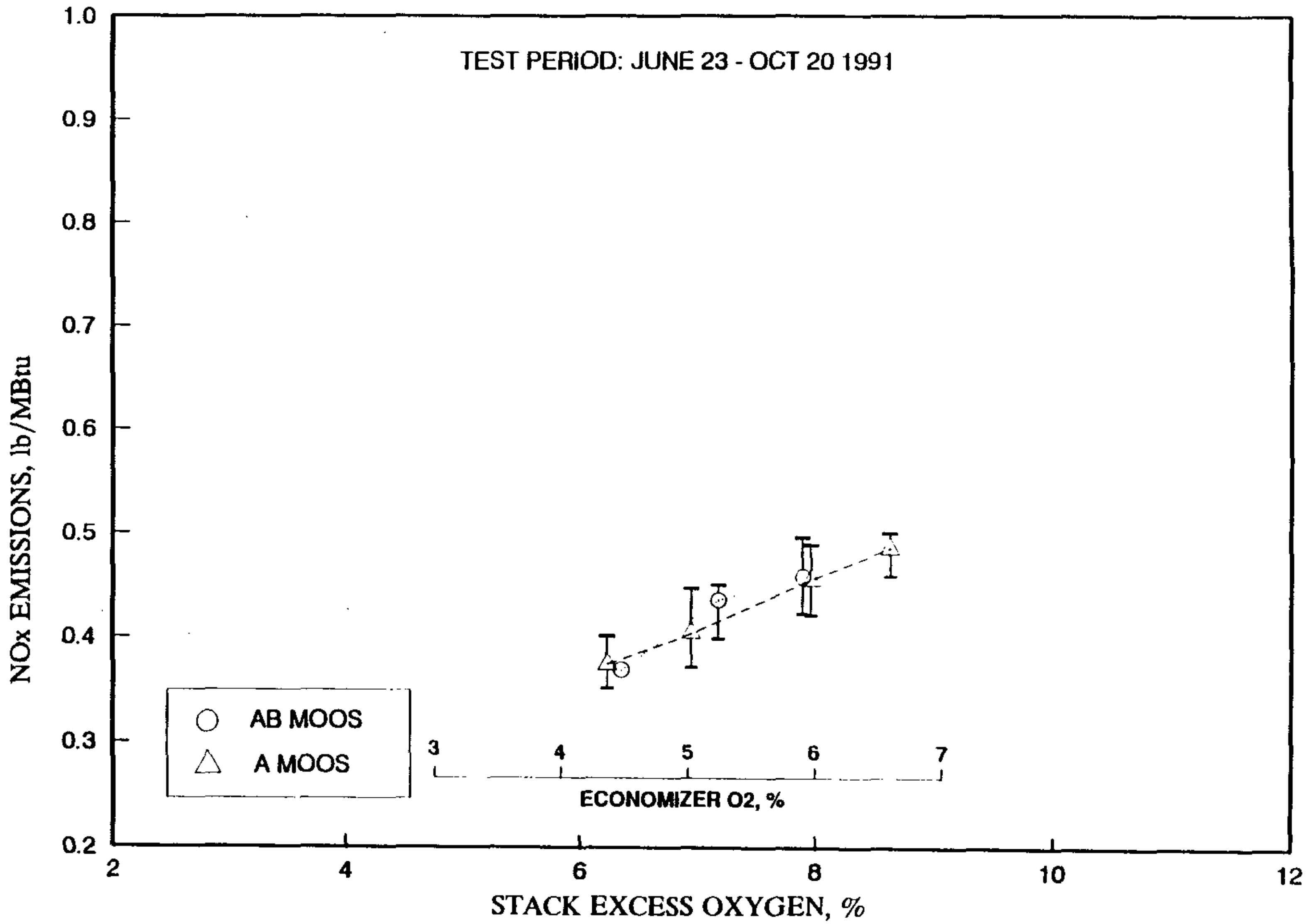

Figure 6-7. 135-MW Excess Oxygen Characteristics

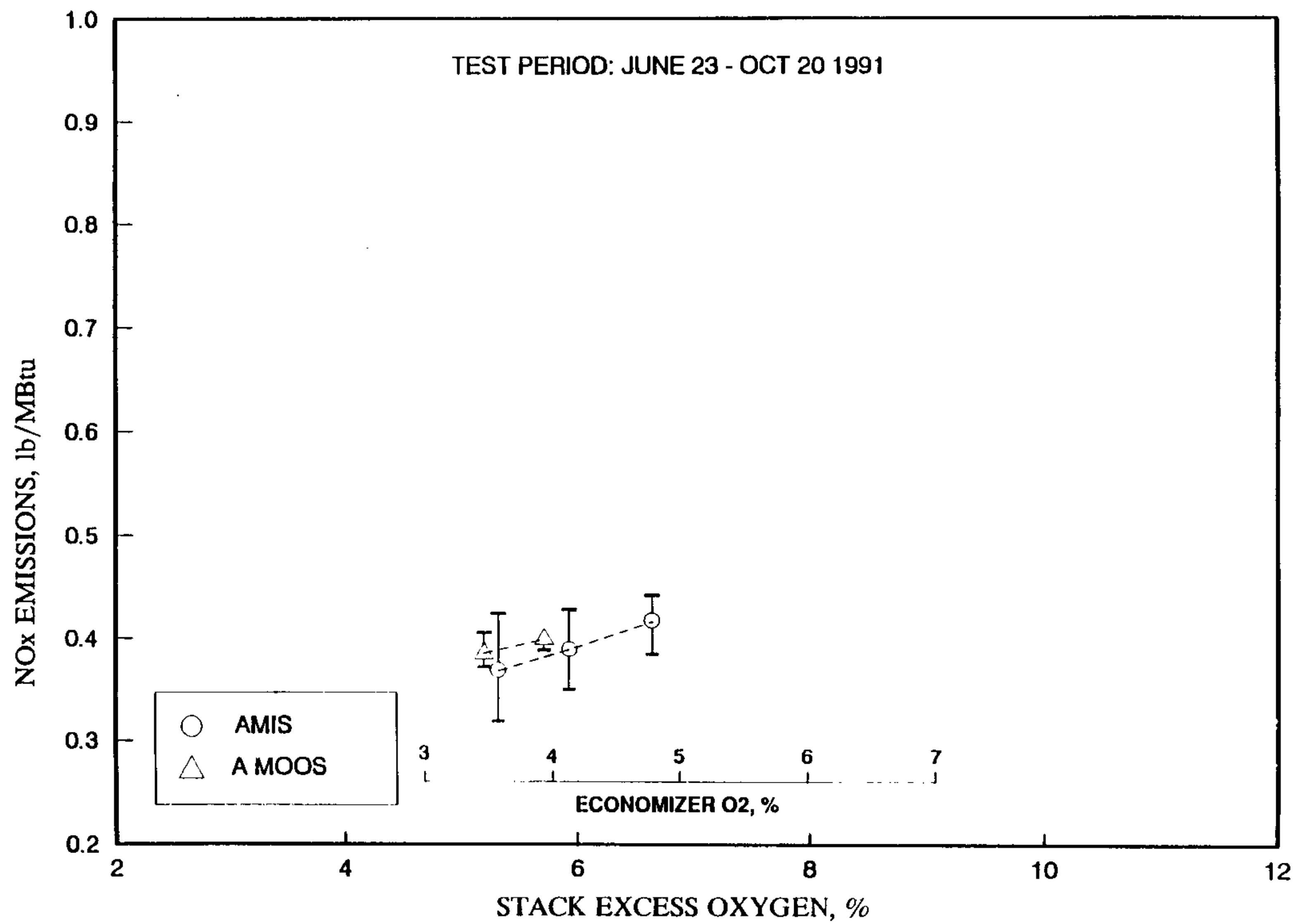

Figure 6-8. 180 - 200-MW Excess Oxygen Characteristics

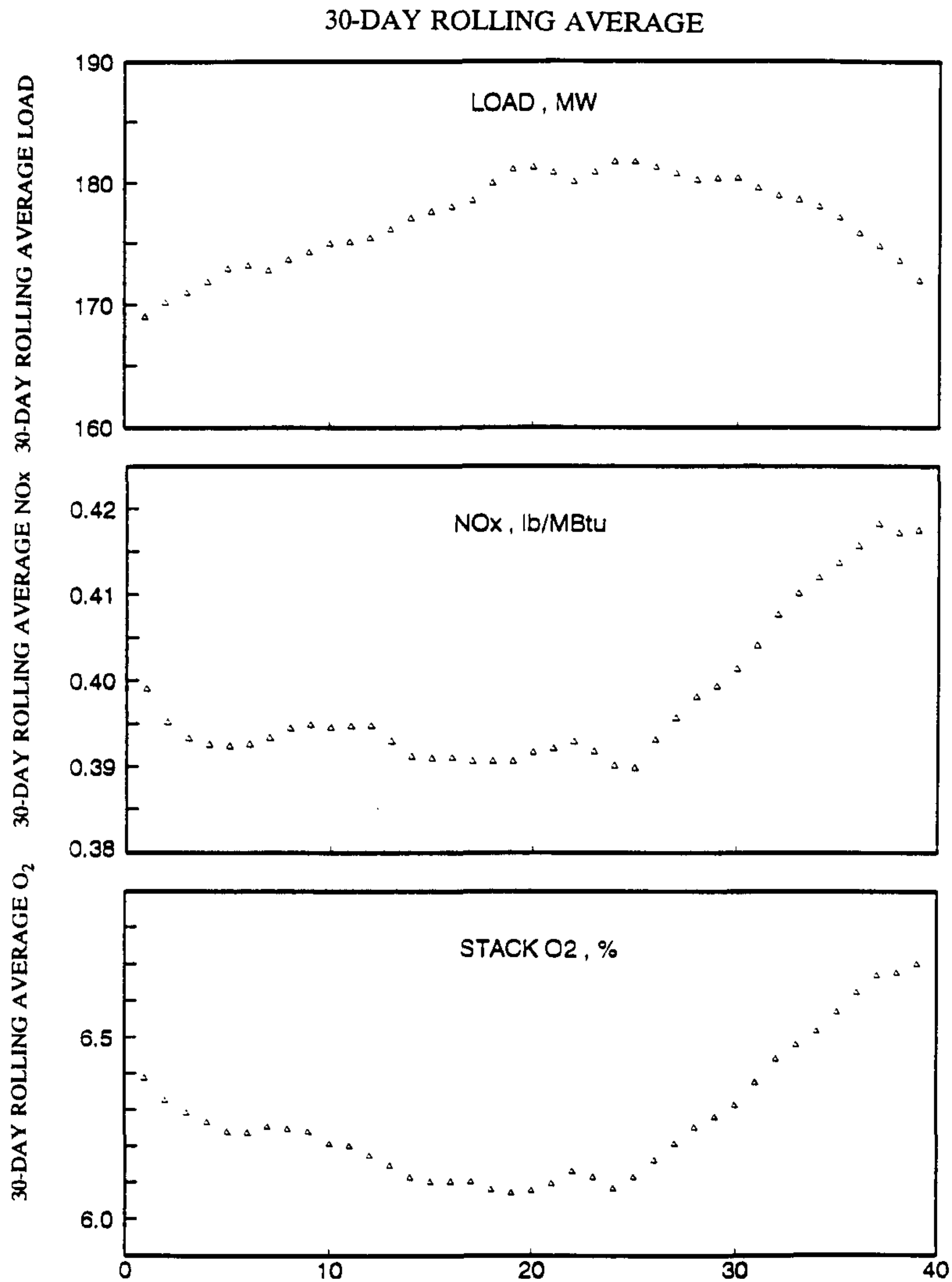

Figure 6-9. 30-Day Rolling Average Characteristics

6.4 Achievable Emission Characterization

In their rulemaking process, EPA establishes an achievable emission level based on daily average data samples obtained from a CEM. Most of these data are from NSPS Subpart Da units or units that used CEMs to obtain data during demonstration programs. The achievable NOx emission limit on a 30-day rolling average basis is determined using the descriptive statistics for 24-hour average NOx emissions. As discussed in Section 4.2.2, the SAS UNIVARIATE and AUTOREG procedures are used to determine the descriptive statistics for the 24-hour average NOx emissions data.

The results of the UNIVARIATE and AUTOREG analyses of the 24-hour average NOx emissions are presented in Table 6-3. The UNIVARIATE analysis indicated that the daily emissions were normally distributed. The AUTOREG analysis also indicated that the day-to-day fluctuations in NOx emissions followed a simple first order autoregressive model.

Based on the EPA criteria, the achievable NOx emission limit should only be exceeded, on average, once per 10 years on a 30-day rolling average basis. The achievable emission depends on the long-term mean, variability, and autocorrelation levels shown in Table 6-3. The achievable emission limit is computed using these values as discussed in Section 4.2.2. Table 6-4 provides the achievable emission level, based on the daily values given in Table 6-3. The achievable NOx emission limits shown in this table are computed for two conditions - no autocorrelation (ρ=0) and the estimated value of 0.72 (which indicates highly time-dependent data). The assumption in this table is that the unit will be operated in the future under similar load dispatching as that during this test phase. As previously explained under other load scenarios, the 30-day rolling averages would be different and therefore the achievable emission level would also be different.

The mean, variability, and autocorrelation levels given in Table 6-3 are estimates. An uncertainty level is implicit in the estimates of each of these statistical parameters. The uncertainty level in the mean is dependent on the variability. The estimated variability is, to some extent, dependent on the level of autocorrelation. Thus, uncertainty levels in the descriptive statistics are linked.

6.5 Comparison of Phase II Long- and Short-Term NOx Data

Section 5.1 presents data for the load characteristics (see Figure 5-2). This data includes a number of mill configurations and a range of excess oxygen levels. Similar data were collected during the long-term effort and are shown in Figure 6-4. This data includes all of the configurations normally experienced during the long-term test period. Figure 6-10 compares these two sets of data showing the upper 95 and lower 5 percentiles of the long-term period. From the comparison, the data obtained during the short-term efforts were, in most cases, within the upper 95- and lower 5-percentile range. The trends differed at the high-load point in that the long-term data showed a continuous decreasing NOx with load while the short-term data showed a decreasing then increasing characteristic.

Table 6-3
Descriptive Statistics for Daily Average NOx Emissions

Number of Daily Values	55
Average Emissions (NOx lb/MBtu)	0.41
Standard Deviation (NOx lb/MBtu)	0.028
Distribution	Normal
First Order Autocorrelation (ρ)	0.72

Table 6-4
30-Day Rolling Average Achievable NOx Emission Limit

	Achievable Emission Limit (NOx lb/MBtu)	
Autocorrelation	**30-Day**	**Annual**
$\rho = 0$	0.42	0.41
$\rho = 0.72$	0.45	0.41

6.6 Comparison of Phase I and Phase II Long-Term Test Results

The true measure of the effectiveness of the particular NOx control technology is represented by the long-term load characteristics. A useful engineering comparison can be made by comparing the mean value of the baseline and the retrofit load characteristics. Figure 6-11 illustrates the load characteristics for both configurations. At 200 MW, the LNCFS Level II retrofit resulted in approximately 39-percent reduction in NOx. Figure 6-12 shows that the NOx reduction effectiveness diminishes as the load is decreased and is particularly dramatic at loads below 100 MW. This reduction in effectiveness is primarily due to the SOFA ports being gradually closed as the load is decreased according to the schedule shown in Figure 1-1. Subsequent to the long-term testing, ABB CE retuned the dampers to eliminate the drastic decrease in NOx reduction at loads below 100 MW. This retuned-damper schedule is shown in Figure 1-1 as the revised schedule. Insufficient time was available to test the unit for extended periods in the retuned configuration to determine if the revised settings reduced NOx emission over a long-term.

Loss-on-ignition data were gathered in both the baseline and the LNCFS Level II configurations and are shown in Figure 6-13. The LNCFS Level II results are consistently lower than the baseline results, however, as shown in the figure, the excess oxygen requirements are higher for the Level II operation due to high CO emissions.

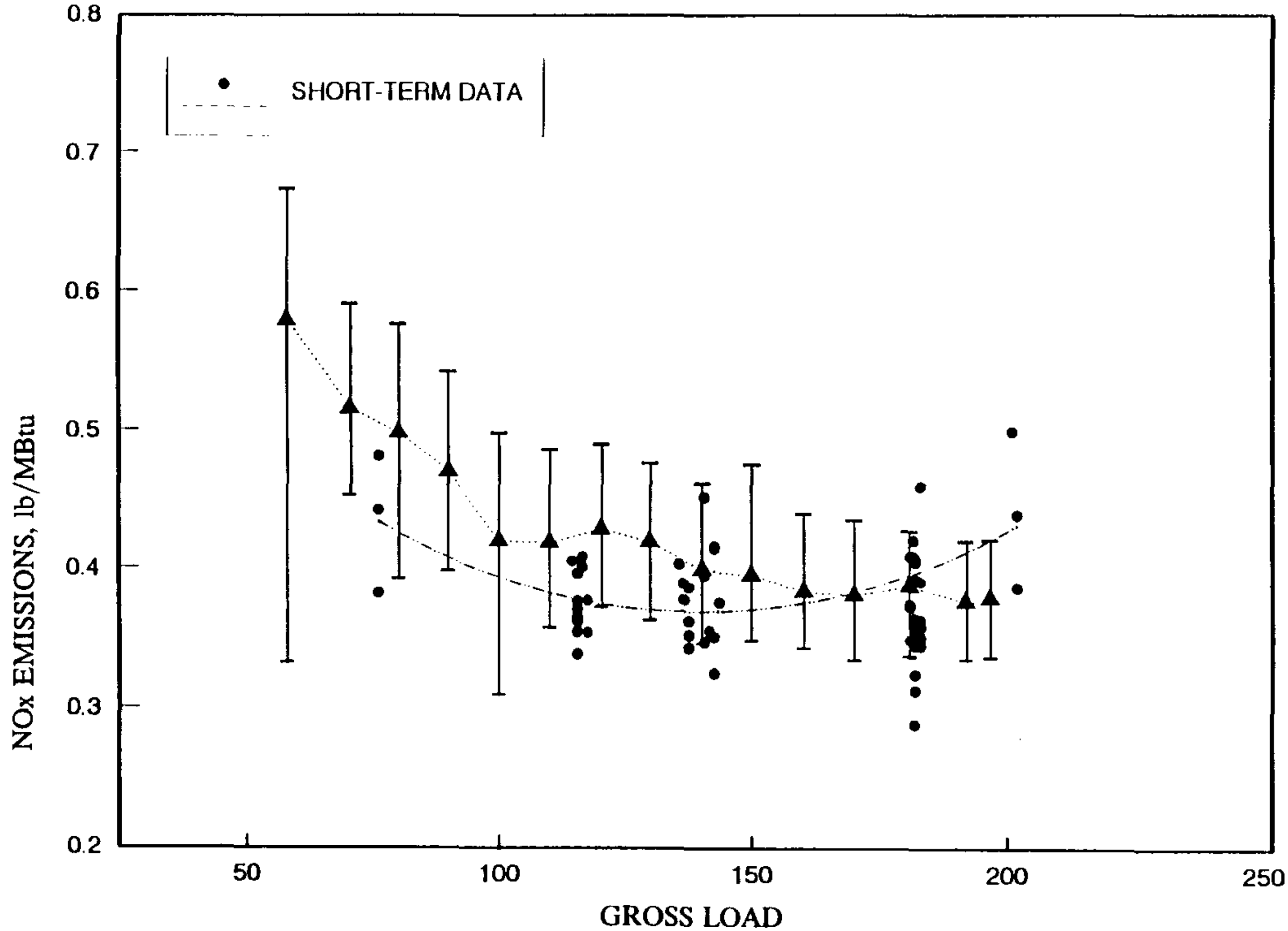

Figure 6-10. Comparison of Long- and Short-Term NOx Data, Medium to High Loads, All Excess Oxygen Levels

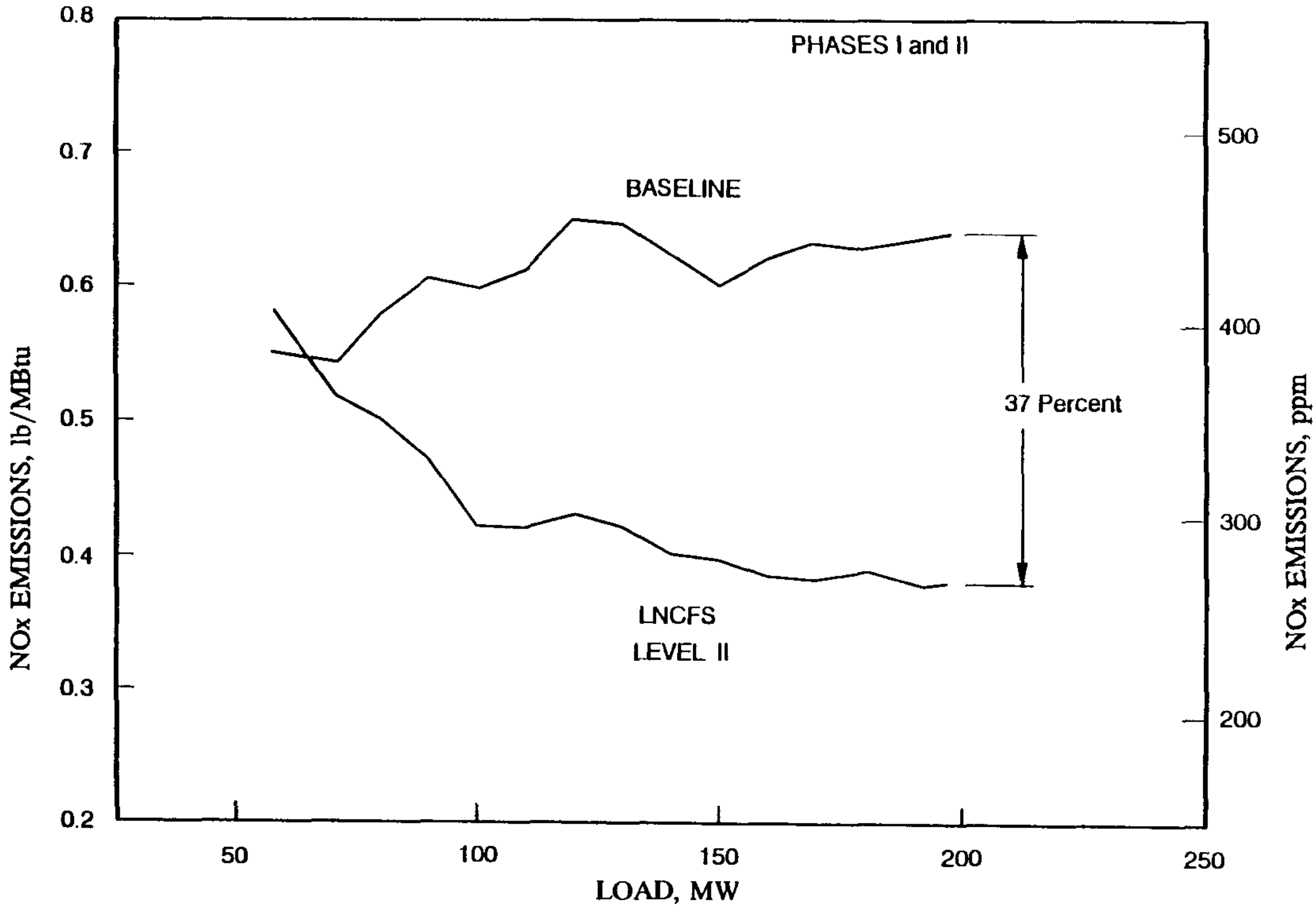

Figure 6-11. Comparison of Phases I and II Long Term NOx Data

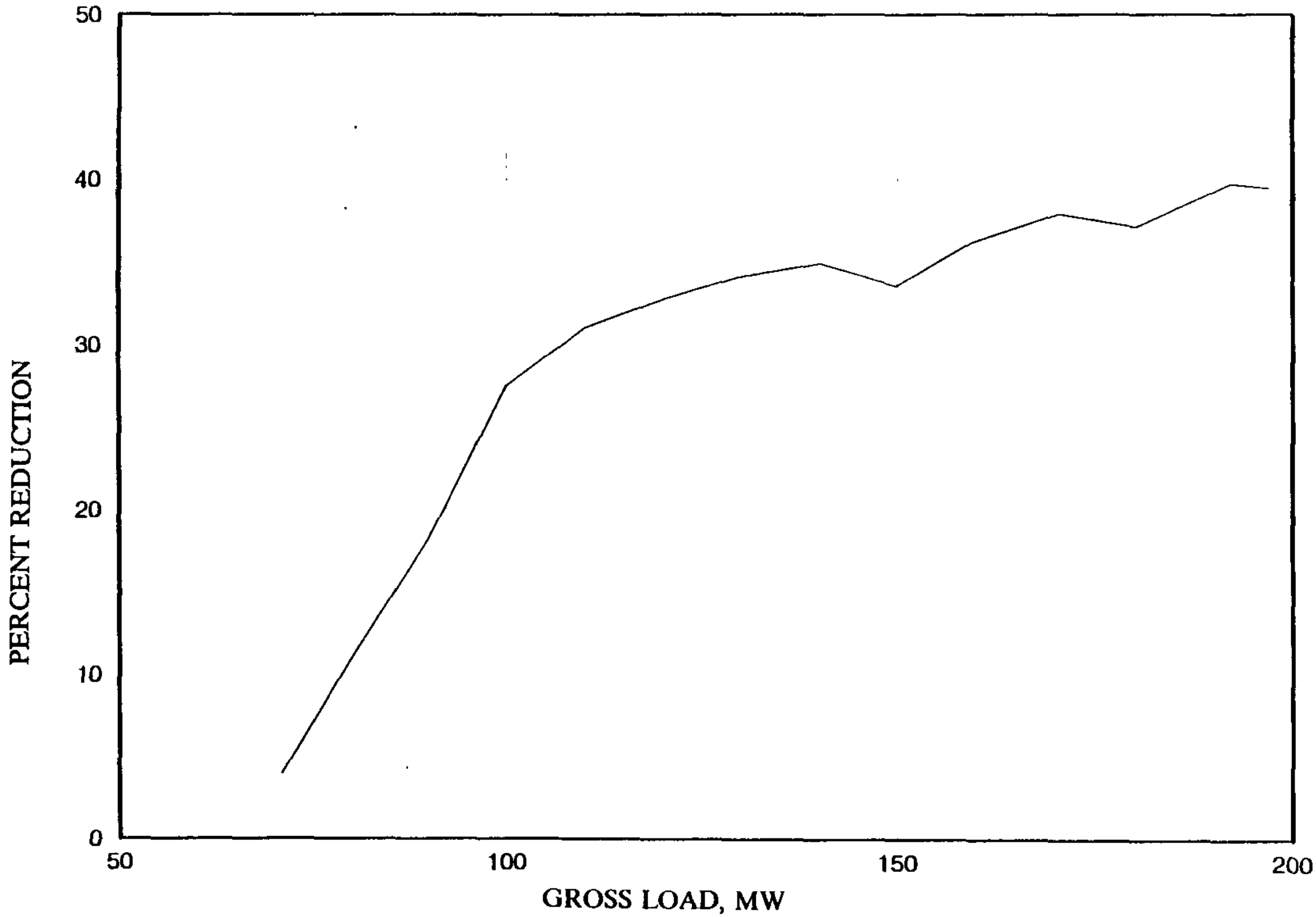

Figure 6-12. LNCFS Level II Retrofit Effectiveness

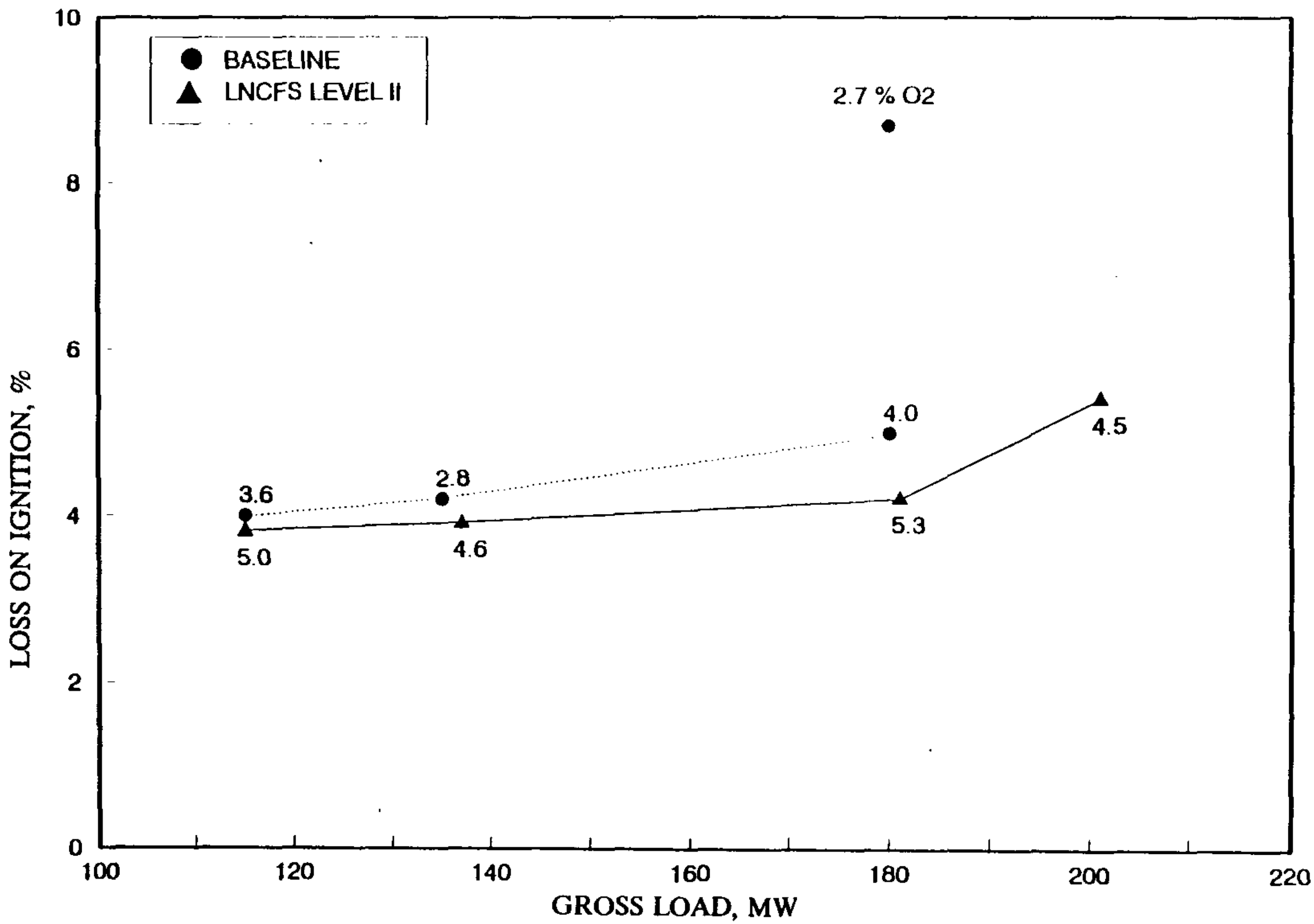

Figure 6-13. Comparison of Phases I and II LOI Results

7.0 CONCLUSIONS

The primary objective of the Phase II test effort was to document the operational and emissions impact of the retrofit of LNCFS Level II on Unit 2 and to establish the NOx emissions under short-term, well controlled conditions as well as under long-term, normal system load dispatch conditions. In addition, other important performance data related to the present operation of the boiler were documented for comparison to those measured during subsequent phases after retrofit of low-NOx combustion control techniques. A major objective of this phase was to establish the NOx control effectiveness of LNCFS Level II. An additional objective was to establish the NOx control effectiveness of LNBFS by disabling the yaws on the auxiliary air and SOFA dampers.

The following paragraphs provide brief discussions of the conclusions that can be drawn from the Phase II short- and long-term test results. Conclusions related to the comparison of the short- and long-term results are also presented. After the completion of the project, detailed comparative analyses will be performed to assess the effectiveness of the individual NOx control techniques with respect to the baseline emissions.

7.1 Short-Term Characterization Tests

During both the diagnostic and performance portions of this test effort, the coal supply remained relatively constant and no significant difficulties with Unit 2 equipment were experienced. The test plan was established based on the characteristics of the unit as determined during the Phase I test program.

During the Phase I short-term testing, protocols were established for test procedures and for instrumentation operation that were used during Phase II. With the exception of minor difficulties with the CEM, all major instrumentation problems had been rectified during the Phase I short-term effort.

7.1.1 Diagnostic Test Conclusions

The conclusions for the diagnostic portion of the testing are based primarily on testing performed at 180, 135, 115, and 70 MW.

1. The variability of the short-term data was found to be relatively as low as it was during Phase I. In general, boiler conditions and NOx data could be repeated with limited data scatter.

2. NOx emissions were well behaved showing the maximum data scatter of approximately ± 10 percent over the load range from 180 to 115 MW, which was slightly greater than that experienced during the baseline effort.

3. All of the trends for all loads and mill patterns exhibited increasing NOx emission with increasing O_2; however, the slopes varied at the different loads. The slope of the NOx emissions profile varied from approximately 40 parts per million/percent O_2 at 180 MW to 20

parts per million/percent O_2 at 115 MW. At the 70-MW load point, the sensitivity increased to approximately 30 parts per million/percent O_2.

4. NOx emissions decreased with loads up to approximately 135 MW and then gradually increased with increasing load. This characteristic is in contrast to the monotonically increasing NOx with load for the baseline configuration.

5. Abbreviated tests in the LNBFS configuration (no auxiliary air yaws) demonstrated that the NOx emissions were increased by only 29 parts per million (8 percent) at full-load over the emissions in the LNCFS Level II configuration. This trend existed at the low-load test point of 110 MW.

7.1.2 Performance Test Conclusions

The performance tests documented the unit characteristics at nominal loads of 180, 135, and 115 MW. Over the 10- to 12-hour period for each of the individual performance tests, the unit operated under stable, normal conditions. The conclusions for the performance tests are:

1. Mill coal flow measurements indicated that the coal flow between mills was nonuniform with a mill-to-mill variation of approximately ± 11 percent at high load resulting in excess oxygen maldistributions in the upper furnace.

2. Coal fineness was from 56 to 63 percent through a 200-mesh screen based on the samples taken in the coal pipes. Sampling at the mill outlet showed mill fineness ranging from approximately 60 to 70 percent through 200 mesh. The measured fineness through a 50-mesh screen was from 97 to 99 percent for samples taken in the coal pipes.

3. Electrostatic precipitator entrance particle size was within the range (referenced in baseline test report) predicted by the EPRI database predictions for precipitator performance.

4. Electrostatic precipitator entrance ash resistivity was within the expected range for this coal.

5. Loss-on-ignition was nominally 5 percent; however, excess oxygen levels were higher than those required during baseline testing. The LOI measurements indicated that LOI increased with decreasing excess oxygen. Carbon in ash was very close to the LOI data and was generally 5 percent lower than the LOI.

7.1.3 Verification Test Conclusions

Based on the results of 29 verification tests at loads of 180, 135, and 115 MW performed after the long-term testing, no significant changes in NOx characteristics occurred during long-term testing.

7.2 Long-Term Characterization Tests

During the long-term test period, the CEM was operated 24-hours per day except during periods of repair and calibration. Sufficient data were collected to perform meaningful statistical analyses for both engineering and regulatory purposes. The following paragraphs provide the major conclusions that can be drawn from the long-term test results.

1. Data confirmed that the unit operates uniformly over the useful load range when it is on line. A majority of the operating time is spent above 150 MW (83 percent of rated load). On this basis, the unit was classified as a base load unit.

2. Daily average NOx emission levels ranged from approximately 0.39 to 0.42 lb/MBtu, while the daily average load ranged from 170 to 180 MW.

3. Data for the various mill patterns indicated that NOx increased with increasing O_2. The data between the upper 95 percentile and the lower 5 percentile for NOx emissions at high-load mill patterns was in the order of ± 0.05 lb/MBtu about the mean.

4. The mean load characteristics showed that NOx emissions generally decreased as load increased from 70 to 180 MW and leveled out at high loads. Mean emissions ranged from 0.57 at low load to 0.39 lb/MBtu at high load. The upper 95- percentile and lower 5-percentile band for NOx emissions over the load range was in the order of ± 0.07 lb/MBtu about the mean.

5. Based on 30-day rolling averages, the data showed that the average load slowly increased from 170 to slightly above 180 MW over the first half of the testing, and decreased steadily thereafter. The 30-day rolling average NOx generally remained stabile during the first half of the period at approximately 0.39 lb/MBtu. As the average load decreased, the 30-day averages increased steadily to a level of approximately 0.42 lb/MBtu.

6. Statistical analyses indicated that the data were autocorrelated with a correlation coefficient of $\rho = 0.72$. The data are therefore highly autocorrelated (time dependent).

7. Nontime dependent ($\rho = 0$) analyses resulted in an a 30-day achievable emission level of 0.42 and an annual average achievable emission level of 0.41 lb/MBtu for the load scenario experienced during long-term testing. Time dependent ($\rho = 0.72$) analyses resulted in a 30-day achievable emission limit of 0.45 and an annual emission level of 0.41 lb/Mbtu.

7.3 Short-Term/Long-Term Comparison Conclusions

The following paragraphs provide the conclusions that can be drawn from the comparison of short- and long-term test results.

1. The NOx trends were dissimilar for both short-and long-term data. The slopes (NOx vs O_2) were similar at low loads but were in disagreement at the higher loads.

2. At all load conditions tested, the emissions for the short-term data fit within the upper 95-percentile and lower 5-percentile band for the long-term data. Few short-term data points fell outside this band.

7.4 Comparison of Phase I and Phase II Emission Data

While the Phase I and Phase II efforts were not performed with the same load scenarios, some general conclusions can be made with regard to the effectiveness of the LNCFS Level II retrofit.

1. Aside from LOI and NOx, all other solid and gaseous emission characteristics remained near the levels of those for the baseline configuration.

2. The LOI emissions remained essentially unchanged over the baseline configuration; however, excess oxygen levels were higher for Phase II.

3. The NOx emissions decreased by 39 percent from the baseline configuration at 200 MW. The emission reduction decreased as the load decreased to the 70-MW load point where the reduction was approximately 3 percent.