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INNOVATIVE CLEAN COAL TECHNOLOGY

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Prepared by:

Southern Company Services, Inc.
Birmingham, Alabama

INNOVATIVE CLEAN COAL TECHNOLOGY (ICCT)

500 MW DEMONSTRATION OF ADVANCED WALL-FIRED COMBUSTION TECHNIQUES FOR THE REDUCTION OF NITROGEN OXIDE (NO_x) EMISSIONS FROM COAL-FIRED BOILERS

Technical Progress Report
First Quarter 1995

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EXECUTIVE SUMMARY

This quarterly report discusses the technical progress of an Innovative Clean Coal Technology (ICCT) demonstration of advanced wall-fired combustion techniques for the reduction of nitrogen oxide (NOx) emissions from coal-fired boilers. The project is being conducted at Georgia Power Company's Plant Hammond Unit 4 located near Rome, Georgia. The primary goal of this project is the characterization of the low NOx combustion equipment through the collection and analysis of long-term emissions data. The project provides a stepwise evaluation of the following NOx reduction technologies: Advanced overfire air (AOFA), Low NOx burners (LNB), LNB with AOFA, and Advanced Digital Controls and Optimization Strategies.

The project has completed the baseline, AOFA, LNB, and LNB+AOFA test segments, fulfilling all testing originally proposed to DOE. Analysis of the LNB long-term data collected show the full load NOx emission levels to be near 0.65 lb/MBtu. This NOx level represents a 48 percent reduction when compared to the baseline, full load value of 1.24 lb/MBtu. These reductions were sustainable over the long-term test period and were consistent over the entire load range. Full load, fly ash LOI values in the LNB configuration were near 8 percent compared to 5 percent for baseline. Results from the LNB+AOFA phase indicate that full load NOx emissions are approximately 0.40 lb/MBtu with a corresponding fly ash LOI value of near 8 percent. Although this NOx level represents a 67 percent reduction from baseline levels, a substantial portion of the incremental change in NOx emissions between the LNB and LNB+AOFA configurations was the result of operational changes and not the result of the AOFA system.

Phase 4 of the project is in progress. During first quarter 1995, design of the advanced control and optimization software and strategies continued. Prototypes of the Generic NO_x Control Intelligent System (GNOCIS) continue to be tested at Alabama Power Company's Gaston Unit 4 and PowerGen's Kingsnorth Unit 1. Installation of the digital control system (DCS) installed as part of Phase 4 of the project has been completed and the system is fully operational. The GNOCIS host platform has been delivered to the site and networked to the Hammond Unit 4 Foxboro I/A digital control system. Two on-line carbon-in-ash (CIA) monitors procured for this project have been installed and are operational. One monitor extracts fly ash from two ports located at the economizer outlet while the other extracts fly ash from a single location at the precipitator inlet.

Process data collected from the DCS is being archived to a server on the plant information network and subsequently transferred to SCS offices in Birmingham for analysis and use in training the neural network combustion models. Approximately 45 days of data have been collected to date for use in the training set and these modeling studies are now underway. In addition to the data obtained from the DCS, long-term emissions data is also being archived to the project's data acquisition system. Short-term testing was performed from March 27 through March 31 and the data collected will be used to augment long-term data. Also, operator training classes were conducted from March 13 through April 7 at the site.

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TABLE OF ABBREVIATIONS

acfm	actual cubic feet per minute
AMIS	All mills in service
AOFA	Advanced Overfire Air
ASME	American Society of Mechanical Engineers
C	carbon
CAA(A)	Clean Air Act (Amendments)
CEM	Continuous emissions monitor
CFSF	Controlled Flow/Split Flame
Cl	chlorine
CO	carbon moNOxide
DAS	data acquisition system
DCS	digital control system
DOE	United States Department of Energy
ECEM	extractive continuous emissions monitor
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ETEC	Energy Technology Consultants
F	Fahrenheit
FC	fixed carbon
FWEC	Foster Wheeler Energy Corporation
Flame	Flame Refractories
GPC	Georgia Power Company
H	hydrogen
HHV	higher heating value
HVT	High velocity thermocouple
ICCT	Innovative Clean Coal Technology
KPPH	kilo pounds per hour
lb(s)	pound(s)
LNB	low NOx burner
LOI	loss on ignition
(M)Btu	(million) British thermal unit
MOOS	Mills out of service
MW	megawatt
N	nitrogen
NO_x	nitrogen oxides
NSPS	New Source Performance Standards
O, O_2	oxygen
OFA	overfire air
PA	primary air
psig	pounds per square inch gauge
PTC	Performance Test Codes

TABLE OF ABBREVIATIONS (continued)

RSD	relative standard deviation
S	sulfur
SCS	specific collection area
SCS	Southern Company Services
SO_2	sulfur dioxide
SoRI	Southern Research Institute
Spectrum	Spectrum Systems Inc.
THC	total hydrocarbons
UARG	Utility Air Regulatory Group
VM	volatile matter

1. INTRODUCTION

This document discusses the technical progress of a U. S. Department of Energy (DOE) Innovative Clean Coal Technology (ICCT) Project demonstrating advanced wall-fired combustion techniques for the reduction of nitrogen oxide (NO_x) emissions from coal-fired boilers. The project is being conducted at Georgia Power Company's Plant Hammond Unit 4 (500 MW) near Rome, Georgia.

The project is being managed by Southern Company Services, Inc. (SCS) on behalf of the project co-funders: The Southern Company, the U. S. Department of Energy (DOE), and the Electric Power Research Institute. In addition to SCS, The Southern Company includes five electric operating companies: Alabama Power, Georgia Power, Gulf Power, Mississippi Power, and Savannah Electric and Power. SCS provides engineering, research, and financial services to The Southern Company.

The Clean Coal Technology Program is a jointly funded effort between government and industry to move the most promising advanced coal-based technologies from the research and development stage to the commercial marketplace. The Clean Coal effort sponsors projects which are different from traditional research and development programs sponsored by the DOE. Traditional projects focus on long range, high risk, high payoff technologies with the DOE providing the majority of the funding. In contrast, the goal of the Clean Coal Program is to demonstrate commercially feasible, advanced coal-based technologies which have already reached the "proof of concept" stage. As a result, the Clean Coal Projects are jointly funded endeavors between the government and the private sector which are conducted as Cooperative Agreements in which the industrial participant contributes at least fifty percent of the total project cost.

The primary objective of the Plant Hammond demonstration is to determine the long-term effects of commercially available wall-fired low NO_x combustion technologies on NO_x emissions and boiler performance. Short-term tests of each technology are also being performed to provide engineering information about emissions and performance trends. A target of achieving fifty percent NO_x reduction using combustion modifications has been established for the project. Specifically, the objectives of the projects are:

1. Demonstrate in a logical stepwise fashion the short-term NO_x reduction capabilities of the following advanced low NO_x combustion technologies:

    a. Advanced overfire air (AOFA)
    b. Low NO_x burners (LNB)
    c. LNB with AOFA
    d. Advanced Digital Controls and Optimization Strategies

2. Determine the dynamic, long-term emissions characteristics of each of these combustion NO_x reduction methods using sophisticated statistical techniques.

3. Evaluate the progressive cost effectiveness (i.e., dollars per ton NO_x removed) of the low NO_x combustion techniques tested.

4. Determine the effects on other combustion parameters (e.g., CO production, carbon carryover, particulate characteristics) of applying the NO_x reduction methods listed above.

2. PROJECT DESCRIPTION

2.1. Test Program Methodology

In order to accomplish the project objectives, a Statement of Work (SOW) was developed which included the Work Breakdown Structure (WBS) found in Table 1. The WBS is designed around a chronological flow of the project. The chronology requires design, construction, and operation activities in each of the first three phases following project award.

Table 1: Work Breakdown Structure

Phase	Task	Description	Date
0	0	Phase 0 Pre-Award Negotiations	
1	1	Phase 1 Baseline Characterization	
	1.1	Project Management and Reporting	8/89 - 4/90
	1.2	Site Preparation	8/89 - 10/89
	1.3	Flow Modeling	9/89 - 6/90
	1.4	Instrumentation	9/89 - 10/89
	1.5	Baseline Testing	11/89 - 4/90
2	2	Phase 2 Advanced Overfire Air Retrofit	
	2.1	Project Management and Reporting	4/90 - 3/91
	2.2	AOFA Design and Retrofit	4/90 - 5/90
	2.3	AOFA Testing	6/90 - 3/91
3	3	Phase 3 Low NOx Burner Retrofit	
	3.1	Project Management and Reporting	3/91 - 8/93*
	3.2	LNB Design and Retrofit	4/91 - 5/91
	3.3	LNB Testing with and without AOFA	5/91 - 8/93*
4*	4*	Advanced Low NOx Digital Control System*	8/93 - 9/95*
5*	5*	Final Reporting and Disposition	
	5.1	Project Management and Reporting	9/95 - 12/95*
	5.2	Disposition of Hardware	12/95*

* Indicates change from original work breakdown structure.

The stepwise approach to evaluating the NOx control technologies requires that three plant outages be used to successively install: (1) the test instrumentation, (2) the AOFA system, and (3) the LNBs. These outages were scheduled to coincide with existing plant maintenance outages in the fall of 1989, spring of 1990, and spring of 1991. The planned retrofit progression has allowed for an evaluation of the AOFA system while operating with the existing pre-retrofit burners. As shown in Figure 1, the AOFA air supply is separately ducted from the existing forced draft secondary air system. Backpressure dampers are provided on the secondary air ducts to allow for the introduction of greater quantities of higher pressure overfire air into the boiler. The burners are designed to be plug-in replacements for the existing circular burners.

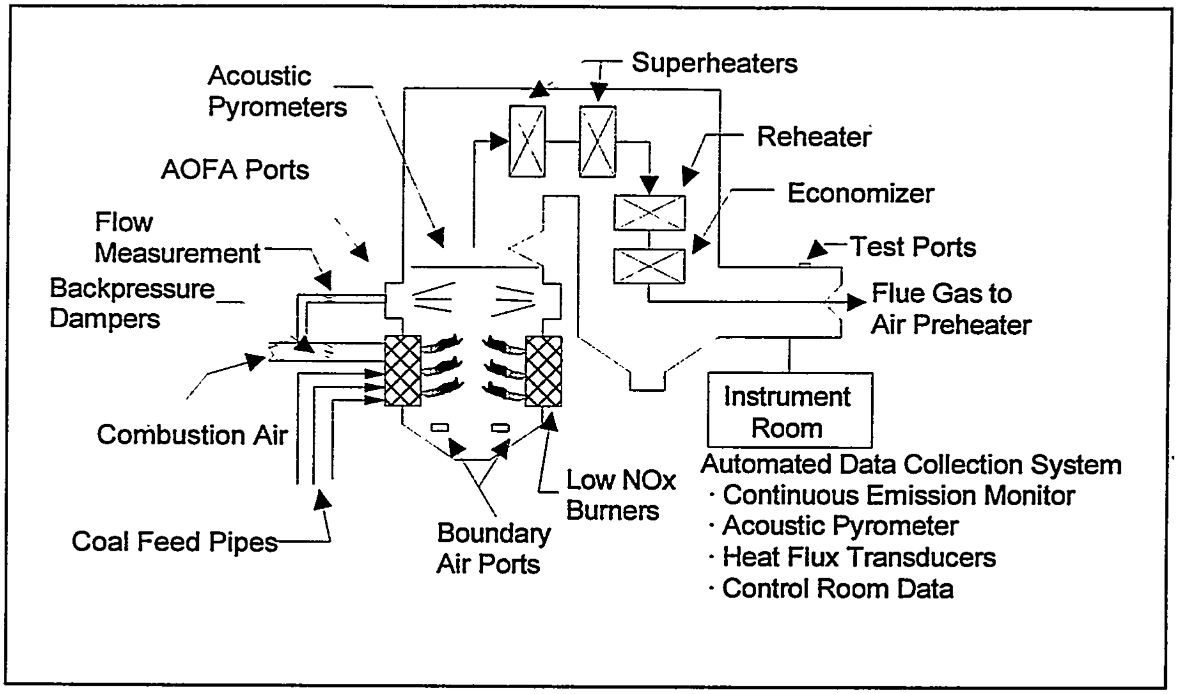

Figure 1: Plant Hammond Unit 4 Boiler

The data acquisition system (DAS) for the Hammond Unit 4 ICCT project is a custom designed microcomputer based system used to collect, format, calculate, store, and transmit data derived from power plant mechanical, thermal, and fluid processes. The extensive process data selected for input to the DAS has in common a relationship with either boiler performance or boiler exhaust gas properties. This system includes a continuous emissions monitoring system (NO_x, SO_2, O_2, THC, CO) with a multi-point flue gas sampling and conditioning system, an acoustic pyrometry and thermal mapping system, furnace tube heat flux transducers, and boiler efficiency instrumentation. The instrumentation system is designed to provide data collection flexibility to meet the schedule and needs of the various testing efforts throughout the demonstration program. A summary of the type of data collected is shown in Table 2.

During each test phase, a series of four groups of tests are conducted. These are: (1) diagnostic, (2) performance, (3) long-term, and (4) verification. The diagnostic, performance, and verification tests consist of short-term data collection during carefully established operating conditions. The diagnostic tests are designed to map the effects of changes in boiler operation on NO_x emissions. The performance tests evaluate a more comprehensive set of boiler and combustion performance indicators. The results from these tests will include particulate characteristics, boiler efficiency, and boiler outlet emissions. Mill performance and air flow distribution are also tested. The verification tests are performed following the end of the long-term testing period and serve to identify any potential changes in plant operating conditions.

Table 2: Inputs to Data Acquisition System	
Boiler Drum Pressure	Superheat Outlet Pressure
Cold Reheat Pressure	Hot Reheat Pressure
Barometric Pressure	Superheat Spray Flow
Reheat Spray Flow	Main Steam Flow
Feedwater Flow	Coal Flows
Secondary Air Flows	Primary Air Flows
Main Steam Temperature	Cold Reheat Temperature
Hot Reheat Temperature	Feedwater Temperature
Desuperheater Outlet Temp.	Desuperheater Inlet Temp.
Economizer Outlet Temp.	Air Heater Air Inlet Temp.
Air Heater Air Outlet Temp.	Ambient Temperature
BFP Discharge Temperature	Relative Humidity
Stack NOx	Stack SO2
Stack O2	Stack Opacity
Generation	Overfire Air Flows

As stated previously, the primary objective of the demonstration is to collect long-term, statistically significant quantities of data under normal operating conditions with and without the various NO_x reduction technologies. Earlier demonstrations of emissions control technologies have relied solely on data from a matrix of carefully established short-term (one to four hour) tests. However, boilers are not typically operated in this manner, considering plant equipment inconsistencies and economic dispatch strategies. Therefore, statistical analysis methods for long-term data are available that can be used to determine the achievable emissions limit or projected emission tonnage of an emissions control technology. These analysis methods have been developed over the past fifteen years by the Control Technology Committee of the Utility Air Regulatory Group (UARG). Because the uncertainty in the analysis methods is reduced with increasing data set size, UARG recommends that acceptable 30 day rolling averages can be achieved with data sets of at least 51 days with each day containing at least 18 valid hourly averages.

2.2. Unit Description

Georgia Power Company's Plant Hammond Unit 4 is a Foster Wheeler Energy Corporation (FWEC) opposed wall-fired boiler, rated at 500 MW gross, with design steam conditions of 2500 psig and 1000/1000°F superheat/reheat temperatures, respectively. The unit was placed into commercial operation on December 14, 1970. Prior to the LNB retrofit, six FWEC Planetary Roller and Table type mills provided pulverized eastern bituminous coal (12,900 Btu/lb, 33% VM, 53% FC, 1.7% S, 1.4% N) to 24 pre-NSPS, Intervane burners. During the LNB outage, the existing burners were replaced with FWEC Control Flow/Split Flame burners. The unit was also retrofitted with six Babcock and Wilcox MPS 75 mills during the course of the demonstration (two each during the spring 1991, spring 1992, and fall 1993 outages). The burners are arranged in a matrix of 12 burners (4W x 3H) on opposing walls with each mill supplying coal to 4 burners per elevation. As part of this demonstration project, the unit was retrofitted with an advanced overfire air system, to be described later. The unit is equipped with a coldside ESP and utilizes two regenerative secondary air preheaters and two regenerative primary air heaters. The unit was designed for pressurized furnace operation but was converted to balanced draft operation in 1977. The unit, equipped with a Bailey pneumatic boiler control system during the baseline, AOFA, LNB, and LNB+AOFA phases of the project, was retrofit with a Foxboro I/A distributed digital control system for Phase 4 of the project.

2.3. Advanced Overfire Air (AOFA) System

Generally, combustion NO_x reduction techniques attempt to stage the introduction of oxygen into the furnace. This staging reduces NO_x production by creating a delay in fuel and air mixing that lowers combustion temperatures. The staging also reduces the quantity of oxygen available to the fuel-bound nitrogen. Typical overfire air (OFA) systems accomplish this staging by diverting 10 to 20 percent of the total combustion air to ports located above the primary combustion zone. AOFA improves this concept by introducing the OFA through separate ductwork with more control and accurate measurement of the AOFA airflow, thereby providing the capability of improved mixing (Figure 2).

Foster Wheeler Energy Corporation (FWEC) was competitively selected to design, fabricate, and install the advanced overfire air system and the opposed-wall, low NO_x burners described below. The FWEC design diverts air from the secondary air ductwork and incorporates four flow control dampers at the corners of the overfire air windbox and four overfire air ports on both the front and rear furnace walls. Due to budgetary and physical constraints, FWEC designed an AOFA system more suitable to the project and unit than that originally proposed. Six air ports per wall were proposed instead of the as-installed configuration of four per wall.

2.4. Low NO_x Burners

Low NO_x burner systems attempt to stage the combustion without the need for the additional ductwork and furnace ports required by OFA and AOFA systems. These commercially-available burner systems introduce the air and coal into the furnace in a well controlled, reduced turbulence manner. To achieve this, the burner must regulate the initial fuel/air mixture, velocities and turbulence to create a fuel-rich core, with sufficient air to sustain combustion at a severely sub-stoichiometric air/fuel ratio. The burner must then control the rate at which additional air, necessary to complete combustion, is mixed with the flame solids and gases to maintain a deficiency of oxygen until the remaining combustibles fall below the peak NO_x producing temperature (around 2800°F). The final excess air can then be allowed to mix with the unburned products so that the combustion is completed at lower temperatures. Burners have been developed for single wall and opposed wall boilers.

In the FWEC Controlled Flow/Split Flame (CFSF) burner (Figure 3), secondary combustion air is divided between inner and outer flow cylinders. A sliding sleeve damper regulates the total secondary air flow entering the burner and is used to balance the burner air flow distribution. An adjustable outer register assembly divides the burners' secondary air into two concentric paths and also imparts some swirl to the air streams. The secondary air which traverses the inner path, flows across an adjustable inner register assembly that, by providing a variable pressure drop, apportions the flow between the inner and outer flow paths. The inner register also controls the degree of additional swirl imparted to the coal/air mixture in the near throat region. The outer air flow enters the furnace axially, providing the remaining air necessary to complete combustion. An axially movable inner sleeve tip provides a means for varying the primary air velocity while maintaining a constant primary flow. The split flame nozzle segregates the coal/air mixture into four concentrated streams, each of which forms an individual flame when entering the furnace. This segregation minimizes mixing between the coal and the primary air, assisting in the staged combustion process. The adjustments to the sleeve dampers, inner registers, outer registers, and tip position are made during the burner optimization process and thereafter remain fixed unless changes in plant operation or equipment condition dictate further adjustments.

2.5. Application of Advanced Digital Control Methodologies

The objective of Phase 4 of the project is to implement and evaluate an advanced digital control/optimization system for use with the combustion NO_x abatement technologies installed on Plant Hammond Unit 4. The advanced system will be customized to minimize NO_x production while simultaneously maintaining and/or improving boiler performance and safety margins. This project will provide documented effectiveness of an advanced digital control /optimization strategy on NO_x emissions and guidelines for retrofitting boiler combustion controls for NO_x emission reduction. The methodology selected for demonstration at Hammond Unit 4 during Phase 4 of the project is the Generic NO_x Control Intelligent System (GNOCIS).

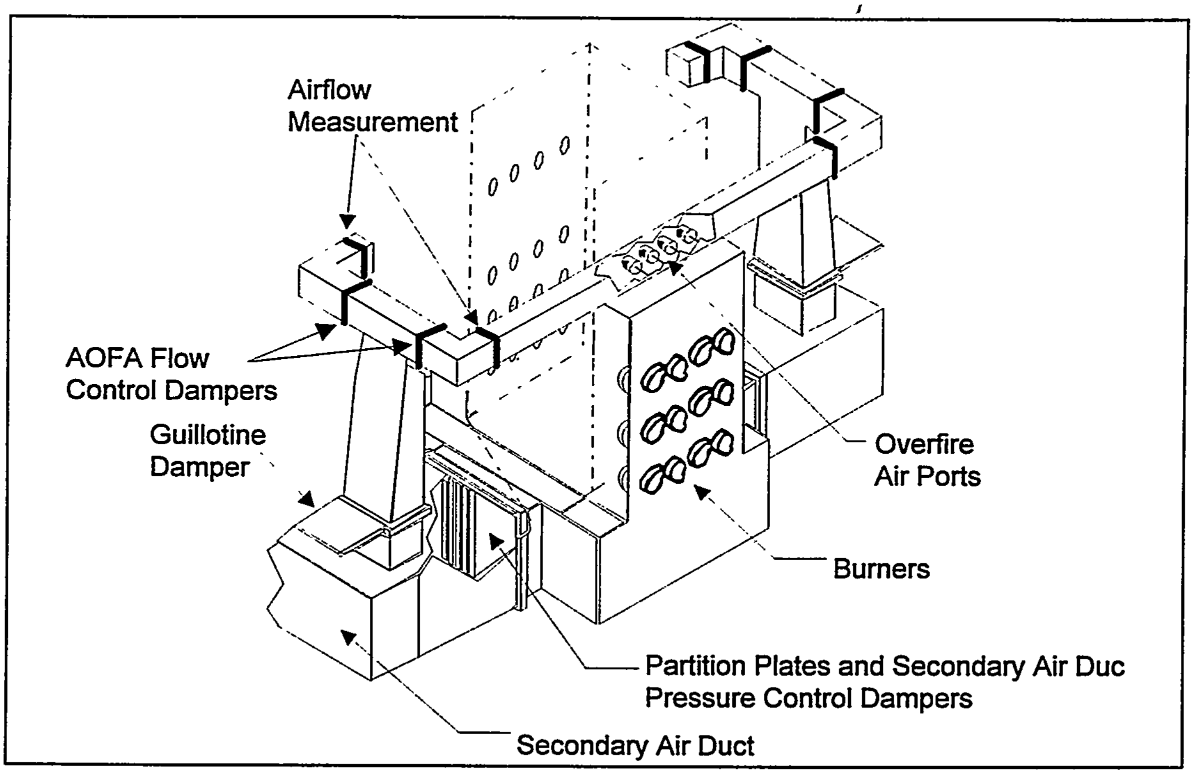

Figure 2: Advanced Overfire Air System

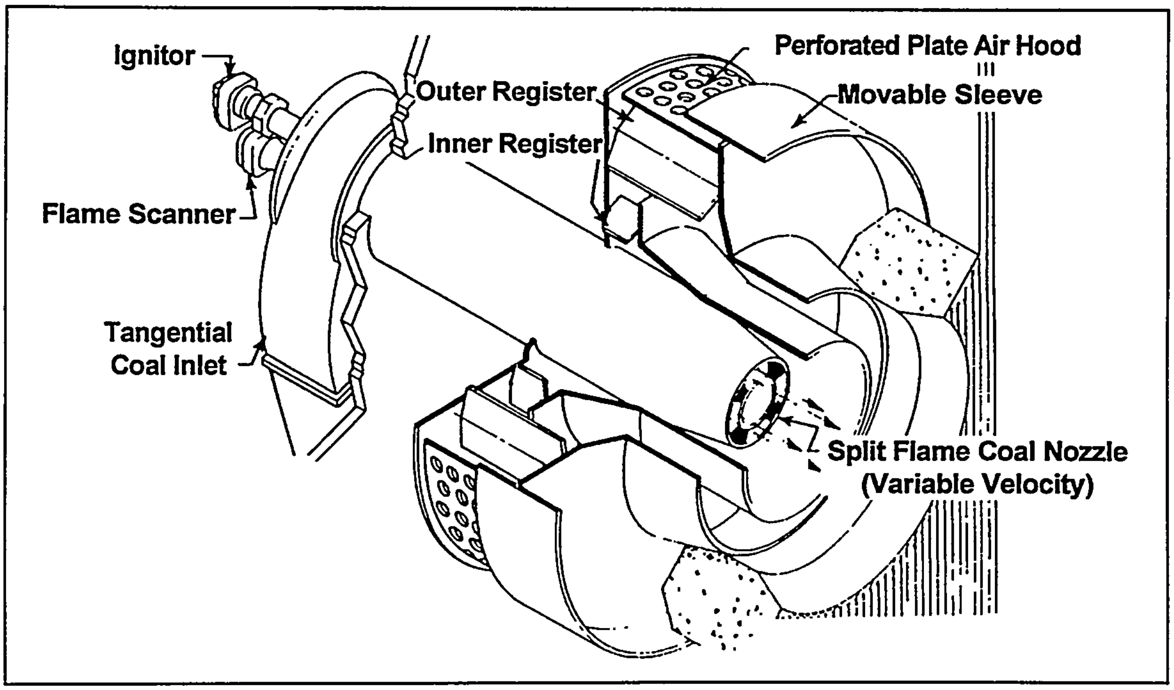

Figure 3: Low NOx Burner Installed at Plant Hammond

3. PROJECT STATUS

3.1. Project Summary

Baseline, AOFA, LNB, and LNB+AOFA test phases have been completed. Details of the testing conducted during each phase can be found in the following reports:

- Phase 1 Baseline Tests Report [1],
- Phase 2 AOFA Tests Report [2],
- Phase 3A Low NO_x Burner Tests Report [3], and
- Phase 3B Low NO_x Burner plus AOFA Tests Report [4].

Chemical emissions testing was also conducted as part of the project and the results have been previously reported [5]. Phase 4 of the project -- evaluation of advanced low NOx digital controls / optimization strategies as applied to NO_x abatement -- is now in progress. A list of the current activities and their current status can be found in Table 3.

Table 3: Phase 4 Milestones / Status

Milestone	Status
Digital control system design, configuration, and installation	Completed
Digital control system startup	Completed
Instrumentation upgrades	Completed
Advanced controls/optimization design	In Progress
Characterization of the unit pre- activation of advanced strategies	In Progress
Characterization of the post- activation of advanced strategies	6/95 - 9/95

3.2. Current Quarter Activities

Phase 4 of the project is in progress. During first quarter 1995, design of the advanced control and optimization software and strategies continued. Prototypes of the Generic NO_x Control Intelligent System (GNOCIS) continue to be tested at Alabama Power Company's Gaston Unit 4 and PowerGen's Kingsnorth Unit 1. Installation of the digital control system (DCS) installed as part of Phase 4 of the project has been completed and the system is fully operational. The GNOCIS host platform has been delivered to the site and networked to the Hammond Unit 4 Foxboro I/A digital control system. Two on-line carbon-in-ash (CIA) monitors procured for this project have been installed and are operational. One monitor extracts fly ash from two ports located at the economizer outlet while the other extracts fly ash from a single location at the precipitator inlet. Consideration is also being given to the installation of additional CIA monitors for further side-by-side comparisons of these devices.

Process data collected from the DCS is being archived to a server on the plant information network and subsequently transferred to SCS offices in Birmingham for analysis and use in training the neural network combustion models. Approximately 45 days of data have been collected to date for use in the training set and these modeling studies are now underway. In addition to the data obtained from the DCS, long-term emissions data is also being archived to the project's data acquisition system. Short-term testing was conducted from March 27 through March 31 and the data collected will be used to augment long-term data.

Plant operator training for the DCS was conducted from March 13 to April 7 at Plant Hammond.

3.3. Phase 4A Testing

Twenty-nine diagnostic tests were conducted from March 27 through March 31. To date, 80 diagnostic tests and 5 performance tests have been conducted during Phase 4A.

3.3.1. Diagnostic Testing

The emphasis of diagnostic testing is to determine the combustion characteristics of the unit. A summary of the March 1995 diagnostic tests is presented in Table 4. Testing was conducted at loads between 450 MW and 480 MW only during this quarter.

As shown in Figure 4, excess O_2 levels were exercised well above and below the design excess O_2 levels yielding variations in NO_x emissions (Figure 5) from approximately 0.38 to 0.52 lb/MBtu. As shown in Figure 6, NO_x emissions for the Phase 4A diagnostic tests were similar to the long-term emission levels observed during Phase 3B, with the Phase 4A emissions generally within the 90 percentile range of the emissions observed during Phase 3B.

Based on the O_2 variations, the NO_x vs. O_2 gradient was determined for the 450 MW level tested (Figure 7). As can be seen, NO_x emissions were highly dependent on excess O_2 and, when corrected for changes in AOFA flow rates, to a great extent, a linear function of excess O_2 over the range tested ($R^2 \cong 0.85$). The slope of the NO_x vs. O_2 curve (approximately 0.065 lb/MBtu per percent O_2) is similiar to what has been reported from prior phases and earlier in Phase 4.

NO_x emissions as a function of AOFA flow rate is shown in Figure 8. As shown, NO_x emissions is a decreasing function of AOFA flow rate. However, when corrected for variations in excess O_2, NO_x emissions appear to be uncorrelated with AOFA flow rate. This is contrary to prior experience and an explanation for this is not yet known, however, it is likely due to the relative magnitude of the slope of NO_x as a function of O_2 and AOFA.

As experienced during prior phases, CO emissions were relatively low -- generally below 50 ppm -- at recommended excess O_2 levels (Figure 9). At 450 MW, as excess O_2 levels were reduced, CO emission levels increased. As shown, the curve corrected to 800,000 lb/hr AOFA flow is above that of the uncorrected values implying that AOFA flow has an adverse impact on CO emissions. This is supported by Figure 10 in which CO emissions are plotted as a function of AOFA flow rate. Assuming a one percent usable range of excess O_2 levels at any particular load condition, CO emissions are more sensitive to AOFA flow rate than excess O_2 levels (~200 ppm vs. ~100 ppm).

Table 4: Diagnostic Test / March 1995

Test	Date	Description	Load MW	Ex. O_2 Percent	OFA Flow lb/hr	NO_x lb/MBtu	CO ppm
145-1	27-Mar-95	Full Load / Nominal	480	3.48	7.49E+05	0.43	19
145-2	27-Mar-95	Full Load / Low OFA	480	3.52	6.56E+05	0.46	14
145-3	27-Mar-95	Full Load Nominal	480	3.68	8.42E+05	0.43	27
145-4	27-Mar-95	Full Load / High OFA	480	3.62	8.27E+05	0.42	24
145-5	27-Mar-95	Full Load / Low OFA	480	3.70	7.84E+05	0.45	14
145-6	27-Mar-95	Full Load / High OFA	480	3.46	8.61E+05	0.43	22
146-1	28-Mar-95	Mid Load / Mill Bias +	455	3.61	7.42E+05	0.41	100
146-2	28-Mar-95	Mid Load / Low OFA / Mill Bias +	455	3.72	6.80E+05	0.45	23
146-3	28-Mar-95	Mid Load / Mill Bias +	455	3.68	8.38E+05	0.41	68
146-4	28-Mar-95	Mid Load / Low OFA / Mill Bias +	455	3.69	7.44E+05	0.42	51
146-5	28-Mar-95	Mid Load / Mill Bias +	455	3.63	8.18E+05	0.41	106
146-6	28-Mar-95	Mid Load / Mill Bias +	455	3.38	6.97E+05	0.40	135
147-1	29-Mar-95	Mid Load / Low OFA	451	3.59	4.83E+05	0.45	16
147-2	29-Mar-95	Mid Load / Mid OFA	451	3.60	6.02E+05	0.44	12
147-3	29-Mar-95	Mid Load / Mid OFA / High O2	451	4.28	6.01E+05	0.49	1
147-4	29-Mar-95	Mid Load / High OFA / Low O2	451	3.26	7.99E+05	0.38	176
147-5	29-Mar-95	Mid Load / High OFA / Mid O2	451	3.60	8.30E+05	0.41	29
148-1	30-Mar-95	Mid Load / Mid OFA / Low O2	450	3.62	6.02E+05	0.43	5
148-2	30-Mar-95	Mid Load / Mid OFA / High O2	450	2.60	5.62E+05	0.39	137
148-3	30-Mar-95	Mid Load / High OFA / High O2	450	4.33	8.24E+05	0.45	1
148-4	30-Mar-95	Mid Load / High OFA / Low O2	450	2.91	7.53E+05	0.38	177
148-5	30-Mar-95	Mid Load / Low OFA / High O2	450	4.02	4.07E+05	0.52	-5
148-6	30-Mar-95	Mid Load / Low OFA / Low O2	450	3.62	3.93E+05	0.48	-3
149-1	31-Mar-95	Mid Load / Mid OFA / Mid O2	452	3.60	6.23E+05	0.41	49
149-2	31-Mar-95	Mid Load / High OFA / Mid O2	451	3.69	8.17E+05	0.42	138
149-3	31-Mar-95	Mid Load / High OFA / Low O2	452	3.30	8.03E+05	0.40	233
149-4	31-Mar-95	Mid Load / Low OFA / Mid O2	452	3.53	4.03E+05	0.47	2
149-5	31-Mar-95	Mid Load / Mid OFA / High O2	452	4.09	6.23E+05	0.46	7
149-6	31-Mar-95	Mid Load / Mid OFA / Low O2	452	3.38	5.89E+05	0.42	123

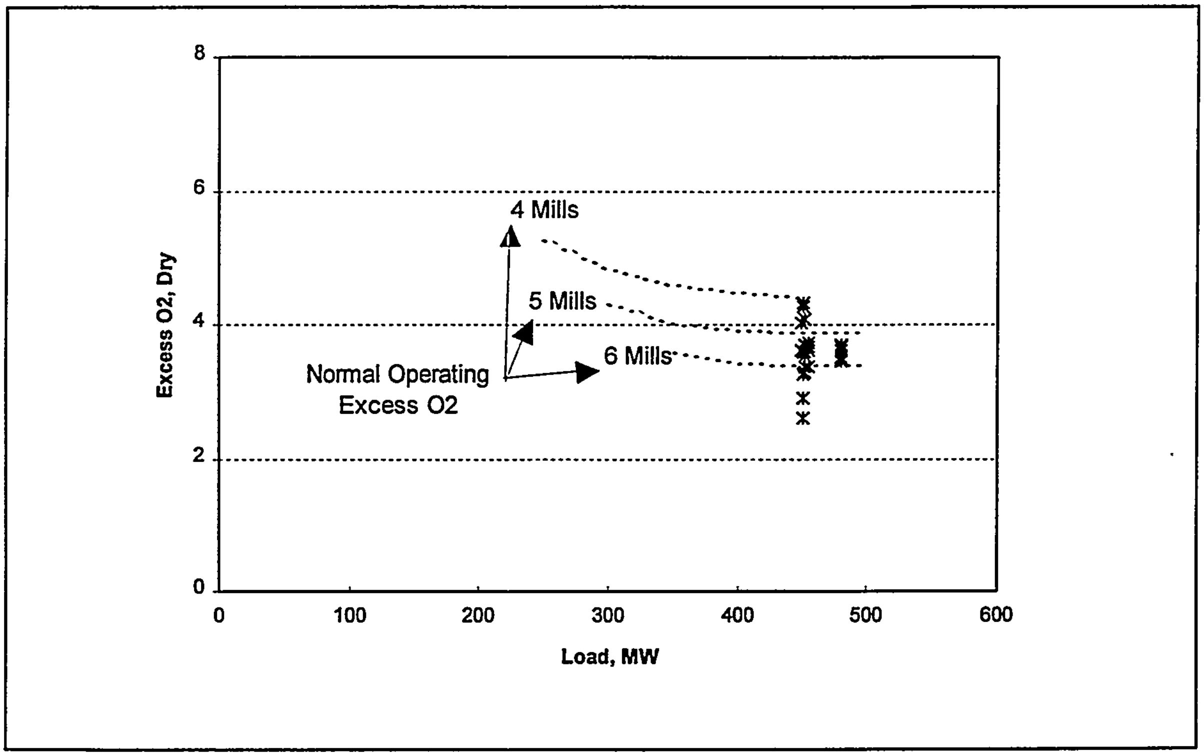

Figure 4: Excess O_2 Levels Tested

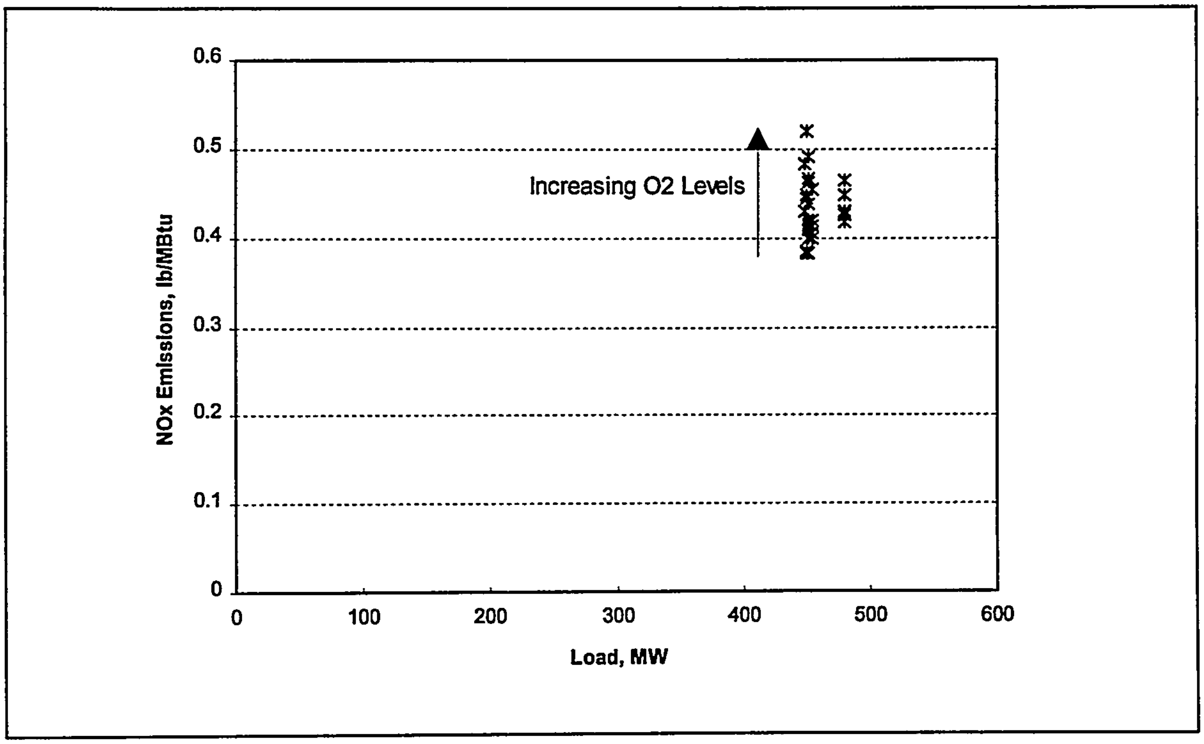

Figure 5: NOx vs. Load

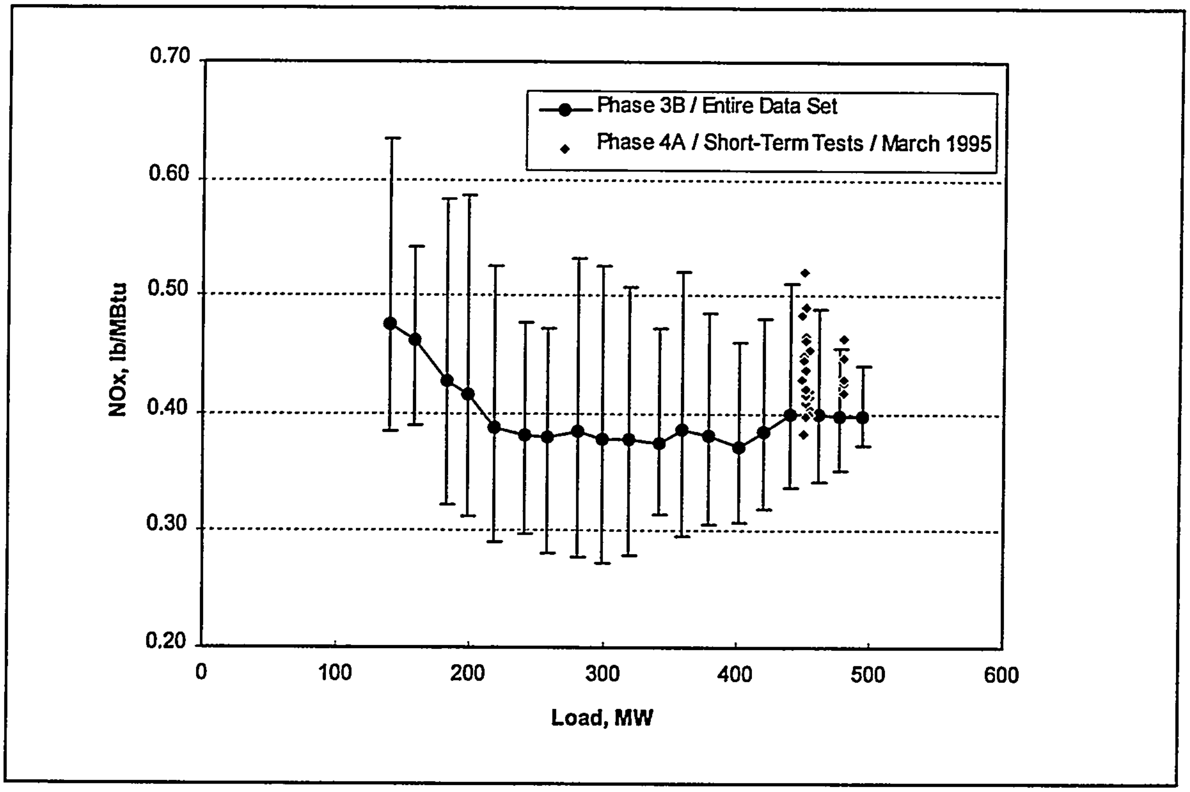

Figure 6: Comparison of 1Q 95 Test Data to Phase 3B Long-Term Data

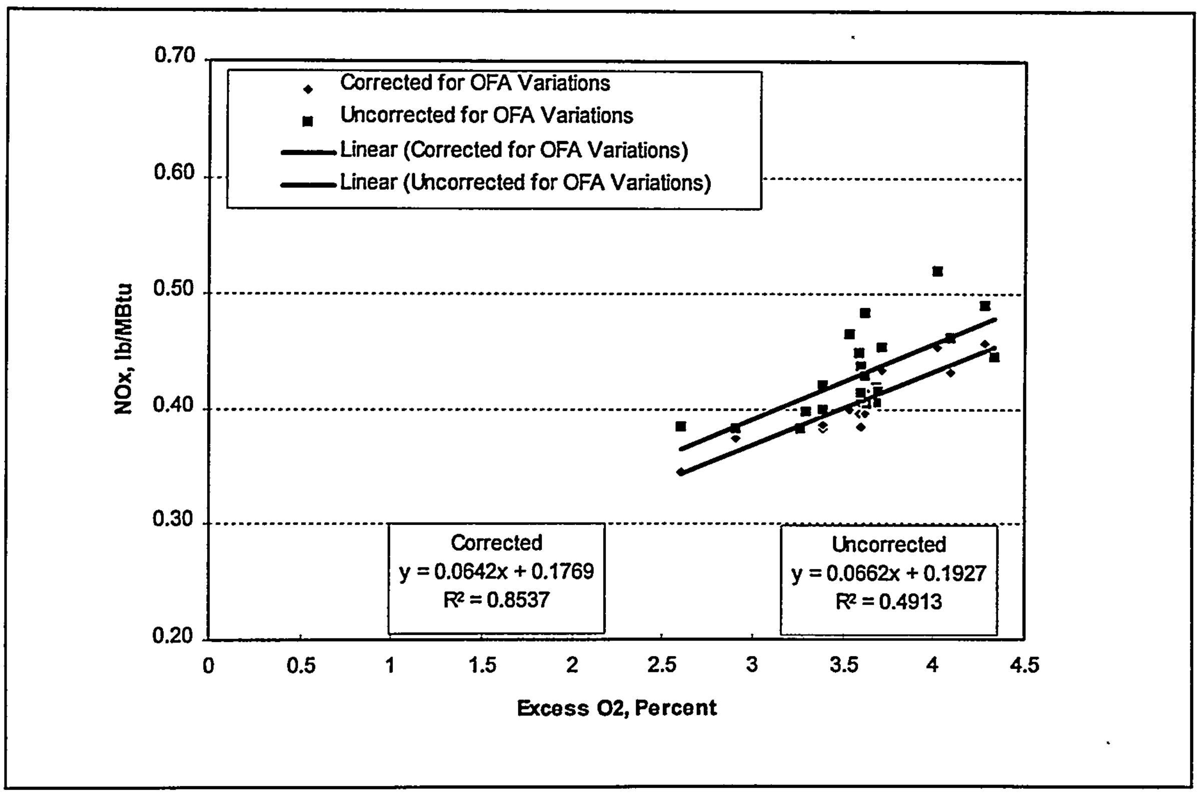

Figure 7: NO_x vs Excess O_2 at 450 MW

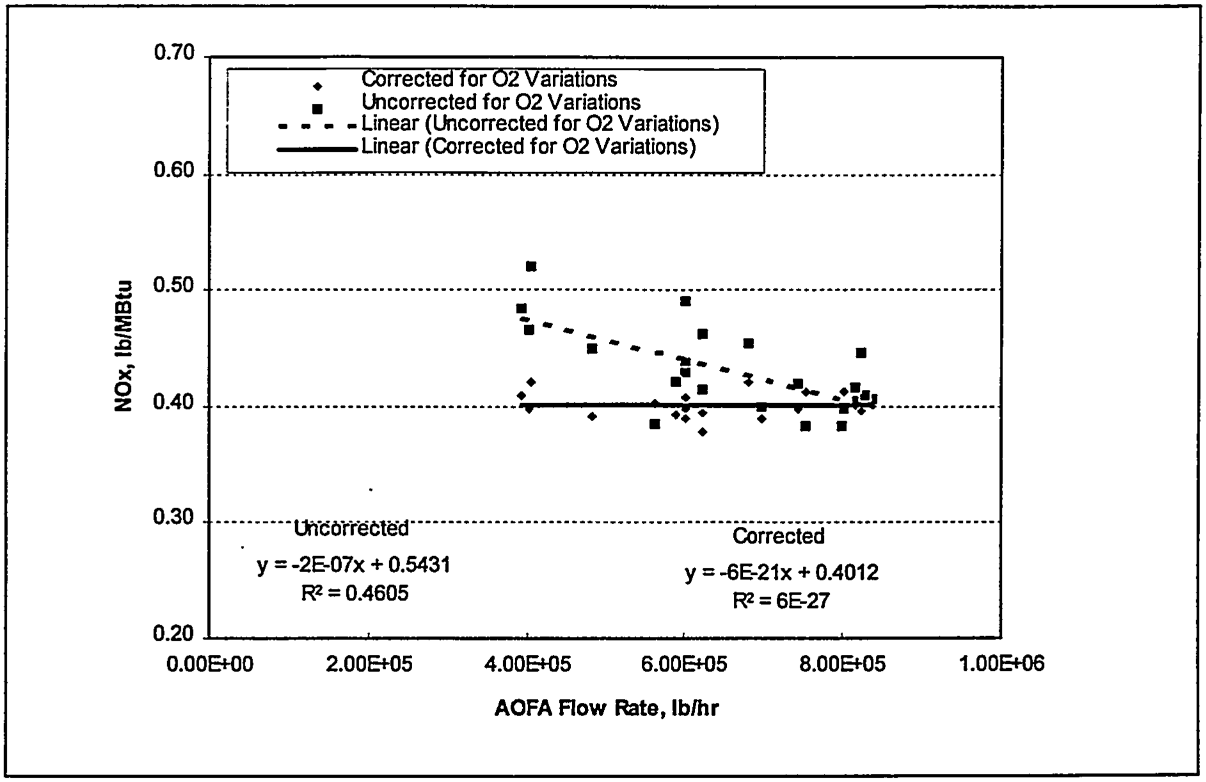

Figure 8: NO_x vs AOFA Flow Rate at 450 MW

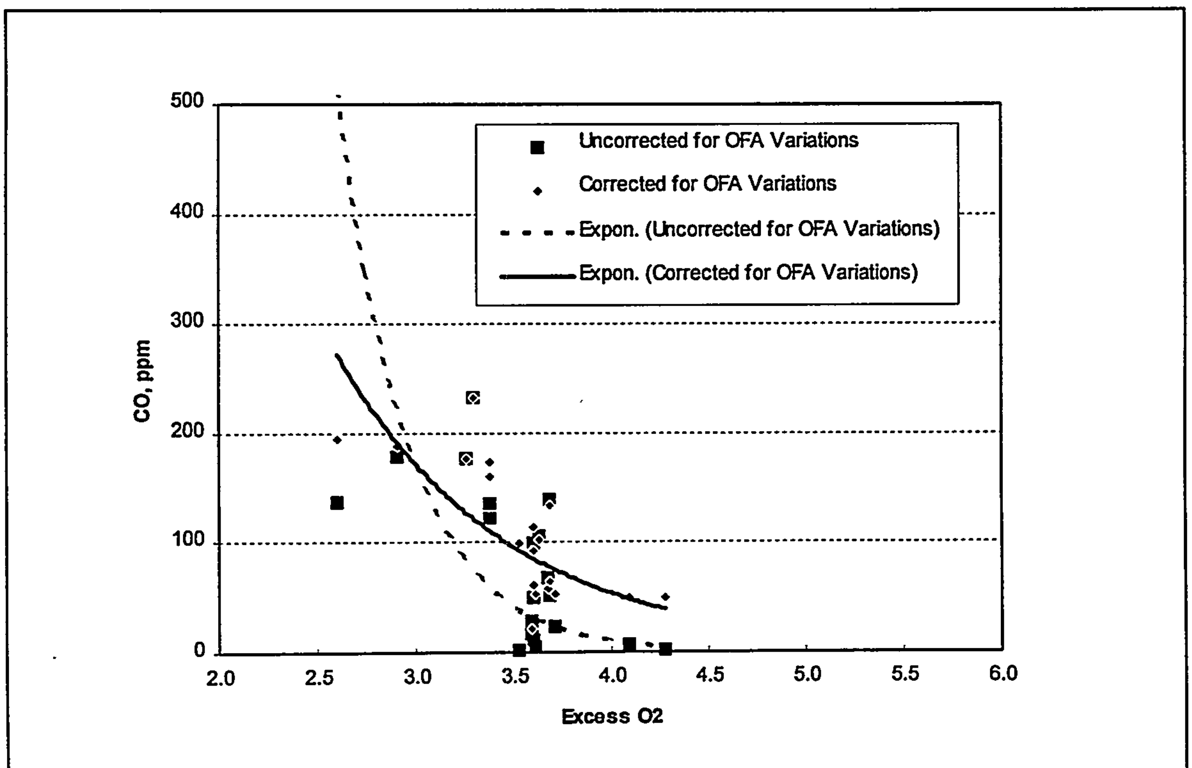

Figure 9: CO vs Excess O_2 at 450 MW

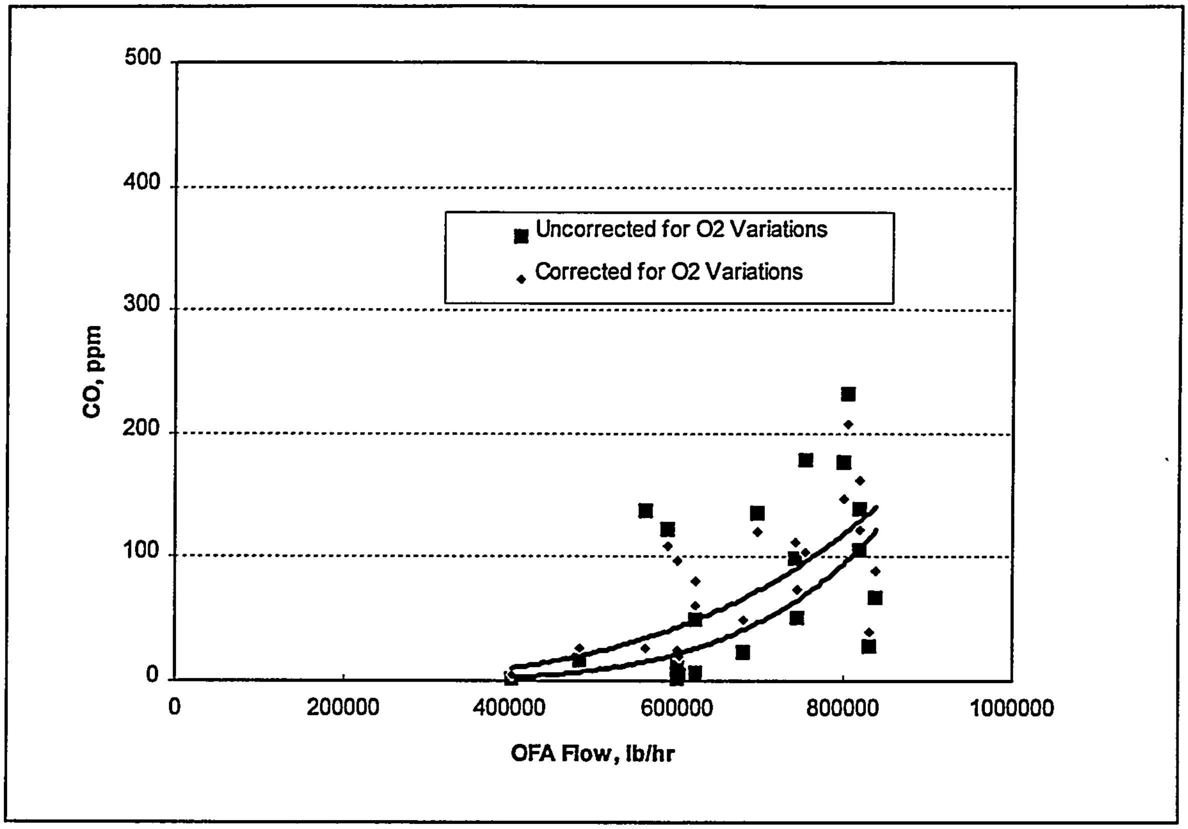

Figure 10: CO vs AOFA Flow Rate at 450 MW

3.3.2. Long-Term Generation and Emissions

Long-term data collection continued during this quarter. Unit generation and emissions for the quarter are provided in Appendix A. As shown in Figure 11, stack O_2 levels for the quarter were similar to that experienced during Phase 3B of the project. This is expected as a result of the similar excess O_2 curves used in the two phases. Corresponding NO_x emissions is shown in Figure 12. As shown, NO_x emissions for the quarter were on average higher than the Phase 3B levels particularly at intermediate loads (around 300 MW). The cause of the difference is unknown at this time, however, one possibility is that due to reduced in-leakage in the furnace backpass, O_2 levels in the furnace were higher than the previous levels. This hypothesis is strengthened since CO emissions during this quarter were generally lower than that observed during Phase 3B (Figure 13).

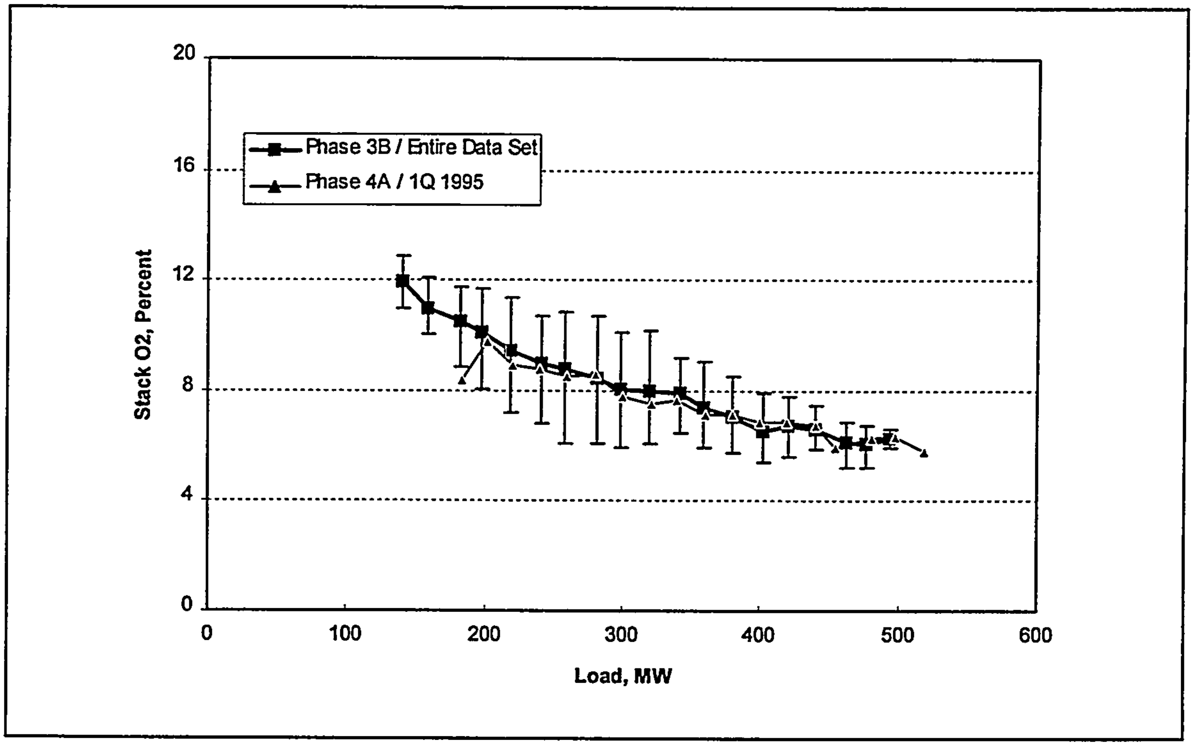

Figure 11: 1st Quarter 1995 Stack O_2 Levels

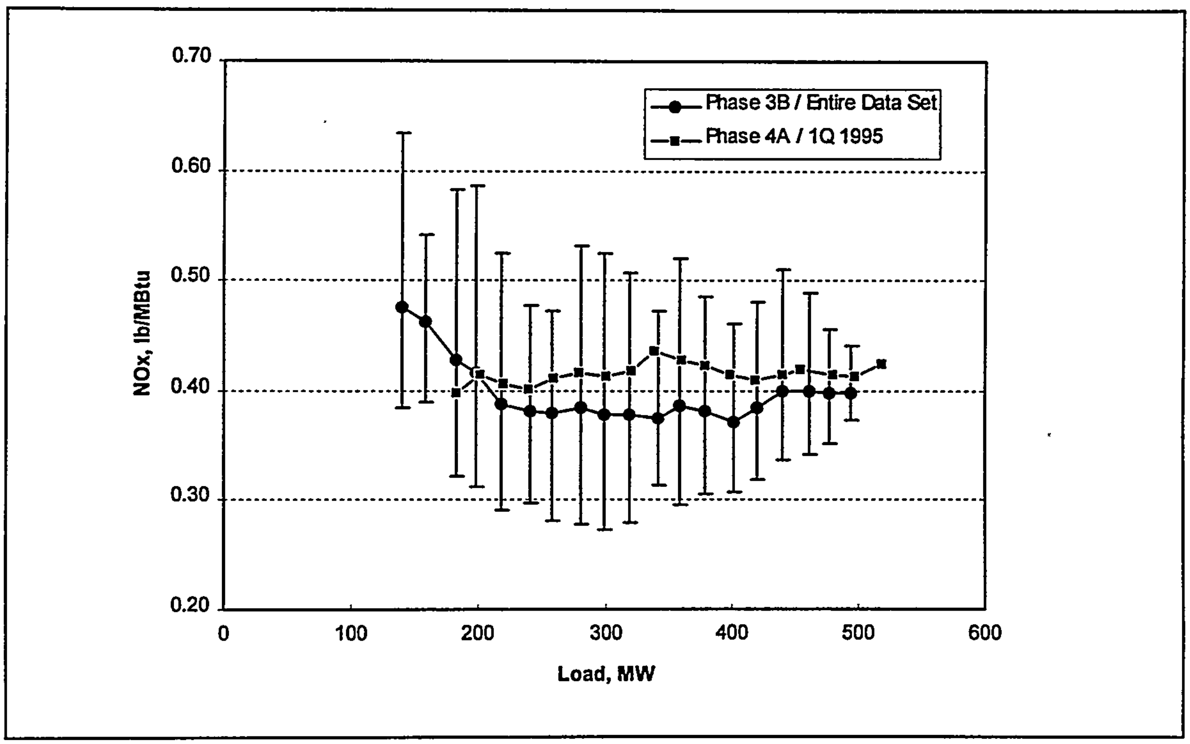

Figure 12: 1st Quarter 1995 NO_x Emission Levels

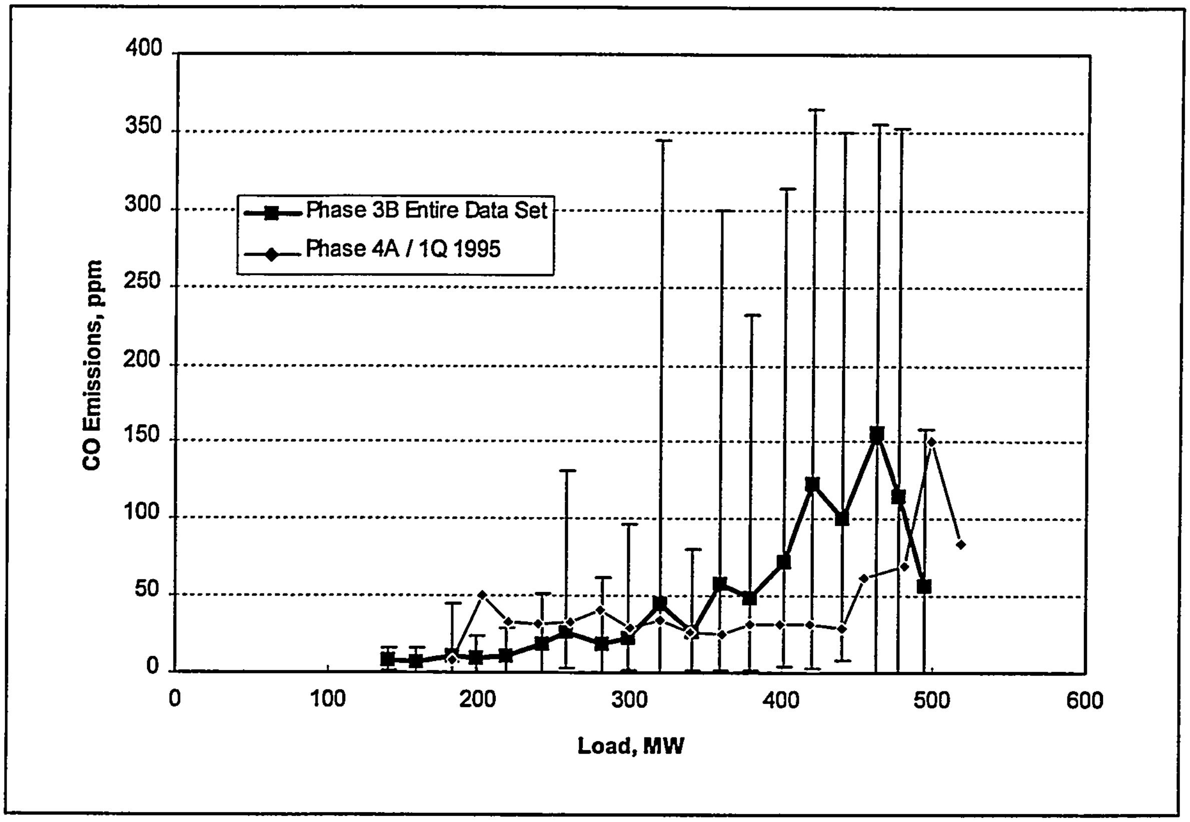

Figure 13: 1st Quarter 1995 CO Emission Levels

3.3.3. Digital Control System

An integral part of Phase 4 of the project was the design and installation of a digital control system to be the host of the advanced control/optimization strategies being developed. SCS Engineering and GPC had overall responsibility for the following major activities:

- Preliminary engineering,
- Procurement,
- Detail engineering,
- Digital control system configuration, and
- Installation and checkout.

This digital control system has been installed and is operational.

Operator training courses for the DCS were conducted from March 13 to April 7 at Plant Hammond. Approximately 35 operations personnel attended the class in groups of around ten. Each class was five days in duration. SCS Engineering conducted the class. The Replacement Control System Operators' Manual was used as the foundation of the training. Excerpts from the Operator's Manual is provided in Appendix B.

3.3.4. Advanced Controls and Optimization

The software and methodology to be demonstrated at Hammond Unit 4 is the Generic NO_x Control Intelligent System (GNOCIS) whose development is being funded by a consortium consisting of the Electric Power Research Institute, PowerGen (a U.K. power producer), The Southern Company, U.K. Department of Trade and Industry, and U.S. Department of Energy [6]. The objective of the GNOCIS project is to develop an on-line enhancement to existing digital control systems that will result in reduced NOx emissions, while meeting other operational constraints on the unit (principally heat rate and other regulated emissions). The core of the system is a model of the combustion characteristics of the boiler, that will reflect both short-term and longer-term shifts in boiler emission characteristics. The software applies an optimizing procedure to identify the best set points for the plant. The recommended set points can be used for closed-loop control of the process or, at the plants discretion, the set points can be conveyed to the plant operators via the DCS. The software incorporates sensor validation techniques and is able to operate during plant transients (i.e. load ramping, fuel disturbances, and others.

GNOCIS is currently under development and has been or is scheduled to be implemented at PowerGen's Kingsnorth Unit 1 (a 500 MW tangentially-fired unit with an ICL Level 3 Low NO_x Concentric Firing System) and Alabama Power's Gaston Unit 4 (a 250 MW B&W unit with B&W XCL low NO_x burners) prior to comprehensive testing at Hammond. Following "re-characterization" of Hammond 4, the advanced controls and optimization strategies will be activated and run open-loop. If the results from the open-loop testing warrant, the advanced controls/optimization package will be operated closed-loop with testing (short- and long-term). A brief review of the major developments during the current quarter as regards the GNOCIS project are provided below.

<u>*Process Insights*</u>

Testing of a Beta release of Pavilion's Process Insights Version 3 is continuing. Due to limitations in the current global constraint implementation, indirect methods were necessary to construct the control models planned. One limitation is that output variables, as specified during model development, can not be used in the global constraint formulations. Thus a constraint, objective, or cost function can not be created using a combination of output variables. Pavilion plans to provide this capability in the commercial release of the software (see below). Another limitation is that combinatorial constraints (necessary for optimizing mill patterns) will not be implemented in Version 3 as expected. Wrapper code has been written to overcome the latter short-coming in the run-time component of the software. The wrapper code has been tested and appears to work satisfactorily. The scheduled commercial release date for Process Insights Version 3 is May 31, 1995. Although the graphical user interface will not change markedly, the commercial release will have a number of significant additional capabilities, not included in the Beta release, that will be extremely useful in a GNOCIS application. The most significant new capabilities include: (1) ability to incorporate sub-models (both in the design- and run-time components) in a global Process Insight model, (2) a subset of tcl, a scripting language, will be added to allow simple imbedded programming, and (3) output, input, state, and external variables will be allowed in the constraint, objective, and cost expressions. All models created with the Beta release will run in the commercial release.

Gaston

At Gaston, modifications have been completed to the Gaston Unit 4 L&N DCS to allow communication between the DCS and GNOCIS host platform. A Process Insights (Version 3 Beta) runtime application is now operating using preliminary control and sensor validation models and the necessary routines have been developed to allow transfer of process and model output data to the WonderWare operator interface. Presently, the GNOCIS operator advisory graphics resides on the NT platform using WonderWare's InTouch graphics software and preliminary screens have been developed. These screens will be migrated to the L&N digital control system pending successful demonstration of GNOCIS and concurrence of the plant.

Collection of Gaston Unit 4 process data is continuing. Data from October 1994 through February 1995 has been obtained from the Leeds & Northrup (L&N) digital control system (DCS) and is being used for model training and GNOCIS performance assessment. Preliminary predictive and control models have been constructed using the October and November 1994 data set collected. These models include a simplified boiler efficiency estimator and a predictor for fly ash carbon based on prior diagnostic testing. The data used to train the models was collected during steady-state operation of the unit and transients were pared from the training set. Based on it's use to date, the control model seems adequate for the application, however, more recent data will be used to re-train the model to make it more reflective of current unit operation.

Preliminary testing of GNOCIS was conducted at Gaston Unit 4 on March 17, 1995. Although GNOCIS had been undergoing tests at SCS offices in Birmingham, this was the first test at the site. The goals of this test were to (1) verify that the mechanisms used to interface with the DCS were operating correctly, (2) identify problems with the run-time software, (3) provide guidance into the design of the operator interface, and (4) assess the robustness of the combustion models. Generally, there were no problems interfacing with the DCS. Problems identified with the run-time components include:

- Failure of the optimizer to converge to a minimum frequently. Pavilion has identified the problem and transmitted to Radian and SCS an updated object library. The modifications have not yet been tested by Radian or SCS.
- Difficulties in modifying constraints and/or objective functions during debugging at the site. To remedy this short-coming, Pavilion plans to provide to Radian and SCS a run-time debugging program (called runtime interface controller or ric) which will allow modification of model parameters at the host site.

WonderWare was used as the operator interface during this testing. As currently implemented, the software provides for only the display of recommendations based upon current operating conditions. However, immediate plans are to enhance the interface to allow the operator to change constraints and setpoints and to enable the operator to use GNOCIS in a what-if mode. The use of WonderWare has facilitated the rapid development of the graphics. As currently envisioned, the operator will be presented with the current operating conditions, a recommendation using the current mills-in-service configuration, and a recommendation based on the optimum mills-in-service configuration.

The combustion model used during this test was based on training data collected during October and November 1994. A formal analysis of the test data collected during this test has not yet been conducted, however, despite the data being collected three to four months previously, predictions for NO_x seemed reasonable. Although preliminary and confirmation through plant testing is required, predicted optimized NO_x levels were near 0.3 lb/MBtu. For these tests, the optimization was limited to the use of mill biasing and excess O_2 was held at normal operating levels.

Kingsnorth

Testing of GNOCIS was conducted during March 1995 at Kingsnorth. Example results are shown in Figures 14 and 15, the bold line corresponding to data obtained while following the advice and the normal line for data obtained when, for various reasons, the advice was ignored. As shown, the effect of following the GNOCIS advice is to reduce both CIA and NO_x; these are normally regarded as opposing variables. The weighted means for the 10-hour period are 415 ppm to 398 ppm NO_x and 9.4% to 7.0% CIA. It is important to emphasize that the objective of the Kingsnorth exercise was to minimize CIA, not NO_x, so the NO_x reduction observed is secondary to the CIA results. This indicates that a further reduction in NO_x is possible if this is the prime objective. When the NO_x constraint is active but not exceeded, the same type of advice will be given. Thus, one set of earlier results have shown a reduction from 7% to 4% CIA using the advice from GNOCIS, for an overall decrease of over 40%, while at the same time NO_x was lowered from 320 ppm to 290 ppm. These latter results were achieved by lowering the burner tilts.

An additional test assessing the five mill settings demonstrated the power of GNOCIS as an optimizer. The E mill feeds the lowest burners in the bank; hence, fuel supplied by this mill has the longest residence time in the furnace. Preferential use of this mill should produce minimum CIA. GNOCIS suggested that this was not the case and that the opposite was true, implying that there are some burners with an incorrect air/fuel ratio being fed by this mill, or that a greater percentage of larger particles (e.g., >50 mesh) are coming from this mill. This unforeseen effect of E mill on CIA was verified by plant testing.

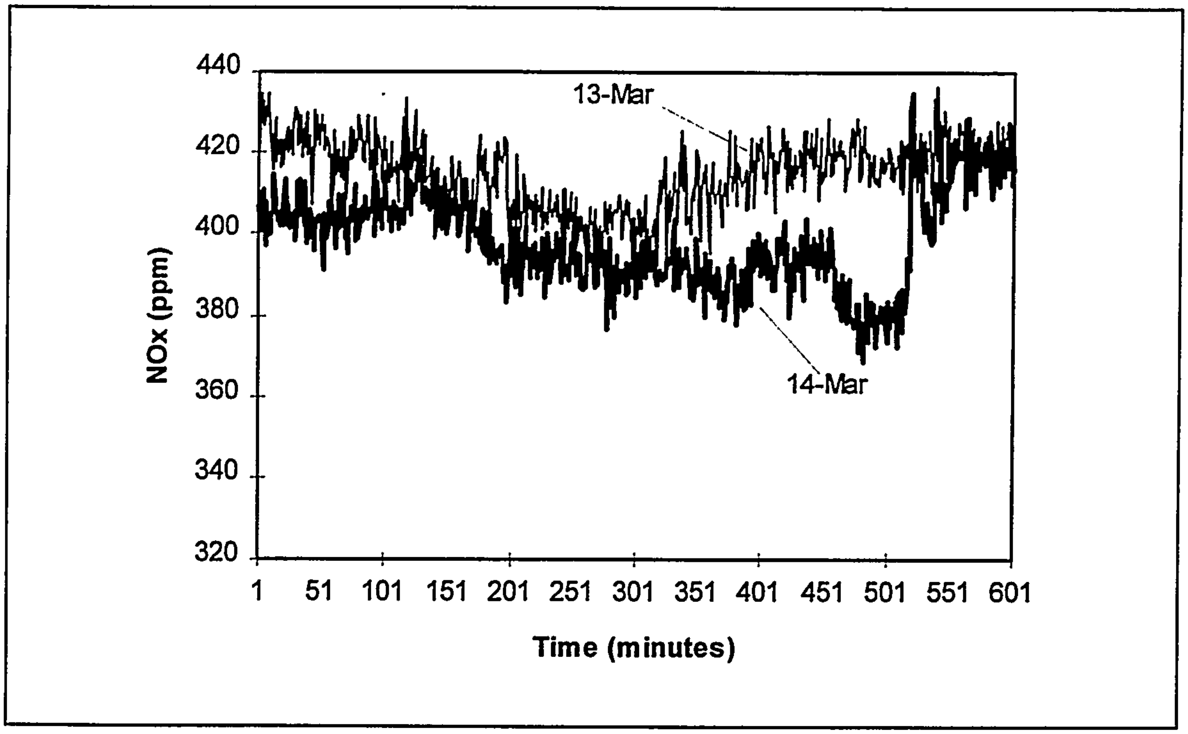

Figure 14: Kingsnorth / NO_x During 10 Hour Period on Consecutive Days

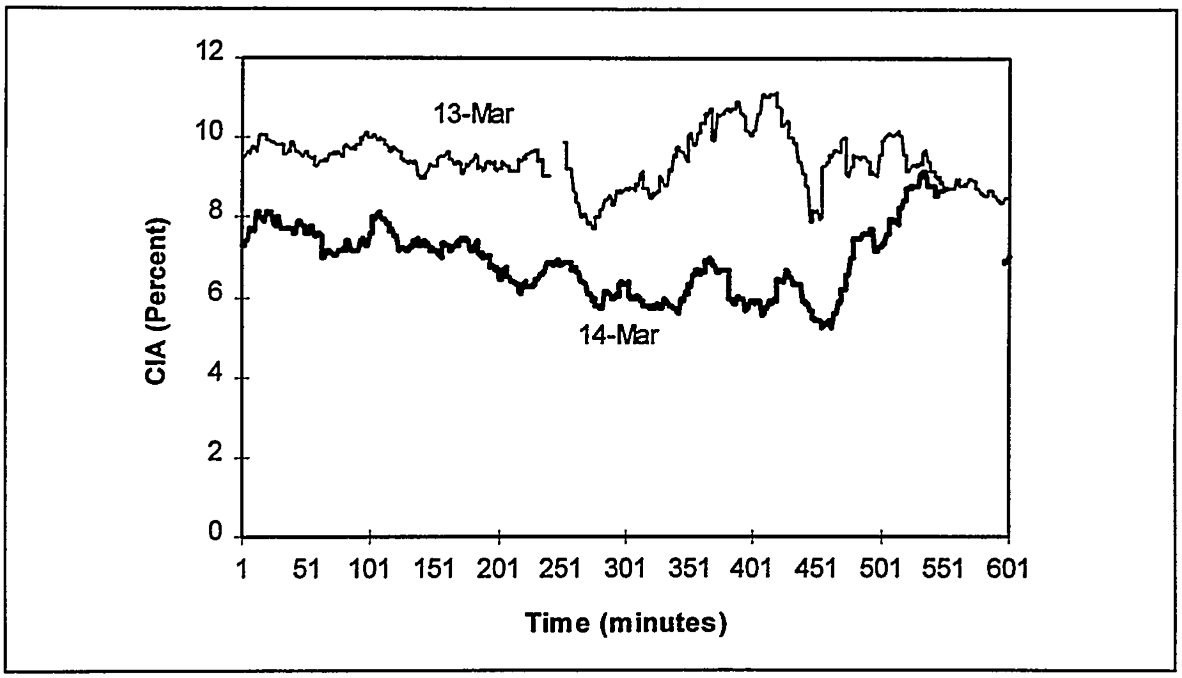

Figure 15: Kingsnorth / CIA During 10 Hour Periods on Consecutive Days

4. FUTURE PLANS

The following table is a quarterly outline of the activities scheduled for the remainder of the project:

Table 5: Future Plans

Quarter	Activity
Second Quarter 1995	o Advanced Controls Testing
Third Quarter 1995	o Advanced Controls Testing o Final Reporting & Disposition
Fourth Quarter 1995	o Final Reporting & Disposition

5. ACKNOWLEDGMENTS

The following project participants are recognized for their dedicated efforts toward the success of this project: Mr. Ernie Padgett and Mr. W.C. Dunaway, Georgia Power Company, and Mr. Mike Nelson and Mr. Robert Kelly, Southern Company Services, for their coordination of the design and retrofit efforts and Mr. Jose Perez, full-time Instrumentation Specialist from Spectrum Systems, Inc. Also Mr. Jim Witt and Mr. Jimmy Horton of Southern Company Services for design, procurement, and installation of the instrumentation systems. The following companies have provided outstanding testing and data analysis efforts: Energy Technology Consultants, Inc., Flame Refractories, Inc., Innovative Combustion Technologies, Southern Research Institute, W. S. Pitts Consulting, and Radian Corporation. Finally, the support from Mr. Scott Smouse, DOE ICCT Project Manager, Mr. Jeff Stallings, EPRI Project Manager, and Mr. Mark Perakis, EPRI Project Manager is greatly appreciated.

BIBLIOGRAPHY

1. *500 MW Demonstration Of Advanced Wall-Fired Combustion Techniques For The Reduction Of Nitrogen Oxide (NOx) Emissions From Coal-Fired Boilers - Phase 1 Baseline Tests Report.* Southern Company Services, Inc., Birmingham, AL: 1992.

2. *500 MW Demonstration Of Advanced Wall-Fired Combustion Techniques For The Reduction Of Nitrogen Oxide (NOx) Emissions From Coal-Fired Boilers - Phase 2 Advanced Overfire Air Tests Report.* Southern Company Services, Inc., Birmingham, AL: 1992.

3. *500 MW Demonstration Of Advanced Wall-Fired Combustion Techniques For The Reduction Of Nitrogen Oxide (NOx) Emissions From Coal-Fired Boilers - Phase 3A Low NOx Burner Tests Report (Draft).* Southern Company Services, Inc., Birmingham, AL: 1993.

4. *500 MW Demonstration Of Advanced Wall-Fired Combustion Techniques For The Reduction Of Nitrogen Oxide (NOx) Emissions From Coal-Fired Boilers - Phase 3B Low NOx Burner Tests & Advanced Overfire Air Report.* Southern Company Services, Inc., Birmingham, AL: 1995.

5. *500 MW Demonstration Of Advanced Wall-Fired Combustion Techniques For The Reduction Of Nitrogen Oxide (NOx) Emissions From Coal-Fired Boilers - Field Chemical Emissions Monitoring: Overfire Air and Overfire Air/Low NOx Burner Operation Final Report.* Southern Company Services, Inc., Birmingham, AL: 1993.

6. Holmes, R., Squires, R., Sorge, J., Chakraborty, R., McIlvried, T., "Progress Report on the Development of a Generic NOx Control Intelligent System (GNOCIS)," EPRI 1994 Workshop on NOx Controls for Utility Boilers, May 11-13, 1994, Scottsdale, Arizona.

Appendix A

Phase 4A Long-Term Emissions (January - March 1995)

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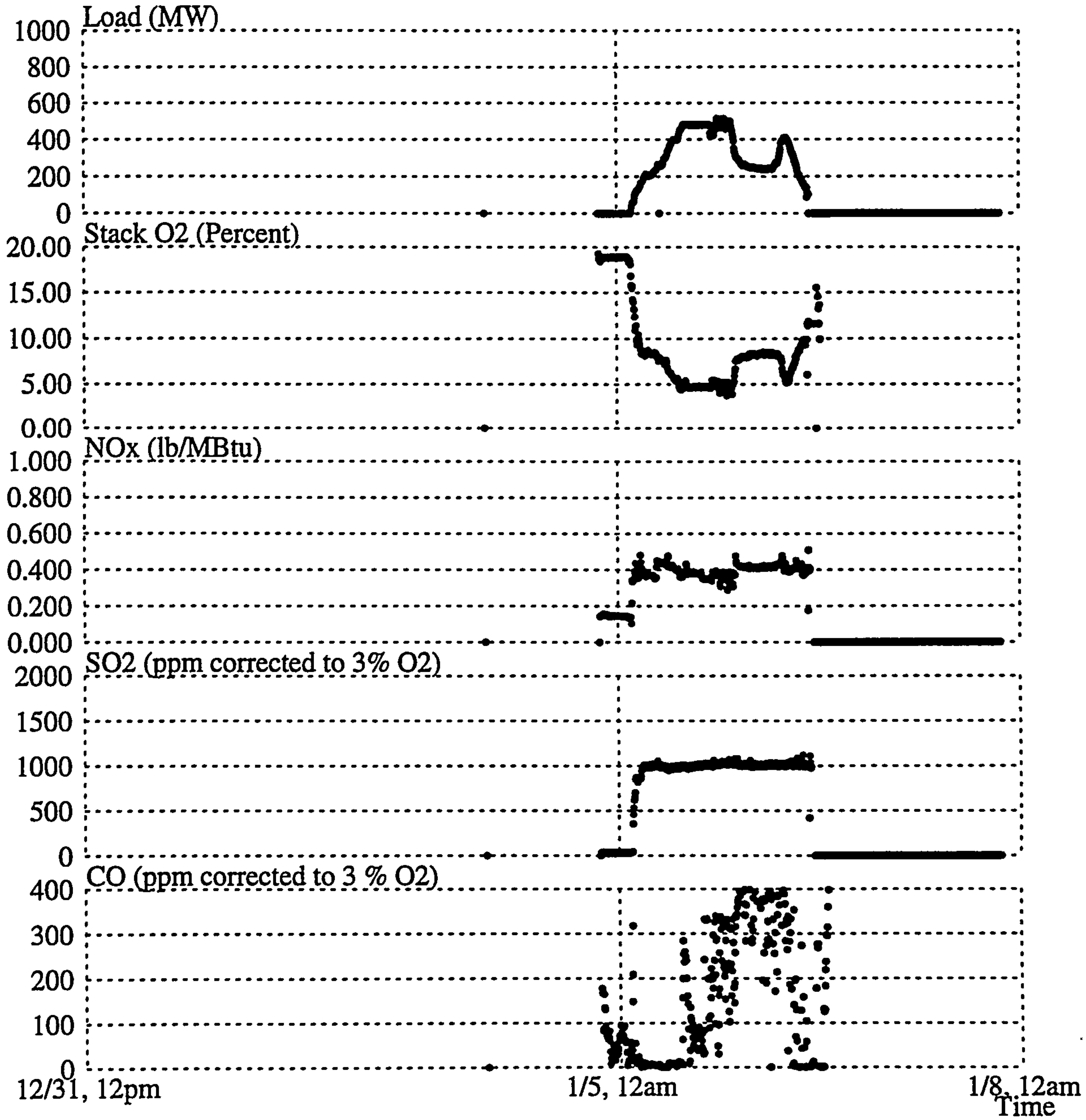

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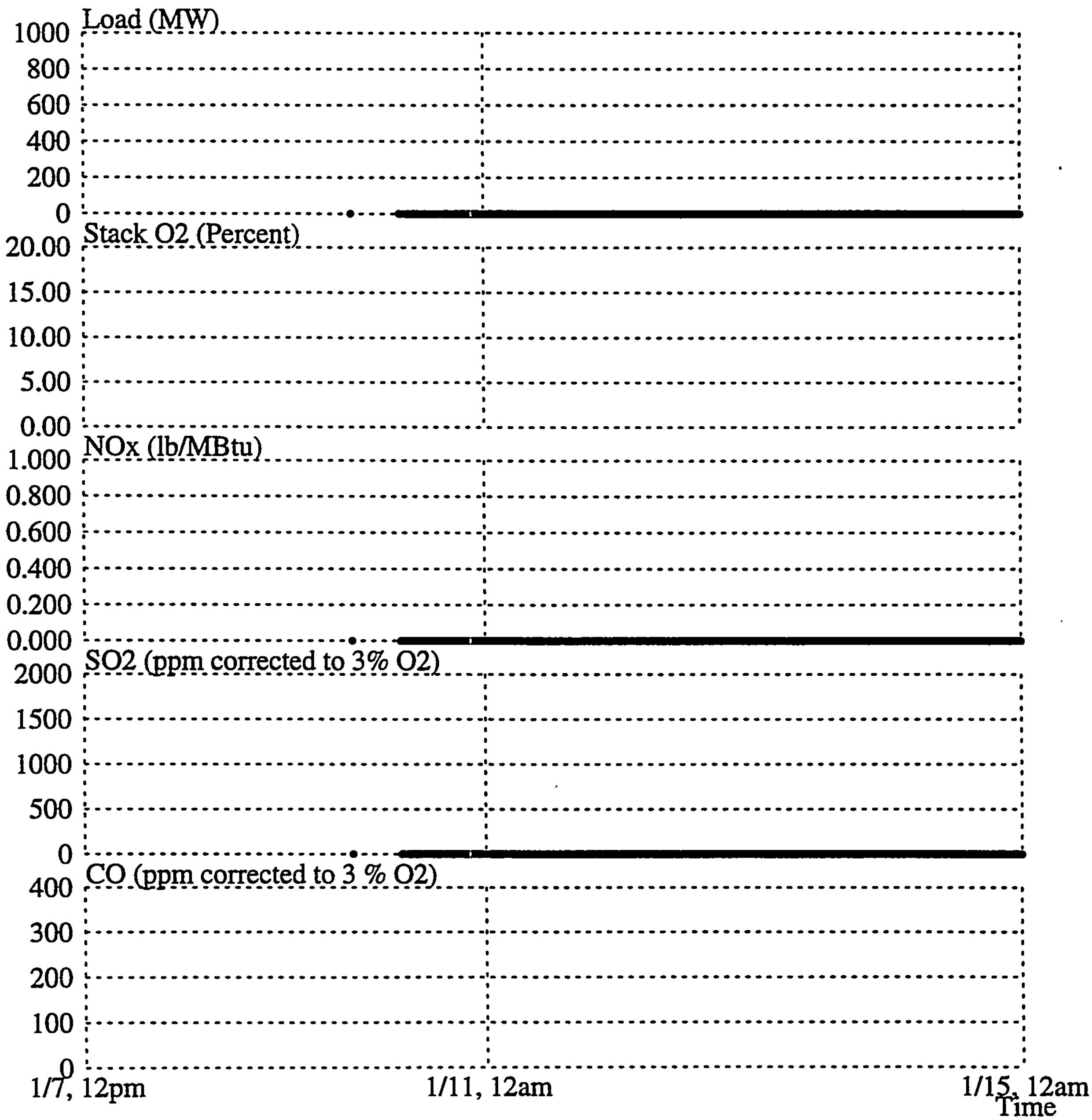

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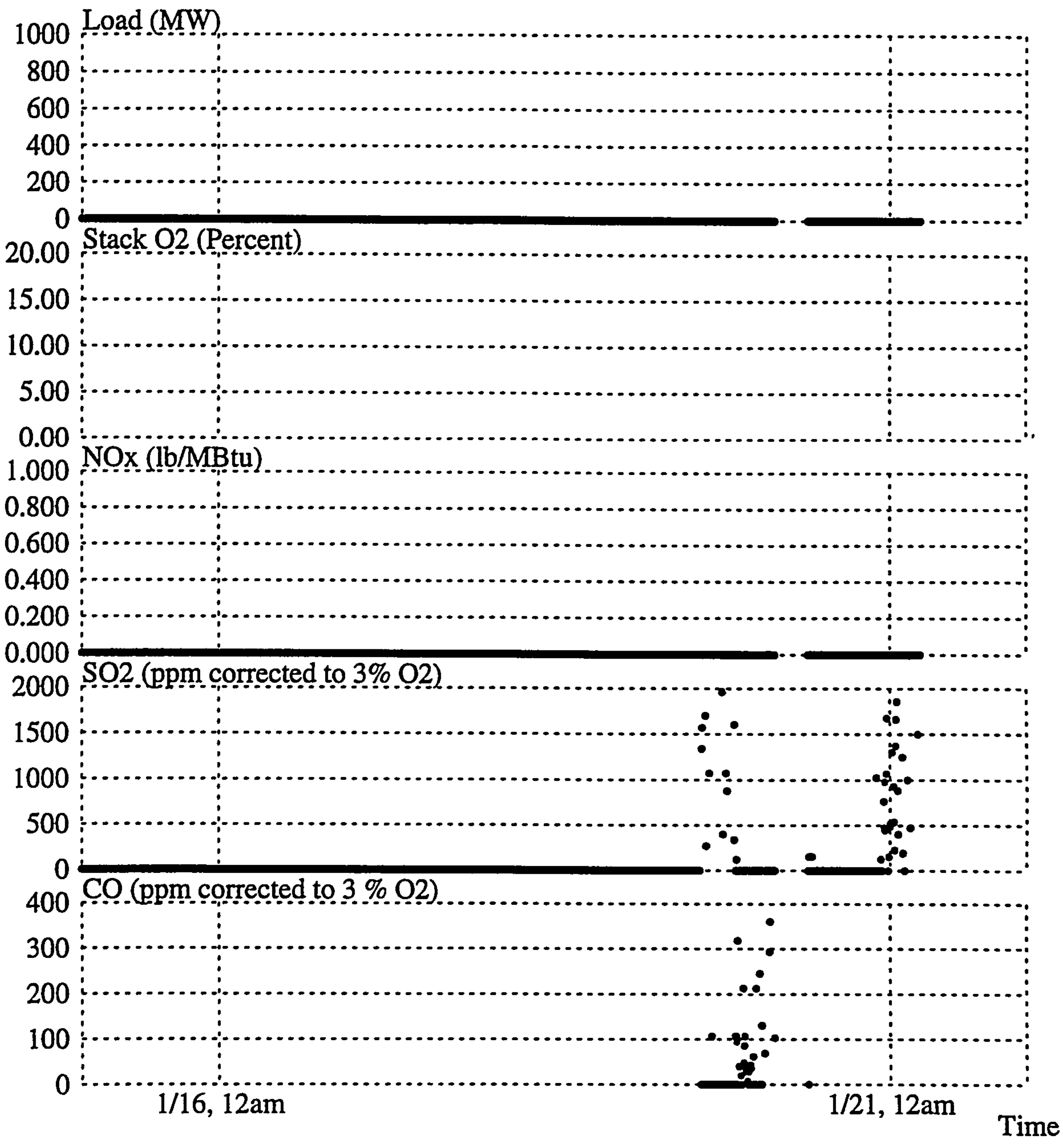

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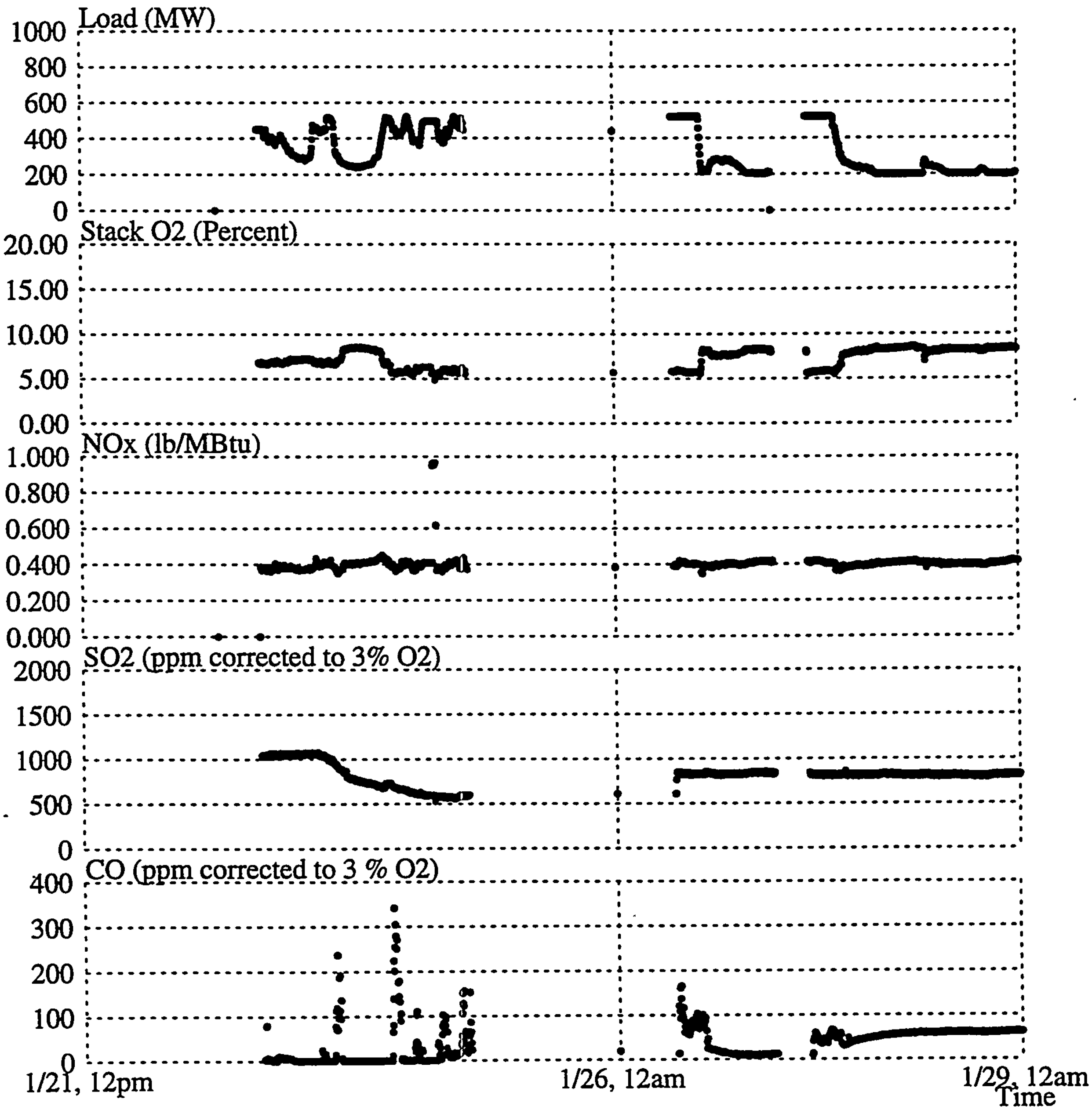

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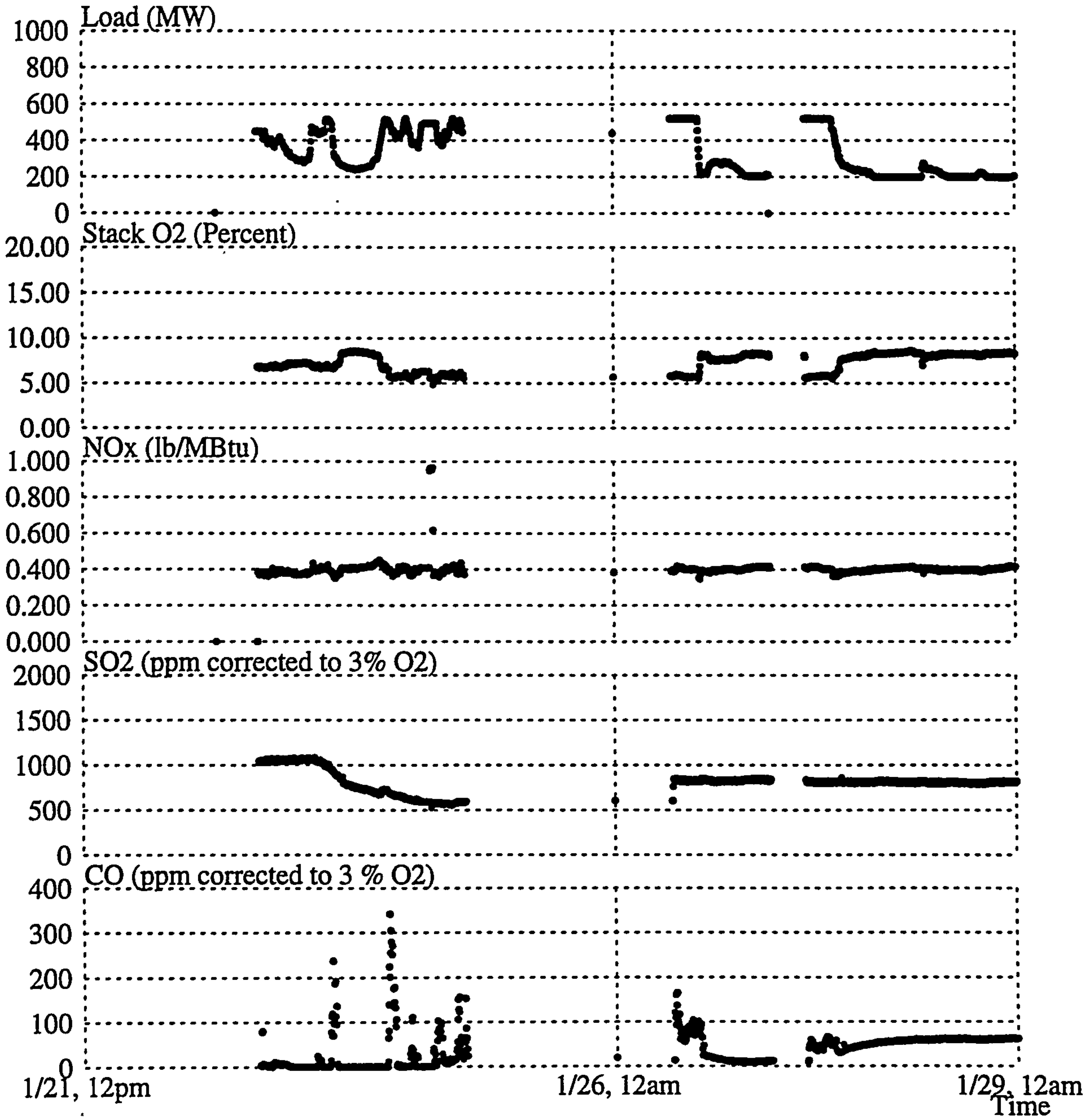

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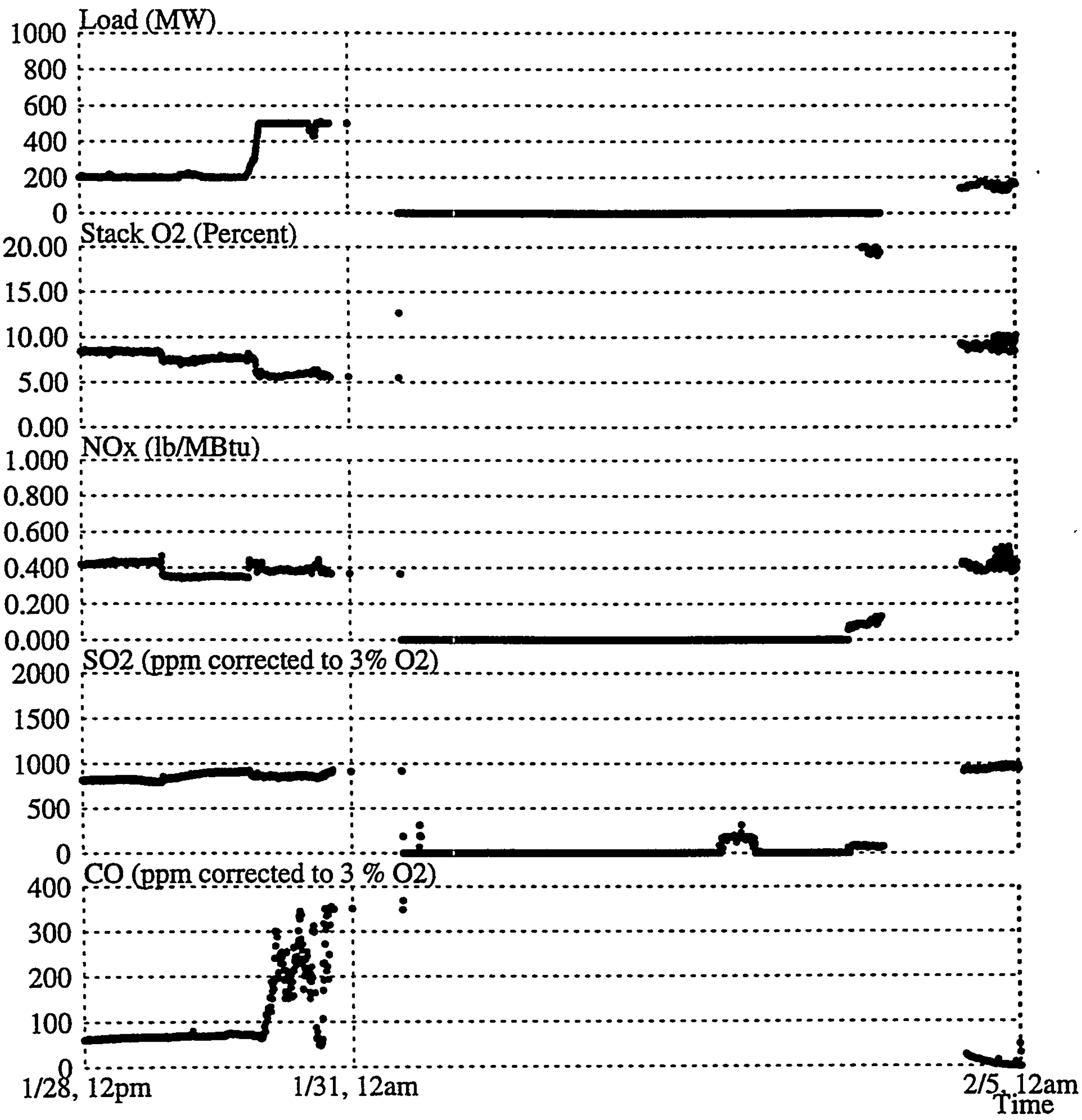

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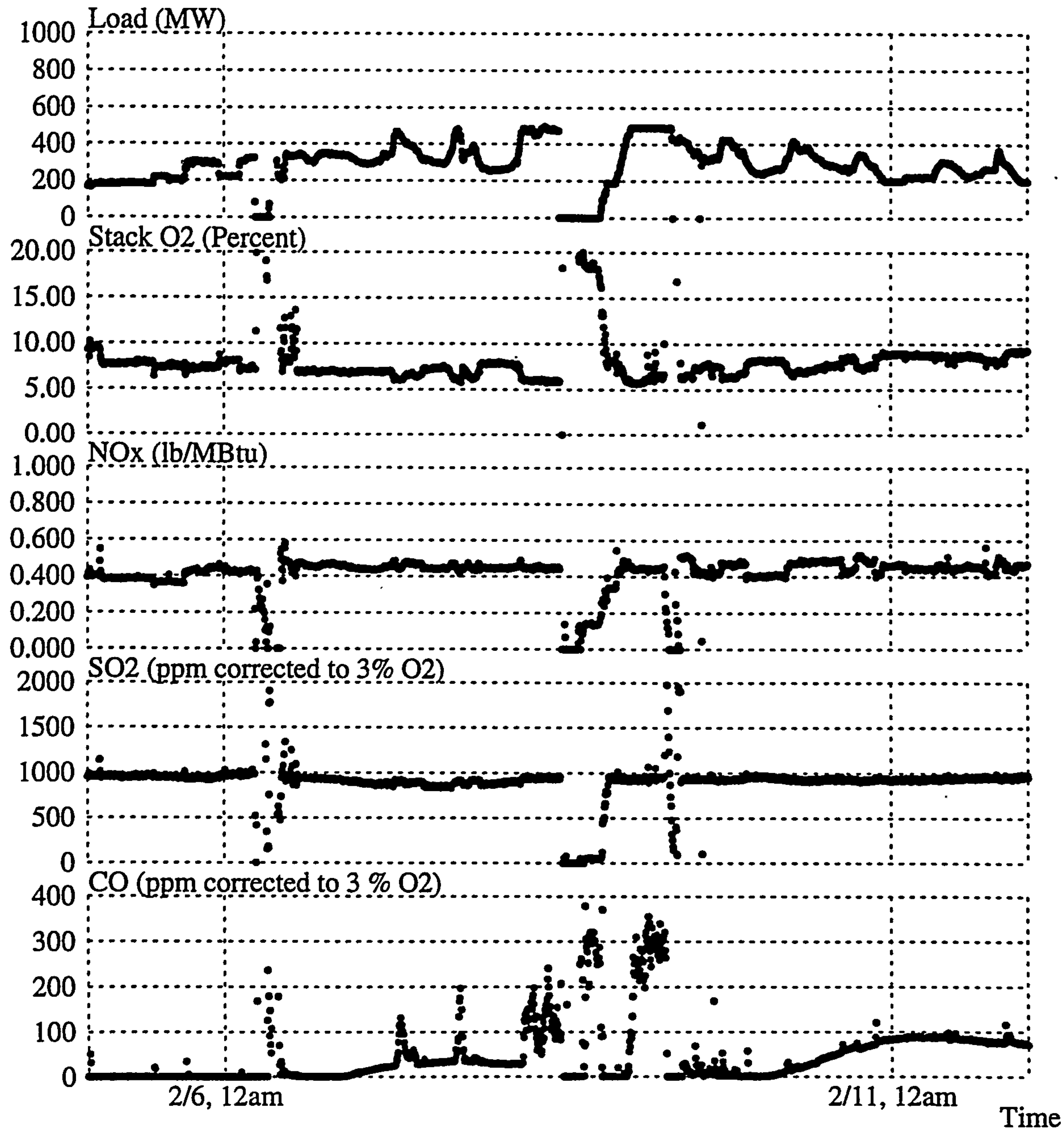

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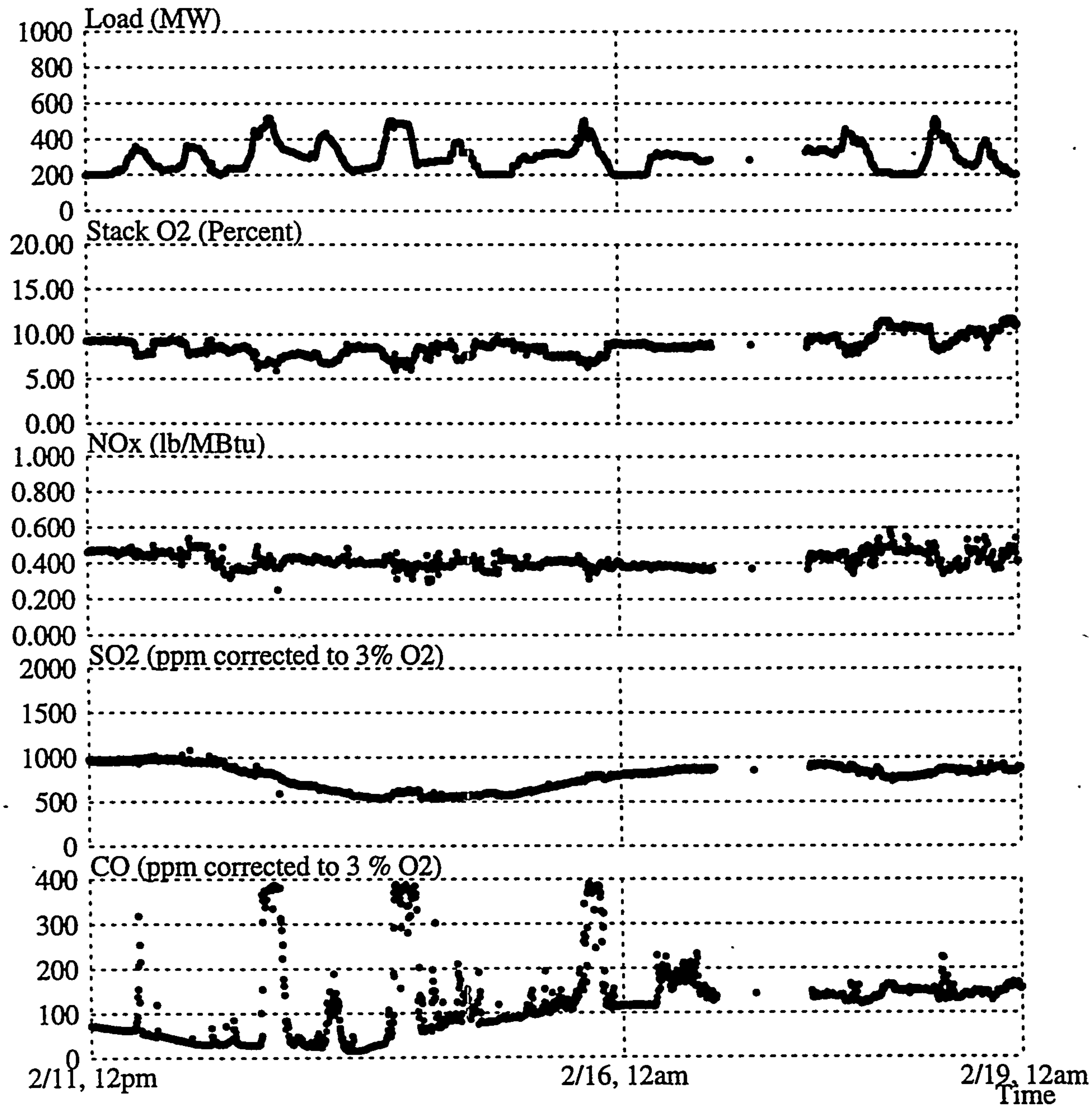

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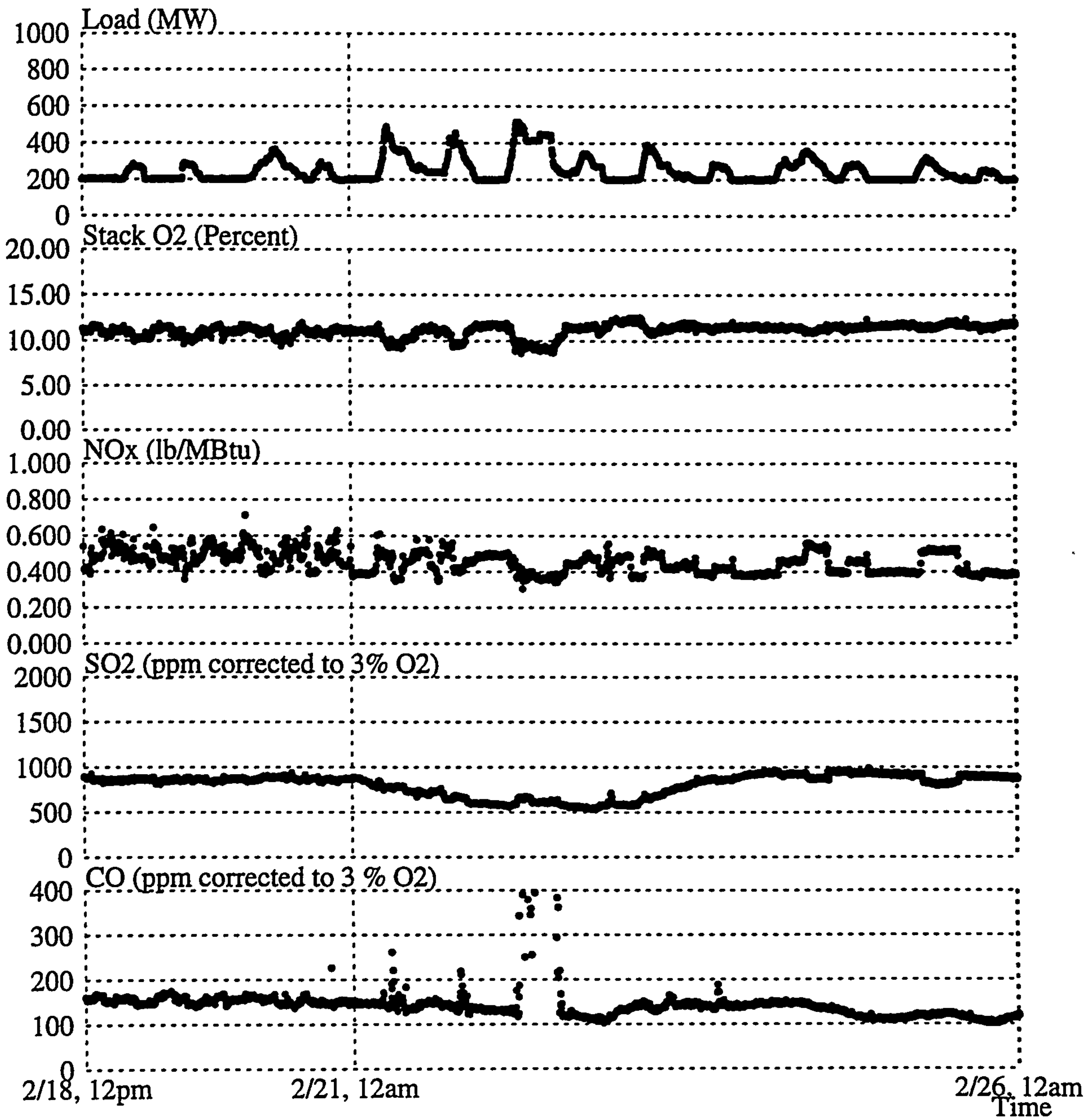

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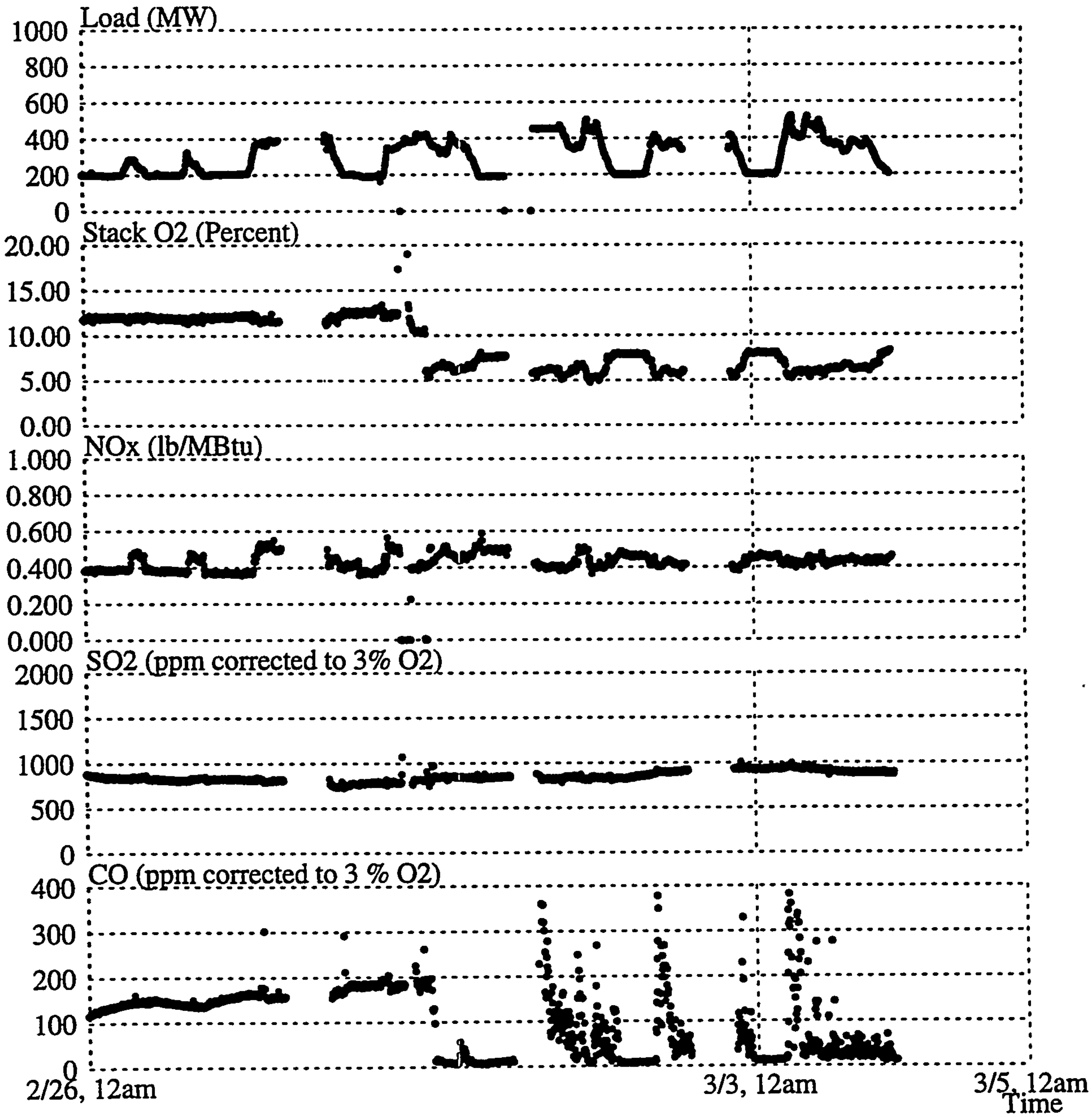

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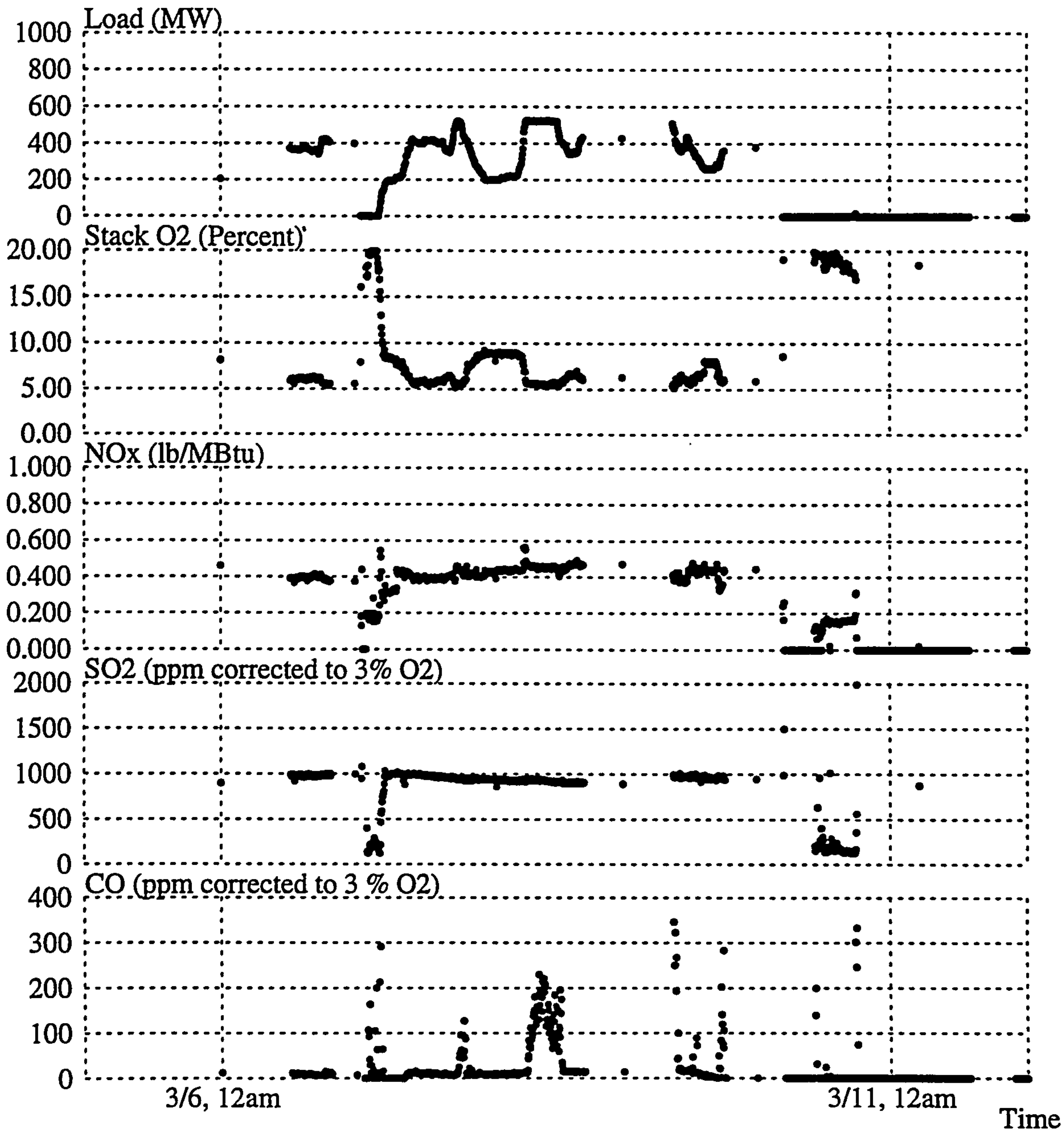

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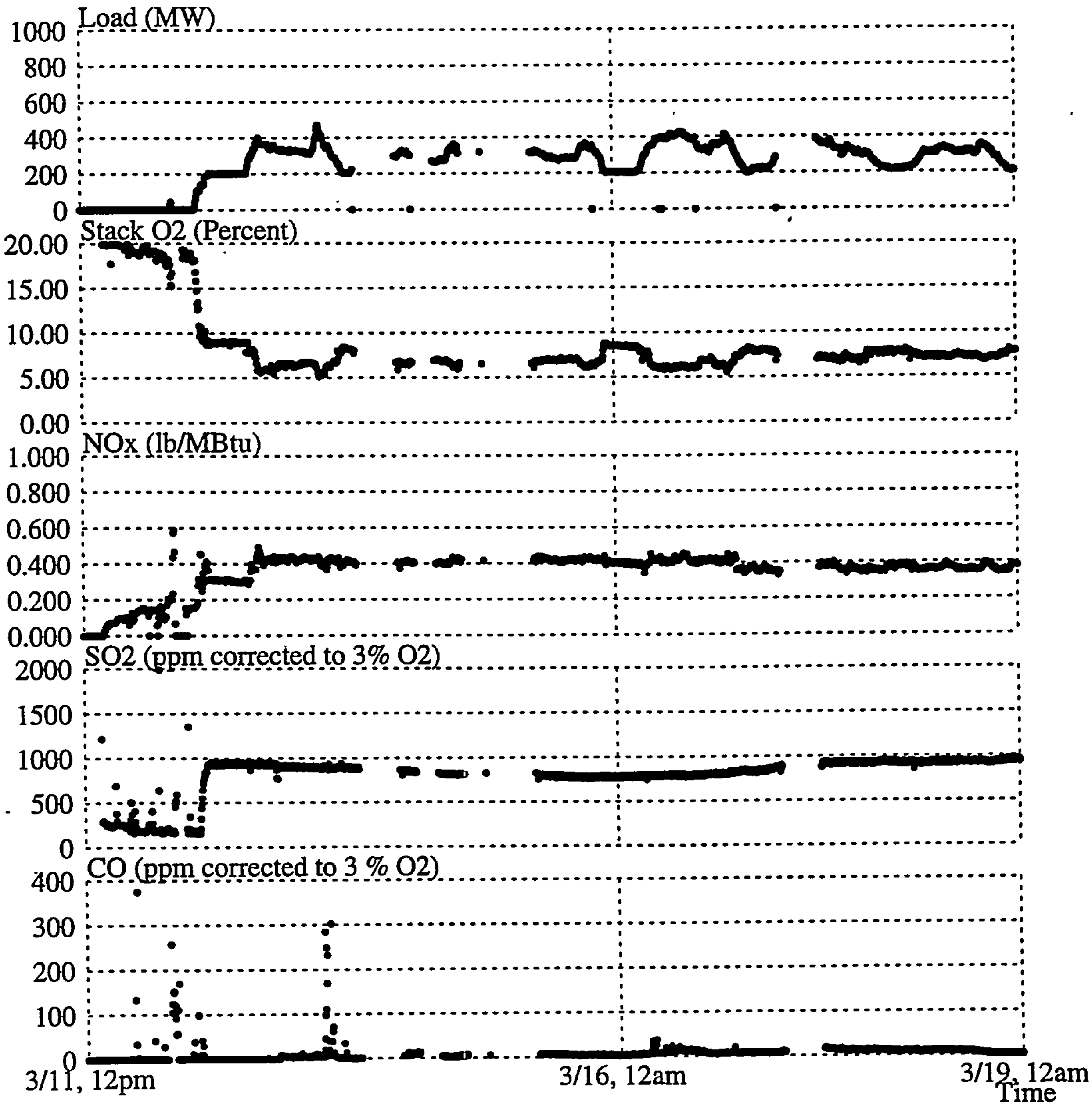

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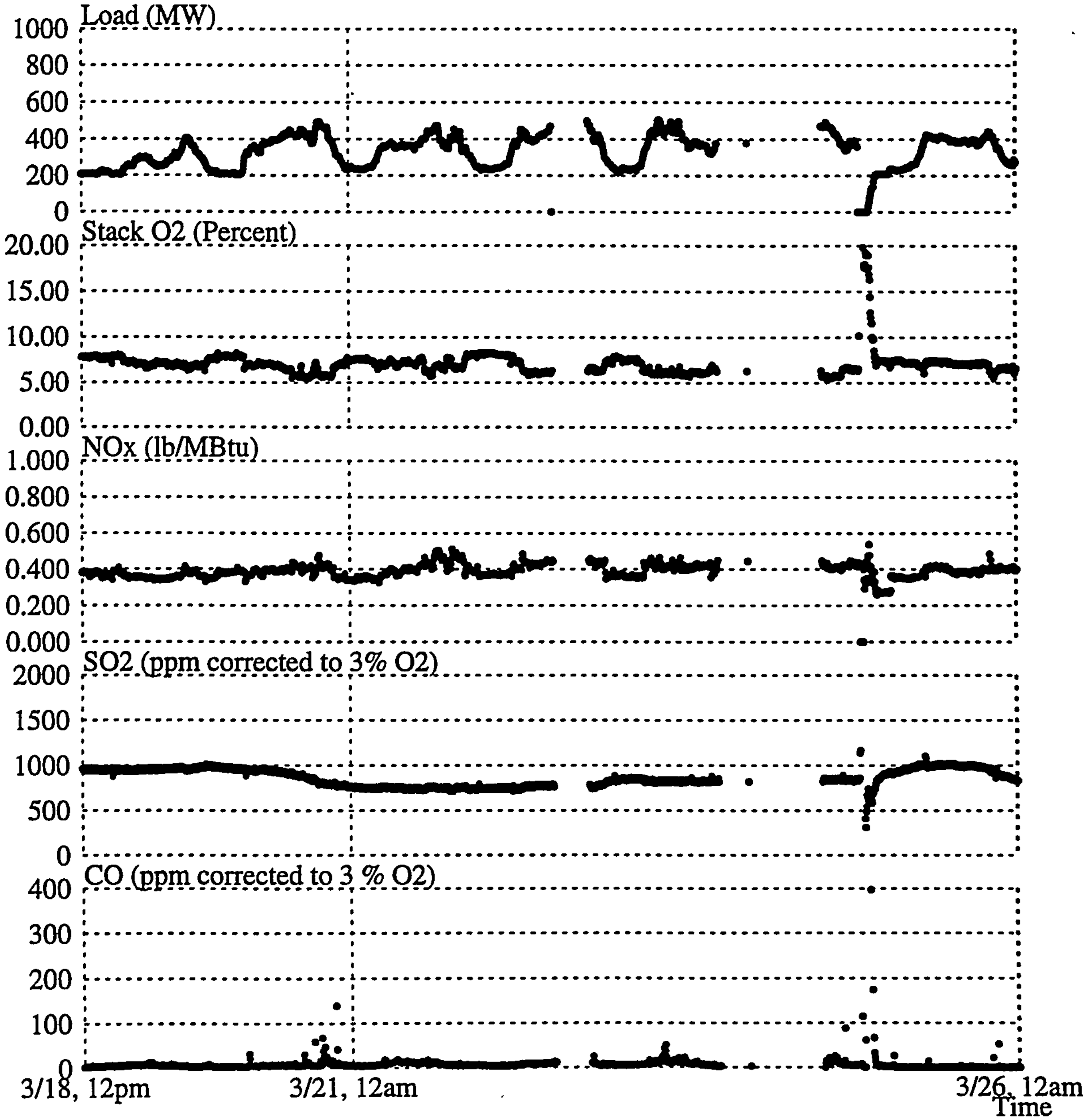

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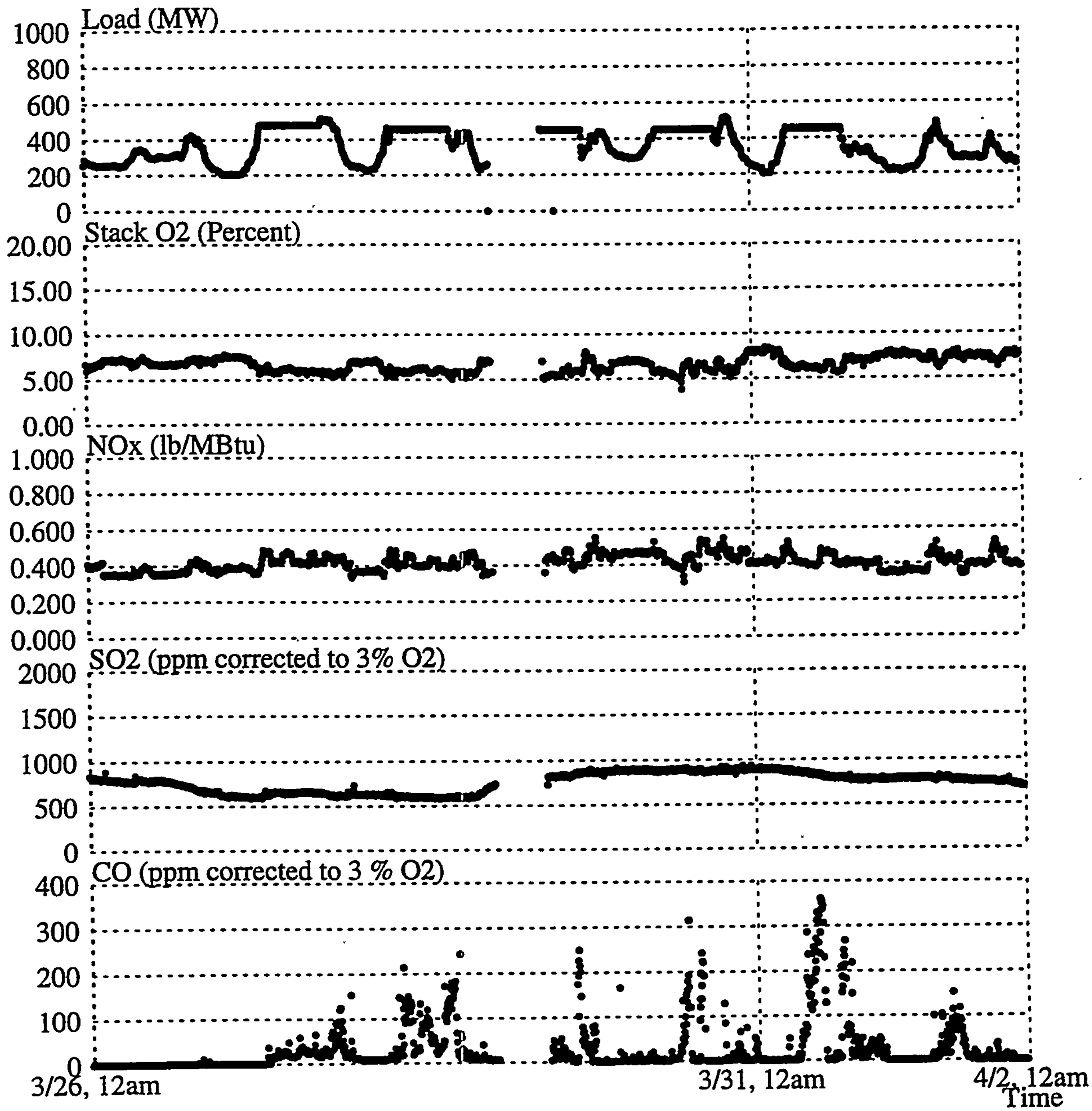

Appendix B

Replacement Control System Operator Manual