DOE/PC/89651--T28

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 1996

DOE Contract Number
DE-FC22-90PC89651

SCS Contract Number
C-91-000027

MASTER

Prepared by:

Southern Company Services, Inc.
P. O. Box 2625
Birmingham, Alabama 35202

Cleared by DOE Patent Counsel on October 24, 1996

DISCLAIMER

DISCLAIMER

LEGAL NOTICE

This report was prepared by Southern Company Services, Inc. pursuant to a cooperative agreement partially funded by the U.S. Department of Energy and neither Southern Company Services, Inc. nor any of its subcontractors nor the U.S. Department of Energy, nor any person acting on behalf of either:

(a) Makes any warranty or representation, express or implied with respect to the accuracy, completeness, or usefulness of the information contained in this report, or process disclosed in this report may not infringe privately-owned rights; or

(b) Assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Department of Energy. The views and opinion of authors expressed herein do not necessarily state or reflect those of the U.S. Department of Energy.

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 (NO_x) 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 NO_x combustion equipment through the collection and analysis of long-term emissions data. The project provides a stepwise evaluation of the following NO_x reduction technologies: Advanced overfire air (AOFA), Low NO_x 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.

Phase 4 of the project, demonstration of advanced control/optimization methodologies for NO_x abatement, is now in progress. The methodology selected for demonstration at Hammond Unit 4 is the Generic NO_x Control Intelligent System (GNOCIS), which is being developed by a consortium consisting of the Electric Power Research Institute, PowerGen, Southern Company, Radian Corporation, U.K. Department of Trade and Industry, and U.S. Department of Energy. GNOCIS is a methodology that can result in improved boiler efficiency and reduced NO_x emissions from fossil fuel fired boilers. Using a numerical model of the combustion process, GNOCIS applies an optimizing procedure to identify the best set points for the plant on a continuous basis. GNOCIS is designed to operate in either advisory or supervisory modes. Prototype testing of GNOCIS is in progress at Alabama Power's Gaston Unit 4 and PowerGen's Kingsnorth Unit 1. The first commercial demonstration of GNOCIS will be at Hammond 4.

During first quarter 1996, testing of GNOCIS was conducted and field testing of three on-line carbon-in-ash monitors was completed. Open- and closed-loop testing of GNOCIS was conducted during February 1996. Tests performed during the month represented load levels of 500 MW, 400 MW, and 300 MW. Various combinations of objectives were tested including minimize NO_x, minimize fly ash carbon-in-ash, and maximize efficiency. Implementation of the GNOCIS recommendations were greatly facilitated as a result of the enhancements made to the digital control system configuration. Preliminary indications on the performance on GNOCIS are encouraging. Also, field testing of three on-line carbon-in-ash monitors being evaluated at Hammond 4 was completed during February 1996. During the past eight to twelve months these monitors have been evaluated as to their accuracy, repeatability, reliability, and service requirements. The instruments that were tested include Applied Synergistics FOCUS, Camrac CAM, and Clyde-Sturtevant SEKAM. Preparation of the project final report is continuing with approximately 50 percent completed to date. Results from Phase 4 of the project will be integrated into the report as it becomes available.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

TABLE OF ABBREVIATIONS

acfm	actual cubic feet per minute	ICCT	Innovative Clean Coal Technology
AMIS	All mills in service	KPPH	kilo pounds per hour
AOFA	Advanced Overfire Air	lb(s)	pound(s)
ASME	American Society of Mechanical Engineers	LNB	low NO_x burner
		LOI	loss on ignition
C	carbon	(M)Btu	(million) British thermal unit
CAA(A)	Clean Air Act (Amendments)	MOOS	Mills out of service
CEM	Continuous emissions monitor	MW	megawatt
CFSF	Controlled Flow/Split Flame	N	nitrogen
Cl	chlorine	NO_x	nitrogen oxides
CO	carbon monoxide	NSPS	New Source Performance Standards
DAS	data acquisition system	O, O_2	oxygen
DCS	digital control system	OFA	overfire air
DOE	U.S. Department of Energy	PA	primary air
ECEM	extractive CEM	psig	pounds per square inch gauge
EPA	Environmental Protection Agency	PTC	Performance Test Codes
EPRI	Electric Power Research Institute	RSD	relative standard deviation
ETEC	Energy Technology Consultants	S	sulfur
F	Fahrenheit	SCA	specific collection area
FC	fixed carbon	SCS	Southern Company Services
FWEC	Foster Wheeler Energy Corporation	SO_2	sulfur dioxide
Flame	Flame Refractories	SoRI	Southern Research Institute
GPC	Georgia Power Company	Spectrum	Spectrum Systems Inc.
H	hydrogen	THC	total hydrocarbons
HHV	higher heating value	UARG	Utility Air Regulatory Group
HVT	High velocity thermocouple	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: Southern Company, U. S. Department of Energy (DOE), and Electric Power Research Institute. SCS is a subsidiary of the Southern Company that provides engineering, research, and financial services to other Southern Company subsidiaries.

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 that are different from traditional research and development programs sponsored by the DOE. Traditional projects focus on long-range, high-risk 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 that 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 that 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. 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:

    - ◊ Advanced overfire air (AOFA)
    - ◊ Low NO_x burners (LNB)
    - ◊ LNB with AOFA
    - ◊ 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 cost effectiveness 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 above NO_x reduction methods.

2. PROJECT DESCRIPTION

2.1. Test Program Methodology

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 NO_x 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 NO_x Digital Control System*	8/93 - 4/96*
5*	5*	Final Reporting and Disposition	
	5.1	Project Management and Reporting	9/95 - 6/96*
	5.2	Disposition of Hardware	6/96*

* Indicates change from original work breakdown structure. Final schedule dependent upon availability of unit.

The stepwise approach to evaluating the NO_x 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.

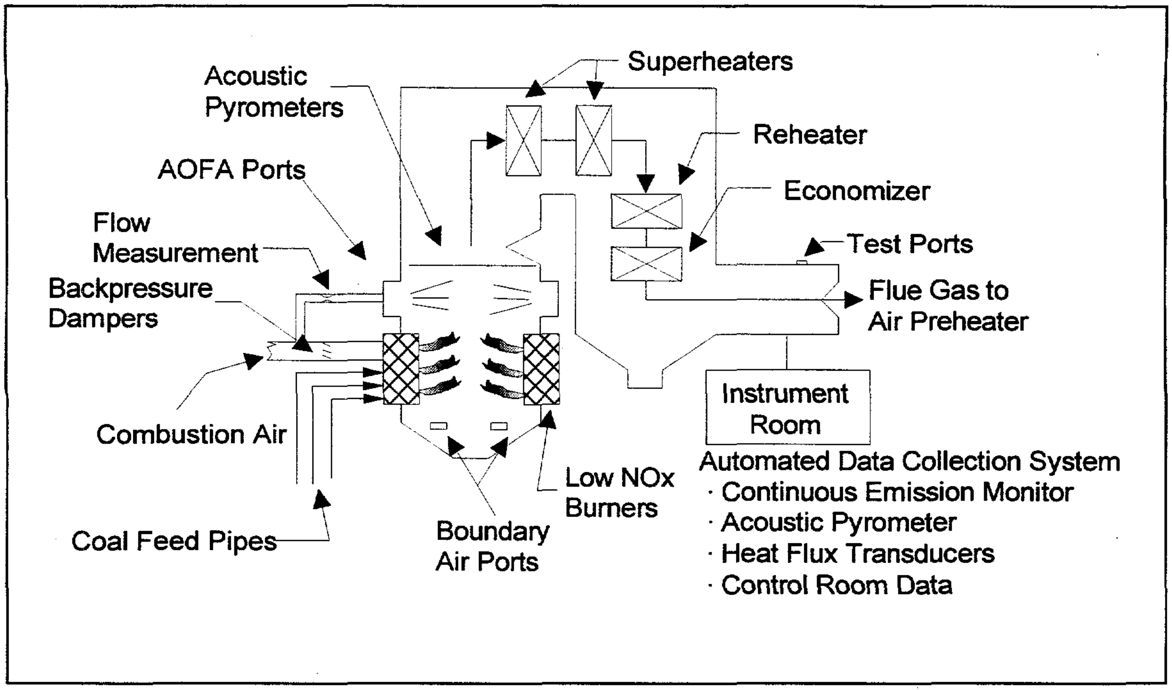


Figure 1: Plant Hammond Unit 4 Boiler

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 pyrometer 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 retrofit 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 retrofit with an advanced overfire air system, to be described later. The unit is equipped with a cold-side

ESP and utilizes two regenerative secondary air pre-heaters 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. As a result of 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, whereas four ports per wall were installed.

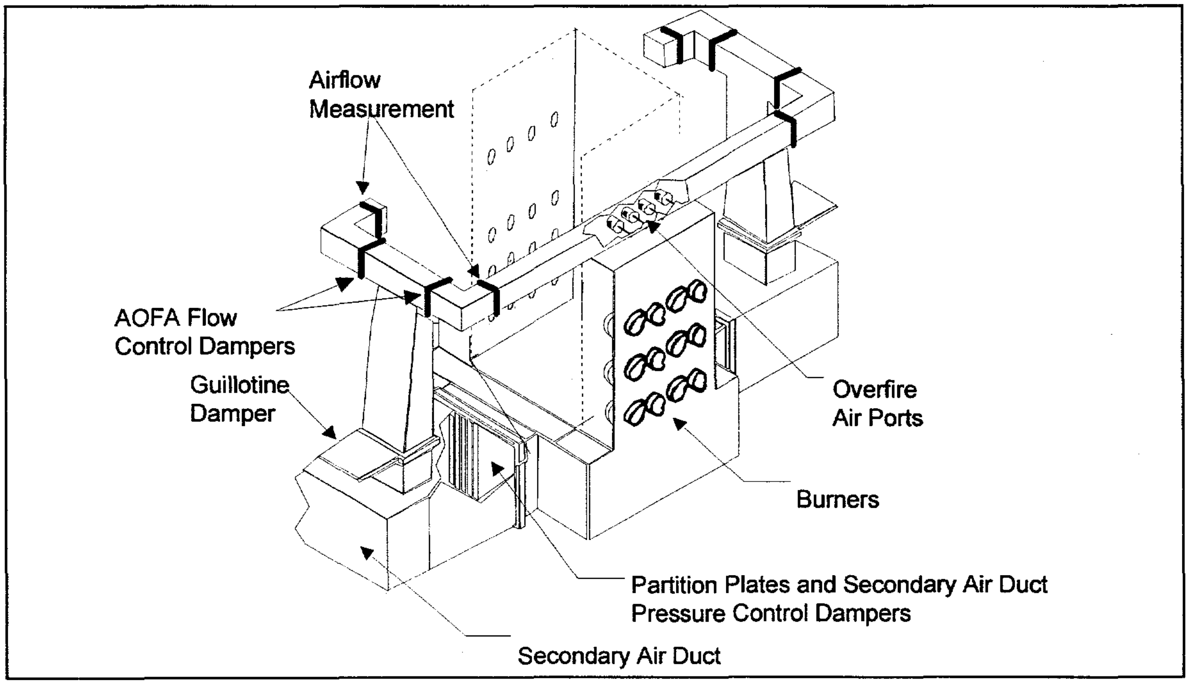


Figure 2: Advanced Overfire Air System

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.

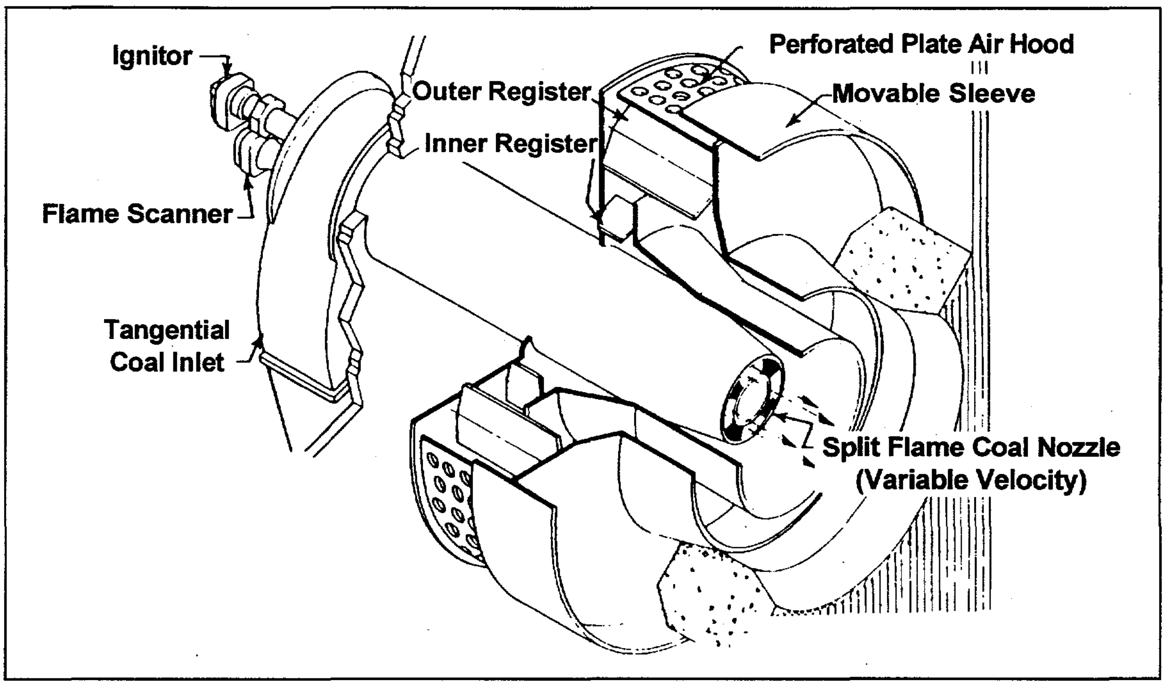


Figure 3: Low NO_x Burner Installed at Plant Hammond

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). The major elements of GNOCIS are shown in Figure 4.

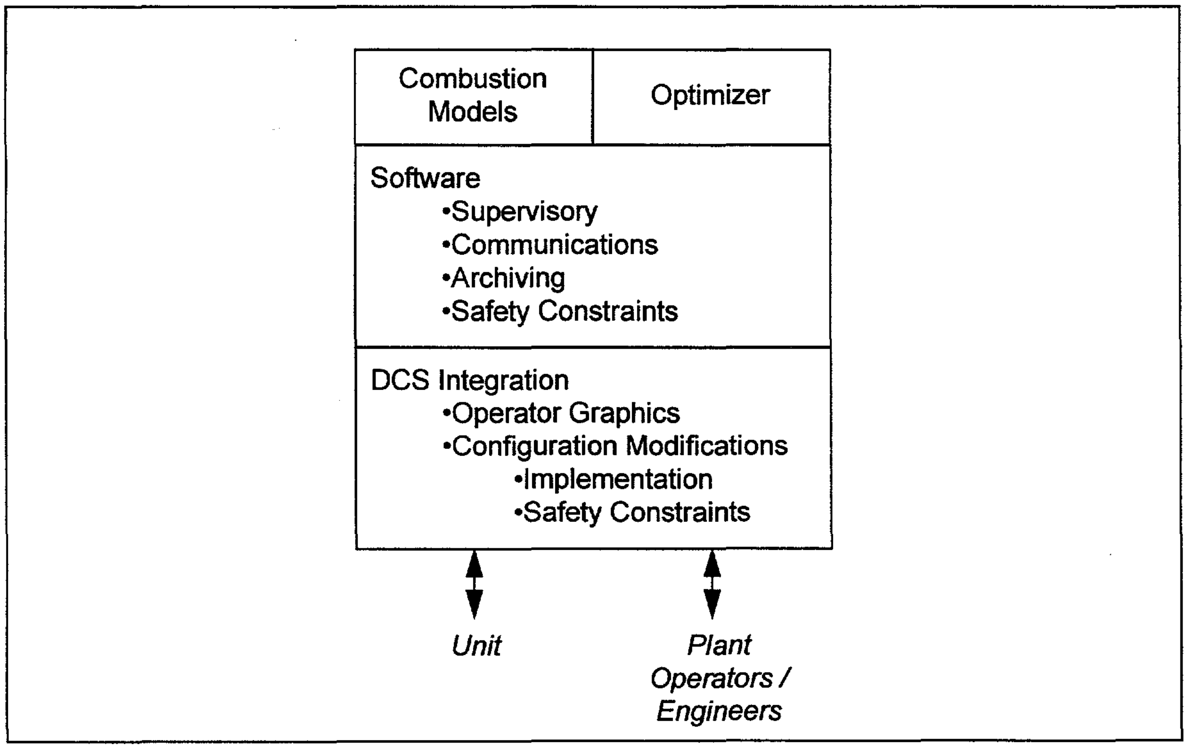


Figure 4: Major Elements of GNOCIS

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 digital optimization / controls 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
Characterization of the unit pre- activation of advanced strategies	Completed
Advanced controls/optimization design	95% completed
Characterization of the post- activation of advanced strategies	In progress

3.2. Summary of Current Quarter Activities

During first quarter 1996, testing of GNOCIS was conducted and field testing of three on-line carbon-in-ash monitors was completed. Open- and closed-loop testing of GNOCIS was conducted during February 1996. Tests were performed during the month at load levels of 500 MW, 400 MW, and 300 MW. Various combinations of objectives were tested including minimize NO_x, minimize fly ash carbon-in-ash, and maximize efficiency. Implementation of the GNOCIS recommendations were greatly facilitated as a result of the enhancements made to the digital control system configuration. Preliminary indications on the performance on GNOCIS are encouraging.

Also, field testing of three on-line carbon-in-ash monitors being evaluated at Hammond 4 was completed during February 1996. During the past eight to twelve months these monitors have been evaluated as to their accuracy, repeatability, reliability, and service requirements. The instruments that were tested include Applied Synergistics FOCUS, Camrac CAM, and Clyde-Sturtevant SEKAM. Preparation of the project final report is continuing with approximately 50 percent completed to date.

3.3. Short-Term Testing

A total of twenty-four short-term tests were conducted first quarter 1996 over a period of six days in February (Table 4). Fifteen of these tests were in association with GNOCIS and nine were for the evaluation of the on-line carbon-in-ash analyzers. These tests are discussed in Sections 3-5 and 3-6, respectively.

3.4. Long-Term Generation and Emissions

Long-term data collection continued during this quarter. Unit generation is shown in Figures 5 and 6. As shown, the unit was run at minimum (approximately 200 MW) to maximum loads (approximately 540 MW) during this quarter. The unit operated at a capacity factor of near 30 percent and was off-line approximately 50 percent of the time this quarter. The capacity factor for the unit was much greater than that exhibited during fourth quarter 1995 (20 percent). Average load was approximately 150 and 285 MW when off-time was included and excluded, respectively. NO_x emissions for this period are shown in Figures 7 through 9. The average NO_x emission rate for the period was 0.42 lb/MBtu -- the emission rate during Phase 3B was approximately 0.40 lb/MBtu. The emission limit for this unit is 0.50 lb/MBtu. NO_x emissions exhibited more dependence on unit load than in prior phases (Figure 9). The band around the mean represents ± two standard deviations. SO_2 emissions during this quarter are shown in Figures 10 through 12. SO_2 emissions were generally consistent during this quarter. The mean SO_2 emission rate for the quarter was approximately 2500 lb/hr with total emissions for the period being near 2500 tons. As shown in Figure 12, the SO_2 emission rate is, as expected, linearly related to load. Stack gas mass flow rates for the period are depicted in Figures 13 through 15. As shown, mean gas flow rate is roughly linear with load.

Table 4: Short-Term Tests Conducted First Quarter 1996

Test	Date	Load	Description	Type	MOOS	NOx	LOI
152-1	8-Feb-96	480	Full-Load / Low O2	LOI	None	.40	9.3
152-2	8-Feb-96	480	Full-Load / Mid O2	LOI	None	.44	8.2
152-3	8-Feb-96	480	Full-Load / High O2	LOI	None	.49	6.3
152-4	8-Feb-96	400	Mid-Load / Mid O2	LOI	E	.44	9.5
152-5	8-Feb-96	400	Mid-Load / Low O2	LOI	E	.38	11.1
153-1	9-Feb-96	300	Mid-Load / Mid O2	LOI	B	.37	7.5
153-2	9-Feb-96	300	Mid-Load / Low O2	LOI	B	.34	9.4
153-3	9-Feb-96	300	Mid-Load / High O2	LOI	B	.42	5.7
153-4	9-Feb-96	390	Mid-Load / High O2	LOI	B	.38	7.6
154-1	13-Feb-96	500	Full-Load / Min NOx	GNOCIS	None	.47	--
154-2	13-Feb-96	500	Full-Load / Min LOI	GNOCIS	None	.46	--
154-3	13-Feb-96	500	Full-Load / Min NOx	GNOCIS	None	.44	--
155-1	15-Feb-96	300	Mid-Load / Min NOx	GNOCIS	B	.39	--
155-2	15-Feb-96	300	Mid-Load / Min NOx	GNOCIS	B	.40	--
155-3	15-Feb-96	300	Mid-Load / Min LOI	GNOCIS	B	.40	--
155-4	15-Feb-96	300	Mid-Load / Min NOx	GNOCIS	B	.38	--
156-1	16-Feb-96	400	Mid-Load / Min NOx	GNOCIS	None	.40	--
156-2	16-Feb-96	400	Mid-Load / Min LOI	GNOCIS	None	.42	--
156-3	16-Feb-96	400	Mid-Load / Max Eff	GNOCIS	None	.39	--
157-1	22-Feb-96	255	Low-Load / Min NOx	GNOCIS	D,F	.30	--
157-2	22-Feb-96	260	Low-Load / Min LOI	GNOCIS	D,F	a	--
157-3	22-Feb-96	250	Low-Load / Min LOI	GNOCIS	C,D	.27	--
157-4	22-Feb-96	250	Low-Load / Min NOx	GNOCIS	C,D	.26	--
157-5	22-Feb-96	250	Low-Load / Max Eff / Min NOx / LOI < 10	GNOCIS	C,D	b	--
157-6	22-Feb-96	220	Low-Load / Min LOI	GNOCIS	C,D	b	--

[a] Test aborted - operator changed mills during test.

[b] Test aborted - failure of GNOCIS optimizer.

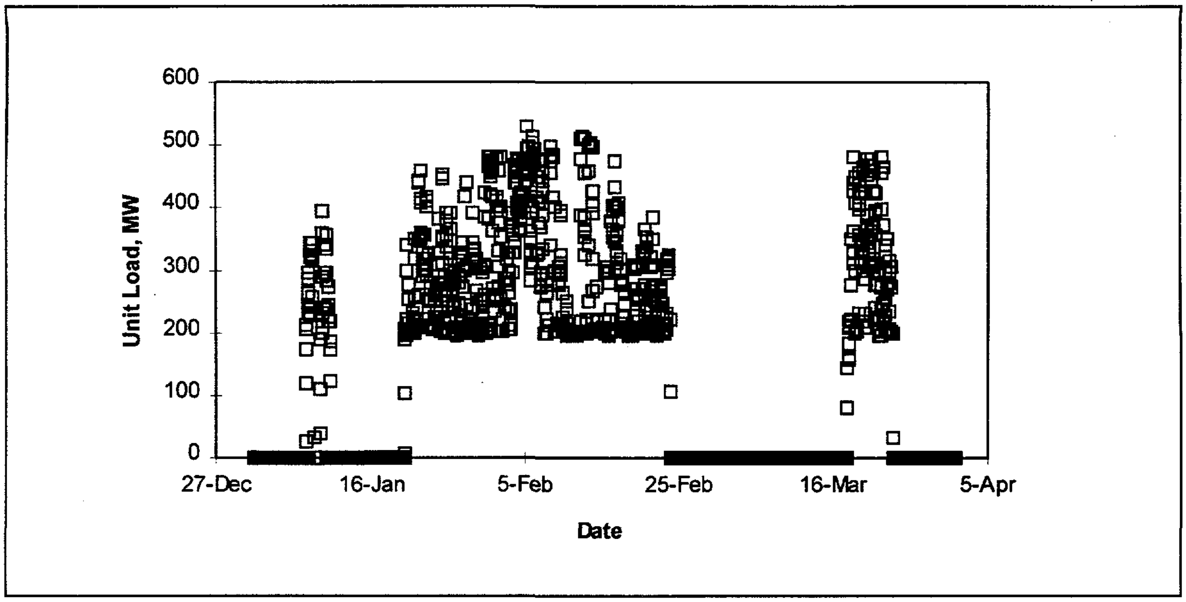


Figure 5: First Quarter 1996 Generation

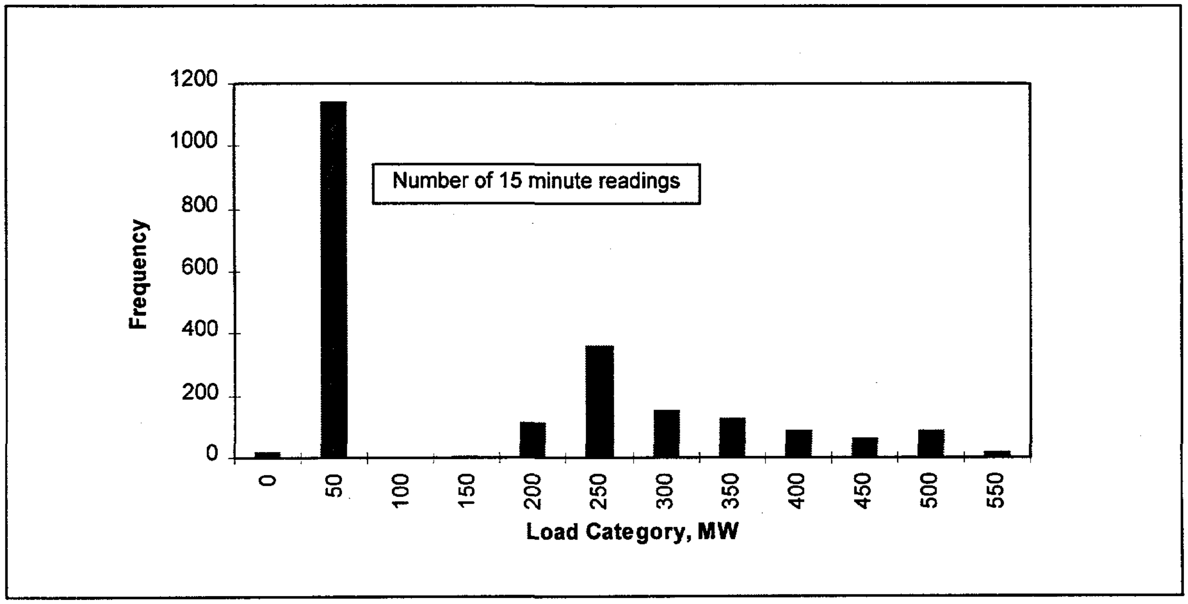


Figure 6: First Quarter 1996 Generation Histogram

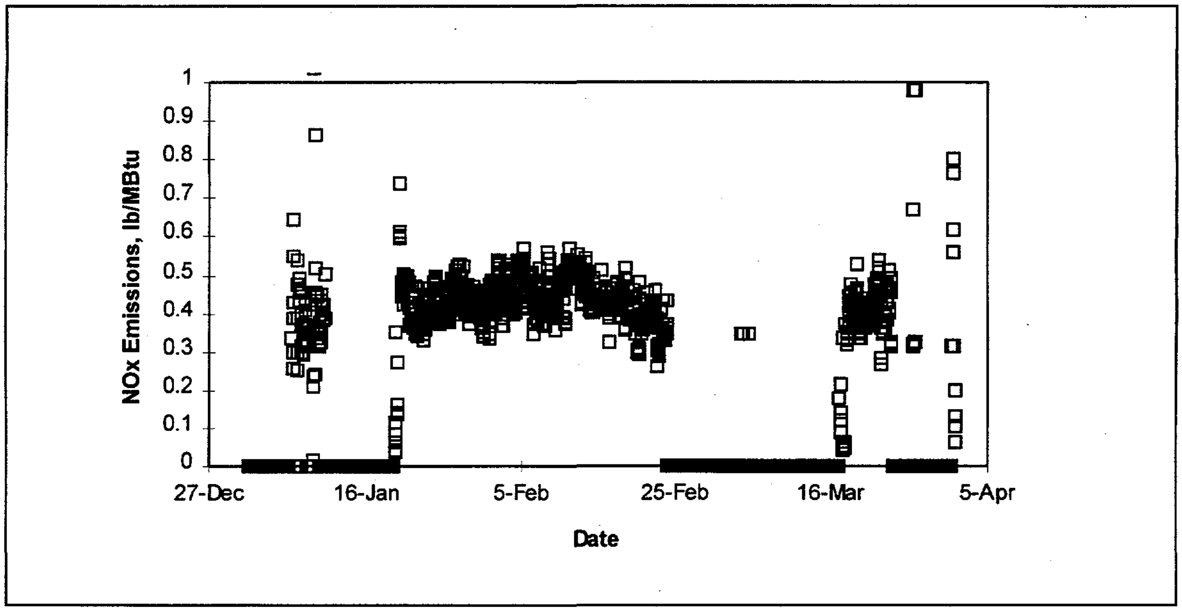


Figure 7: First Quarter 1996 NO_x Emission Levels

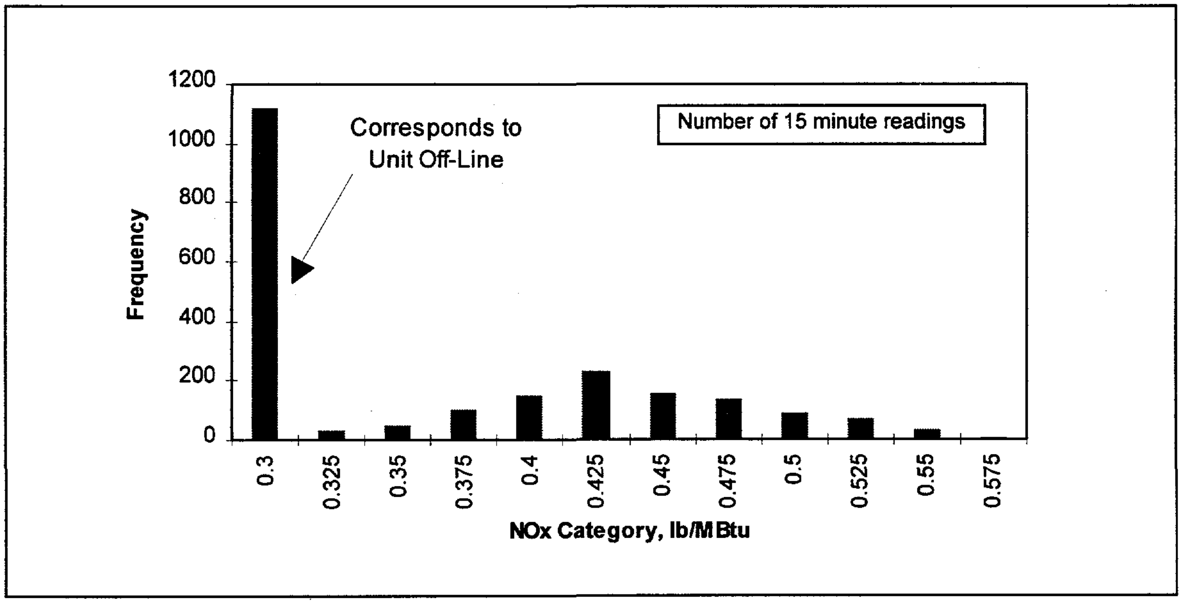


Figure 8: First Quarter 1996 NO_x Emission Level Histogram

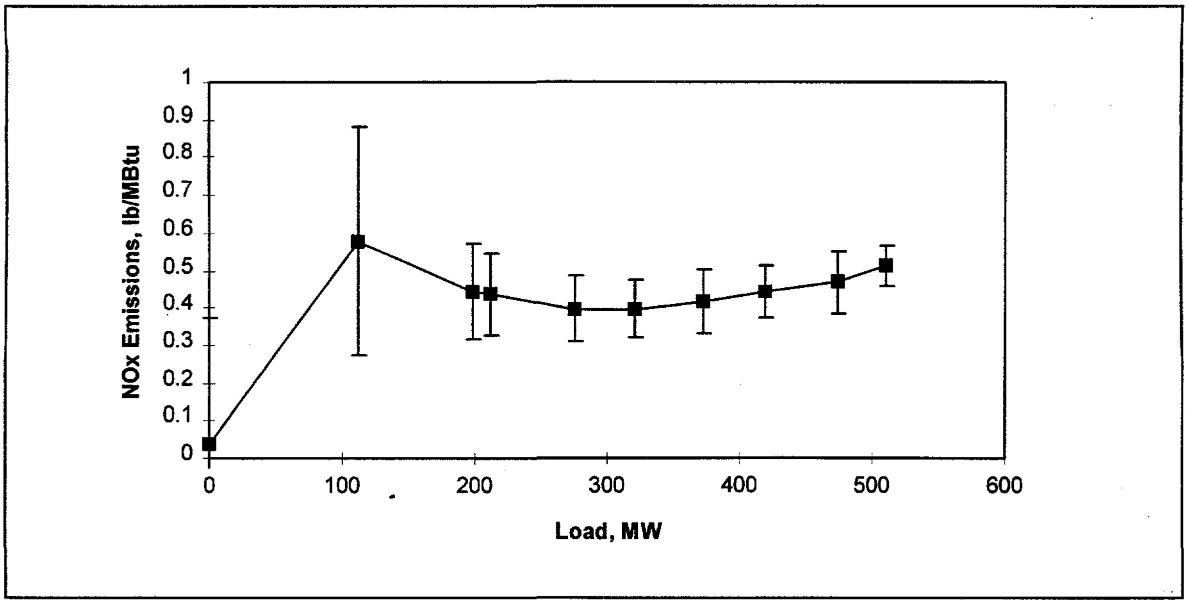


Figure 9: First Quarter 1996 NO_x Emission vs. Load Characteristic

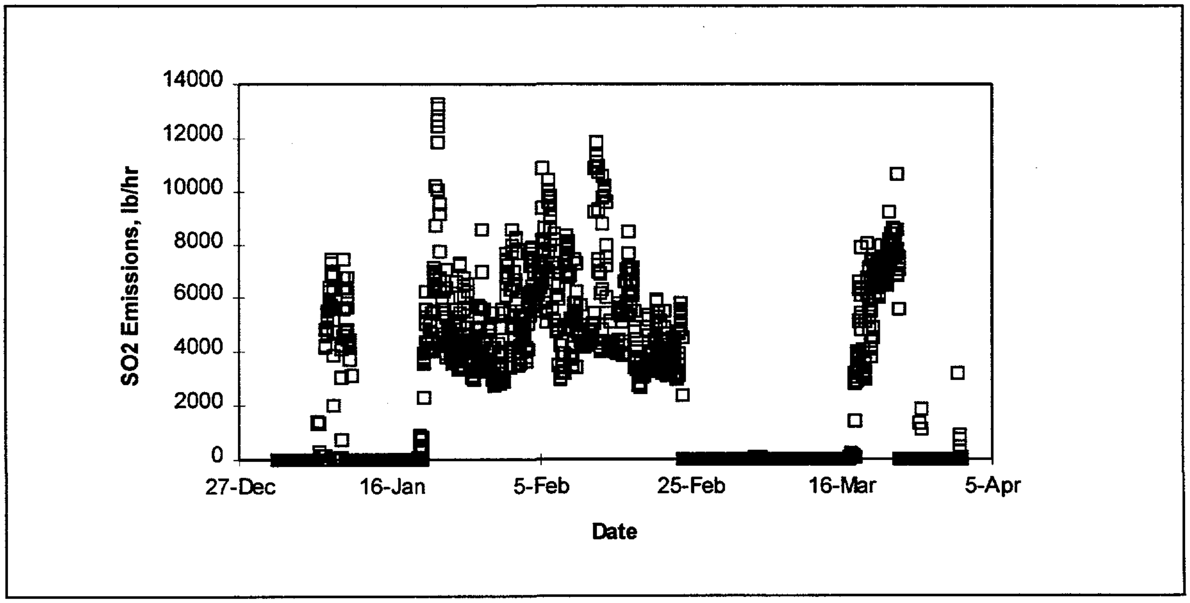


Figure 10: First Quarter 1996 SO_2 Emission Levels

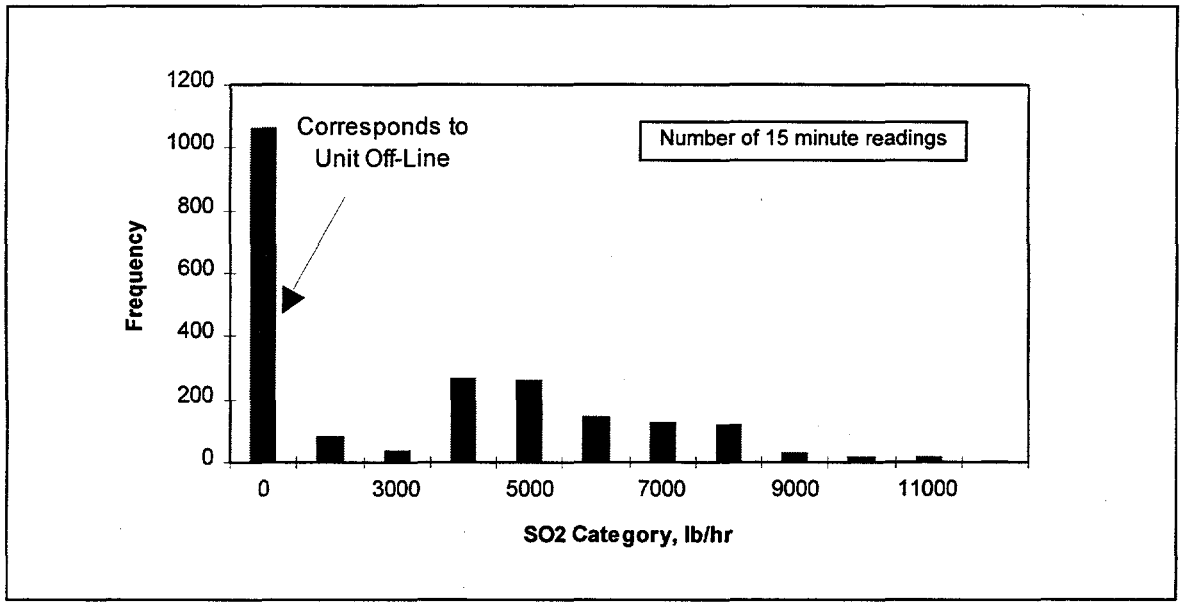


Figure 11: First Quarter 1996 SO_2 Emission Histogram

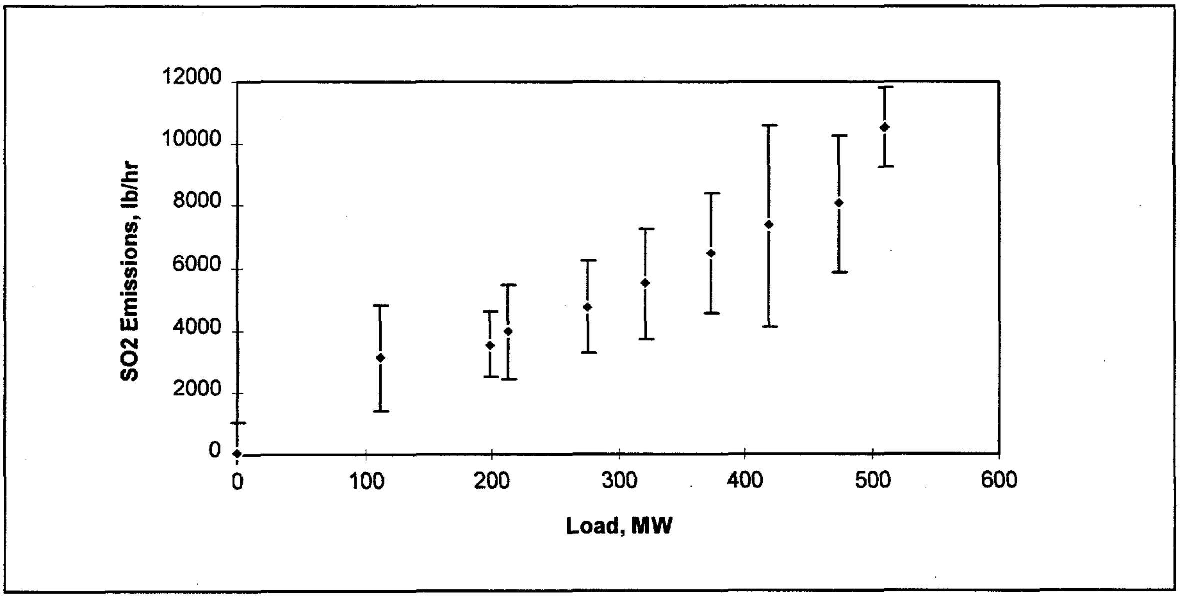


Figure 12: First Quarter 1996 SO_2 Emissions vs. Load Characteristic

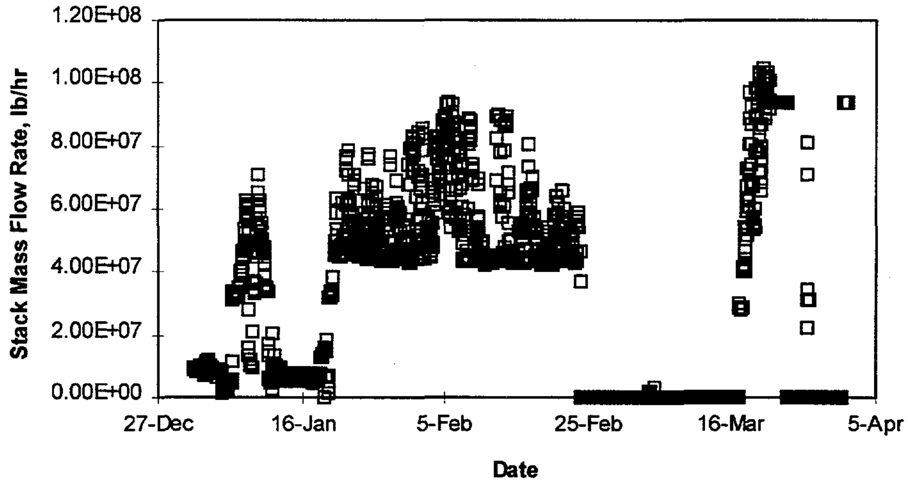


Figure 13: First Quarter 1996 Stack Mass Flow Rate Levels

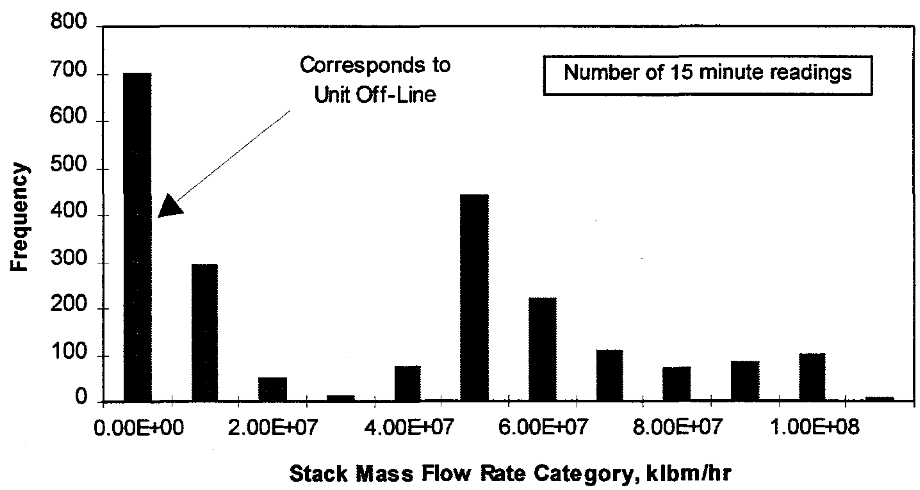


Figure 14: First Quarter 1996 Stack Mass Flow Rate Histogram

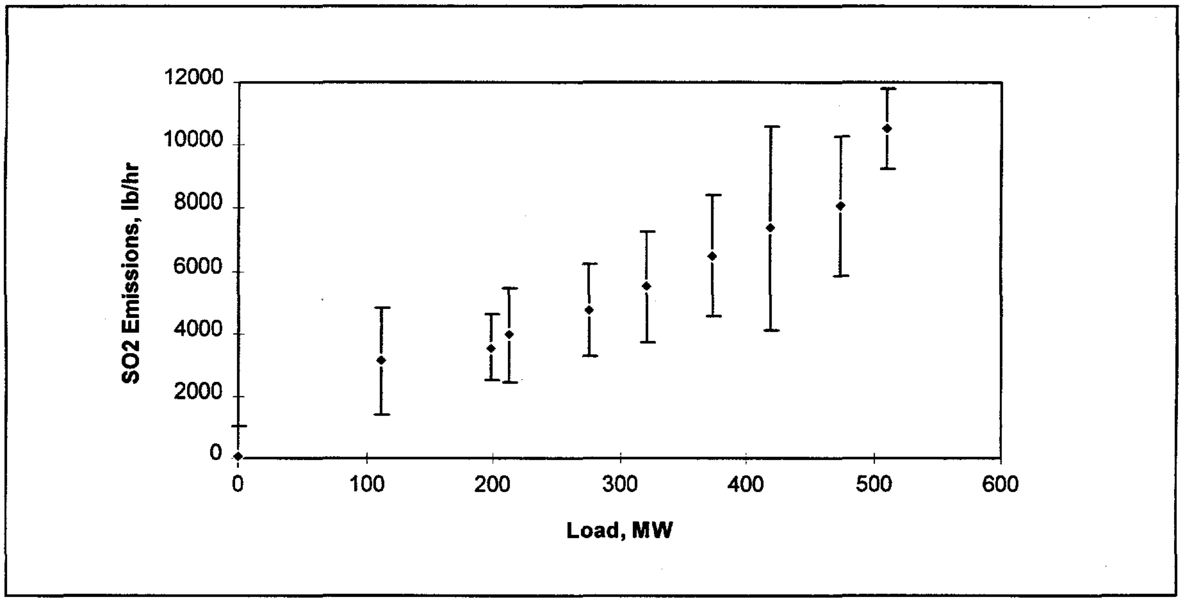


Figure 15: First Quarter 1996 Stack Mass Flow Rate vs. Load Characteristic

3.5. 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), Southern Company, U.K. Department of Trade and Industry, and U.S. Department of Energy [6]. GNOCIS is a methodology that can result in improved boiler efficiency and reduced NO_x emissions from fossil fuel fired boilers. Using a numerical model of the combustion process, GNOCIS applies an optimizing procedure to identify the best set points for the plant on a continuous basis. The optimization occurs over a wide range of operating conditions. Once determined, the recommended set points can be implemented automatically without operator intervention (closed-loop), or, at the plant's discretion, conveyed to the plant operators for implementation (open-loop). GNOCIS is designed to run on a stand-alone workstation networked to the digital control system, or internally on some digital control systems.

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 ICL separated and close-coupled overfire air NO_x combustion 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 fourth quarter 1995 regarding the GNOCIS activities at Gaston, Kingsnorth, and Hammond are provided below.

<u>Gaston</u>

A summary of the activities and status of the GNOCIS project at Gaston Unit 4 follows:

- As originally conceived and proposed to the project funders, the Gaston 4 implementation of GNOCIS was to be open-loop only. Although GNOCIS can be used in this manner, in order to obtain the full-benefit of GNOCIS, a closed-loop implementation is required. To this end, the GNOCIS implementation at Gaston 4 has been enhanced to allow closed-loop operation. GNOCIS first went closed-loop on April 3. No major problems were found.
- Preliminary testing followed the completion of the closed-loop modifications. The primary purpose of this testing was to test the functionality of the closed-loop mode and to detect any software problems. Based on results from these tests, it was evident that the combustion model required retraining in regards to NO_x. The boiler efficiency and LOI predictions appeared satisfactory. Since Unit 3 data is now available, an evaluation will be made as to how best to incorporate data from that unit to improve the Unit 4 model predictions for NO_x. Although preliminary, efficiency improvements on the order of 0.5 percent were achieved during these tests.
- Modifications have been made to the Unit 3 DCS to enable monitoring and archiving of data from that unit for use in the GNOCIS models. The data is being archived on

the GNOCIS NT platform. These modifications were made to support the Unit 4 GNOCIS model development but can also be used for the GNOCIS implementation on this unit.

- A Mark & Wedell (M&W) on-line carbon-in-ash monitor has been installed on Gaston Unit 4. The LOI data from this instrument is being incorporated into the GNOCIS models. An example of the output of the device is provided in Attachment A. To date, the instrument has shown high reliability. Although not part of the GNOCIS program at Gaston, the analyzer will be evaluated for availability, accuracy, and maintainability.
- The Gaston 4 Site Report is now being prepared. This not-for-public-release report will document the implementation and performance of GNOCIS at Gaston 4. PowerGen and SCS will jointly issue a report addressing GNOCIS at Kingsnorth and Gaston. This combined report is intended for public release.

Kingsnorth

Testing of GNOCIS at Kingsnorth has been completed and GNOCIS is now being used in a production mode at the plant, however, further ad hoc testing of GNOCIS may be conducted at Kingsnorth in the future. The current GNOCIS installation at Kingsnorth is based on a linear model and constrained linear optimization routines. This installation may be modified to incorporate the non-linear models, such as those used at Gaston and Hammond.

Hammond

Following the completion of installation, preliminary testing of GNOCIS at Hammond 4 began during February 1996 with tests being conducted at loads of 500 MW, 400 MW, and 300 MW (Table 5). Various combinations of objectives were tested including minimizing NO_x emissions, minimizing carbon-in-ash, and maximizing efficiency in both open- and closed-loop modes. Implementation of the GNOCIS recommendations were greatly facilitated as a result of enhancements made to the DCS. The primary purpose of these initial tests was to identify problems with the GNOCIS model(s) and implementation. For these tests, recommendations were provided by GNOCIS for excess oxygen, individual mill coal flows, and overfire air flow to each corner of the windbox. GNOCIS operated in both open- and closed-loop modes.

Table 5: GNOCIS Testing Conducted First Quarter 1996

Test	Date Appr. Start Time Appr. Stop Time	Mode	Goals	Constraints	Notes
154-1	13-Feb-96 12:30 13:30	Open-Loop Min NOx	0.2 < NOx < 0.2 0<LOI<20 0<Eff<100	-0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	
154-2	13-Feb-96 13:00 14:30	Open-Loop Min LOI	0.2 < NOx < 1.0 0<LOI<0 0<Eff<100	-0.2 < ΔO2 < 0.2 -5.2 < Mills < 5.2 AOFA clamped	
154-3	13-Feb-96 14:00 15:30	Open-Loop Min NOx	0.2 < NOx < 0.2 0<LOI<20 0<Eff<100	-0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	
155-1	15-Feb-96 9:40 11:40	Open-Loop Min NOx	0.2 < NOx < 0.2 0<LOI<20 0<Eff<100	-0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	
155-2	15-Feb-96 10:30 12:50	Open-Loop Min LOI	0.2 < NOx < 1.0 0<LOI<0 0<Eff<100	-0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	
155-3	15-Feb-96 12:10 14:30	Open-Loop Min LOI	0.2 < NOx < 1.0 0<LOI<0 0<Eff<100	-0.2 < ΔO2 < 0.2 -5.2 < Mills < 5.2 AOFA clamped	• O_2 recommendation flip flops.
155-4	15-Feb-96 14:00 15:20	Open-Loop Min NOx	0.2 < NOx < 0.2 0<LOI<20 0<Eff<100	0.2 < ΔO2 < 0.2 -5.2 < Mills < 5.2 B Mill clamped AOFA clamped	
156-1	16-Feb-96 11:30 13:30	Open-Loop Min NOx	0.2 < NOx < 0.2 0<LOI<20 0<Eff<100	0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	
156-2	16-Feb-96 12:50 14:00	Open-Loop Min LOI	0.2 < NOx < 0.2 0<LOI<20 0<Eff<100	0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	
156-3	16-Feb-96 13:45 15:00	Open-Loop Max Eff	0.2 < NOx < 1.0 0<LOI<20 100<Eff<100	0.2 < ΔO2 < 0.2 -5.2 < Mills < 5.2 -5 < AOFA < 5	
157-1	22-Feb-96 14:30 16:00	Open-Loop Min NOx	0.2 < NOx < 0.2 0<LOI<20 0<Eff<100	0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	
157-2	22-Feb-96 15:30 17:30	Closed-Loop Min LOI	0.2 < NOx < 1.0 0<LOI<0 0<Eff<100	0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	• First closed-loop test. • Test aborted when operator changed mills in service.
157-3	22-Feb-96 17:30 19:00	Closed-Loop Min LOI	0.2 < NOx < 1.0 0<LOI<0 0<Eff<100	0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	• Move suppresion on O_2 zero.
157-4	22-Feb-96 19:00 19:30	Closed-Loop Min NOx	0.2 < NOx < 0.2 0<LOI<20 0<Eff<100	0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	• Move suppresion on O_2 zero.
157-5	22-Feb-96 19:30 20:00	Closed-Loop Min NOx, Max Eff LOI < 10	0.2 < NOx < 0.2 0<LOI<10 100<Eff<100		• Optimizer failure due to starting point being outside feasible region.
157-6	22-Feb-96 20:00 21:00	Closed-Loop Min LOI	0.2 < NOx < 1.0 0<LOI<0 0<Eff<100		• Optimizer failure due to starting point being outside feasible region.

3.6. On-Line Carbon-in-Ash Monitors

A subsidiary goal of the Wall-Fired project is the evaluation of advanced instrumentation as applied to combustion control. Based on this goal, three on-line carbon-in-ash (CIA) monitors have been procured for this project and are being evaluated as to their:

- Reliability and maintenance,
- Accuracy and repeatability, and
- Suitability for use in the control strategies being demonstrated at Hammond Unit 4.

A Clyde-Sturtevant SEKAM monitor samples from two fixed locations at the economizer outlet. The outputs (carbon-in-ash and system alarm) have been connected to the DCS for archival purposes and incorporation into the control logic. This monitor was commissioned during November 1994. A CAMRAC Corporation CAM monitor, installed February 1995, samples from a single movable location at the precipitator inlet. An Applied Synergistics' FOCUS, commissioned July 1995, is installed near the nose of the furnace. These CAM and SEKAM were described previously in the *Third Quarter 1994 Technical Progress Report.* The FOCUS system was described in the *Second Quarter 1995 Technical Progress Report.*

The first round of testing of these instruments was conducted July 20 and 21, 1995 and was described previoulsy in the *Third Quarter 1995 Technical Progress Report.* A subsequent round of testing was conducted on February 8 and 9, 1996 (Appendix B). As with the July 1995 tests, during each of the nine tests, composite duct samples were collected from the flue gas stream at the precipitator inlet – one each from the A and B side of the precipitator. These samples were collected at three different loads (500, 400, and 300 MW) and oxygen levels (low, nominal, and high). In addition to the composite duct samples, precipitator hopper samples were collected from the first row of hoppers (out of three rows total) on the A and B sides during each test. An effort was made to clear the hoppers before each test. The first row of hoppers typically receive near 80 percent of the fly ash collected by the precipitator.

Aspects of the accuracy of these instruments include:

- Representativeness of Sample Used in the Analysis (Spatial) - For all these instruments, only a subset of the ash passing into the precipitator is observed or collected for further analysis. Since this flue gas/ash stream is in general non-homogenous, the sampling technique can lead to substantial error in the estimate.
- Accuracy of the Measurement Techniques (Inherent) - All the devices tested infer carbon content of the "collected" sample indirectly. SEKAM uses a correlation based on sample capacitance, CAM uses microwave absorption, and FOCUS uses a method based on hot particle counting. The accuracy of these techniques depends on numerous assumptions concerning the characteristics of the flue gas/ash stream.
- Timeliness (Temporal) - Delays and time lags in the sampling and analysis mechanisms employed by the instruments affect their use for on-line control of fly ash carbon.

Results of the testing conducted with the carbon-in-ash analyzers this quarter are discussed below.

Percent Carbon vs. LOI

Loss-on-ignition (LOI) is a measure of the combustibles contained in a sample and is used frequently to represent carbon content of the sample; however, the two are not synonymous. The LOI indication is also affected by other non-carbonaceous combustible material in the ash, such as sulfur.

As in the July 1995 testings and as can be seen from Figure B-1, for the ash collected at Hammond, LOI is an excellent estimator of the carbon content in the sample. As a result of other combustibles in the ash sample, the LOI percentage is slightly greater (less than 0.5 percent) than the carbon percentage.

Using Hopper Samples to Estimate Boiler Carbon Losses

In most instances, it is easier and less time consuming to obtain fly ash to be used in determining boiler carbon losses from the precipitator hoppers rather than from the flue gas stream directly. However, there are numerous problems with this approach including:

- Correlating ash collection times with boiler operating conditions, and
- Weighting of the collected ash samples so that the combined sample is representative of the ash in the flue gas stream.

These problems are not substantially different than that of the carbon-in-ash monitors. Because this method is used frequently, it was felt that it would serve as a useful benchmark for the other methods. Figures B-2 through B-3 show results from Tests 152 and 153 conducted during the February 1996 testing. As shown in these two figures, the B-side hopper samples provided a much better estimate of the isokinetic samples than the A-side. For the July 1995 tests, the converse was true. The reason for this swap is unknown, however, it does exhibit some of the difficulty in using this method.

SEKAM vs. Isokinetic Sample LOI

A comparison of the SEKAM readings, obtained by time averaging over the duration of the tests the signal to the DCS, with the LOI of the samples collected manually is shown in Figure B-4. Due to problems with the SEKAM sampling system, this system was not available for the first five tests conducted during February (152-1 through 152-5). Although available for the balance of the tests, the sampling system was still problematic and may have contributed to the relatively poor performance of the SEKAM unit for these tests as compared to this unit during the July 1995 tests. It should be noted that the averaged readings obtained from the SEKAM were not compensated for delays or lags in sampling and analysis inherent in the system.

CAM vs. Isokinetic Sample LOI

A comparison of the CAM readings, obtained by time averaging over the duration of the tests the signal to the DCS, with the LOI of the samples collected manually is shown in Figure B-5. As shown, the CAM unit appeared to represent trends well during these tests. As with the SEKAM, the CAM readings were not compensated for delays or lags in sampling and analysis.

FOCUS vs. Isokinetic Sample LOI

A comparison of the FOCUS readings and the isokinetic samples is shown in Figures B-6 and B-7. The FOCUS values are derived using equations provided by Applied Synergistics. These equations utilize the counts per second providec by the FOCUS system, in addition to excess oxygen and load to estimate LOI. As shown, that although the FOCUS system provided general trends, it is evident that the sensitivity of the device to changes in LOI was relatively small for these particular tests.

The test phase of these analyzers is now completed and a report is being prepared documenting their performance.

4. FUTURE PLANS

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

Table 6: Future Plans

Quarter	Activity
Second Quarter 1996	• Advanced Controls Testing • Final Reporting & Disposition
Third Quarter 1996	• Advanced Controls Testing • Final Reporting & Disposition
Fourth Quarter 1996	• Final Reporting & Disposition

BIBLIOGRAPHY

1. *500 MW Demonstration Of Advanced Wall-Fired Combustion Techniques For The Reduction Of Nitrogen Oxide (NO_X) 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 (NO_X) 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 (NO_X) Emissions From Coal-Fired Boilers - Phase 3A Low* NO_x *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 (NO_X) Emissions From Coal-Fired Boilers - Phase 3B Low* NO_x *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 (NO_X) Emissions From Coal-Fired Boilers - Field Chemical Emissions Monitoring: Overfire Air and Overfire Air/Low* NO_x *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 NO_x Control Intelligent System (GNOCIS)," EPRI 1994 Workshop on NO_x Controls for Utility Boilers, May 11-13, 1994, Scottsdale, Arizona.

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

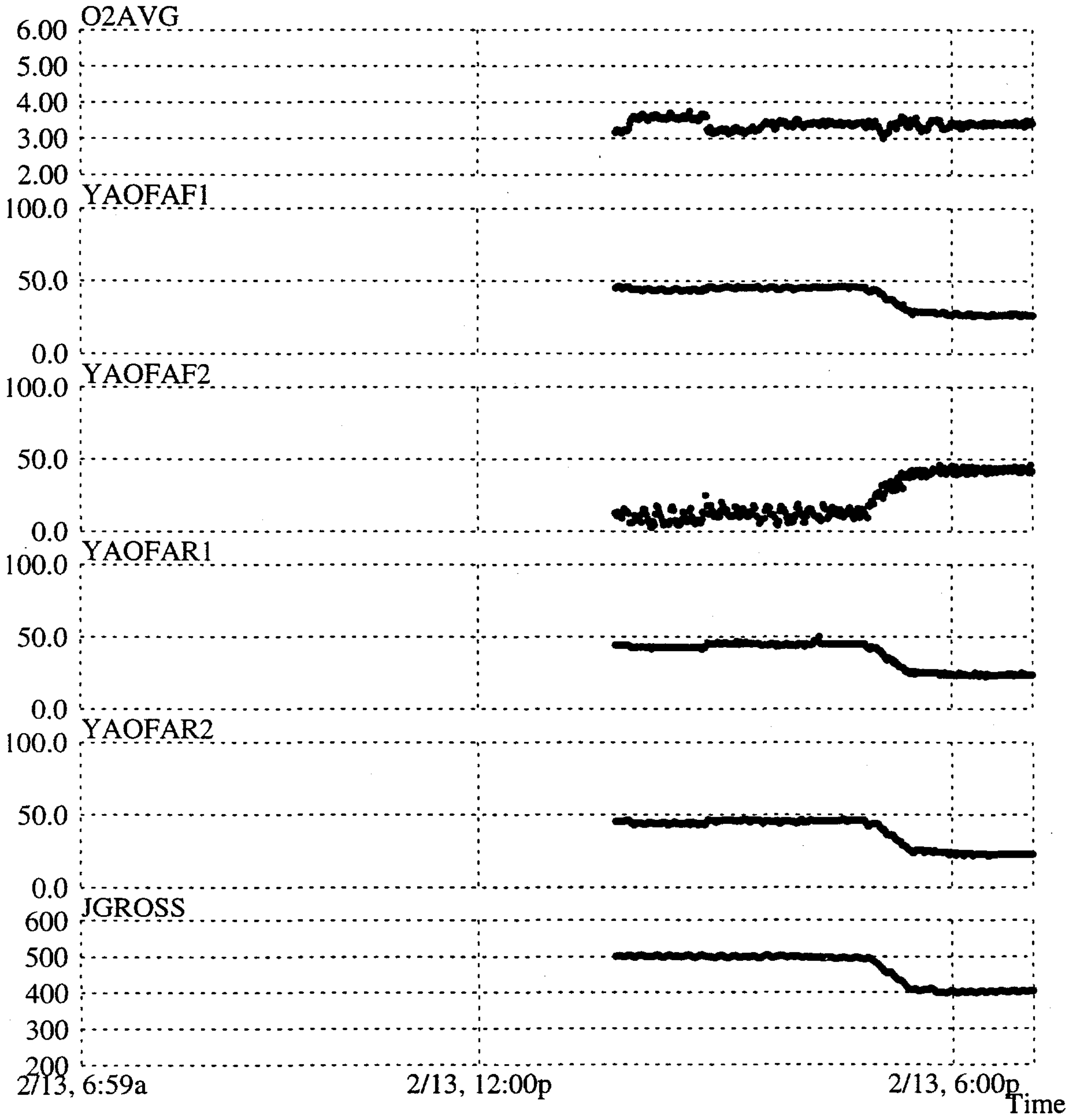
Appendix A

GNOCIS Testing Conducted First Quarter 1996

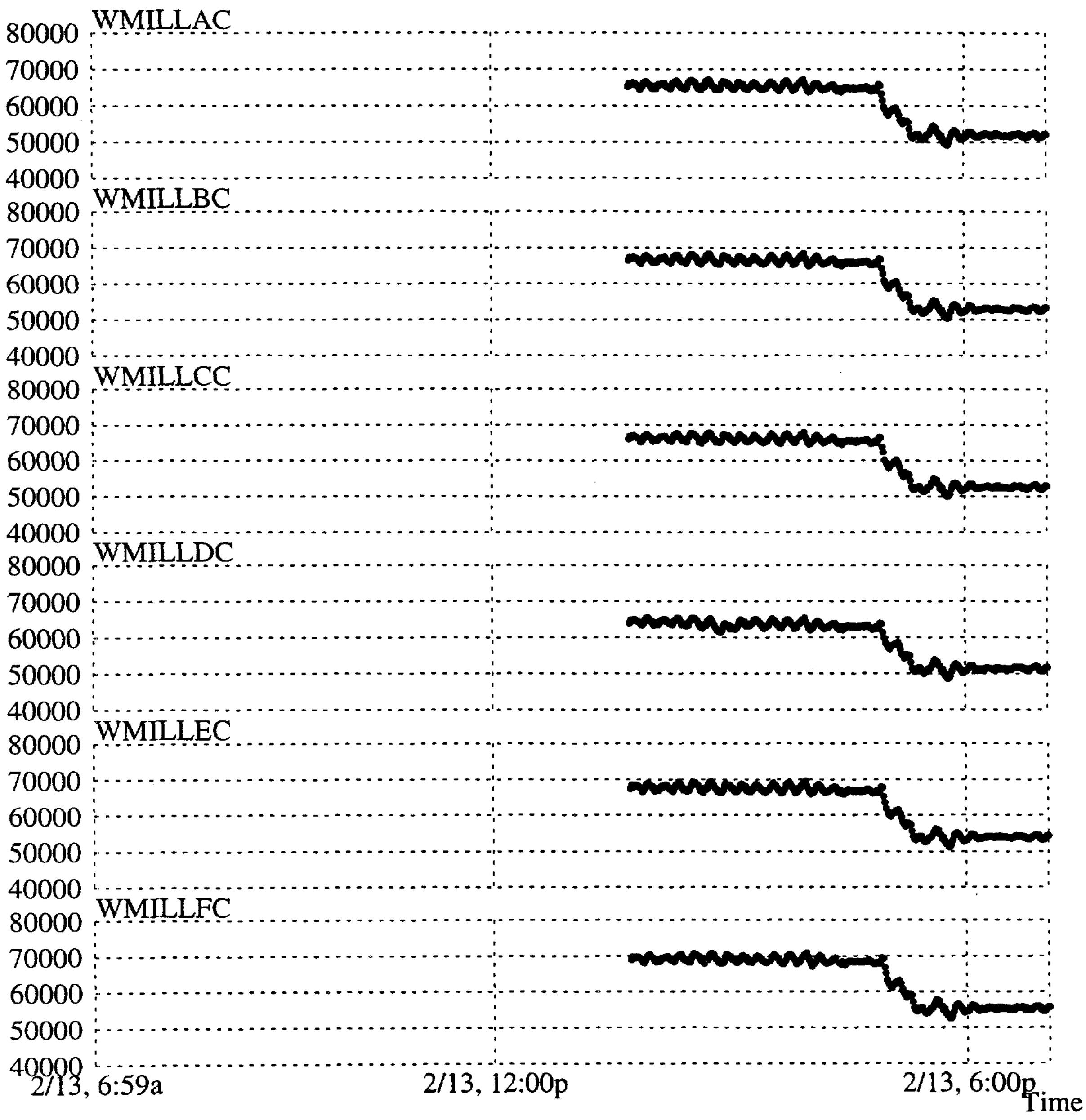
GNOCIS Testing Conducted February 13, 1996

Test	Date Appr. Start Time Appr. Stop Time	Load	Mills Out of Service	Model	Mode	Goals	Constraints	Notes
154-1	13-Feb-96 12:30 13:30	500	None	Hamcon31FC	Open-Loop Min NOx	0.2 < NOx < 0.2 0<LOI<20 0<Eff<100	-0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	
154-2	13-Feb-96 13:00 14:30	500	None	Hamcon31FC	Open-Loop Min LOI	0.2 < NOx < 1.0 0<LOI<0 0<Eff<100	-0.2 < ΔO2 < 0.2 -5.2 < Mills < 5.2 AOFA clamped	
154-3	13-Feb-96 14:00 15:30	500	None	Hamcon31FC	Open-Loop Min NOx	0.2 < NOx < 0.2 0<LOI<20 0<Eff<100	-0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	
155-1	15-Feb-96 9:40 11:40	300	B	Hamcon31FC	Open-Loop Min NOx	0.2 < NOx < 0.2 0<LOI<20 0<Eff<100	-0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	

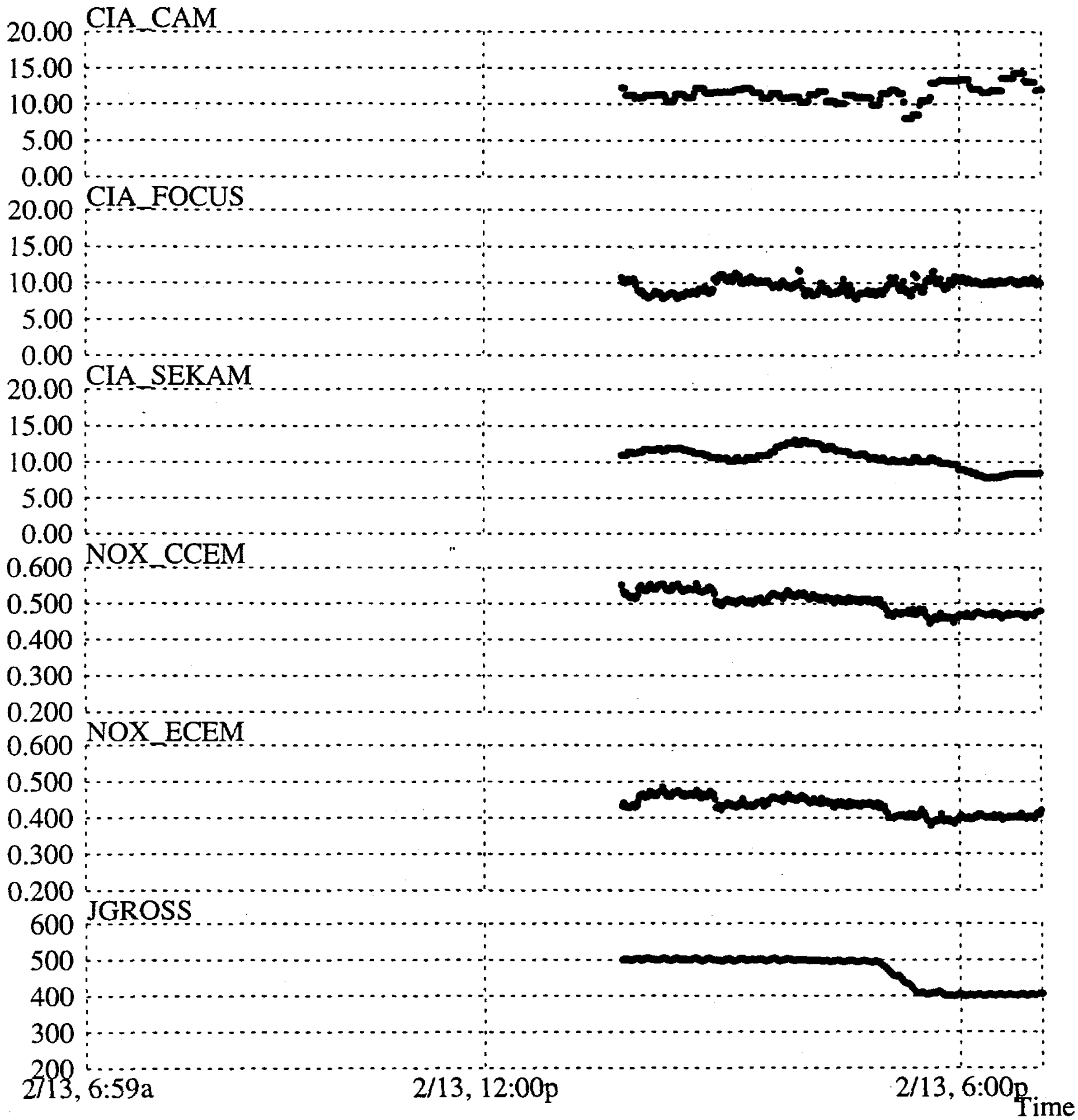
Data: 9602
Date: 09/19/96 08:49:48



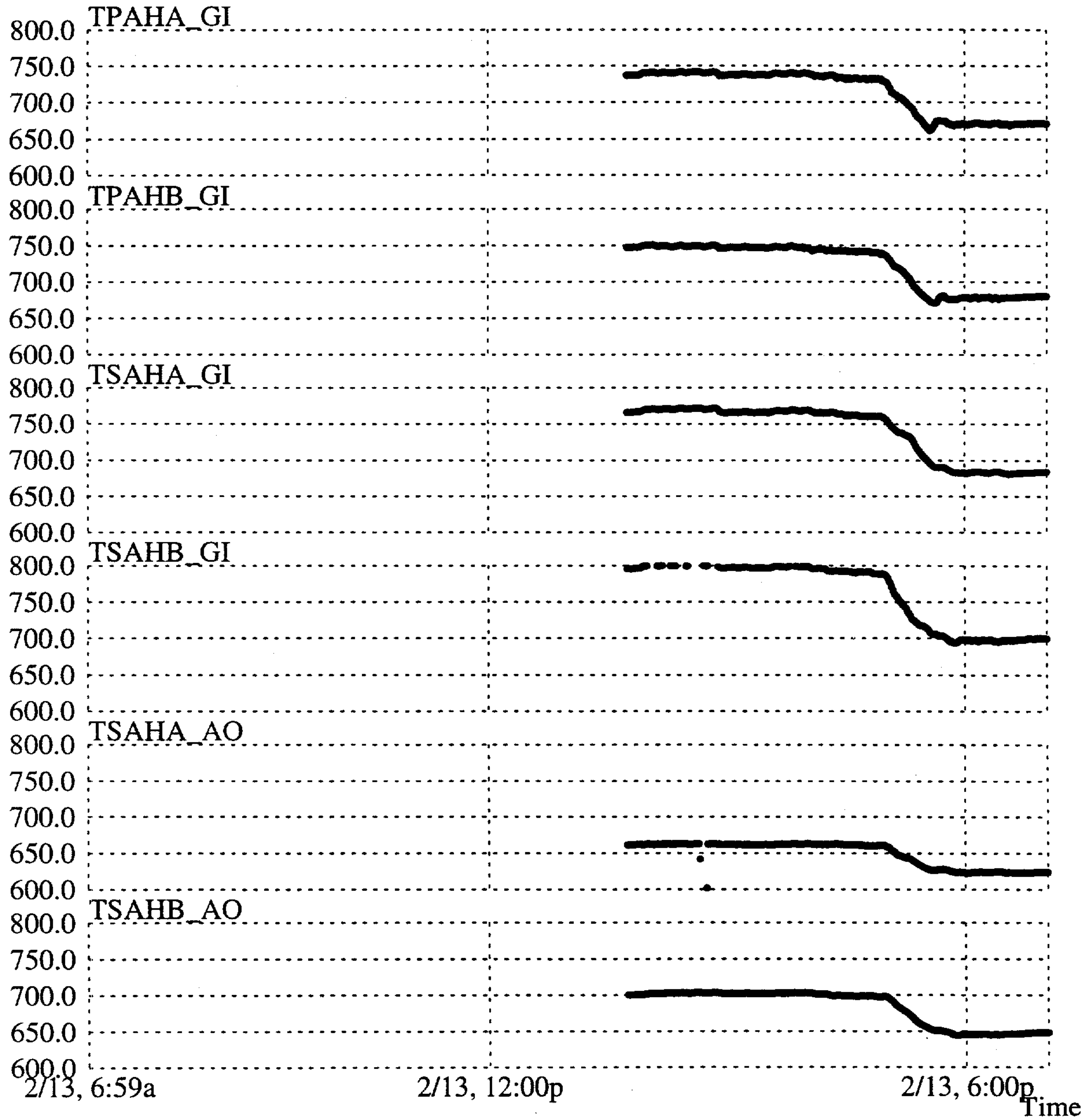
Data: 9602
Date: 09/19/96 08:20:15



Data: 9602
Date: 09/19/96 09:14:24



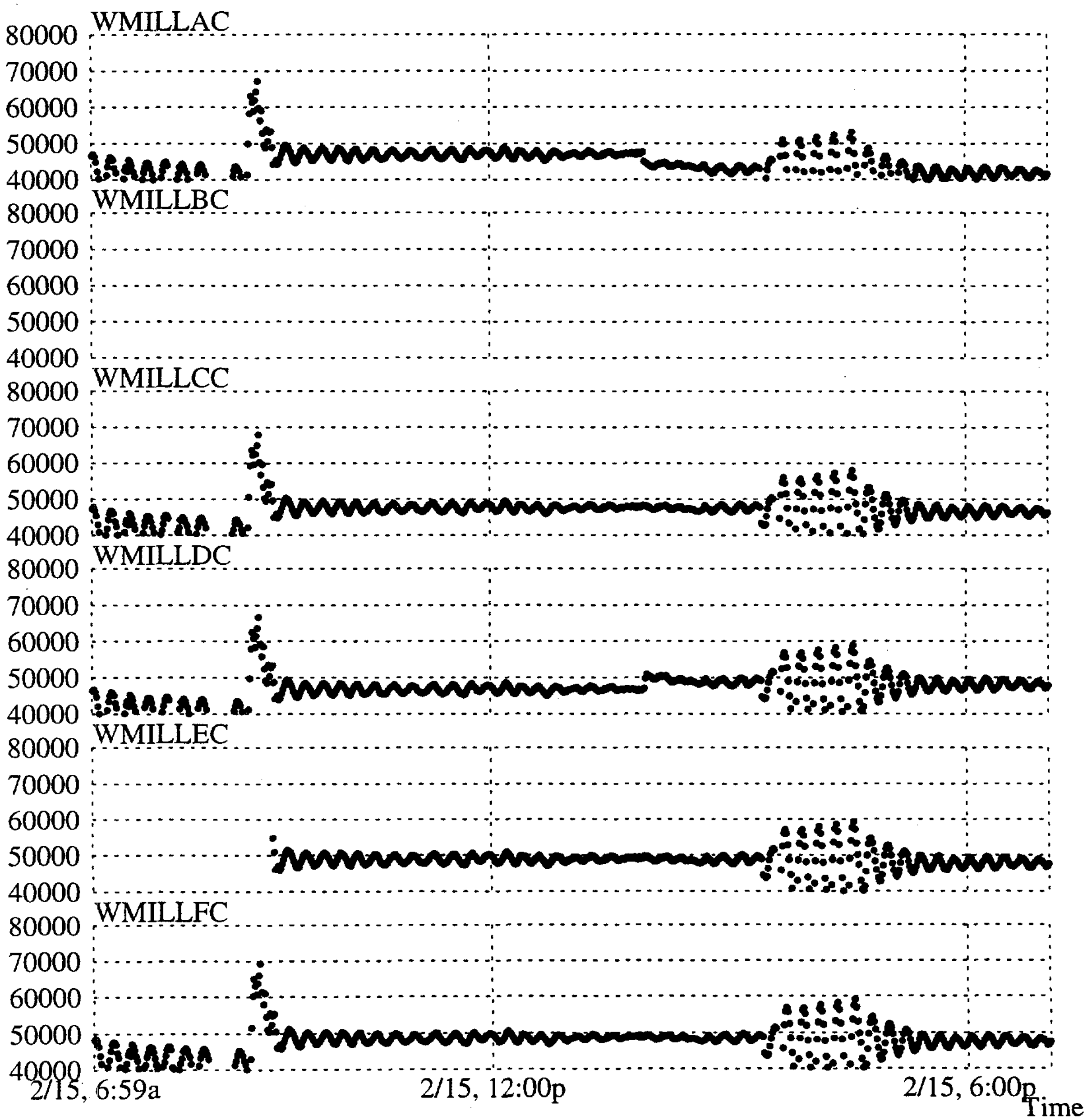
Data: 9602
Date: 09/19/96 09:25:38



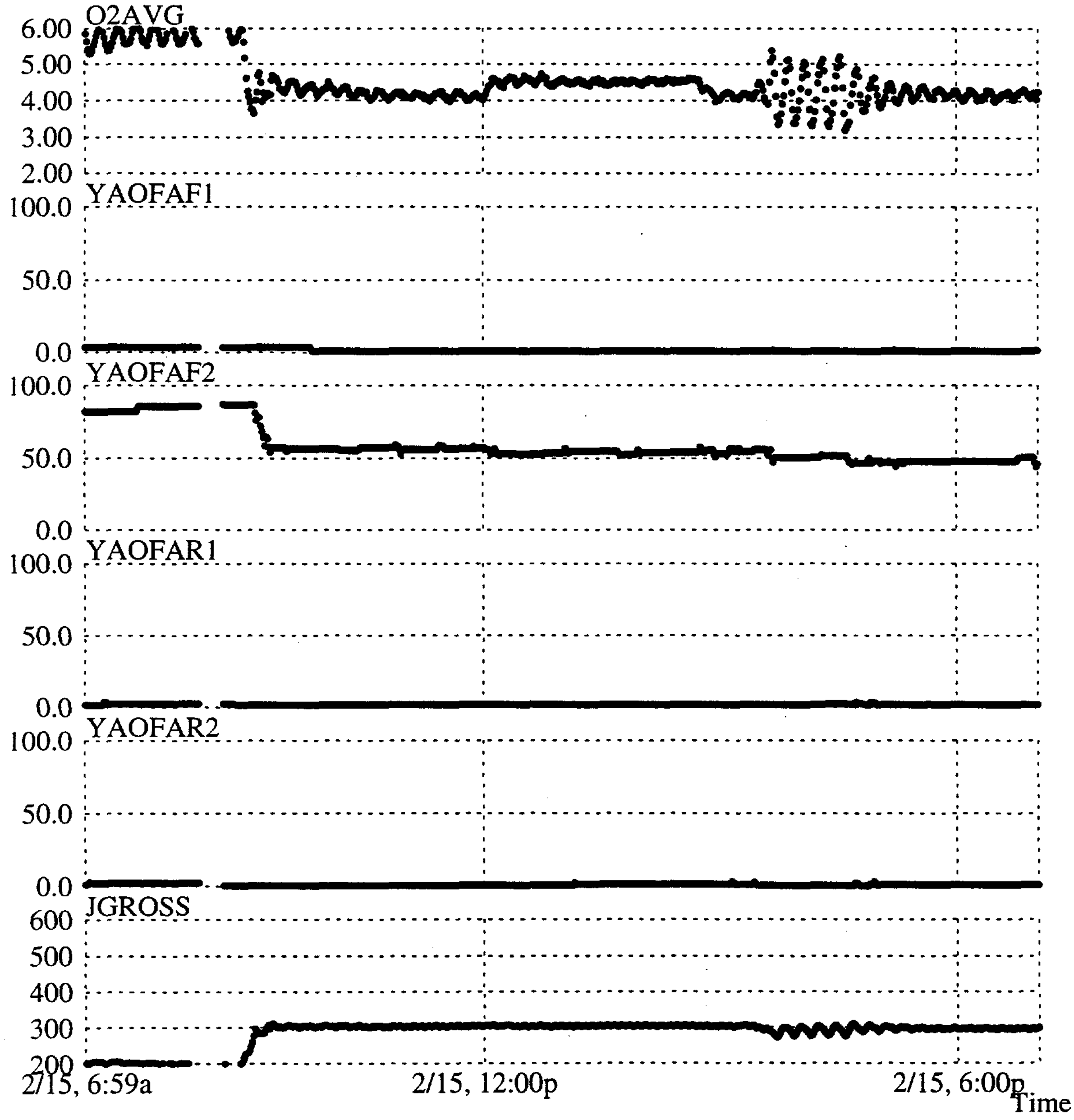
GNOCIS Testing Conducted February 15, 1996

Test	Date Appr. Start Time Appr. Stop Time	Load	Mills Out of Service	Model	Mode	Goals	Constraints	Notes
155-2	15-Feb-96 10:30 12:50	300	B	Hamcon31FC	Open-Loop Min LOI	0.2 < NOx < 1.0 0<LOI<0 0<Eff<100	$-0.2 < \Delta O2 < 0.2$ Mills clamped AOFA clamped	
155-3	15-Feb-96 12:10 14:30	300	B	Hamcon31FC	Open-Loop Min LOI	0.2 < NOx < 1.0 0<LOI<0 0<Eff<100	$-0.2 < \Delta O2 < 0.2$ -5.2 < Mills < 5.2 AOFA clamped	• O_2 recommendation flip flops.
155-4	15-Feb-96 14:00 15:20	300	B	Hamcon31FC	Open-Loop Min NOx	0.2 < NOx < 0.2 0<LOI<20 0<Eff<100	$0.2 < \Delta O2 < 0.2$ -5.2 < Mills < 5.2 B Mill clamped AOFA clamped	

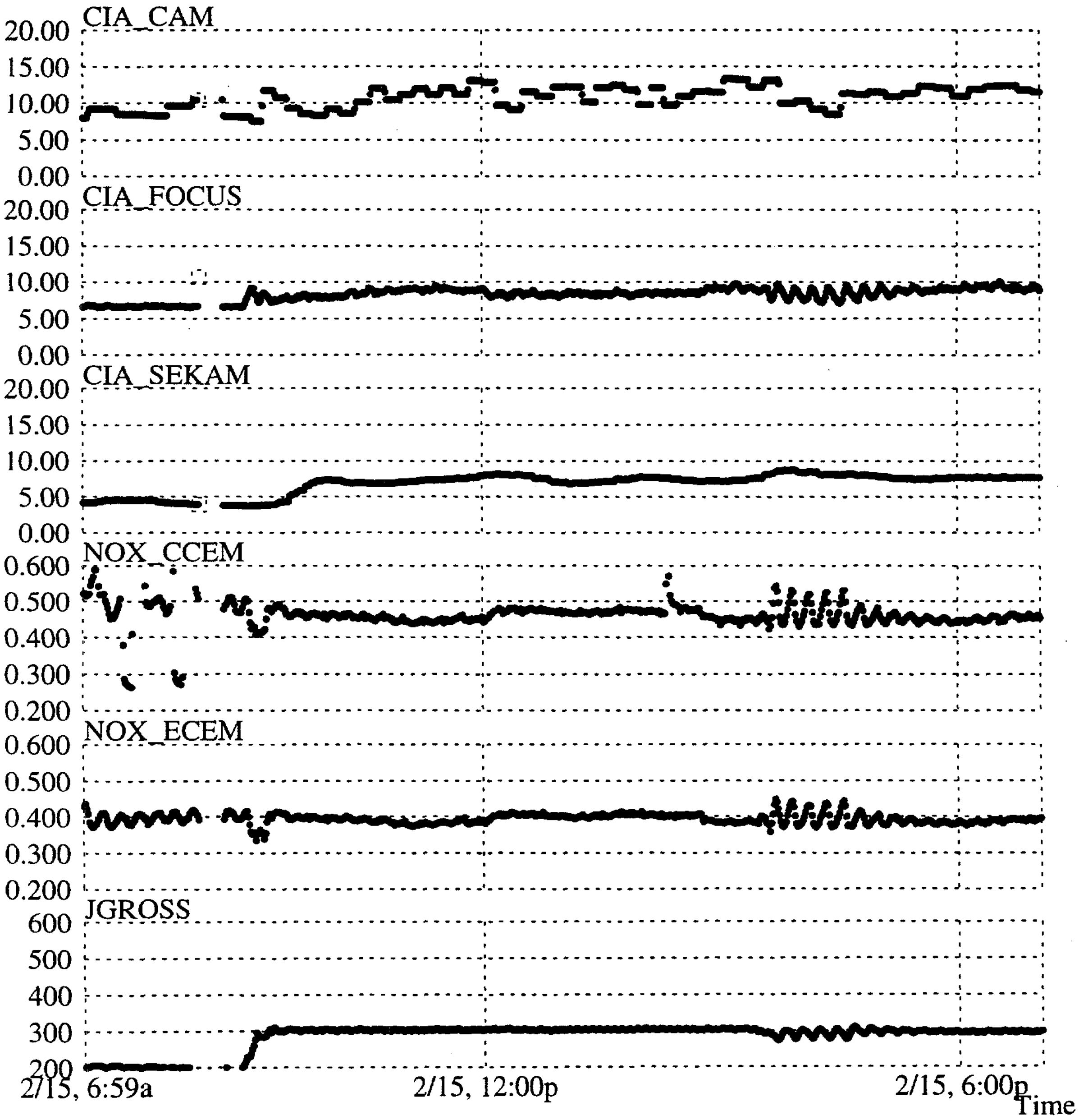
Data: 9602
Date: 09/19/96 08:21:08



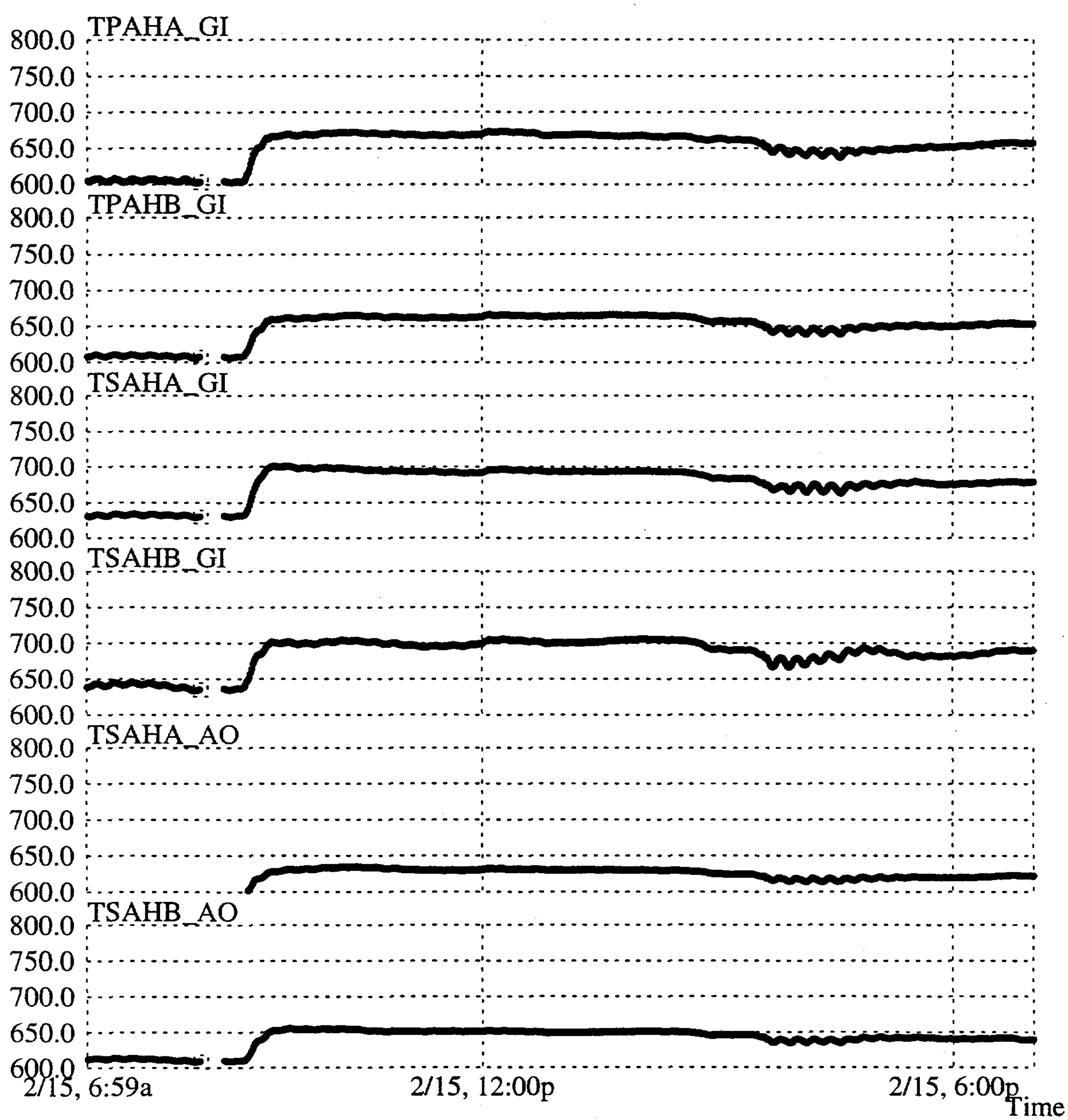
Data: 9602
Date: 09/19/96 08:50:40



Data: 9602
Date: 09/19/96 09:15:06



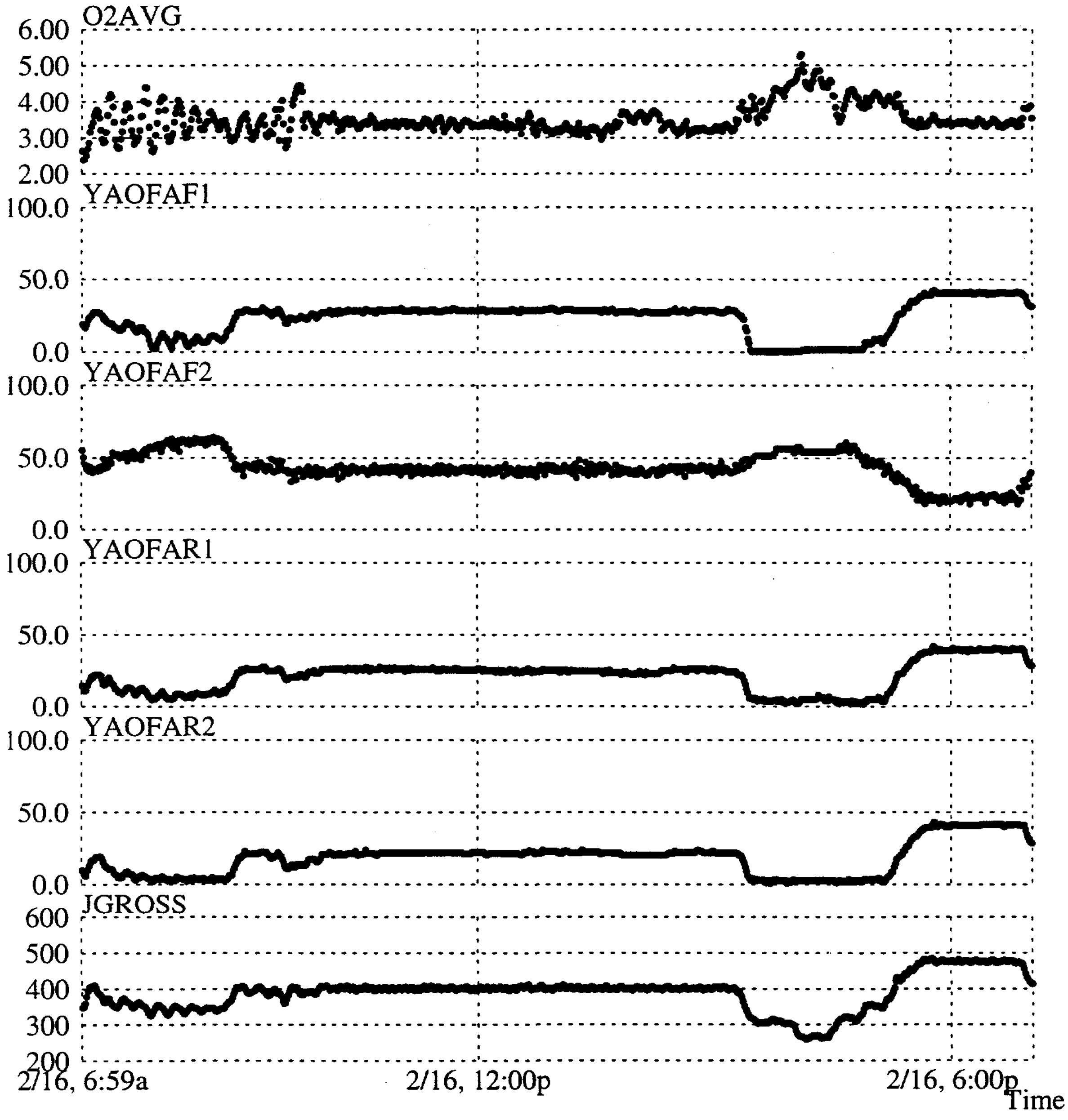
Data: 9602
Date: 09/19/96 09:25:54



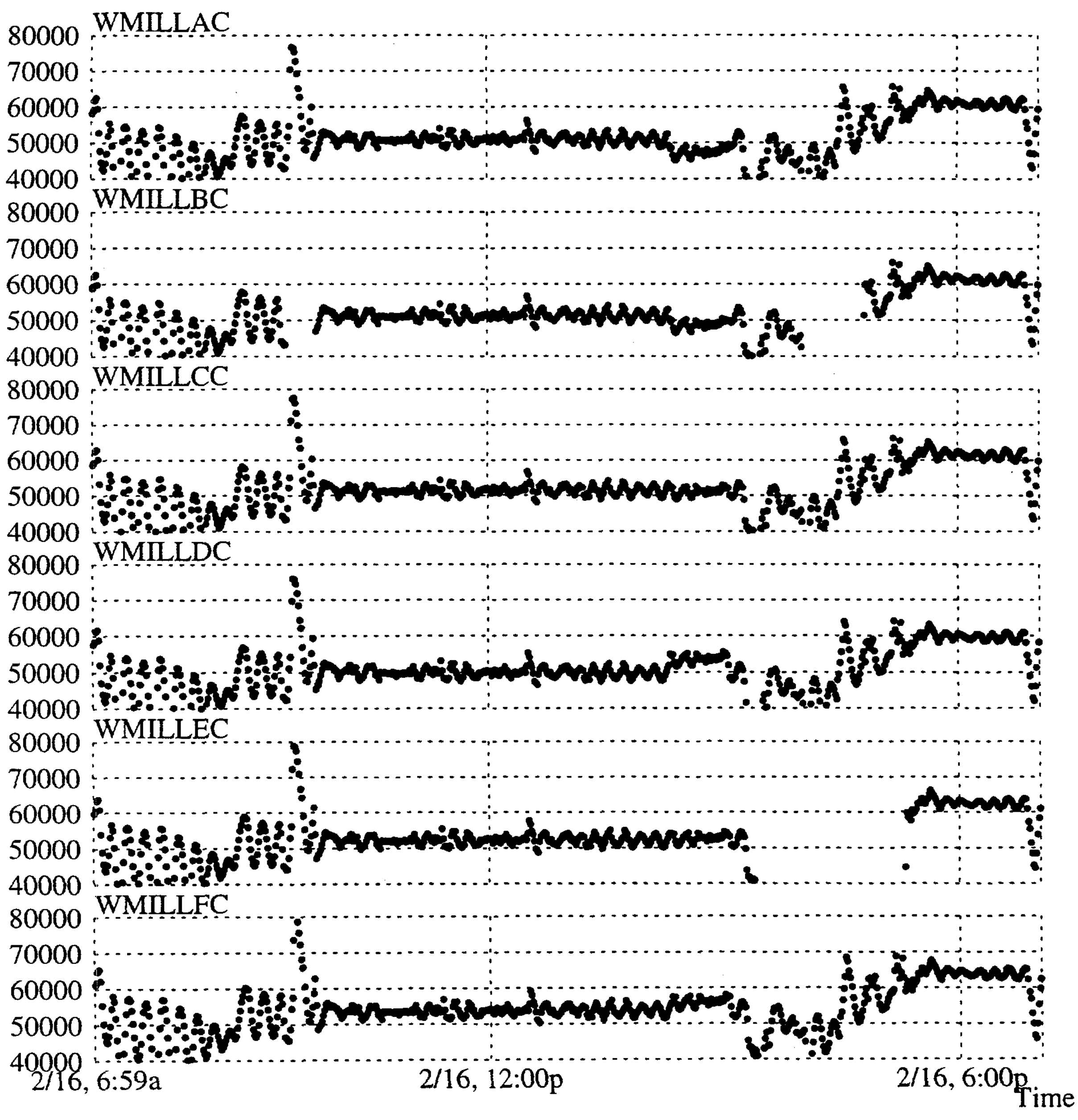
GNOCIS Testing Conducted February 16, 1996

Test	Date Appr. Start Time Appr. Stop Time	Load	Mills Out of Service	Model	Mode	Goals	Constraints	Notes
156-1	16-Feb-96 11:30 13:30	400	None	Hamcon31FC	Open-Loop Min NOx	0.2 < NOx < 0.2 0<LOI<20 0<Eff<100	0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	
156-2	16-Feb-96 12:50 14:00	400	None	Hamcon31FC	Open-Loop Min LOI	0.2 < NOx < 0.2 0<LOI<20 0<Eff<100	0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	
156-3	16-Feb-96 13:45 15:00	400	None	Hamcon31FC	Open-Loop Max Eff	0.2 < NOx < 1.0 0<LOI<20 100<Eff<100	0.2 < ΔO2 < 0.2 -5.2 < Mills < 5.2 -5 < AOFA < 5	

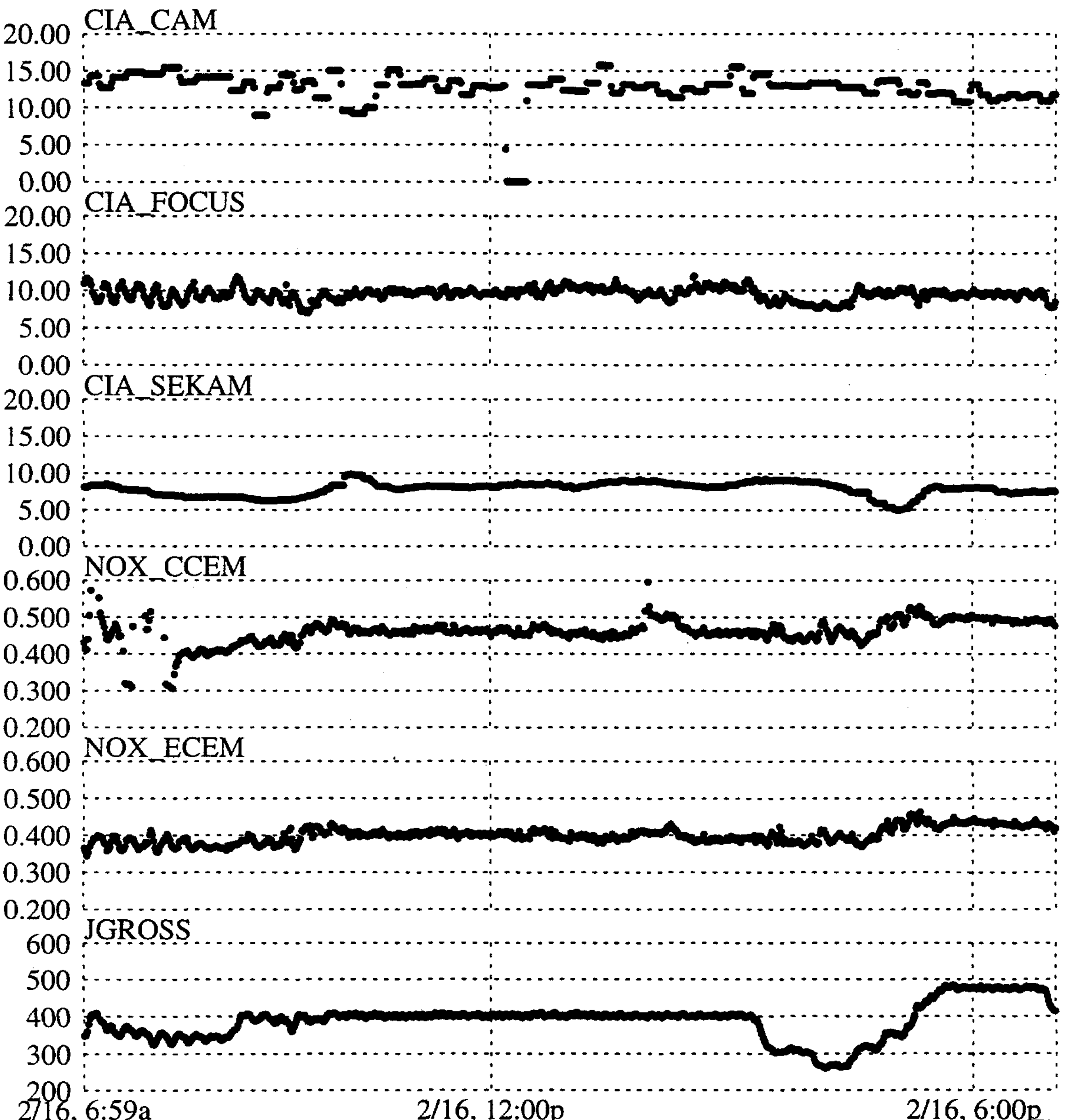
Data: 9602
Date: 09/19/96 08:51:04



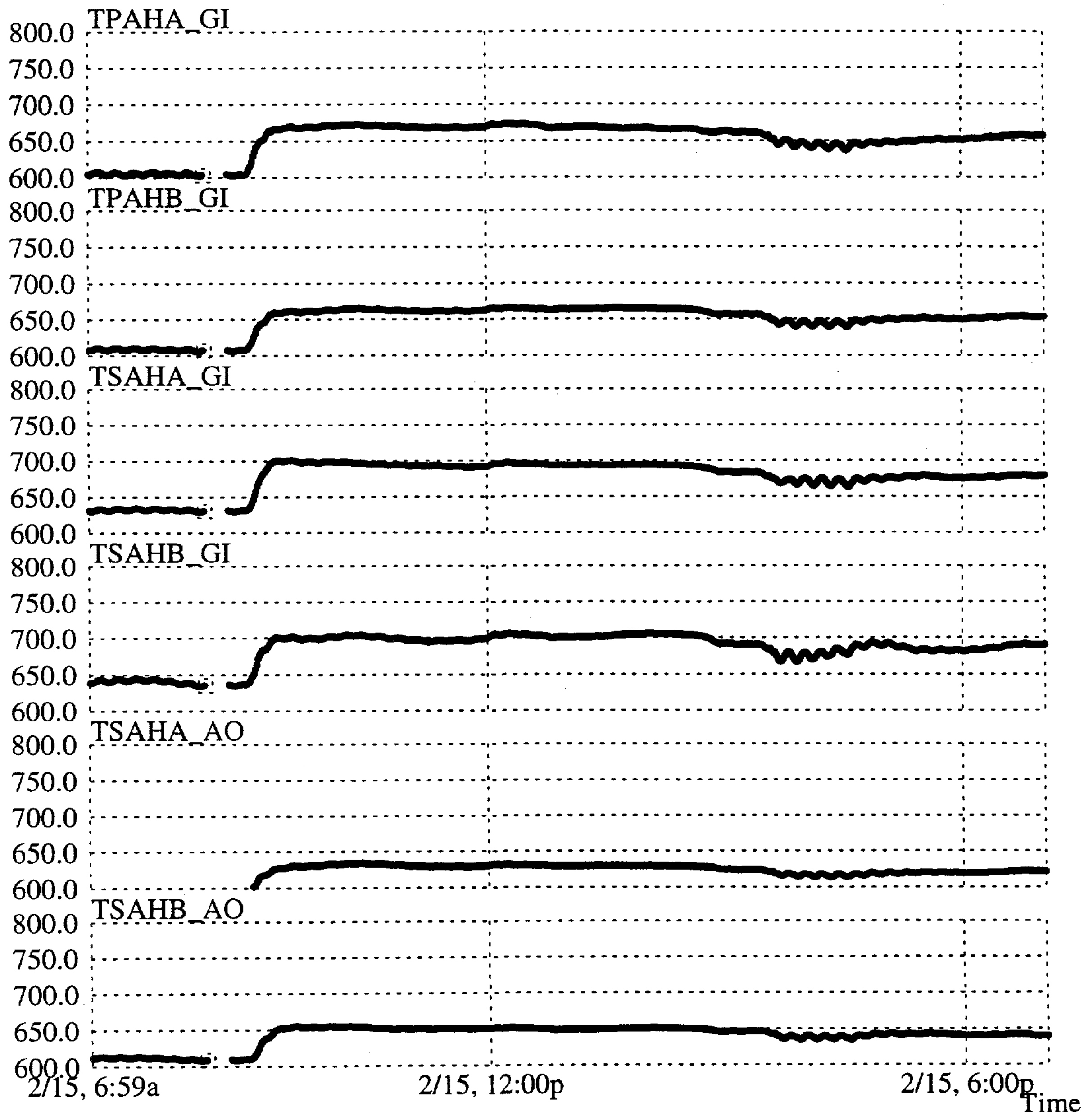
Data: 9602
Date: 09/19/96 08:21:54



Data: 9602
Date: 09/19/96 09:15:20



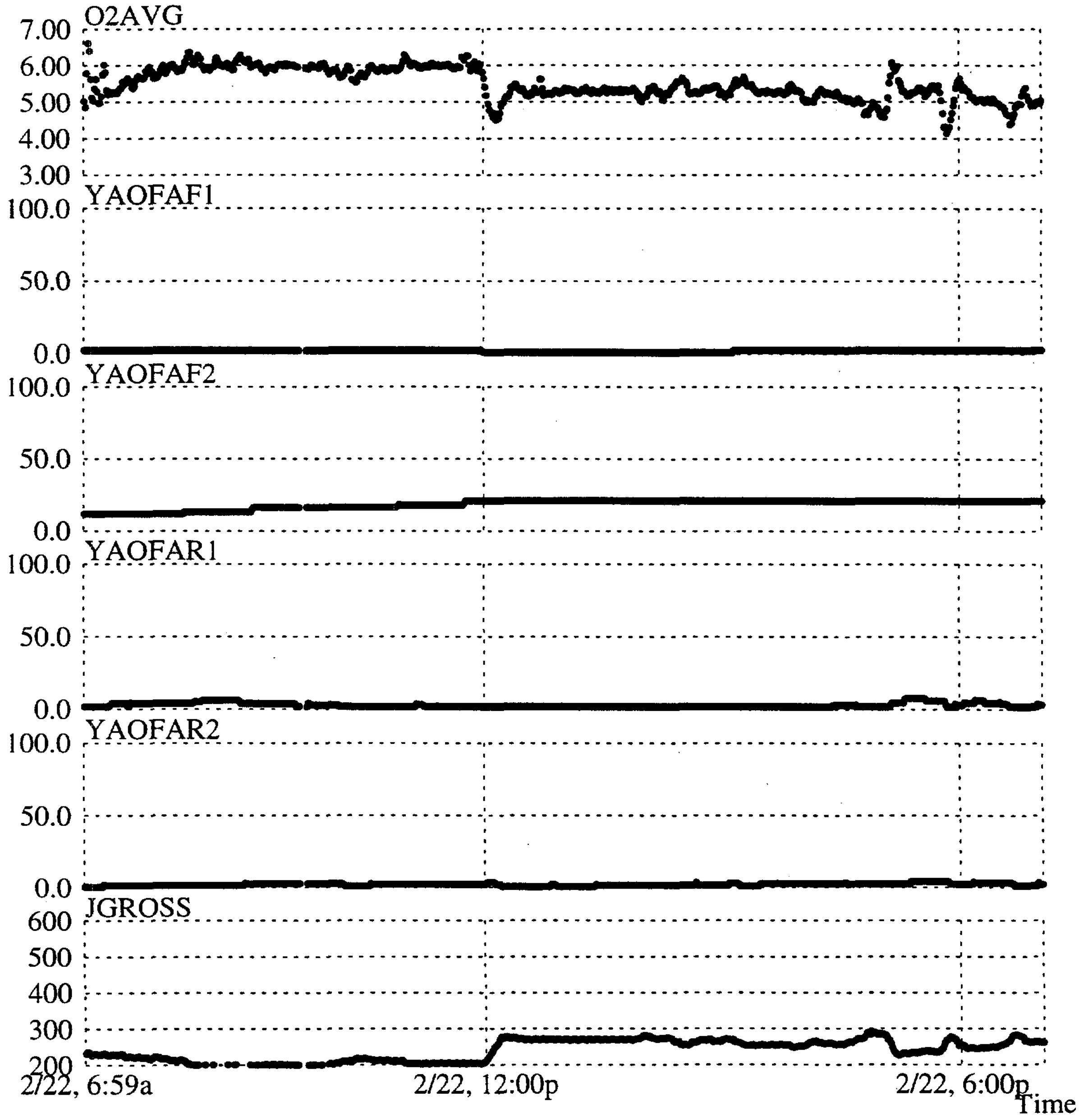
Data: 9602
Date: 09/19/96 09:26:05



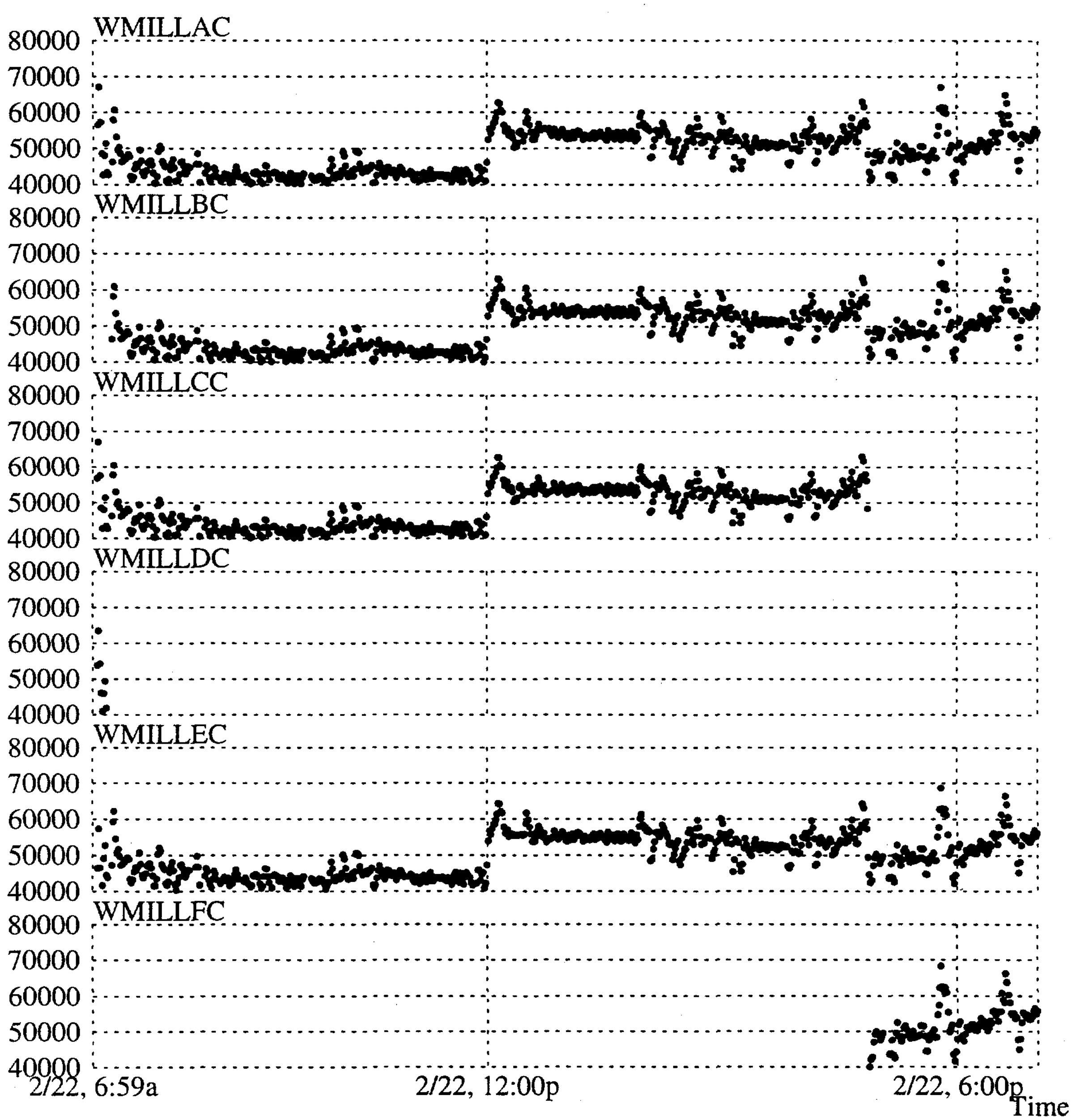
GNOCIS Testing Conducted February 22, 1996

Test	Date Appr. Start Time Appr. Stop Time	Load	Mills Out of Service	Model	Mode	Goals	Constraints	Notes
157-1	22-Feb-96 14:30 16:00	255	D,F	Hamcon31FC	Open-Loop Min NOx	0.2 < NOx < 0.2 0<LOI<20 0<Eff<100	0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	
157-2	22-Feb-96 15:30 17:30	260	D,F	Hamcon31FC	Closed-Loop Min LOI	0.2 < NOx < 1.0 0<LOI<0 0<Eff<100	0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	• First closed-loop test. • Test aborted when operator changed mills in service.
157-3	22-Feb-96 17:30 19:00	250	C,D	Hamcon31FC	Closed-Loop Min LOI	0.2 < NOx < 1.0 0<LOI<0 0<Eff<100	0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	• Move suppresion on O_2 zero.
157-4	22-Feb-96 19:00 19:30	250	C,D	Hamcon31FC	Closed-Loop Min NOx	0.2 < NOx < 0.2 0<LOI<20 0<Eff<100	0.2 < ΔO2 < 0.2 Mills clamped AOFA clamped	• Move suppresion on O_2 zero.
157-5	22-Feb-96 19:30 20:00	250	C,D	Hamcon31FC	Closed-Loop Min NOx, Max Eff LOI < 10	0.2 < NOx < 0.2 0<LOI<10 100<Eff<100		• Optimzer failure due to starting point being outside feasible region.
157-6	22-Feb-96 20:00 21:00	250	C,D	Hamcon31FC	Closed-Loop Min LOI	0.2 < NOx < 1.0 0<LOI<0 0<Eff<100		• Optimzer failure due to starting point being outside feasible region.

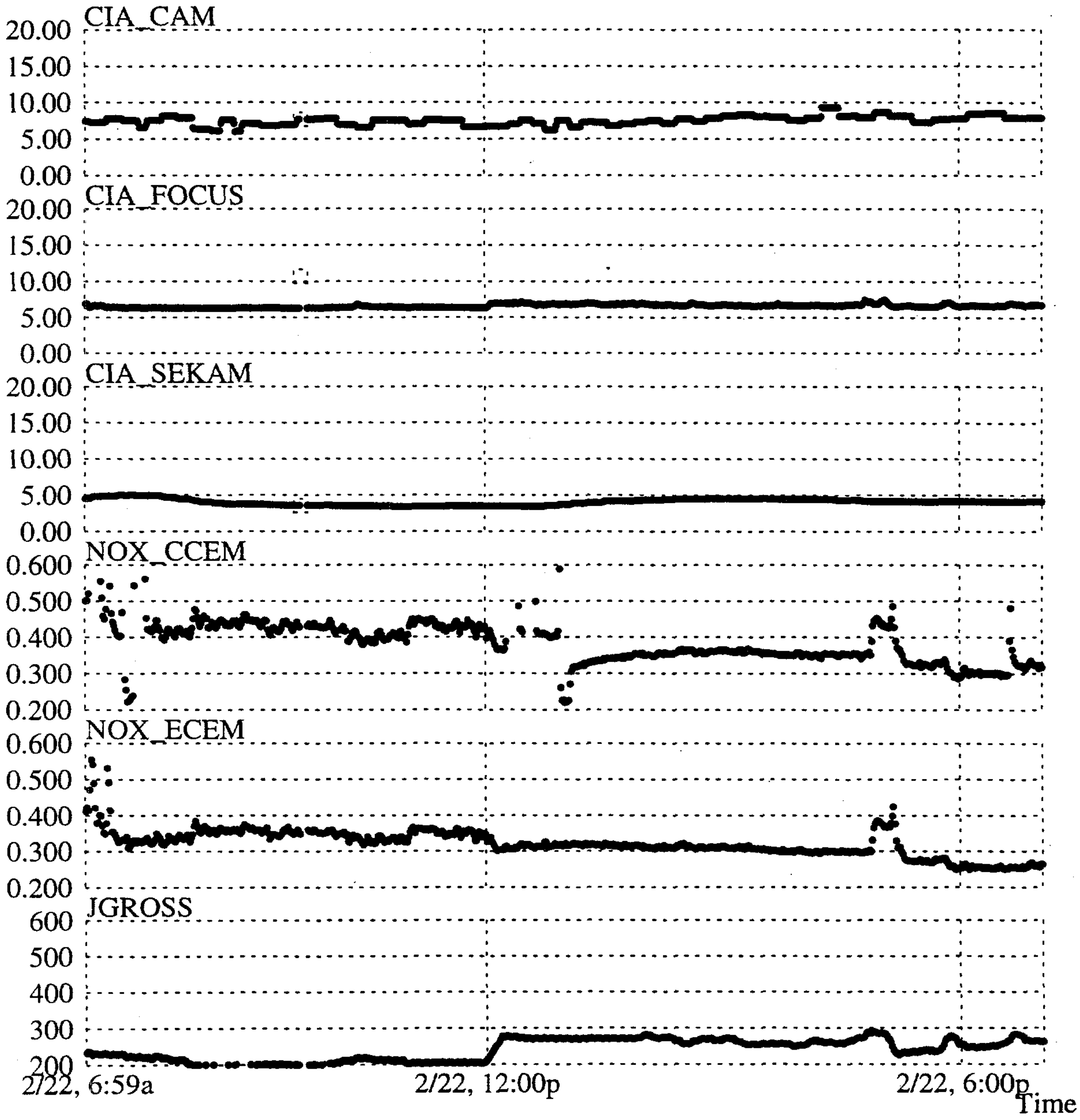
Data: 9602
Date: 09/19/96 08:52:00



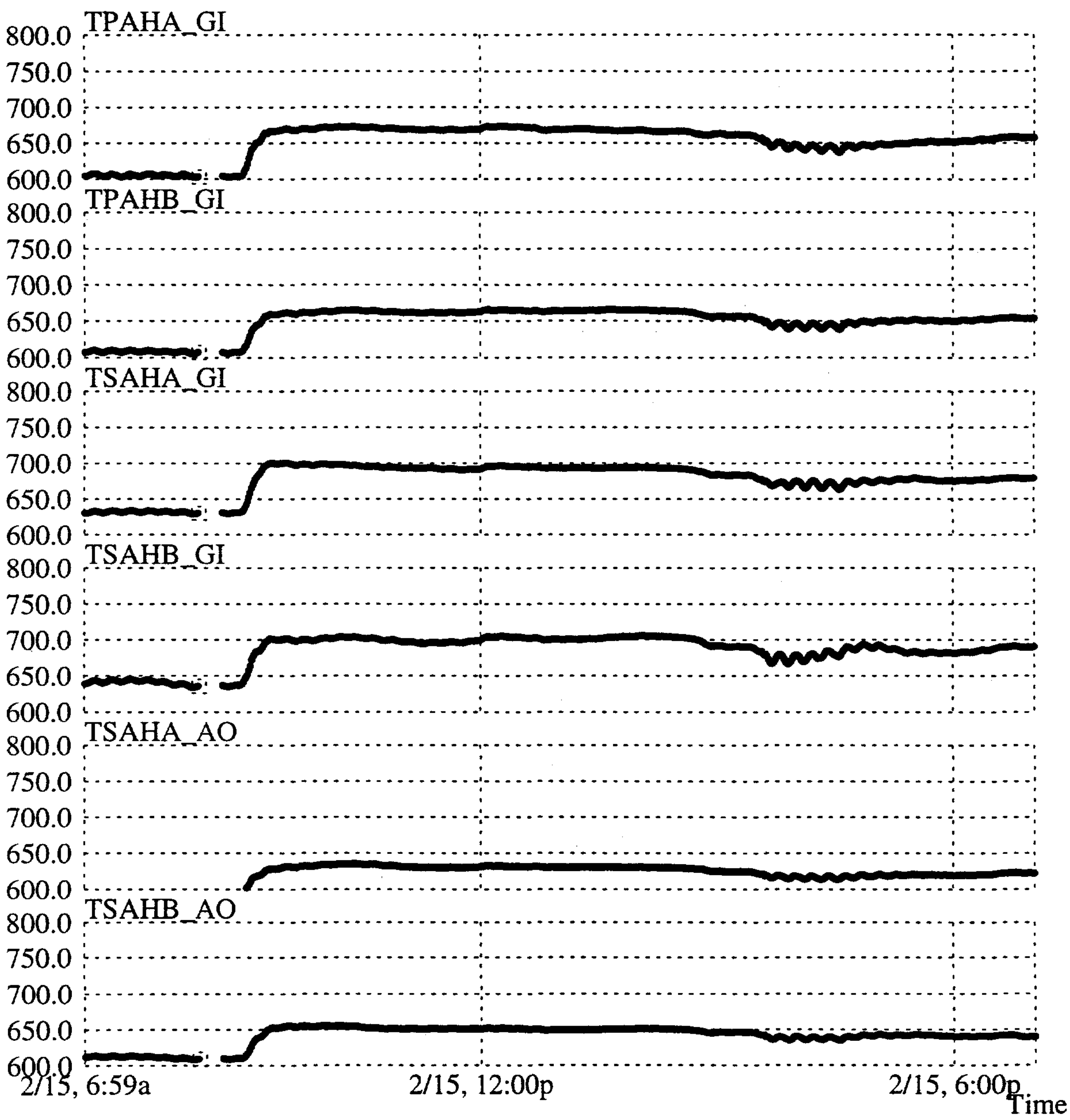
Data: 9602
Date: 09/19/96 08:22:22



Data: 9602
Date: 09/19/96 09:15:44



Data: 9602
Date: 09/19/96 09:26:16



Appendix B

Testing of On-Line Carbon-in-Ash Analyzers

February 1996

Table B-1
Results of Isokinetic Sampling

Test #	Date	Time	O Excess	Load	CAM %LOI	SEKAM %LOI	FOCUS	Duct	Lab % LOI	%Carbon	Sample ID	Inventory#
152-1	2/8/96	10:40 AM	3.40	500	12.97	NA	8.29	A	10.26	9.46	AA08611	H4PH4B-001
							7.17	B	8.37	7.77	08612	002
152-2	2/8/96	1:30 PM	3.70	500	11.64	NA	7.78	A	9.63	8.88	08613	003
							6.37	B	6.84	6.01	08614	004
152-3	2/8/96	3:30 PM	4.26	500	10.34	NA	6.40	A	6.47	6.12	08615	005
							5.10	B	6.09	5.71	08616	006
152-4	2/8/96	6:30 PM	4.35	400	13.7	NA	5.60	A	7.94	6.78	08617	007
							5.93	B	11.01	9.99	08618	008
152-5	2/8/96	8:30 PM	3.54	400	16.28	NA	7.07	A	11.19	11.29	08619	009
							8.33	B	11.05	10.13	08620	010
153-1	2/9/96	10:20 AM	4.34	300	10.54	5.94	7.15	A	7.73	6.42	AA08738	051
							5.00	B	7.25	6.22	08739	052
153-2	2/9/96	12:05 PM	3.57	300	13.40	6.09	7.18	A	10.59	9.57	08740	053
							5.58	B	8.27	7.20	08741	054
153-3	2/9/96	1:30 PM	5.09	300	9.03	6.51	7.07	A	5.38	4.47	08742	055
							4.23	B	5.98	4.9	08743	056
153-4	2/9/96	3:23 PM	4.57	400	10.92	9.55	6.18	A	8.32	6.76	08744	057
							5.50	B	6.81	5.73	08745	058

Retest

Test #	Date	Time	O Excess	Load	CAM %LOI	SEKAM %LOI	FOCUS	Duct	Lab % LOI	%Carbon	Sample ID	Inventory#
152-4	2/8/96	6:30 PM	4.35	400	13.7	NA	5.60	A	8.17	7.11	AA08617	H4PH4B-007
							5.93	B	11.35	10.1	08618	008
152-5	2/8/96	8:30 PM	3.54	400	16.28	NA	7.07	A	11.36	11.69	08619	009
							8.33	B	10.68	10.13	08620	010

Table B-2
Hopper Sampling

Test#	Date	Time	Load	O Excess	Hopper #	Lab %LOI	Sample ID	Inventory#
152-1	2/8/96	10:40 AM	500	3.40	AA1	10.19	AA08621	H4PH4B-011
					AA2	11.14	08622	012
					AA3	7.78	08623	013
					AA4	7.40	08624	014
					BA1	6.31	08625	015
					BA2	7.10	08626	016
					BA3	7.54	08627	017
					BA4	8.96	08628	018
152-2	2/8/96	1:30 PM	500	3.70	AA1	9.55	08629	019
					AA2	10.07	08630	020
					AA3	7.72	08631	021
					AA4	8.01	08632	022
					BA1	5.95	08633	023
					BA2	6.66	08634	024
					BA3	8.25	08635	025
					BA4	9.01	08636	026
152-3	2/8/96	3:30 PM	500	4.26	AA1	7.61	08637	027
					AA2	9.49	08638	028
					AA3	5.82	08639	029
					AA4	5.08	08640	030
					BA1	4.64	08641	031
					BA2	5.05	08642	032
					BA3	7.10	08643	033
					BA4	6.72	08644	034
152-4	2/8/96	6:30 PM	400	4.35	AA1	11.99	08645	035
					AA2	11.19	08646	036
					AA3	7.37	AA08724	037
					AA4	10.40	08725	038
					BA1	6.27	08726	039
					BA2	8.31	08727	040
					BA3	12.00	08728	041
					BA4	10.57	08729	042
152-5	2/8/96	8:30 PM	400	3.54	AA1	12.67	08730	043
					AA2	12.79	08731	044
					AA3	7.66	08732	045
					AA4	7.31	08733	046
					BA1	10.17	08734	047

Table B-2 (continued)
Hopper Sampling

Test#	Date	Time	Load	O Excess	Hopper #	Lab %LOI	Sample ID	Inventory#
152-5	2/8/96	8:30 PM	400	3.54	BA2	9.53	08735	H4PH4B-048
					BA3	13.47	08736	049
					BA4	11.85	08737	050
153-1	2/9/96	10:20 AM	300	4.34	AA1	6.92	AA08746	059
					AA2	7.25	08747	060
					AA3	5.78	AA08794	061
					AA4	5.79	08795	062
					BA1	5.00	08796	063
					BA2	6.20	08797	064
					BA3	6.59	08798	065
					BA4	6.41	08799	066
153-2	2/9/96	12:05 PM	300	3.57	AA1	5.99	08800	067
					AA2	8.07	08801	068
					AA3	7.06	08802	069
					AA4	5.86	08803	070
					BA1	5.74	08804	071
					BA2	6.47	08805	072
					BA3	7.41	08806	073
					BA4	7.33	08807	074
153-3	2/9/96	1:30 PM	300	5.09	AA1	5.75	08808	075
					AA2	8.51	08809	076
					AA3	8.87	08810	077
					AA4	6.99	08811	078
					BA1	3.84	08812	079
					BA2	5.29	08813	080
					BA3	6.22	08814	081
					BA4	6.37	08815	082
153-4	2/9/96	3:23 PM	400	4.57	AA1	9.96	08816	083
					AA2	10.13	08817	084
					AA3	6.25	08818	085
					AA4	6.55	08819	086
					BA1	4.31	08820	087
					BA2	4.79	08821	088
					BA3	6.85	08822	089
					BA4	7.19	08823	090

Figure B-1
Fly Ash Carbon vs. LOI

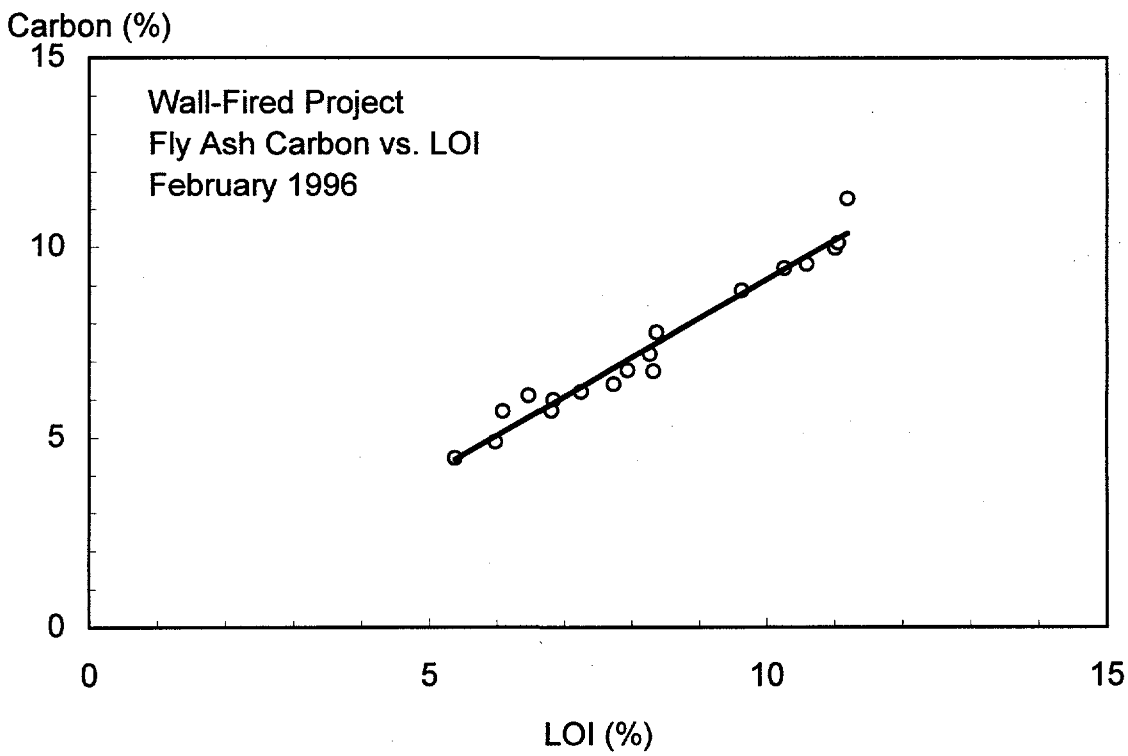


Figure B-2
Hopper Sample vs. Isokinetic Sample (Side A)

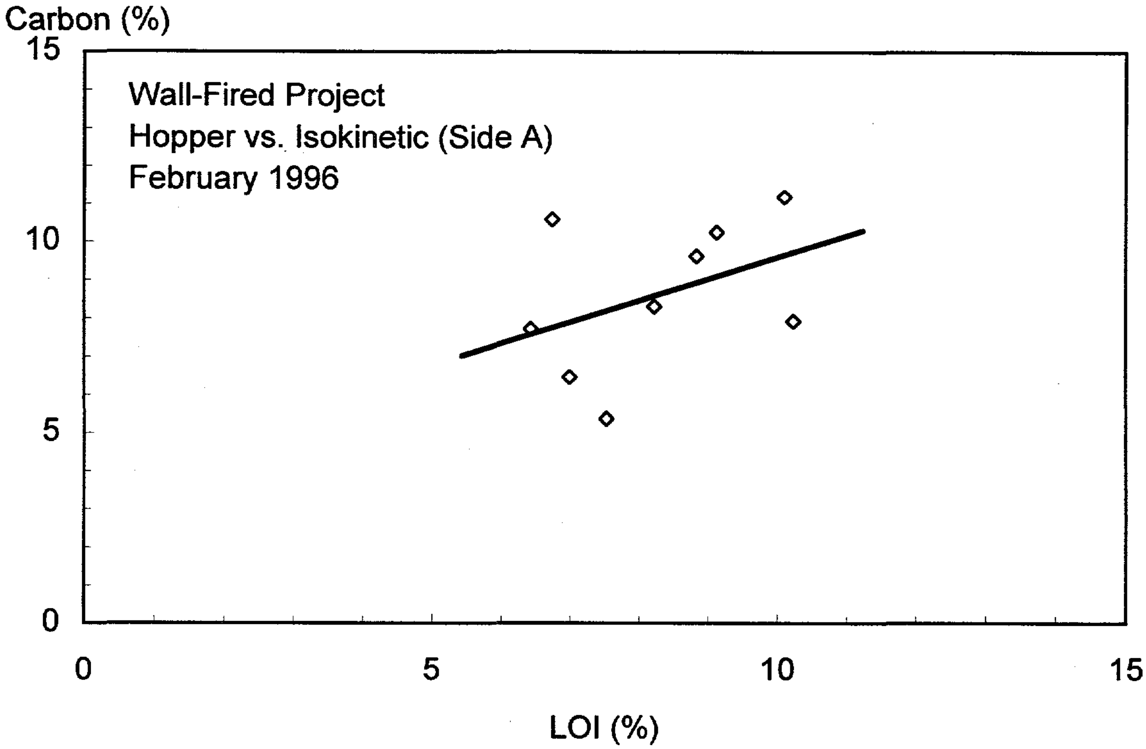


Figure B-3
Hopper Sample vs. Isokinetic Sample (Side B)

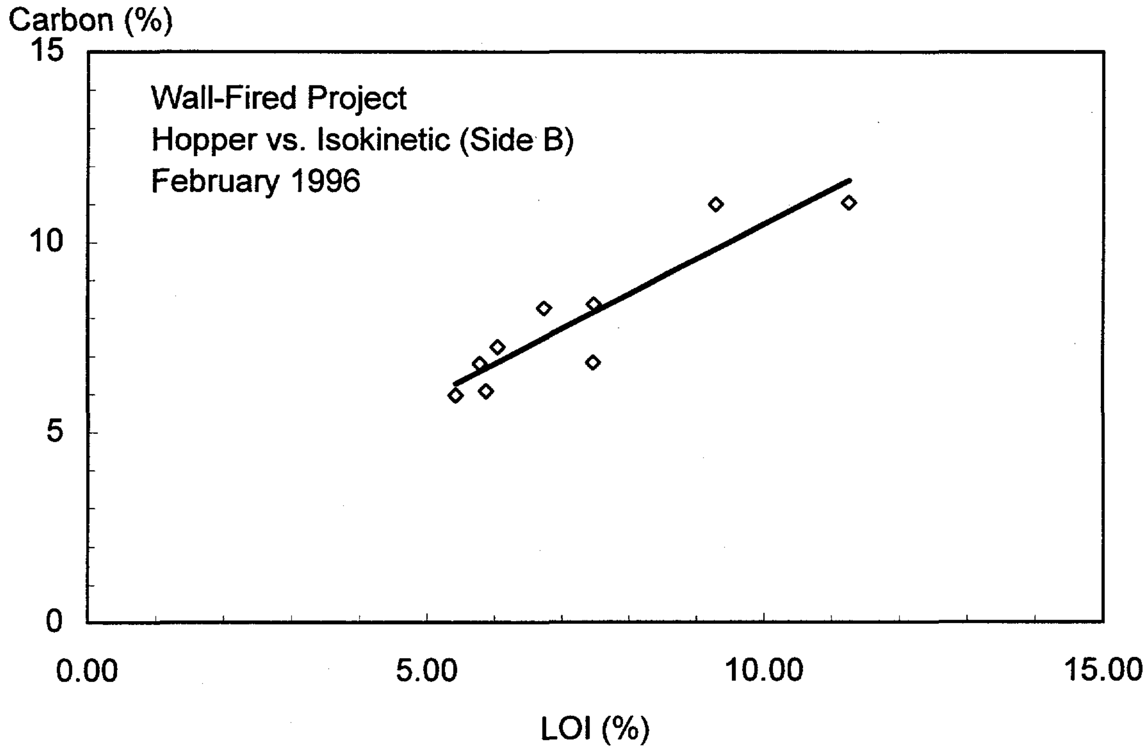


Figure B-4
SEKAM vs. Isokinetic LOI

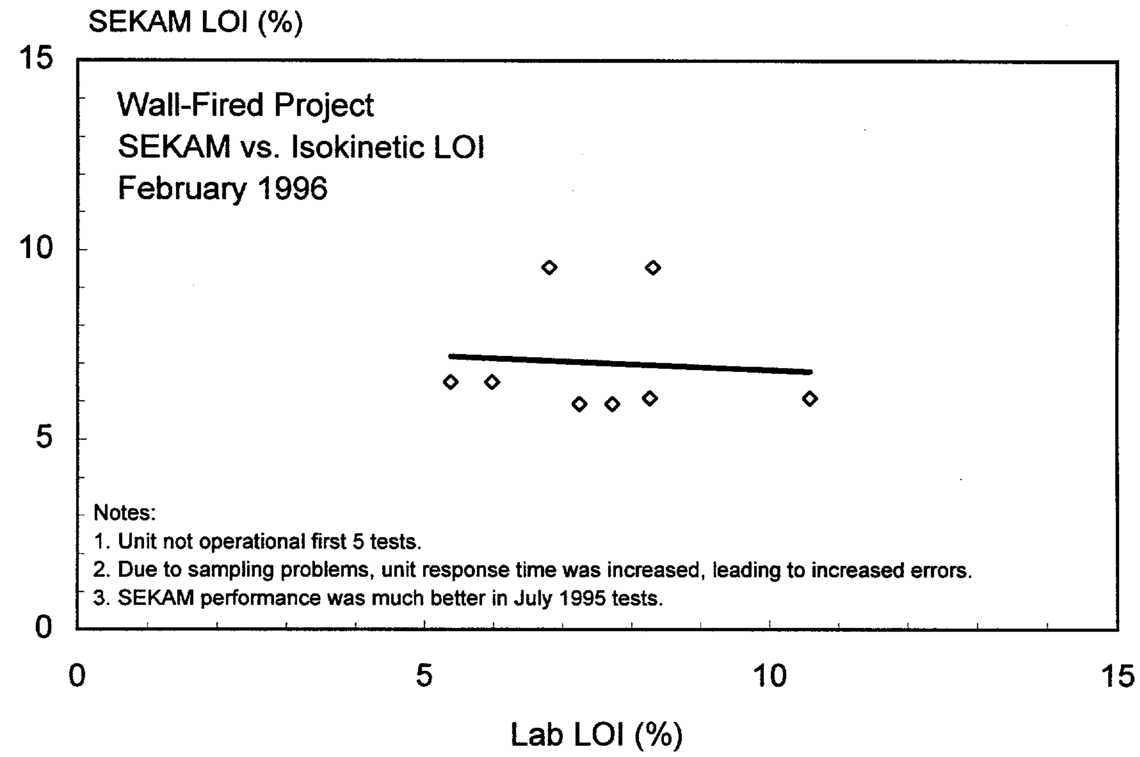


Figure B-5
CAM vs. Isokinetic LOI

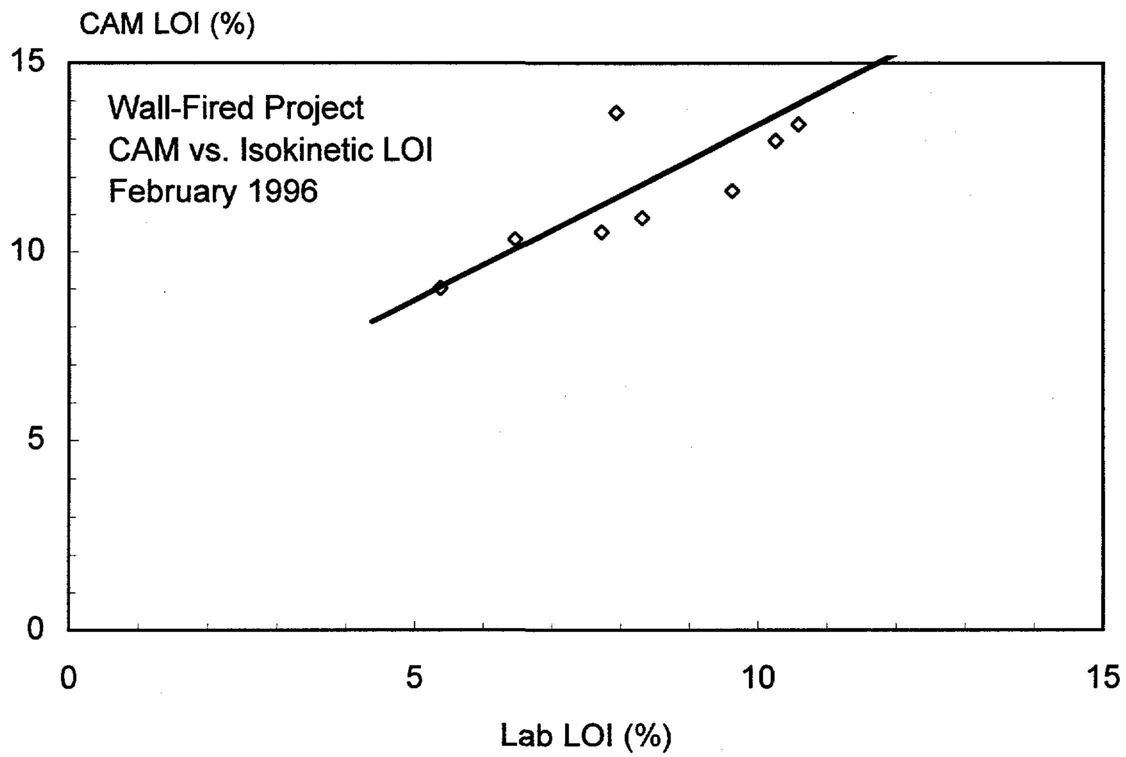


Figure B-6
FOCUS vs. Isokinetic LOI (Side A)

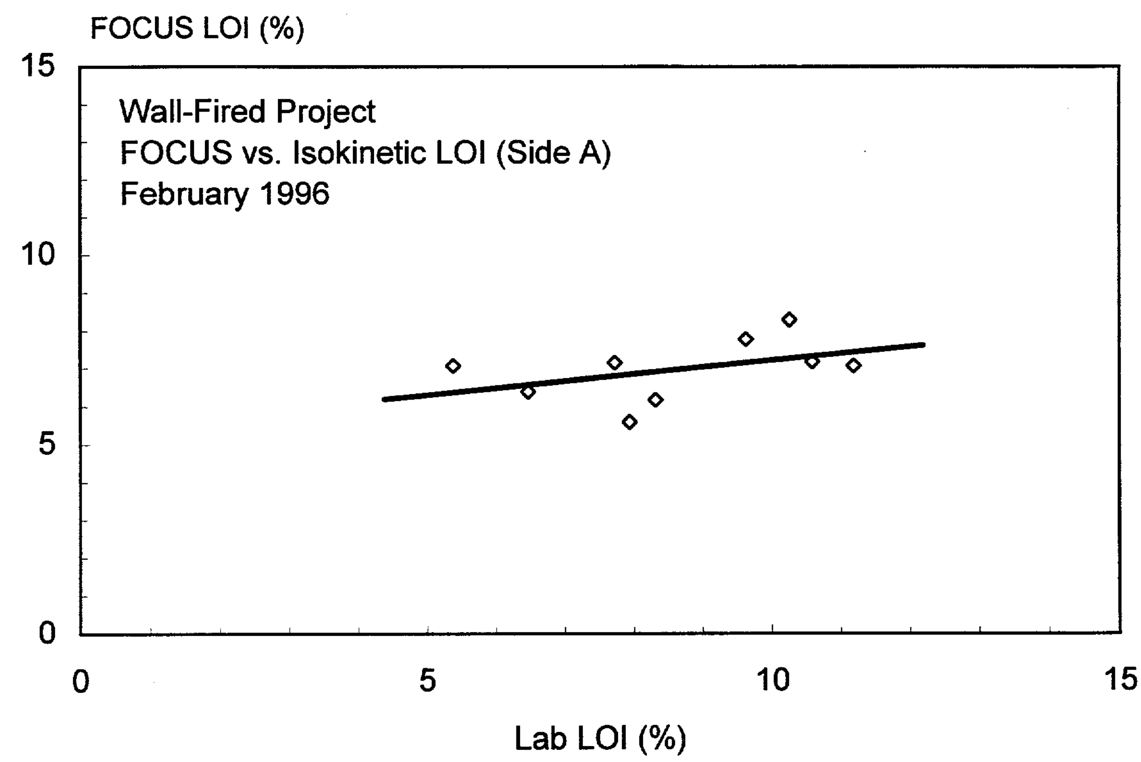


Figure B-7
FOCUS vs. Isokinetic LOI (Side B)