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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
Third Quarter 1993**

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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 (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. A target of achieving fifty percent NO_x reduction using combustion modifications has been established for the project. The project provides a stepwise retrofit of an advanced overfire air (AOFA) system followed by low NO_x burners (LNB). During each test phase of the project, diagnostic, performance, long-term, and verification testing will be performed. These tests are used to quantify the NO_x reductions of each technology and evaluate the effects of those reductions on other combustion parameters such as particulate characteristics and boiler efficiency.

Baseline, AOFA, LNB, and LNB plus AOFA test segments have been completed. Analysis of the 94 days of LNB long-term data collected show the full-load NO_x emission levels to be approximately 0.65 lb/MBtu with fly ash LOI values of approximately 8 percent. Corresponding values for the AOFA configuration are 0.94 lb/MBtu and approximately 10 percent. For comparison, the long-term, full-load, baseline NO_x emission level was approximately 1.24 lb/MBtu at 5.2 percent LOI. Comprehensive testing in the LNB+AOFA configuration indicate that at full-load, NO_x emissions and fly ash LOI are near 0.40 lb/MBtu and 8 percent, respectively. However, it is believed that a substantial portion of the incremental change in NO_x emissions between the LNB and LNB+AOFA configurations is the result of additional burner tuning and other operational adjustments and is not the result of the AOFA system.

During this quarter, LNB+AOFA testing was concluded. Testing performed during this quarter included long-term and verification testing in the LNB+AOFA configuration. On September 3, 1993, Hammond Unit 4 began a nine month outage. The major activities planned during this outage include (1) installation of the Advanced Low NO_x Digital Control System, (2) replacement of the two remaining Foster Wheeler mills with Babcock and Wilcox MPS 75 mills, (3) replacement of the precipitator, and (4) upgrade of the low pressure turbine. Configuration of the digital control system is in progress at SCS facilities in Birmingham and control functional diagrams are now undergoing internal

review. The control room is now being modified to accept the digital control system which is scheduled for installation during the first and second quarter 1994. A joint DOE/EPRI/SCS meeting on the application of artificial intelligence to NOx controls was held September 28-29, 1993 at the DOE Pittsburgh Energy Technology Center. A primary objective of this meeting was to evaluate advanced control/optimization packages for use at Hammond 4.

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TABLE OF ABBREVIATIONS

AMIS	All mills in service
AOFA	Advanced Overfire Air
ASME	American Society of Mechanical Engineers
C	carbon
CEM	Continuous emissions monitor
CFSF	Controlled Flow/Split Flame
Cl	chlorine
CO	carbon monoxide
DAS	data acquisition system
DOE	United States Department of Energy
ECEM	extractive continuous emissions monitor
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
F	Fahrenheit
FC	fixed carbon
FWEC	Foster Wheeler Energy Corporation
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 NO _x burner
LOI	loss on ignition
(M)Btu	(million) British thermal unit
MOOS	Mills out of service
MW	megawatt
N	nitrogen
NO _x	nitrogen oxides
O, O ₂	oxygen
PA	primary air
psig	pounds per square inch gauge
PTC	Performance Test Codes
RSD	relative standard deviation
S	sulfur
SCS	Southern Company Services
SO ₂	sulfur dioxide
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
- 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			
500 MW Demonstration of Advanced Wall-Fired Combustion Techniques for the Reduction of Nitrogen Oxide (NO _x) Emissions from Coal-Fired Boilers			
Phase	Task	Description	Date
0	1.0	Phase 0 Pre-Award Negotiations	
1	1.1	Phase 1 Baseline Characterization	8/89 - 4/90
	1.1.1	Project Management and Reporting	8/89 - 10/89
	1.1.2	Site Preparation	9/89 - 6/90
	1.1.3	Flow Modeling	9/89 - 10/89
	1.1.4	Instrumentation	11/89 - 4/90
	1.1.5	Baseline Testing	
2	1.2	Phase 2 Advanced Overfire Air Retrofit	4/90 - 3/91
	1.2.1	Project Management and Reporting	4/90 - 5/90
	1.2.2	AOFA Design and Retrofit	5/90 - 3/91
	1.2.3	AOFA Testing	
3	1.3	Phase 3 Low NO _x Burner Retrofit ¹	
	1.3.1	Project Management and Reporting	3/91 - 4/93
	1.3.2	LNB Design and Retrofit	3/91 - 5/91
	1.3.3	LNB Testing with and without AOFA	5/91 - 9/93
4	1.4	Final Reporting and Disposition ^{1,2}	
	1.4.1	Project Management and Reporting	9/93 - 12/93
	1.4.2	Disposition of Hardware	12/93

¹Dates of these tasks reflects change from original project schedule.

²Final reporting and disposition will be renumbered to Task 5 upon final approval of the digital controls extension to this project.

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 Figures 1 and 2, 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.

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.

Table 2. Plant Data Points	
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 NO_x	Stack SO_2
Stack O_2	Stack Opacity
Generation	Overfire Air Flows

Following each outage, a series of four groups of tests are planned. 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.

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 (Figure 1) 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 four Babcock and Wilcox MPS 75 mills during the course of the demonstration (two each during the spring 1991 and spring 1992 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 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.

Figure 1. Plant Hammond Unit 4 Boiler

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.

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.

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.

Figure 3. Low NO_x Burner Installed at Plant Hammond

3. PROJECT STATUS

3.1. Quarterly Summary

During this quarter, LNB+AOFA testing was concluded. Testing performed during this quarter included long-term and verification testing in the LNB+AOFA configuration. On September 3, 1993, Hammond Unit 4 began a nine month outage. The major activities planned during this outage include (1) installation of the Advanced Low NO_x Digital Control System, (2) replacement of the two remaining Foster Wheeler mills with Babcock and Wilcox MPS 75 mills, (3) replacement of the precipitator, and (4) upgrade of the low pressure turbine. Configuration of the digital control system is in progress at SCS facilities in Birmingham and control functional diagrams are now undergoing internal review. The control room is now being modified to accept the digital control system which is scheduled for installation during the first and second quarter 1994. A joint DOE/SCS/EPRI meeting on the application of artificial intelligence to NO_x controls was held September 28-29, 1993 at the DOE Pittsburgh Energy Technology Center. A primary objective of this meeting was to evaluate advanced control/optimization packages for use at Hammond 4.

3.2. Phase 1 - Baseline Characterization

Phase 1 baseline testing ended in April 1990. During baseline testing, 52 days of long-term data were collected producing an average NO_x emission level of 1.12 lb/MBtu. NO_x emissions generally increased with load and ranged from 0.9 to 1.3 lb/MBtu. The band about the mean represents the range between the 5th and 95th percentiles of the data set and show the variability of NO_x emissions during long-term operation. The long-term data demonstrates a full-load, mean NO_x level of approximately 1.24 lb/MBtu. Details of this test phase can be found in the *Phase 1 Baseline Tests Report*.¹

3.3. Phase 2 - Advanced Overfire Air Retrofit and Characterization

The AOFA system was installed during a four week unit outage during spring 1990. For more information on the outage and installation see the *Second Quarter 1990 Technical Progress Report*.²

Following optimization by FWEC, AOFA tests at Plant Hammond (with the pre-NSPS

Intervane burners still in operation) were completed in March 1991. During the AOFA test phase, the unit was operated according to FWEC instructions provided in the design manuals. During AOFA testing, 86 days of long-term data were collected for which the average NO_x emission level was 0.92 lb/MBtu and the full-load, mean, NO_x emission level was 0.94 lb/MBtu. Details of this test phase can be found in the *Phase 2 AOFA Tests Report*.³

3.4. Phase 3A - Low NO_x Burner Retrofit and Characterization

The LNBs were installed during a seven week unit outage during spring 1991. For more information on the outage and installation see the *Second Quarter 1991 Technical Progress Report*.⁴

Following optimization by FWEC, characterization of the low NO_x burner system began in June 1991 and ended in January 1992. Diagnostic testing was performed from July 9 to July 20, 1991 and performance testing began July 16, 1991. During the LNB test phase, the unit was operated according to FWEC instructions provided in the design manuals. This testing indicated that the low NO_x burners were not optimally configured and, therefore, testing was postponed for four days to allow FWEC personnel to make additional adjustments to the new burners and ancillary systems. Testing continued on July 22 and was completed July 28, 1991.

Long-term testing of the low NO_x burners began on August 7, 1991 and was completed on December 19, 1991. Ninety-four days of long-term data were collected for which the average NO_x emission level was 0.53 lb/MBtu and the full-load, mean, NO_x emission level was 0.65 lb/MBtu.

3.5. Phase 3B - LNB+AOFA Characterization

Following completion of the LNB test phase during January 1992, testing in the low NO_x burner and advanced overfire air configuration was to begin with completion scheduled for late March 1992. However, due to delays associated with increased stack particulate emissions following the LNB installation, it was not possible to complete testing in the LNB+AOFA configuration prior to the Spring 1992 outage during which two new mills were to be installed. To obtain operating data prior to this outage, abbreviated testing (designated 3B') in the LNB+AOFA configuration was performed during February and

March 1992. In order to maintain stack particulate compliance, the unit ran at reduced loads (less than 450 MW) until Spring 1993. During this period, long-term data was collected and the NOx vs. LOI tests were performed. Hammond Unit 4 was given permission from the state to resume full-load operation on March 26, 1993. Following resumption of full load operation on March 26, 1993, FWEC personnel re-optimized the unit for LNB+AOFA operation from March 30, 1993 through May 6, 1993.

The short-term testing consisted of first performing diagnostic testing to establish the general NOx and operating trends followed by performance testing to establish the characteristics of the fuel/air feed systems and the solid and gaseous emissions for the most representative configuration. Following the performance testing, the NOx emissions and unit operating parameters were monitored continuously, 24-hours per day, for a period of 61 days. At the end of the long-term test period a short series of verification tests was conducted, similar to diagnostic testing, to determine whether any change had occurred in the basic unit emission characteristics over the long-term period. All tests during the diagnostic, performance, and verification portions of the short-term test effort were conducted within the normal limits of operating parameters for the unit, with the exception of excess oxygen. Excess oxygen was exercised well above and below the plant specified range at each load level to the potential levels that might be encountered during transients in the long-term test phase. All major boiler components, as well as ancillary equipment, were in the normal "as found" operating condition. The fuel burned throughout the Phase 3B short-term program was from the normal supply source and was handled according to common plant practice. For all Phase 3B testing (LNB with AOFA) the main AOFA guillotine dampers and AOFA port dampers were full open and the AOFA flow control dampers were nominally open to the settings recommended by FWEC over the load range. For some diagnostic and verification tests the AOFA flow control dampers were opened more or less than the nominal settings to determine the effects of AOFA flow on NOx emissions and on operating parameters. For all tests, the AOFA flow was read from the AOFA flow meter readouts in the control room, which represented the air flows to the front and rear, east and west quadrants of the AOFA windbox. During the performance testing, additional measurements were made of the air flow into each OFA quadrant by means of pitot traverses performed in accordance with ASME and EPA test procedures.

The following paragraphs describe the abbreviated, diagnostic, performance and verification testing performed during Phase 3B.

3.5.1. Diagnostic Tests

The initial Phase 3B short-term characterization testing was begun on May 6, 1993 and was completed on August 26, 1993. A total of 53 diagnostic tests was performed during this period. The Phase 3B diagnostic effort consisted of characterizing emissions under normal operating conditions with the LNB's installed and the AOFA flow control dampers opened to the settings recommend by FWEC, as well as greater and lesser settings. The tests were performed at nominal loads of 180, 300, 400, 450 and 480 MW. The diagnostic test efforts were interrupted to accomplish the performance testing due to scheduling conflicts. Diagnostic testing was then completed after the performance testing was completed. The initial diagnostic testing began shortly after FWEC completed start-up testing for the LNB/AOFA configuration. Each test condition (load, excess oxygen, AOFA flow and mill configuration) was held steady for a period of from one to three hours depending upon the type of test performed. During this period manual data were collected from the control room, automated boiler operational data were recorded on the DAS, and economizer exit and preheater exit gas species and temperatures were recorded utilizing the sample distribution manifold and were recorded on the DAS. When sufficient time permitted, furnace backpass ash grab samples were collected from the CEGRIT ash samplers and coal samples were collected from the individual pulverizer feeders.

During the diagnostic test efforts no unusual operating conditions were encountered that placed restrictions on the test effort, except that testing at high load was at times restricted by high opacity emissions due to poor ESP performance. For that reason, some 450 MW tests were conducted when the 480 MW level could not be reached without excessive opacity.

Table 3 presents the "as tested" conditions during the diagnostic portion of the testing. Sixteen days of testing were executed comprising the 53 various excess oxygen, mill pattern, AOFA, and load conditions. Because historic load profiles indicated much greater operating times at 400 MW and above, compared to lower loads, diagnostic testing was done more extensively at the higher load levels.

The range of excess oxygen and resulting NO_x emissions for the four nominal load levels tested during the diagnostic portion of the Phase 3B effort are shown in Figures 4 and 5. The conditions represented in these figures include the tested ranges of excess oxygen variation, mill-out-of-service variation, mill biasing, AOFA flow, etc.

Figure 4 illustrates that the testing was performed over a range of excess oxygen levels that were both below and above the levels recommended for this unit. The solid line represents the recommended minimum excess oxygen operating level over the load range. During system dispatch control of the unit, excursions to the extreme O₂ levels are frequently experienced during transient load conditions. Thus, the range of excess O₂ levels was tested to permit a valid comparison between the short-term and long-term emission characteristics.

Figure 5 is a summary of all of the NO_x data obtained for all test configurations. These configurations represented the range of normal configurations that were believed to be the predominant modes of operation that might be experienced during the system load dispatch mode of operation during long-term testing. The data scatter is partially due to the fact the different firing configurations are represented. The shaded area represents the range of NO_x values experienced at excess O₂ levels within a $\pm 0.5\%$ O₂ variation about the recommended O₂ level, and with nominal OFA flow. It should be emphasized that analyses performed for data gathered during the long-term testing, where virtually thousands of data points were used for the characterization, provide a more statistically appropriate NO_x band than that presented in Figure 5.

Short-term characterization of the NO_x emissions generally were made for trends determined on the same day of testing for a particular configuration to eliminate, to some extent, the influence of the uncontrollable parameters. Figures 6 through 10 show the diagnostic test results for the five nominal loads tested - 480, 450, 400, 300 and 180 MW, respectively. The legend for each data point indicates the test day and run for the data point in the format X-Y, where X is the test day and Y is the run. The 450 MW tests were conducted because of the difficulty in achieving the 480 MW load level at times, due to the deteriorating performance of the unit ESP which is scheduled to be replaced entirely following the conclusion of the Phase 3B testing.

The dependency of NO_x emissions on AOFA flow rate at 480 MW is shown in Figure 11. As seen, based on a linear extrapolation of the AOFA flowrate to zero flow, the data infers that the unit would have been capable of obtaining NO_x emission levels near 0.48 lb/MBtu without the AOFA system. This represents an approximate 17 percent NO_x reduction potential which is consistent with that found during the AOFA test phase.

3.5.2. Performance Tests

Performance testing was performed June 17-23, 1993. Six performance tests were conducted at nominal gross loads of 480, 400, and 300 MW. Testing at each load point required two consecutive days to complete sampling of all of the parameters included in the performance matrix. At each nominal load the coal firing rate was kept as constant as possible and the electric load allowed to swing slightly as affected by coal variations, boiler ash deposits, ambient temperature, etc.

The unit excess O₂ and OFA flow rates were maintained as recommended by FWEC at each load level. The coal feed rate to all in-service pulverizers was kept as nearly equal as possible, based upon the control room coal feed readouts. Each performance test covered a period from ten to twelve hours during which time manual and automated boiler operational data were recorded, fuel and ash samples acquired, gaseous and solid emissions measurements made, fly ash resistivity measured in-situ, and the engineering performance tests conducted.

Gaseous Emissions. During the performance tests, gaseous emissions were measured with the CEM operating in the manual mode. At various times during the performance tests, flue gas was sampled from selected probes or probe groups in the primary and secondary air preheater inlet and outlet ducts. These groupings consisted of composites of the individual east and west economizer exit ducts and individual measurements from each probe in these ducts. Composite grouping was performed to establish the overall emission characteristics while the individual probe measurements were made to establish spatial distributions of emission species. Composite average values of O₂ and NO_x measured during each test segment are shown in Table 4.

Solid Emissions. Ash particulate emissions were measured both for total mass emission rate and for characteristic properties related to ash collection within an ESP. The specific measurements and analyses that were performed included (1) total mass emissions, (2) particle size, (3) chemical composition, (4) ash resistivity, and (5) SO₃ concentration in the flue gas. These measurements were made immediately after the air preheater. Table 6 presents the results of the Method 17 tests performed at each test condition. The results shown for each test represent the average of three replicate samples.

Mill Performance The air flow to each mill and the particle size and mass flow

distributions of coal to each burner were measured. Tests were performed at three load levels (480, 300 and 400 MW). Table 7 summarizes the results of these tests. From this table, it can be seen that, despite the mills being set to approximately equal coal flows with the boiler controls, the measured coal flows varied considerably from mill to mill. Also, the measured PA flow rates varied considerably, producing a wide range of Fuel/PA ratios. It should be noted that the pipe-to-pipe variations in coal mass flow rates are large (over 3:1 for test 115) - indicating that the localized flame stoichiometry within the furnace may be highly non-uniform. The coal fineness was excellent for all mills except B and D, the two remaining older mills currently scheduled for replacement.

Secondary Air Supply. The total secondary combustion air flow was measured at the main secondary air supply ducts and at each corner (quadrant) of the OFA windbox. Table 8 presents the results of the primary, secondary and AOFA air flow measurements. Total unit air flow, at full load, was 6 to 10 percent higher than observed during previous tests.

Coal Characteristics. During each day of performance testing, samples were obtained of coal entering the active mills, furnace fly ash, fly ash collected in the ESP (east and west sides) and bottom ash. The coal samples were analyzed for proximate and ultimate composition, calorific value, grindability and ash fusion properties. Appendix A presents the results of these analyses, which show that the coal properties remained very consistent over the duration of the testing and are consistent with the analyses obtained during the previous testing phases of the program.

3.5.3. Verification Tests

A short series of verification tests were conducted to ascertain whether any significant changes had occurred in the Hammond Unit 4 NO_x emission characteristics during the long-term testing which might influence the long-term data analysis. Table 5 summarizes the results of those tests. As observed during the diagnostic testing, the Unit 4 ESP could not accommodate high load operation on a regular basis without producing excessive opacity emissions. For that reason the high load testing which could be achieved during the verification phase was substantially restricted. Also, because of system load demands, testing at loads below 300 MW was not possible. Therefore, most of the verification test results were obtained at 300 to 400 MW. These data points are included in the diagnostic test plots of NO_x vs. O₂. It can be seen that the NO_x emissions during the verification

testing were comparable to the earlier emission levels under comparable operating conditions. It is therefore concluded that no fundamental changes occurred in the unit emission characteristics during the long-term testing.

3.5.4. Long-Term Tests

Long-term testing of the LNB+AOFA concluded on August 13, 1993. Appendix B contains a summary of the NO_x emissions and load from May to August 1993 (the unit began an extended outage in September). A total of sixty-one (61) days of valid long-term data were collected. Full load (480 MW), long-term NO_x emissions are approximately 0.40 lb/MBtu which is consistent with that found during the performance testing (Figure 12). However, at 300 MW, long-term NO_x emissions are near 0.38 lb/MBtu, nearly 0.05 lb/MBtu higher than the short-term emissions at the same load with approximately the same excess air and AOFA flow rate. The cause of this disparity is unknown. Despite this difference, the short-term data for normal operating conditions lies within the 90th percentile range of the long-term data. The spread of the NO_x emissions data is similar to that seen during the Phase 3A LNB test phase and substantially smaller than the baseline and AOFA phases, especially at high loads.

Long-term, stack O₂ levels during this phase were lower than any of the previous phases averaging approximately 6 percent at full-load (Figure 13). This low O₂ level contrasts with results obtained during the performance tests where full-load stack O₂ levels were approximately 6.6 percent and measured total combustion air flow was higher than in previous phases. The reduced excess O₂ levels contributed to the lower NO_x levels and higher CO levels found during long-term testing (Figure 14). As shown in this figure, stack CO levels showed a wide dispersion and were generally higher during this phase than in previous phases.

As can be seen in Figure 15, in general, NO_x emissions were, as expected, highly correlated with stack O₂ levels at any given load. However, at full-load, this figure implies that NO_x emissions did not exhibit show any clear dependency on O₂. The cause of this discrepancy is at this time not known.

Thirty-day rolling averages for load, stack O₂, and NO_x are presented in Figures 16 through 18, respectively. As shown, NO_x emissions ranged from approximately 0.48 lb/MBtu to 0.40 lb/MBtu. The generally downward trend is likely the result of excess O₂

also trending down.

Various mill patterns were used below 400 MW (Table 9). Mill patterns can have an impact on NO_x emissions and operating parameters even at similar excess O₂ levels. This effect of NO_x emissions can be clearly seen in Figure 19. This change in emission characteristics with mill pattern accounts for the increased NO_x dispersion at lower loads.

3.5.5. Abbreviated Tests

Abbreviated, short-term testing of the LNB+AOFA combined system was conducted during February and March 1992. Full-load NO_x emissions during this test frame were approximately 0.54 lb/MBtu and corresponding LOI levels were near 12 percent (Figure 20). These results were substantially different from the results obtained during the comprehensive testing of the LNB+AOFA configuration this past summer.

Based on the data analysis to date, the additional NO_x reduction is likely the result of the following factors:

- *Re-Optimization of the Burner.* As previously mentioned, FWEC personnel re-optimized the burners following Georgia Power obtaining permission from the State of Georgia to resume full load operation on Hammond Unit 4. As an antecedent to the LNB+AOFA tests, FWEC performed boiler optimization for 34 days. After these abbreviated 1992 LNB+AOFA tests and prior to comprehensive LNB+AOFA testing, FWEC personnel were on site an additional 35 days to conduct further optimization. During the latter 35 days, FWEC made adjustments to (1) burner register settings (2) burner sliding tip settings, and (3) secondary and overfire air distribution with no change in total overfire air flow. Further optimization of the LNBs alone may have provided similar increases in their NO_x reduction effectiveness. FWEC was on site 29 days conducting optimization in the LNB only configuration.
- *More NO_x Favorable Biasing of the Primary Coal and Air Flows.* The fuel bias pattern used in the latest LNB+AOFA test phase produced lower NO_x emissions than the fuel bias patterns used during the LNB test phase. As was found during parametric testing of this unit, other than excess O₂, fuel biasing had more impact on NO_x emissions than the burner adjustments. As this and other demonstrations progress, the operators and vendors continue to learn more of the proper operation of

low NOx burners.

- *Lower Excess O₂ Levels.* The unit ran at lower excess O₂ levels during the LNB+AOFA test phase than in any of the previous test phases. During the LNB+AOFA long-term testing, plant operators may have limited the maximum O₂ levels to help maintain stack particulate compliance. This was not an issue during the AOFA or the abbreviated LNB+AOFA test phases.
- *Non availability of Long-Term Data from the Abbreviated Tests.* Data from the abbreviated LNB+AOFA was limited and did not include a statistically significant quantity of long-term data needed to accurately determine the NOx emission characteristic of the unit.

In order to assess the actual incremental effectiveness of the AOFA system accurately, the factors discussed above should be taken into consideration. One method of performing this analysis is to use the NOx vs. AOFA flow sensitivity developed during parametric testing of the unit. Figure 11 shows NOx emissions as a function of AOFA damper position for the LNB+AOFA test phase. Using this curve to extrapolate to zero overfire air flow, the NOx emission level of the furnace without AOFA can be estimated. Using this procedure for the LNB+AOFA test phase, the effectiveness of the AOFA system when added to the LNBs was approximately 17 percent indicating that much of the incremental NOx reduction achieved was not the result of the AOFA system, but was a result of other furnace operating conditions and burner adjustments. Also, the 17 percent incremental NOx reduction effectiveness of AOFA is more in concordance with our expectations of the capability of this technology. This leads to the conclusion that this unit could achieve approximately 0.48 lb/MBtu (61 percent NOx reduction) with LNBs alone. This NOx reduction is consistent with original projections made by the vendor for this boiler operated with low NOx burners only.

3.6. Advanced Low NOx Digital Controls System

The objective of this addition to the ICCT project at Plant Hammond Unit 4 is to evaluate and demonstrate the effectiveness of advanced digital control/optimization methods as applied to NOx abatement technologies in coal-fired power plants. The advanced low NOx control system project will provide documented effectiveness of advanced digital controls on NOx emissions and guidelines for retrofitting boiler combustion controls for

NOx emission reduction. The work breakdown structure for this extension is shown in Table 10.

The following are the major activities during the third quarter 1993:

- Verification of input/output (I/O) list,
- Allocation of I/O to controllers and I/O cards,
- Documentation development, including equipment list, rack arrangements, instrumentation data sheets,
- Development of functional control diagrams and ladder logic,
- Cable tray and conduit layout design,
- Operator console / bench board design,
- Removal of existing pneumatic control system from Hammond 4 control room,
- Continuation of digital control system configuration,
- Meeting held in Pittsburgh on artificial intelligence as applied to utility applications to evaluate candidate advanced control methodologies.

An overview of the DCS is shown in Figure 21. The system has a total of 628 I/O points consisting of 132 analog inputs, 12 analog outputs, 238 digital inputs, and 246 digital outputs. The I/O count is subject to revision as design of the system progresses. The major plant systems included in this DCS are (1) air flow control, (2) fuel control, (3) and burner management system.

A cost saving feature of the control system to be installed on Hammond Unit 4 is that the input/output (I/O) cards will be geographically distributed. Current plans are for an I/O cabinets to be located at the following areas: (1) lower furnace near the pulverizers, (2) upper furnace on (8th floor), and (3) cable spread room below the unit control room. The system will also interface to the programmable logic controllers (PLC) being used to control the electrostatic precipitator and ash handling system.

A sketch of the new operator console is shown in Figure 22. As can be seen from this figure, most control will be through the CRTs and very few hard manual/auto stations will be used. At the end of the quarter, the existing operator console at the plant had been removed and the new console was being fabricated.

The schedule for major milestones for this project addition is as is shown in the following table. A detail schedule of the ALNDCS phase of the project can be found in Appendix C.

Milestone	Date
Selection of advanced control core	Nov. 1993
Delivery of digital control system to site	Feb. 1994
Digital control system startup	Jun. 1994
Begin testing of advanced control methodologies	Sep. 1994

3.7. Data Comparison

3.7.1. NOx Reductions

Figure 23 compares the baseline, AOFA, LNB, and LNB+AOFA long-term NOx emissions data for Hammond Unit 4. Baseline testing was performed in an "as found" condition and the unit was not tuned for NOx emissions for this test phase. For the AOFA, LNB, and LNB+AOFA test phases, following optimization of the unit by FWEC personnel, the unit was operated according to FWEC instructions provided in the design manuals. As shown, the AOFA and LNBs provide a long-term, *full load*, NOx reduction of 24 and 48 percent, respectively. For the LNBs, the NOx reduction was consistent over the load range, averaging approximately 50 percent; however, the effectiveness of the AOFA system decreased with decreasing load. For the baseline, AOFA, LNB, and LNB+AOFA phases, the NOx vs. load characteristic is based on normal operation of the unit in excess of 51 days. Long-term NOx emissions reduction in the LNB+AOFA configuration is approximately 67 percent at full load. As previously discussed, preliminary results from this phase indicate the actual NOx reduction effectiveness of the LNB+AOFA above the LNBs alone is near 17 percent, with the majority of the improvement coming from additional tuning of the balance of the combustion system and other operational factors.

The NOx emissions averaged over the baseline, AOFA, LNB, and LNB+AOFA test phases are shown in Table 11. Since NOx emissions are generally dependent on unit load, the NOx values shown in this table are influenced by the load dispatch of the unit during the corresponding test frame.

The results from the performance tests are shown in Figure 24. As can be seen from comparing Figures 23 and 24, short-term NOx emissions can be considerably different from that obtained during long-term testing. The various causes of these differences have previously been described (*Phase 1 Baseline Tests Report*).

3.7.2. LOI Performance

The fly ash loss-on-ignition (LOI) values increased significantly for the AOFA and LNB test phases (Figure 25). Fly ash LOI level during the comprehensive LNB+AOFA was near that seen during the LNB phase. These LOI increases were evident over the load range. The LOI measurements were made during each performance test using EPA's Method 17 at the secondary air heater outlet. As shown in Table 12, mill performance was generally better in the AOFA, LNB, and LNB+AOFA test phases than during baseline. The improvement in coal fineness was likely responsible for the reduction in fly ash LOI levels during the May-August 1993 LNB+AOFA test phase. Although it is commonly recognized that fuel fineness can have a pronounced affect on fly ash LOI, results from Plant Smith, Plant Gaston, and other sources indicate the direct impact of fuel fineness on NO_x emissions is small. As previously reported, the post LNB retrofit increase in fly ash LOI along with increases in combustion air requirements and fly ash loading to the precipitator, has had an adverse impact on the unit's stack particulate emissions.

3.7.3. Excess O₂ Levels

Long-term, economizer outlet O₂ levels for the AOFA, and LNB, and LNB+AOFA test phases were generally higher than the corresponding baseline values (Figure 26). This change in O₂ level for these configurations is mostly attributable to an increase in combustion air requirements for the low NO_x combustion configurations, however, factors unrelated to the retrofits, such as leakage in the furnace backpass, can also affect these levels. The impact of this leakage and varying O₂ levels on emissions and unit performance will be investigated and discussed in future reports.

Table 3. LNB+AOFA Diagnostic Tests Summary									
TEST NUMBER	DATE	LOAD MW	MOOS PATTERN	OFA FLOW KPPH	CO ppm	STACK O2 Percent	ECONO O2 Percent	NOX lb/MMBtu	TEST CONDITIONS
101-1	05/06/93	449	AMIS	600	26	5.8	3.5	0.465	HIGH LOAD TEST AFTER FWEC TUNING
101-2	05/06/93	452	AMIS	455	75	5.8	3.6	0.488	HI LOAD - 75% OF OFA
101-3	05/06/93	446	AMIS	300	29	5.6	3.6	0.525	HI LOAD - 50% OF OFA
102-1	05/07/93	394	AMIS	400	14	6.5	4.4	0.479	MID LOAD - HIGH O2
102-2	05/07/93	397	AMIS	400	27	5.5	3.3	0.404	MID LOAD - NORMAL O2
102-3	05/07/93	397	AMIS	400	145	5.2	2.7	0.349	MID LOAD - MINIMUM O2
102-4	05/07/93	479	AMIS	763	234	5.3	3.1	0.405	HI LOAD - OPACITY TEST (FAILED)
103-1	05/08/93	407	E	310	18	6.2	4.1	0.492	MID LOAD - E MOOS NORMAL O2
103-2	05/08/93	402	B	320	33	6.8	4.6	0.476	MID LOAD - B MOOS HI O2
103-3	05/08/93	398	B	300	27	6.1	4.0	0.440	MID LOAD - B MOOS NORMAL O2
103-4	05/08/93	399	B	303	82	5.5	3.1	0.365	MID LOAD - B MOOS LOW O2
104-1	05/09/93	305	D&F	305	10	7.4	5.2	0.344	LOW LOAD - HI O2 DF MOOS (Not Normal)
104-2	05/09/93	295	D&F	295	11	6.1	3.9	0.286	LOW LOAD - LO O2 DF MOOS (Not Normal)
105-1	05/10/93	395	F	300	68	6.0	3.9	0.362	MID LOAD - NORM O2 F MOOS (Not Norm)
105-2	05/10/93	396	F	344	32	6.9	5.1	0.442	MID LOAD - HI O2 F MOOS (Not Norm)
106-1	06/08/93	450	AMIS	595	234	6.4	3.6	0.367	HIGH LOAD - LOW O2 - FA OUT
106-2	06/08/93	477	AMIS	794	140	6.6	3.9	0.391	HIGH LOAD - NORMAL O2
106-3	06/08/93	468	AMIS	829	14	7.1	4.5	0.441	HIGH LOAD - HIGH O2
107-1	06/09/93	465	AMIS	813	20	6.8	4.0	0.501	HIGH LOAD - HIGH O2
108-1	06/10/93	463	AMIS	824	28	6.9	4.1	0.395	HIGH LOAD - HIGH O2
108-2	06/10/93	449	AMIS	792	62	6.6	3.8	0.371	HIGH LOAD - NORMAL O2
108-3	06/10/93	472	AMIS	802	239	5.9	3.1	0.351	HIGH LOAD - LOW O2
109-1	06/11/93	470	AMIS	797	100	6.5	3.7	0.380	NORMAL O2 - NORMAL OFA
109-2	06/11/93	470	AMIS	932	183	6.4	3.5	0.369	NORMAL O2 - HIGH OFA
109-3	06/11/93	474	AMIS	611	183	6.2	3.6	0.405	NORMAL O2 - LOW OFA
110-1	06/12/93	302	E	314	9	8.1	5.3	0.404	NORMAL O2 - "E" MOOS NOT NORMAL
110-2	06/12/93	305	B&E	250	57	7.6	4.6	0.318	LOW O2
110-3	06/12/93	305	B&E	326	12	8.3	5.5	0.369	NORMAL O2
110-4	06/12/93	302	B&E	315	9	8.9	6.4	0.421	HIGH O2
110-5	06/12/93	394	B	327	19	8.1	5.6	0.489	HIGH O2
110-6	06/12/93	391	B	313	59	7.1	4.3	0.402	NORMAL O2 - LOW OFA
110-7	06/12/93	391	B	403	50	7.0	4.3	0.377	NORMAL O2 - NORMAL OFA
111-1	06/13/93	293	B&D	310	8	8.8	6.3	0.410	HIGH O2
111-2	06/13/93	295	B&D	317	11	7.9	5.0	0.345	NORMAL O2
111-3	06/13/93	292	B&D	306	30	7.3	4.3	0.309	LOW O2
112-1	06/14/93	400	AMIS	396	96	7.0	4.3	0.423	NORMAL O2
112-2	06/14/93	400	Test Aborted						
112-3	06/14/93	404	AMIS	416	50	7.3	4.7	0.447	NORMAL O2
113-1	06/15/93	476	AMIS	799	128	6.5	3.8	0.395	HIGH OFA
113-2	06/15/93	474	AMIS	585	217	6.2	3.6	0.422	MEDIUM OFA
113-3	06/15/93	474	AMIS	276	315	6.2	3.4	0.451	LOW OFA
114-1	06/16/93	179	B,D,E	94	7	9.5	6.8	0.412	HIGH O2
114-2	06/16/93	186	B,D,E	93	10	8.5	5.4	0.377	MEDIUM O2
114-3	06/16/93	183	B,D,E	90	14	7.8	4.5	0.346	LOW O2

Table 3. LNB+AOFA Diagnostic Tests Summary (Con't)

TEST NUMBER	DATE	LOAD MW	MOOS PATTERN	OFA FLOW KPPH	CO ppm	STACK O2 Percent	ECONO O2 Percent	NOX lbs/Mbtu	TEST CONDITIONS
121-1	06/24/93	483	AMIS	954	43	6.3	3.7	0.411	MAX OFA FLOW
121-2	06/24/93	482	AMIS	791	58	6.4	3.9	0.413	NOMINAL OFA FLOW
121-3	06/24/93	481	AMIS	603	191	6.2	3.8	0.414	LOW OFA FLOW
121-4	06/24/93	495	AMIS	777	43	6.3	3.8	0.421	500 MW, NOMINAL OFA FLOW
122-1	06/25/93	401	AMIS	409	55	6.6	4.0	0.365	DIAGNOSTIC - NOM OFA - NOM O2
122-2	06/25/93	402	AMIS	275	44	6.7	4.1	0.399	DIAGNOSTIC - LOW OFA - NOM O2
122-3	06/25/93	397	AMIS	516	34	6.7	4.2	0.348	DIAGNOSTIC - HIGH OFA - NOM O2
122-4	06/25/93	396	AMIS	510	15	7.1	4.7	0.385	DIAGNOSTIC - HIGH OFA - HIGH O2
122-5	06/25/93	395	AMIS	401	14	7.1	4.7	0.404	DIAGNOSTIC - NOM OFA - HIGH O2
122-6	06/25/92	392	AMIS	395	82	5.9	3.3	0.321	DIAGNOSTIC - NOM OFA - LOW O2
126-1	8/26/93	480	AMIS	870	52	6.8	4.1	0.417	FULL LOAD VERIFICATION, NOMINAL O2/OFA

Table 4. LNB+AOFA Performance Tests Summary

TEST NUMBER	DATE	LOAD MW	MOOS PATTERN	OFA FLOW KPPH	CO ppm	STACK O2 Percent	ECONO O2 Percent	NOX lbs/Mbtu	TEST CONDITIONS
115-1A	08/17/83	480	AMIS	790	31	6.6	3.8	0.433	PERFORMANCE TEST 480 MW
115-1B	08/17/83	487	AMIS	784	29	6.7	4.0	0.441	PERFORMANCE TEST 480 MW
115-1C	08/17/83	482	AMIS	774	38	6.8	3.9	0.427	PERFORMANCE TEST 480 MW
116-1A	08/18/83	478	AMIS	787	54	6.5	3.9	0.421	PERFORMANCE TEST 480 MW
116-1B	08/18/83	472	AMIS	805	300	6.4	3.8	0.412	PERFORMANCE TEST 480 MW
117-1A	08/18/83	303	B	311	62	6.9	4.0	0.320	PERFORMANCE TEST 300 MW
117-1B	08/18/83	289	B	297	40	7.1	4.1	0.320	PERFORMANCE TEST 300 MW
118-1A	08/20/83	302	B	321	37	7.1	4.3	0.317	PERFORMANCE TEST 300 MW
118-1B	08/20/83	298	B	308	41	7.2	4.3	0.315	PERFORMANCE TEST 300 MW
119-1A	08/21/83	400	B	427	105	7.2	4.5	0.413	PERFORMANCE TEST 400 MW
119-1B	08/22/83	400	B	409	123	7.2	4.5	0.424	PERFORMANCE TEST 400 MW
120-1A	08/22/83	401	B	421	87	7.2	4.5	0.415	PERFORMANCE TEST 400 MW
120-1B	08/23/83	401	B	424	91	7.5	4.6	0.419	PERFORMANCE TEST 400 MW

Table 5. LNB+AOFA Verification Tests Summary

TEST NUMBER	DATE	LOAD MW	MOOS PATTERN	OFA FLOW KPPH	CO ppm	STACK O2 Percent	ECONO O2 Percent	NOX lbs/Mbtu	TEST CONDITIONS
123-1	08/09/93	301	B	304	8	7.5	4.3	0.353	VERIFICATION - NOM O2 300 MW
123-2	08/10/93	296	B	318	7	8.1	5.3	0.386	- HIGH O2
123-3	08/10/93	304	B	311	13	7.0	3.8	0.329	- LOW O2
123-4	08/10/93	304	B	312	9	7.3	4.2	0.348	- NOM O2
123-5	08/10/93	304	B,D	316	8	7.5	4.4	0.358	- NOM O2; MILL VARIATION
124-1	08/10/93	384	B	307	124	7.3	4.7	0.382	VERIFICATION - NOM O2 400 MW
125-1	08/24/93	397	B	319	27	7.8	5.1	0.437	VERIFICATION - HIGH O2 - NOM OFA
125-2	08/25/93	393	B	283	217	6.8	3.8	0.357	VERIFICATION - LOW O2 - NOM OFA
125-3	08/25/93	393	B	300	59	7.4	4.5	0.401	VERIFICATION - NOM O2 - NOM OFA
125-4	08/25/93	394	B	417	79	7.4	4.7	0.384	VERIFICATION - NOM O2 - HIGH OFA
125-5	08/25/93	393	B	230	81	7.3	4.6	0.414	VERIFICATION - NOM O2 - LOW OFA
126-1	8/26/93	480	AMIS	870	52	6.8	4.1	0.417	FULL LOAD VERIFICATION, NOMINAL O2/OFA

Table 6. Summary of Solid Mass Emissions Tests (LNB+AOFA)

Test Number	Load MW	O ₂ % Dry	Loading gr/dscf	Gas Flow dscfm*10 ⁻⁶	Carbon %	LOI %
115	472	4.0	2.98	2.12	7.2	8.0
117	301	4.0	2.92	1.32	5.2	5.7
119	400	4.5	2.96	1.82	5.6	6.4

Table 7. Mill Performance (LNB+AOFA)

Test	Load MW	Parameter	Total	Pulverizer					
				A	B	C	D	E	F
115	480	Measured Coal Flow, Klb/hr	392.06	80.77	52.67	65.13	46.29	61.35	85.85
		Measured PA Flow, Klb/hr	836.8	146.9	151.2	139.2	134.2	137.5	127.8
		A/F Ratio	2.13	1.83	3.08	2.31	3.29	2.35	1.63
		Avg. Burner Pipe Velocity, FPM	6,473	5,805	8,183	5,860	7,696	5,737	5,355
		High Pipe Coal Flow, Klb/hr	27.9	23.1	14.3	19.4	17.9	16.2	27.9
		Low Pipe Coal Flow, Klb/hr	7.7	15.7	12.1	15.0	7.7	14.7	18.0
		Avg. Passing 200 Mesh, Pct.	72.59	76.94	66.86	74.08	63.43	80.02	74.20
		Avg. Passing 50 Mesh, Pct.	99.00	99.75	98.33	99.26	96.86	99.90	99.87
117	300	Measured Coal Flow, Klb/hr	279.17	60.14	0	57.20	43.34	57.08	61.41
		Measured PA Flow, Klb/hr	734.2	137.9	54.3	135.3	141.9	145.8	119.1
		A/F Ratio	2.63	2.32	0	2.50	3.63	2.94	2.18
		Avg. Burner Pipe Velocity, FPM	6,154	5,521	0	5,572	7,951	6,588	5,139
		High Pipe Coal Flow, Klb/hr	18.3	16.9	0	18.3	15.4	15.3	17.8
		Low Pipe Coal Flow, Klb/hr	7.1	13.1	0	11.7	7.1	13.0	12.9
		Avg. Passing 200 Mesh, Pct.	75.48	78.74	NA	75.14	67.12	76.86	79.54
		Avg. Passing 50 Mesh, Pct.	99.50	99.87	NA	99.83	98.21	99.74	99.85
119	400	Measured Coal Flow, Klb/hr	325.55	70.48	0	66.87	46.59	71.08	69.81
		Measured PA Flow, Klb/hr	801.5	145.6	67.4	143.8	153.4	143.6	147.7
		A/F Ratio	2.46	2.29	0	2.36	3.50	2.11	2.31
		Avg. Burner Pipe Velocity, FPM	6,668	6,487	0	6,192	8,270	5,958	6,435
		High Pipe Coal Flow, Klb/hr	21.9	20.3	0	21.9	17.2	18.6	18.8
		Low Pipe Coal Flow, Klb/hr	7.7	13.3	0	13.1	7.7	16.7	16.7
		Avg. Passing 200 Mesh, Pct.	73.50	77.98	NA	74.25	66.26	77.64	71.37
		Avg. Passing 50 Mesh, Pct.	99.23	99.81	NA	99.77	97.03	99.72	99.84

Table 8. Summary of Combustion Air Flows (LNB+AOFA)

Test	Load MW	OFA Dampers		Economizer	Air Flow Rates				
		Front	Rear	Excess O ₂	Secondary Air	Primary Air		Overfire Air	
		Percent Open		(Dry %)	lb/hr	lb/hr	Percent of Total	lb/hr	Percent of Total
115	472	47/47	44/46	3.8	2,437,598	836,841	20.0	847,935	20.3
116	476	55/51	45/51	3.9	2,490,624	832,546	19.5	880,120	20.6
117	301	36/22	30/21	3.9	1,628,886	734,279	27.3	259,776	9.7
118	300	36/26	31/22	4.2	1,589,363	716,699	26.6	349,802	13.0
119	400	32/24	26/22	4.4	2,350,423	801,480	21.9	446,909	12.2
120	401	32/27	26/20	4.5	2,349,506	756,031	20.5	487,798	13.2

Table 9. Mill Patterns/Long-Term/LNB+AOFA		
Load Category	Mills in Service	Number of Values
180 - 190 MW	A,C,F	722
180 - 190 MW	A,C,E	384
290 - 300 MW	A,C,E,F	90
290 - 300 MW	A,C,D,E,F	40
390 - 400 MW	A,B,C,D,E	39
390 - 400 MW	A,B,C,D,E,F	132
470 - 480 MW	A,B,C,D,E,F	1090

Table 10. Digital Control System Work Breakdown Structure		
Task	Description	Date
4.1	Project Management and Reporting	1/94 - 4/95
4.1.1	SCS R&EA Management and Reporting	
4.1.2	Environmental Reporting	
4.2	Design & Retrofit	
4.2.1	Preliminary Design - SCS Engineering	
4.2.2	Detail Design - SCS Engineering	
4.2.3	Digital Control System Hardware Design	
4.2.4	Configuration - SCS Engineering	
4.2.5	Installation & Checkout - SCS Engineering	
4.2.6	Materials	
4.3	Advanced Low NOx Digital Control System Testing	6/94 - 4/95
4.3.1	Test Coordination	
4.3.2	Long-Term Statistical Analysis	
4.3.3	Environmental Testing	
4.3.4	Performance Testing	
4.3.5	On-Site Technical Support	
4.3.6	Laboratory Analysis	
4.3.7	Other Testing	
4.3.8	Miscellaneous	
4.4	Advanced Controls	1/94 - 4/95
4.4.1	Advanced Hardware and Software Customization	

Table 11. Long-Term NOx Emissions								
Unit Configuration -->	Baseline		AOFA		LNB		LNB+AOFA	
	Mean	RSD,%	Mean	RSD,%	Mean	RSD,%	Mean	RSD,%
Number of Daily Averaged Values	52	-	86	-	94	-	63	-
Average Load (MW)	407	9.4	386	17.9	305	17.7	293	23.9
Average NOx Emissions (lb/MBtu)	1.12	9.5	0.92	8.6	0.53	13.7	0.41	12.9
Average O2 Level (percent at stack)	5.8	11.7	7.3	12.6	8.4	7.7	8.73	16.3
NOx 30 Day AEL (lb/MBtu)	1.24	-	1.03	-	0.64	-	0.51	-
NOx Annual AEL (lb MBtu)	1.13	-	0.93	-	0.55	-	0.42	-

Table 12. Mill Performance Summary		
Technology	Coal Fineness	
	Passing 200 Mesh Percent	Remaining 50 Mesh Percent
Baseline	63	2.8
AOFA	67	2.6
LNB	67	1.4
LNB+AOFA	74	0.6

Figure 4. LNB+AOFA Short-Term Test - Range of O₂ Levels Tested by Load

Figure 5. LNB+AOFA Short-Term Test - Range of NO_x Levels Tested by Load

Figure 8. LNB+AOFA Short-Term Test - NO_x vs. O₂ 400 MW

Figure 9. LNB+AOFA Short-Term Test - NO_x vs. O₂ 300 MW

Figure 10. LNB+AOFA Short-Term Test - NO_x vs. O₂ 180 MW

Figure 11. LNB+AOFA Short-Term Test - NO_x vs. AOFA Flow - 480 MW

Figure 12. LNB+AOFA Long-Term NO_x Trend

Figure 13. LNB+AOFA Long-Term Stack O₂ Trend

Figure 14. LNB+AOFA Long-Term Stack CO Trend

Figure 15. LNB+AOFA Long-Term NOx vs. Stack O2

Figure 16. Load Thirty Day Rolling Average (LNB+AOFA)

Figure 17. Stack O₂ Thirty Day Rolling Average (LNB+AOFA)

Figure 18. NOx Thirty Day Rolling Average (LNB+AOFA)

Figure 19. NOx vs. O2 at 180 MW by Mill

Figure 20. LNB+AOFA Abbreviated Tests - NO_x vs. Load

Figure 21. Digital Control System Configuration

Figure 22. Digital Control System Console Layout

Figure 23. Long-Term NO_x Emissions Comparison

Figure 24. Performance Testing NO_x Emissions Comparison

Figure 25. Performance Testing Fly Ash Combustibles Loss-on-Ignition

4. FUTURE PLANS

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

Table 13. Future Plans	
Quarter	Activity
Forth Quarter 1993	<ul style="list-style-type: none">• Phase 3B Report Issued• Chemical Emissions Tests Report Issued• Continue Control System Configuration
First Quarter 1994	<ul style="list-style-type: none">• Install Digital Control at Site• Design Advanced Controls
Second Quarter 1993	<ul style="list-style-type: none">• Startup of DCS

5. ACKNOWLEDGMENTS

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 - ² *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 - Second Quarter 1990.* Southern Company Services, Inc., Birmingham, AL: 1991.
 - ³ *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 - Phase 1 Baseline Tests Report.* Southern Company Services, Inc., Birmingham, AL: 1992.
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APPENDIX A
Phase 3B Coal Analysis

Plant Hammond Unit 4
Phase 3B Coal Analysis (As Received)

Field Log #	Test #	Date	H ₂ O, %	C, %	H, %	N, %	Cl, %	S, %	Ash, %	O, %	TOTAL	Ht of C. BTU/lb
H4PH3-717	106	08/08/93	6.58	69.10	4.59	1.45	0.04	1.70	10.17	6.41	100.04	12208
H4PH3-718	107	08/09/93	5.65	69.79	4.66	1.48	0.04	1.89	10.92	5.81	100.04	12263
H4PH3-603,604	108	08/10/93	6.53	68.99	4.57	1.43	0.06	1.69	9.85	6.94	100.06	12323
H4PH3-719	108	08/10/93	7.02	68.62	4.57	1.42	0.03	1.79	10.27	6.30	100.02	12013
H4PH3-609,610	109	08/11/93	6.69	69.11	4.58	1.44	0.06	1.80	10.28	6.11	100.05	12240
H4PH3-720	109	08/11/93	6.15	69.23	4.64	1.47	0.06	1.87	9.81	6.83	100.06	12220
H4PH3-606,607	110	08/12/93	6.03	69.54	4.60	1.46	0.06	1.84	10.02	6.50	100.07	12350
H4PH3-721	110	08/12/93	6.79	68.36	4.59	1.44	0.06	1.73	10.32	6.78	100.07	12102
H4PH3-618,619	111	08/13/93	6.68	69.41	4.62	1.40	0.06	1.77	10.19	5.93	100.06	12246
H4PH3-722	111	08/13/93	7.69	67.75	4.54	1.39	0.02	1.86	10.52	6.25	100.02	11956
H4PH3-597,598	112	08/14/93	7.40	68.88	4.52	1.44	0.02	1.83	10.18	5.78	100.03	12130
H4PH3-723	112	08/14/93	6.25	67.25	4.54	1.36	0.06	1.82	10.21	6.57	100.06	11790
H4PH3-600,601	113	08/15/93	7.44	68.57	4.50	1.39	0.05	1.83	10.82	5.86	100.06	12055
H4PH3-724	113	08/15/93	5.40	73.18	4.66	1.33	0.02	1.47	8.33	5.62	100.01	12966
H4PH3-725	114	08/16/93	5.19	74.03	4.72	1.34	0.02	1.54	7.86	5.33	100.03	13128
H4PH3-726	115	08/17/93	6.19	70.37	4.61	1.42	0.04	1.75	9.63	6.03	100.04	12495
H4PH3-680,681	115A	08/17/93	6.16	72.22	4.67	1.32	0.02	1.58	8.69	5.36	100.02	12780
H4PH3-657,658	115B	08/17/93	5.62	71.46	4.72	1.35	0.03	1.64	8.97	6.25	100.04	12765
H4PH3-654,655	115C	08/17/93	6.36	71.46	4.64	1.40	0.06	1.67	9.05	5.40	100.06	12810
H4PH3-727	116	08/18/93	6.87	68.76	4.61	1.46	0.06	1.80	10.04	6.46	100.06	12093
H4PH3-630,631	116A	08/18/93	6.81	69.92	4.63	1.34	0.03	1.69	9.74	5.87	100.03	12368
Referee (632)	116A	08/18/93	7.34	69.51	4.52	1.34	0.06	1.70	9.70	5.89	100.06	12297
H4PH3-633,634	116B	08/18/93	7.49	69.06	4.60	1.34	0.06	1.79	9.86	5.83	100.06	12199
H4PH3-636,637	116C	08/18/93	6.71	70.73	4.60	1.40	0.06	1.82	9.86	4.86	100.06	12358
H4PH3-728	117	08/19/93	6.25	67.76	4.53	1.39	0.03	1.82	9.87	6.37	100.04	11976
H4PH3-621,622	117A	08/19/93	7.10	69.95	4.66	1.36	0.05	1.72	9.93	5.25	100.04	12327
H4PH3-624,625	117B	08/19/93	6.82	69.33	4.64	1.41	0.05	1.71	10.20	5.69	100.05	12272
H4PH3-627,628	117C	08/19/93	7.04	69.36	4.61	1.40	0.03	1.72	10.06	5.79	100.03	12187
H4PH3-729	118	08/20/93	7.76	68.53	4.57	1.41	0.02	1.93	10.25	5.56	100.03	11984
H4PH3-663,664	118A	08/20/93	6.59	69.05	4.66	1.42	0.02	1.96	10.20	6.12	100.02	12287
H4PH3-666,667	118B	08/20/93	6.76	69.69	4.62	1.49	0.02	1.64	9.52	6.28	100.02	12334
H4PH3-669,670	118C	08/20/93	7.08	69.46	4.65	1.43	0.03	1.75	9.92	5.71	100.03	12212
H4PH3-730	119	08/21/93	5.41	73.24	4.73	1.40	0.03	1.51	8.87	4.83	100.02	12662
H4PH3-731	119	08/22/93	5.93	71.94	4.67	1.39	0.03	1.57	9.40	5.10	100.03	12687
H4PH3-645,646	119A	08/21/93	6.27	71.13	4.68	1.37	0.05	1.56	9.49	5.51	100.06	12497
H4PH3-648,649	119B	08/21/93	5.14	72.93	4.71	1.41	0.07	1.51	8.99	5.31	100.07	12843
H4PH3-651,652	119C	08/21/93	5.68	72.35	4.76	1.44	0.07	1.57	8.99	5.21	100.07	12712
Referee (653)	119C	08/21/93	5.93	71.98	4.70	1.43	0.06	1.61	9.11	5.24	100.06	12801
H4PH3-732	120	08/23/93	5.42	72.23	4.64	1.38	0.06	1.65	9.27	5.41	100.06	12716
H4PH3-612,613	120A	08/22/93	5.95	71.57	4.64	1.36	0.04	1.54	9.18	5.76	100.04	12730

Plant Hammond Unit 4
Phase 3B Coal Analysis (As Received)

Field Log #	Test #	Date	H ₂ O, %	C, %	H, %	N, %	Cl, %	S, %	Ash, %	O, %	TOTAL	Ht of C. BTU/lb
H4PH3-615,616	1208	08/23/93	5.64	73.52	4.78	1.44	0.03	1.51	8.93	4.21	100.04	12915
H4PH3-733	121	08/24/93	9.78	68.37	4.40	1.32	0.04	1.55	8.90	5.70	100.04	12022
H4PH3-639,640	121-2	08/24/93	4.81	72.68	4.79	1.40	0.05	1.50	8.74	6.08	100.05	12984
H4PH3-734	122	08/25/93	7.34	71.30	4.74	1.32	0.03	1.59	9.01	4.70	100.03	12842
H4PH3-642,643	122-2	08/25/93	5.71	72.47	4.76	1.39	0.05	1.53	9.07	5.07	100.05	12859
H4PH3-743,744	123	08/09/93	6.56	71.21	4.56	1.31	0.02	1.66	10.36	4.34	100.02	12536
H4PH3-746,747	125	08/25/93	7.51	68.99	4.50	1.31	0.02	1.81	10.78	5.09	100.01	12153
H4PH3-749,750	126	08/26/93	8.36	67.69	4.43	1.31	0.03	1.84	10.71	5.66	100.03	11852
H4PH3-710	LONG TERM	08/01/93	8.97	67.25	4.53	1.47	0.03	1.55	9.99	6.24	100.03	11836
H4PH3-711	LONG TERM	08/02/93	6.90	68.46	4.60	1.45	0.03	1.78	9.92	6.89	100.03	12083
H4PH3-712	LONG TERM	08/03/93	6.39	69.60	4.67	1.45	0.04	1.64	9.59	6.67	100.05	12281
H4PH3-713	LONG TERM	08/04/93	6.70	69.36	4.63	1.45	0.04	1.73	9.88	6.26	100.05	12249
H4PH3-714	LONG TERM	08/05/93	7.32	68.39	4.62	1.49	0.03	1.82	10.27	6.10	100.04	12045
H4PH3-715	LONG TERM	08/06/93	5.94	70.28	4.70	1.50	0.06	1.81	9.72	6.05	100.06	12364
H4PH3-716	LONG TERM	08/07/93	7.54	68.20	4.50	1.43	0.04	1.67	10.20	6.45	100.03	11934
H4PH3-735	LONG TERM	08/26/93	5.80	72.21	4.70	1.34	0.03	1.56	9.69	4.90	100.03	12799
H4PH3-736	LONG TERM	08/27/93	5.42	72.57	4.72	1.35	0.01	1.64	9.30	5.00	100.01	12830
H4PH3-737	LONG TERM	08/28/93	5.10	73.19	4.79	1.39	0.03	1.70	9.11	4.73	100.04	12959
H4PH3-738	LONG TERM	08/29/93	5.57	71.37	4.67	1.41	0.04	1.76	10.63	4.59	100.04	12857
H4PH3-739	LONG TERM	08/30/93	8.84	67.23	4.42	1.37	0.03	1.71	10.99	5.73	100.02	11865
H4PH3-740,741	LONG TERM	07/03/93	8.63	67.35	4.50	1.32	0.01	1.96	10.38	5.88	100.01	11876

Average

Std Dev

Variance

6.67	70.12	4.62	1.40	0.04	1.70	9.74	5.74	100.04	12379
1.05	1.85	0.09	0.05	0.02	0.13	0.65	0.65	0.02	350
1.09	3.36	0.01	0.00	0.00	0.02	0.42	0.41	0.00	120433

Plant Hammond Unit 4
Phase 3B Coal Analysis (As Received)

Field Log #	Test #	Date	Grind. Ind., SU	Volat., %	Fixed C, %	Sulfur lb/mmBTU	IT	Ash Fusion			Fixed C/ Volatile	Oxygen/ Nitrogen
								ST	HT	FT		
H4PH3-717	106	08/08/93	—	34.07	49.18	1.39	2220	2415	2495	2645	1.44	4.42
H4PH3-718	107	08/08/93	—	33.84	49.59	1.54	2200	2410	2490	2645	1.47	3.79
H4PH3-603,604	108	08/10/93	48.0	34.54	49.08	1.37	2170	2418	2515	2705	1.42	4.85
H4PH3-719	108	08/10/93	—	34.10	48.61	1.49	2235	2475	2525	2880	1.43	4.44
H4PH3-609,610	109	08/11/93	45.5	34.24	48.80	1.47	2165	2440	2505	2670	1.43	4.24
H4PH3-720	109	08/11/93	—	34.08	49.97	1.53	2155	2380	2440	2800	1.47	4.65
H4PH3-606,607	110	08/12/93	44.5	35.10	48.86	1.49	2170	2436	2515	2880	1.39	4.39
H4PH3-721	110	08/12/93	—	34.11	48.79	1.43	2215	2375	2425	2580	1.43	4.71
H4PH3-618,619	111	08/13/93	45.5	34.14	48.99	1.45	2165	2474	2550	2670	1.43	4.24
H4PH3-722	111	08/13/93	—	34.03	47.75	1.56	2210	2380	2425	2585	1.40	4.50
H4PH3-597,598	112	08/14/93	46.5	34.28	48.14	1.51	2170	2408	2475	2675	1.40	4.00
H4PH3-723	112	08/14/93	—	33.74	47.80	1.54	2250	2470	2525	2840	1.42	4.83
H4PH3-600,601	113	08/15/93	44.0	33.80	48.14	1.52	2170	2425	2505	2685	1.42	4.07
H4PH3-724	113	08/15/93	—	32.86	53.40	1.13	2185	2410	2485	2640	1.63	4.23
H4PH3-725	114	08/16/93	—	32.87	54.08	1.17	2200	2375	2480	2635	1.65	3.98
H4PH3-726	115	08/17/93	—	33.50	50.68	1.40	2190	2410	2480	2650	1.51	4.25
H4PH3-660,661	115A	08/17/93	53.0	32.21	52.94	1.24	2140	2380	2445	2620	1.64	4.06
H4PH3-657,658	115B	08/17/93	49.0	33.54	51.87	1.28	2145	2385	2450	2620	1.55	4.63
H4PH3-654,655	115C	08/17/93	48.5	33.30	51.29	1.32	2130	2410	2480	2650	1.54	3.86
H4PH3-727	116	08/18/93	—	33.95	49.14	1.49	2220	2465	2530	2840	1.45	4.42
H4PH3-630,631	116A	08/18/93	49.5	33.61	49.84	1.37	2180	2420	2490	2655	1.48	4.38
Referee (632)	116A	08/18/93	—	32.54	50.42	1.38	2380	2480	2510	2800	1.55	4.40
H4PH3-633,634	116B	08/18/93	49.5	33.39	49.24	1.47	2190	2425	2480	2650	1.47	4.35
H4PH3-636,637	116C	08/18/93	47.5	33.66	49.77	1.47	2240	2455	2530	2655	1.48	3.49
H4PH3-728	117	08/19/93	—	33.30	48.56	1.52	2160	2365	2420	2590	1.46	4.58
H4PH3-621,622	117A	08/19/93	48.5	33.17	49.80	1.40	2160	2440	2490	2670	1.50	3.80
H4PH3-624,625	117B	08/19/93	46.0	33.53	49.45	1.39	2195	2450	2510	2685	1.47	4.18
H4PH3-627,628	117C	08/19/93	48.5	34.51	48.39	1.41	2130	2380	2435	2650	1.40	4.14
H4PH3-729	118	08/20/93	—	33.28	48.71	1.61	2222	2440	2510	2640	1.46	3.94
H4PH3-663,664	118A	08/20/93	50.5	34.05	49.16	1.60	2150	2420	2485	2605	1.44	4.31
H4PH3-666,667	118B	08/20/93	47.5	34.01	49.71	1.33	2200	2475	2535	2700	1.46	4.21
H4PH3-669,670	118C	08/20/93	48.0	33.73	49.27	1.43	2185	2495	2545	2700	1.46	3.99
H4PH3-730	119	08/21/93	—	33.06	52.66	1.17	2230	2480	2525	2655	1.59	3.45
H4PH3-731	119	08/22/93	—	33.29	51.38	1.24	2215	2445	2505	2650	1.54	3.67
H4PH3-645,646	119A	08/21/93	49.5	33.35	50.90	1.25	2235	2457	2530	2680	1.53	4.02
H4PH3-648,649	119B	08/21/93	48.5	34.46	51.40	1.18	2130	2480	2545	2695	1.49	3.77
H4PH3-651,652	119C	08/21/93	48.5	34.20	51.13	1.24	2130	2430	2490	2670	1.50	3.62
Referee (653)	119C	08/21/93	—	33.16	51.80	1.26	2380	2430	2480	2550	1.56	3.66
H4PH3-732	120	08/23/93	—	33.23	52.09	1.30	2250	2485	2550	2635	1.57	3.92
H4PH3-612,613	120A	08/22/93	48.0	33.56	51.31	1.21	2160	2474	2550	2680	1.53	4.24

**Plant Hammond Unit 4
Phase 3B Coal Analysis (As Received)**

Field Log #	Test #	Date	Grind. Ind., SU	Volat., %	Fixed C, %	Sulfur lb/mmBTU	IT	Ash Fusion ST	HT	FT	Fixed C/ Volatile	Oxygen/ Nitrogen
H4PH3-615,616	120B	06/23/93	50.5	33.43	52.00	1.17	2195	2470	2530	2700	1.56	2.92
H4PH3-733	121	06/24/93	—	31.88	49.46	1.29	2270	2459	2530	2640	1.55	4.32
H4PH3-639,640	121-2	06/24/93	48.0	33.90	52.55	1.16	2275	2520	2595	2720	1.55	4.34
H4PH3-734	122	06/25/93	—	32.24	51.42	1.28	2220	2455	2520	2620	1.59	3.58
H4PH3-642,643	122-2	06/25/93	49.5	33.53	51.69	1.19	2280	2515	2595	2720	1.54	3.65
H4PH3-743,744	123	06/09/93	51.0	31.23	51.85	1.32	2190	2365	2455	2620	1.66	3.31
H4PH3-746,747	125	06/25/93	53.0	31.56	50.15	1.49	2230	2418	2480	2605	1.59	3.89
H4PH3-749,750	126	06/26/93	51.0	32.51	48.41	1.55	2235	2445	2510	2610	1.49	4.32
H4PH3-710	LONG TERM	06/01/93	—	33.03	48.01	1.31	2230	2370	2445	2620	1.45	4.24
H4PH3-711	LONG TERM	06/02/93	—	34.07	49.11	1.48	2175	2375	2430	2610	1.44	4.75
H4PH3-712	LONG TERM	06/03/93	—	33.94	50.08	1.34	2220	2410	2480	2645	1.48	4.60
H4PH3-713	LONG TERM	06/04/93	—	33.78	49.64	1.41	2235	2420	2470	2650	1.47	4.32
H4PH3-714	LONG TERM	06/05/93	—	33.93	48.48	1.51	2220	2410	2470	2620	1.43	4.09
H4PH3-715	LONG TERM	06/06/93	—	34.76	49.59	1.48	2222	2430	2470	2640	1.43	4.03
H4PH3-716	LONG TERM	06/07/93	—	33.61	48.65	1.40	2235	2455	2505	2640	1.45	4.51
H4PH3-735	LONG TERM	06/26/93	—	33.05	51.66	1.22	2280	2490	2550	2650	1.56	3.66
H4PH3-736	LONG TERM	06/27/93	—	32.96	52.32	1.28	2235	2480	2535	2640	1.59	3.70
H4PH3-737	LONG TERM	06/28/93	—	33.17	52.62	1.31	2185	2400	2465	2625	1.59	3.40
H4PH3-738	LONG TERM	06/29/93	—	32.20	51.60	1.39	2188	2423	2465	2630	1.60	3.28
H4PH3-739	LONG TERM	06/30/93	—	32.07	48.40	1.44	2190	2385	2466	2620	1.51	4.18
H4FH3-740,741	LONG TERM	07/03/93	51.5	32.70	48.31	1.65	2195	2420	2485	2615	1.48	4.45

Average

Std Dev

Variance

48.4	33.46	50.13	1.38	2205	2431	2486	2645	1.50	4.10
2.3	0.78	1.60	0.13	49	39	40	35	0.07	0.42
5.2	0.59	2.50	0.02	2353	1489	1595	1214	0.00	0.17

APPENDIX B
Phase 3B Long-Term NOx and Generation

HAMMOND UNIT FOUR

PHASE 3B(C) LONG TERM DATA FOR THE WEEK OF 09-15 MAY 1993

H4PH3B01.WK4

HAMMOND UNIT FOUR

PHASE 3B(C) LONG TERM DATA FOR THE WEEK OF 16-22 MAY 1993

H4PH3B02.WK4

HAMMOND UNIT FOUR

PHASE 3B(C) LONG TERM DATA FOR THE WEEK OF 23-29 MAY 1993

H4PH3B03.WK4

HAMMOND UNIT FOUR

PHASE 3B(C) LONG TERM DATA FOR THE WEEK OF 30 MAY - 05 JUNE 1993

H4PH3B04.WK4

HAMMOND UNIT FOUR

PHASE 3B(C) LONG TERM DATA FOR THE WEEK OF 06-12 JUNE 1993

H4PH3B05.WK4

HAMMOND UNIT FOUR

PHASE 3B(C) LONG TERM DATA FOR THE WEEK OF 13-19 JUNE 1993

H4PH3B06.WK4

HAMMOND UNIT FOUR

PHASE 3B(C) LONG TERM DATA FOR THE WEEK OF 20-26 JUNE 1993

H4PH3B07.WK4

HAMMOND UNIT FOUR

PHASE 3B(C) LONG TERM DATA FOR THE WEEK OF 27 JUNE - 03 JULY 1993

H4PH3B08.WK4

HAMMOND UNIT FOUR

PHASE 3B(C) LONG TERM DATA FOR THE WEEK OF 04-10 JULY 1993

H4PH3B09.WK4

HAMMOND UNIT FOUR

PHASE 3B(C) LONG TERM DATA FOR THE WEEK OF 11-17 JULY 1993

H4PH3B10.WK4

HAMMOND UNIT FOUR

PHASE 3B(C) LONG TERM DATA FOR THE WEEK OF 18-24 JULY 1993

H4PH3B11.WK4

HAMMOND UNIT FOUR

PHASE 3B(C) LONG TERM DATA FOR THE WEEK OF 25-31 JULY 1993

H4PH3B12.WK4

HAMMOND UNIT FOUR

PHASE 3B(C) LONG TERM DATA FOR THE WEEK OF 01-07 AUGUST 1993

H4PH3B13.WK4

HAMMOND UNIT FOUR

PHASE 3B(C) LONG TERM DATA FOR THE WEEK OF 08-14 AUGUST 1993

H4PH3B14.WK4

APPENDIX C
Digital Control System Installation Schedule

DATE

FILMED

8 / 1 / 94

END