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INNOVATIVE CLEAN COAL TECHNOLOGY (ICCT): 500 MW DEMONSTRATION OF ADVANCED WALL-FIRED COMBUSTION TECHNIQUES FOR THE REDUCTION OF NITROGEN OXIDE (NOX) EMISSIONS FROM COAL-FIRED BOILERS

Phase I Baseline Tests Report

December 5, 1990

Work Performed Under Contract No. FC22-9OPC89651

For
Southern Company Services, Inc.
Birmingham, Alabama

By
Energy Technology Consultants, Inc.
Irvine, California

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PHASE I BASELINE TESTS REPORT

DOE Contract Number
DE-FC22-90PC89651

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C-91 -000027

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EXECUTIVE SUMMARY

This Phase 1 Baseline Tests Report summarizes the technical activities and results for one phase 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 NOx 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. 'This demonstration, project is divided into five phases:

Phase 0	- Pre-award activities
Phase 1	- Baseline "as-found" testing
Phase 2	- AOFA installation and testing
Phase 3	- LNB and LNB + AOFA installation and testing
Phase 4	- Final reporting

The Phase 1 baseline configuration is the subject of this report. The "as-found" configuration is defined as the configuration under which the unit has operated in the recent past. Described in this report are the test program plans, data collection procedures and measurements, and data analysis methodologies. In addition, results from both short- and long-term baseline tests are presented.

The primary objective of the Phase 1 tests effort was to document the existing condition of Unit 4 and to establish the NO_X emissions under short-term well controlled conditions and under long-term normal dispatch conditions. Short-term testing indicated baseline full-load NO_X emissions of approximately 1.35 lb/MMBtu and loss-on-ignition (LOI) values of 5.2 percent. The daily average NO_X emissions for the unit during baseline long-term testing was found to be 1.17 lb/MMBtu.

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

ADVANCED WALL-FIRED LOW NOx

COMBUSTION DEMONSTRATION

PHASE I BASELINE TESTS

Prepared by
LOWEEE L. SMITH
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JULY 1991

ETEC 90-20056

LEGAL NOTICE

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ACKNOWLEDGMENT

Energy Technology Consultants would like to acknowledge the efforts expended by the four test subcontractors in providing written material, data and data analyses for inclusion in this report.

Mr. Jose Perez of Spectrum Systems provided invaluable assistance in collecting all of the short-term and long-term data. In addition Mr. Perez maintained the instrumentation in excellent working condition during the entire Phase I effort.

Mr. Wallace Pitts of W. S. Pitts Consulting, Inc. provided all of the statistical analyses presented in this report and provided supporting written material describing the analyses.

Both Southern Research Institute under the direction of Mr. Carl Landham and Flame Refractories, Inc. under the direction of Mr. Dick Storm provided the highest quality "testing -elated to characterization of the boiler input and output materials and emissions. Both organizations submitted substantial written material in the form of test reports which were used to provide summaries of the pertinent findings in this Baseline report.

ETEC would like to acknowledge Mr. Ernie Padgett of the Hammond Plant for his efforts in insuring that the testing progressed with the maximum level of efficiency through his coordination efforts.

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1.0 INTRODUCTION

1.0 INTRODUCTION

This Innovative Clean Coal Technology II project to evaluate NOx control techniques on a 500 MWe utility boiler is funded by three organizations:

1) U.S. Department of Energy (DOE),
2) Southern Company Services, Inc. (SCS),
and 3) Electric Power Research Institute (EPRI).

Georgia Power Company (GPC) provides Hammond Unit 4 as the host site and provides on-site assistance and coordination for the project. The following briefly describes the overall organization and describes in detail the organization related to the test and evaluation activities.

1.1 Project Description

On December 20, 1989, Southern Company Services was awarded a DOE Innovative Clean Coal Technology II (ICCT II) contract for the project, "500 MWe Demonstration of Advanced Wall-Fired Combustion Techniques for the Reduction of Nitrogen oxide (NOx) Emissions from Coal-fired Boilers". The Project will investigate NOx reduction techniques on Unit 4 at Georgia Power Company's Hammond Plant located in Rome, Georgia. The four Phase Project will characterize emissions and performance of a wall-fired boiler operating in the following configurations:

1) Baseline "as-found" configuration - PHASE I,
2) Retrofitted Advanced overfire air (AOFA) - PHASE IT,
3) Retrofitted Low NOx Burners (LNB) - PHASE III,
4) Combined AOFA and LNB configuration -PHASE IIIb..

The major objectives of the project are to:

1) Demonstrate (in a logical stepwise fashion) the performance of three combustion NOx control technology es, i.e., AOFA, LNB and AOFA plus LNB.

2) Determine the short-term NOx emission trends for each of the operating configurations,

3) Determine the dynamic long-term NOx emission characteristics for each of the operating configurations using sophisticated statistical techniques,

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

5) Determine the effects on other combustion parameters (e.g., CO production, carbon carry-over, particulate characteristics) of applying the low NOx combustion technologies.

Each of the four Phases of the Project involves three distinct testing periods - Short-term Characterization, Long-Term Characterization and Short-Term Verification. The Short-Term Characterization testing establishes the trends of NOx versus various parameters and establishes the influence of the operating mode on other combustion parameters. The Long-Term Characterization testing establishes the dynamic response of the NOx emissions to all of the influencing parameters encountered. The Short-Term Verification testing documents any fundamental changes in NOx emission characteristics that may have occurred during the Long-Term test period (50 to 80 continuous days of testing). The subsequent sections of this Interim Report provide a detailed description of the Phase I Short-term Characterization efforts and provide background information relative to the overall Phase I effort.

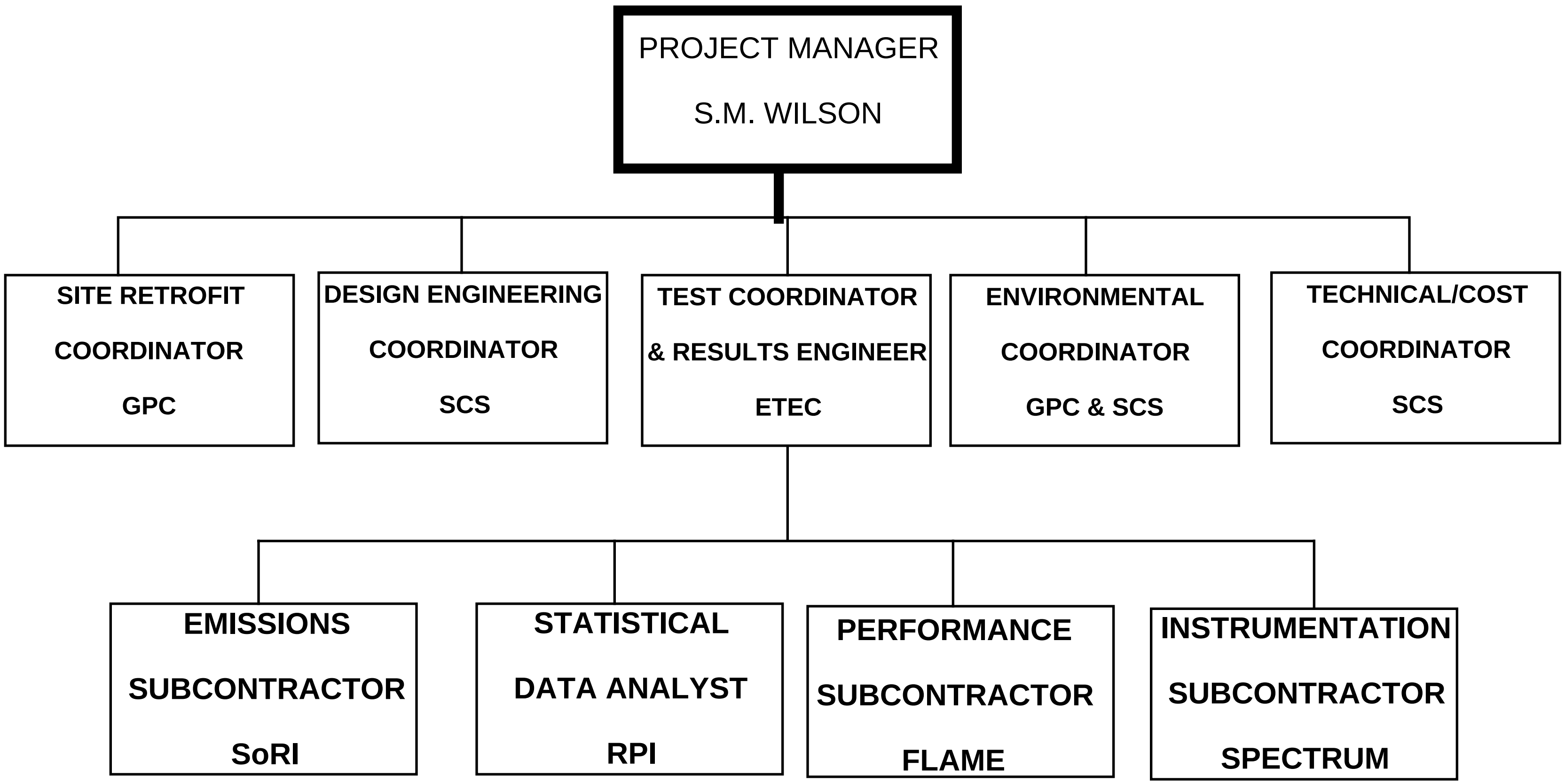
1.2 Project Organization

The Project Manager for the DOE ICCT Demonstration Project being conducted at the Hammond Plant is Mr. Steven M. Wilson of Southern Company Services, Inc. (SCS) who has overall responsibility for execution of the project. The Project Manager directs in-house (SCS) and GPC personnel to perform various duties related to site coordination, design engineering, environmental matters and cost coordination. The Manager also directs subcontracted efforts of the burner manufacturer, installation contractors and test coordination contractor. Foster Wheeler Energy Corporation (FWEC) is the subcontractor supplying the NOx Emissions Control Systems. Flame Refractories, Inc. provides the mechanical installation of the emission control systems and White Electrical supplies services related to I & C installation. Energy Technology Consultants, Inc., (ETEC) provides Test Coordination and Results Services. The United States Department of Energy (DOE) and the Electric Power Research institute (EPRI) provide direction and technical input to the Project.

Energy Technology Consultants, Inc. Energy Technology Consultants (ETEC) has responsibility for the on-site testing and analysis of the data obtained for all Phases of the project. This responsibility falls under the TEST COORDINATOR & RESULTS ENGINEER functional area under Southern Company Services direction. ETEC is responsible for overall management of the test efforts including preparation of test plans, coordination and on-site direction of the test and data analysis contractors, analysis and interpretation of short-term data and preparation of the interim and final test reports. Figure 1-1 provides a test organization chart for the Plant Hammond Wall-Fired NOx Demonstration Project. The following lists the responsibilities of the testing and analysis subcontractors that are under the direction of ETEC.

Spectrum Systems, Inc. Spectrum provides a full-time, on-site instrument technician who is responsible for operation and maintenance of the data acquisition system (DAS) housed within

FIGURE 1-1 HAMMOND PROJECT ORGANIZATION



the Instrument Control Room. The DAS was newly constructed for this project. During the Short-Term Characterization and Short-Term Verification activities, Spectrum personnel continuously man the Instrumentation Control Room during the daily test periods and collect and record all data transmitted to the Instrumentation Control Room. For the full duration of the program (Short- Term Characterization, Long-term Characterization and Short-term Verification for all four Phases), Spectrum maintains and repairs, as necessary, the Instrumentation System and monitors the function of the Data Acquisition System (DAS) on a daily basis.

Southern Research Institute. Southern Research Institute, (SoRI) is responsible for testing related to flue gas particulate measurements during the Performance testing portion of the Short-Term Characterization for all four project Phases. SoRI provides all manpower and equipment to perform total particulate matter (TPM), particle sizing, vapor phase SO_3 concentration and in-situ resistivity measurements. SoRI is also responsible for collection of ESP hopper ash samples for laboratory resistivity and loss-on-ignition (LOI) analyses. In addition to the testing activities, SoRI is responsible for ESP modeling efforts for each of the four Phases.

Flame Refractories. Inc. Flame Refractories, Inc. (Flame) is responsible for activities related to fuel/air input parameters and furnace output temperature measurements during the Performance testing portion of the Short-Term Characterization for all four Phases. During this period, Flame provides all manpower and equipment to perform the following tests: primary air flow, pulverizer outlet air/rue! ratios! coal fineness, coal pipe dirty air velocity, coat pipe clean air velocity and secondary air flows at the windbox entrance and furnace gas temperature and species measurements.

W. S. Pitts Consulting Inc. W. S. Pitts, Inc. (WSPC) is responsible for data analysis of the emission and performance data for the Long-Term Characterization Phases of the program. WSPC activities include reduction and statistical analysis of the Long-Term emissions data, review of the Experimental Design of Short-Term Characterization activities and definition of quality assurance measures for the continuous emission monitor and gas analysis system data.

During the Phase I Short-Term Characterization, each of the test and analysis subcontractors reporting to ETEC provided written material describing the results of their activities during the Phase I activities. Both raw and reduced data are archived by the subcontractors as well as ETEC for future reference.

1.3 Hammond Unit 4 Description

Hammond Unit 4 is a Foster Wheeler (FW) designed, opposed wall-fired boiler rated at 500 MWe with design steam conditions of 2500 psig and 1000/1000^0 F superheat/reheat temperatures, respectively. Table 1-1 provides information on the design parameters for Unit 4. Figure 1-2 illustrates the side-view of Hammond Unit 4. Six FW Planetary Roller and Table type MB-21.5 mills provide pulverized eastern bituminous coal to twenty four (24) intervene burners arranged in a matrix of twelve each on the front and rear walls. Each mill provides coal to four burners as illustrated in Figure 1-3.

Unit 4 is a balanced draft unit utilizing two forced draft and three induced draft fans. The unit is equipped with a coldside Electrostatic Precipitator (ESP). The flue gases exit the economizer through two Ljungstrom air preheaters and into the coldside ESP then through the induced draft fans and finally out to the stack. Figure 1-4 schematically illustrates the side-view of the complete system flow path. Figure 1-4 also shows the test points used by the various subcontractors to gather the test data. The type of data collected at each test point is described briefly in Table 1-2 and in more detail in Section 3.0.

1.4 Report Organization

The remainder of this Phase I Baseline Test Report is organized into six sections. Section 2.0 provides background material for the project and describes the program methodology. Section 3.0 provides details on the instrumentation and the data collection methods. The data analyses methods for both Short-Term and Long-Term data are described in Section 4.0. The results for the Short-Term Characterization portion of the Phase I effort are presented in Section 5.0. Section 6.0 will provide a description of the statistical approach used to analyze the Continuous Emission Monitor (CEM) data. Section 7.0 provides conclusions for the analyses of both the Short-Term and Long-Term data.

TABLE 1-1 HAMMOND UNIT 4 DESIGN SPECIFICATIONS

Purchaser Georgia Power Company — Proposal No. 0-2 79713-A

Location Plant Hammond - Unit No. 4 — Date December 2, 1966

Design Pressure 2875/725 — Dwg. No. PD-660-157

Load - % of MCR		25%	50%	75%	100%	Peak
Fuel		COAL	COAL	COAL	COAL	COAL
Steam	Mlb/hr	906.5	1813.0	2719.5	3626..0	3817.5
Pressure superheater outlet_____	psig	2405	2421	2448	2486	2609
Temperature steam superheater outlet	F	940	1000	1000	1000	1000
Pressure boiler drum	psig	2414	2458	2530	2632	2770
Reheat Steam	Mlb/hr	750.65	1629.0	1420.0	3206.5	3369.0
Temperature steam entering reheater___	F	443	553	607	650	650
Temperature steam leaving reheater	F	892	1000	1000	1000	1000
Pressure steam entering reheater	psig	135	300	452	601	632
Pressure steam leaving reheater	psig	130	290	437	581	611
Temp feed entering unit	F	356	418	456	486	491
Temp feed leaving econ.	F	439	494	551	593	609
Temp air entering unit_Avg. of Pri&Sec	F	147	124	109	96	96
Temp air leaving air heater_ Avg.	F	410	505	545	575	583
Temp gas leaving furnace HVT	F	1242	1546	1703	1840	1868
Temp gas leaving boiler	F	1217	1516	1675	1810	1838
Temp gas leaving economizer Avg.	F	480	587	636	708	720
Temp gas leaving air heater Avg.	F	222	244	263	282	285
Ditto corrected for leakage Avg.	F	212	231	252	267	272
Excess air leaving	%	40	23	18	18	18
Wet gas entering air heater Total	Mlb/hr	138.0	2589.0	3585.0	4595.7	4818.4
Wet gas leaving air heater Total	Mlb/hr	1660.0	2882.0	3920.0	4952.2	5184.5
Air entering air heater Total	Mlb/hr	1575.0	12683.0	3640.0	4596.5	4816.0
Air leaving air heater Total	Mlb/hr	1293.0	2390.0	3310.0	4240.0	4450.0
Draft in furnace	in H_2O					
Gas side loss thru boiler	in H_2O	-	-	-	-	-
Gas side loss thru suphtr. & rehtr	in H_2O	0.89	2.93	3.68	5.31	5.70
Gas side loss thru economizer	in H_2O	0.71	2.01	2.57	3.60	3.80
Gas side loss thru air heater Sec.	in H_2O	0.80	2.70	4.75	7.70	8.35
Gas side loss thru flues & Damper	in H_2O	0.07	0.21	0.31	0.47	0.52
Gas side loss thru dust collector	in H_2O					
Air side loss thru air heater Sec.	in H_2O	0.75	1.80	3.30	4.95	5.45
Air side loss thru ducts	in H_2O	0.22	0.62	1.12	1.77	1.95
Air side loss thru burners	in. H_2O	1.60	2.20	2.70	2.50	2.75
Air side loss Meas. Device	in H_2O	0.09	0.32	0.61	1.00	1.10
Air side loss, Steam Coils	in H_2O	0.07	0.26	0.49	0.80	0.88
Air & gas loss total	in H_2O	5.20	13.05	19.53	28.10	30.50
Pressure loss drum to SHO Hdr	in H_2O	9	37	82	146	161
Fuel burned	Mlb/hr or cfm	99.6	210.0	303.0	389.0	407.0
Liberation	Btu/hr/cu ft total vol	4950	9780	14200	18350	19250
Furn. Cooling Factor	net Btu/hr/sq.ft.	18000	38300	55600	72000	75500
Unit efficiency	%	91.17	90.26	89.81	89.01	88.87

FIGURE 1-2 HAMMOND UNIT 4 SIDE-VIEW

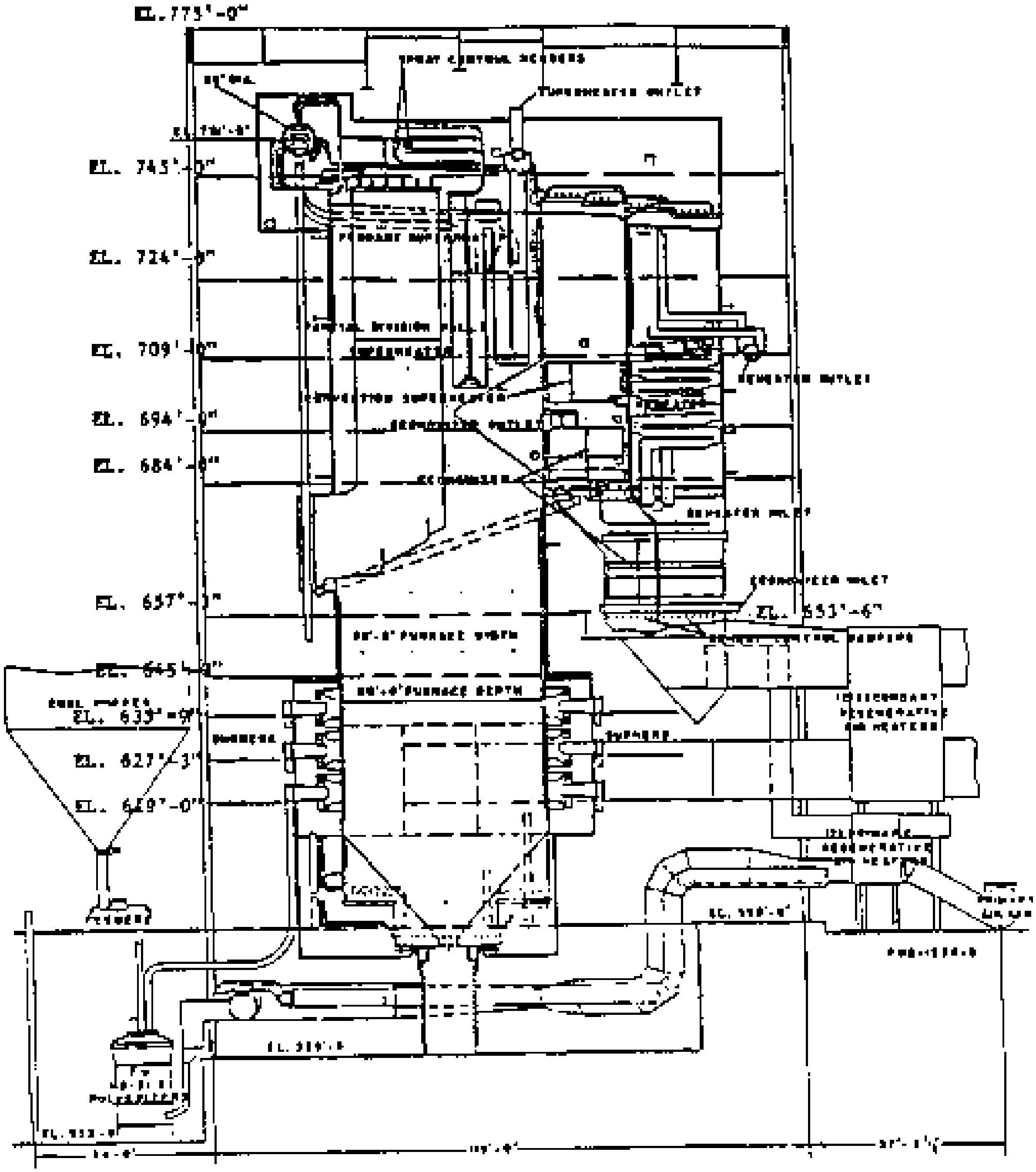


FIGURE 1-3 BURNER CONFIGURATION

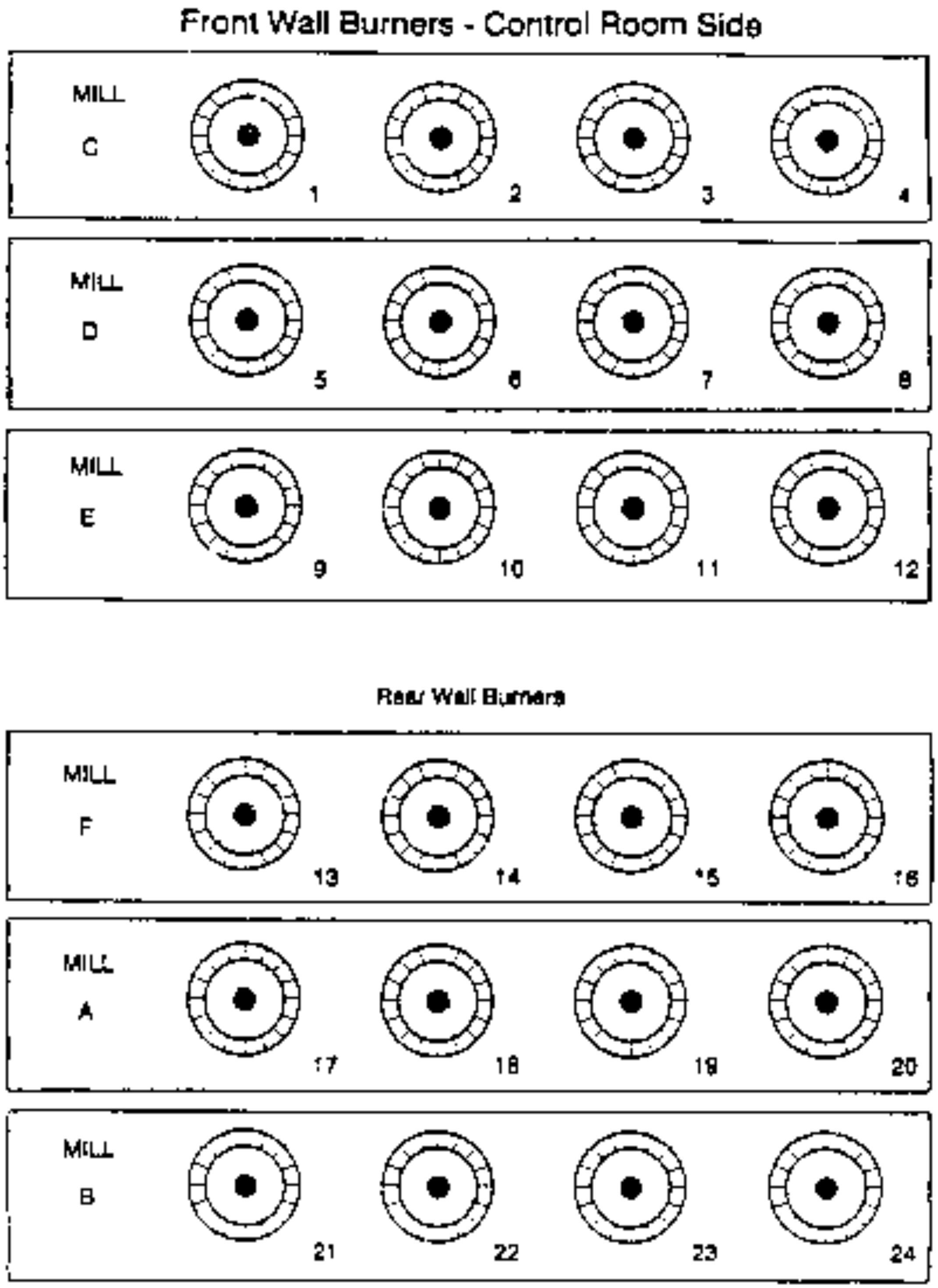


FIGURE 1-4 HAMMOND UNIT 4 TEST SITE LOCATIONS

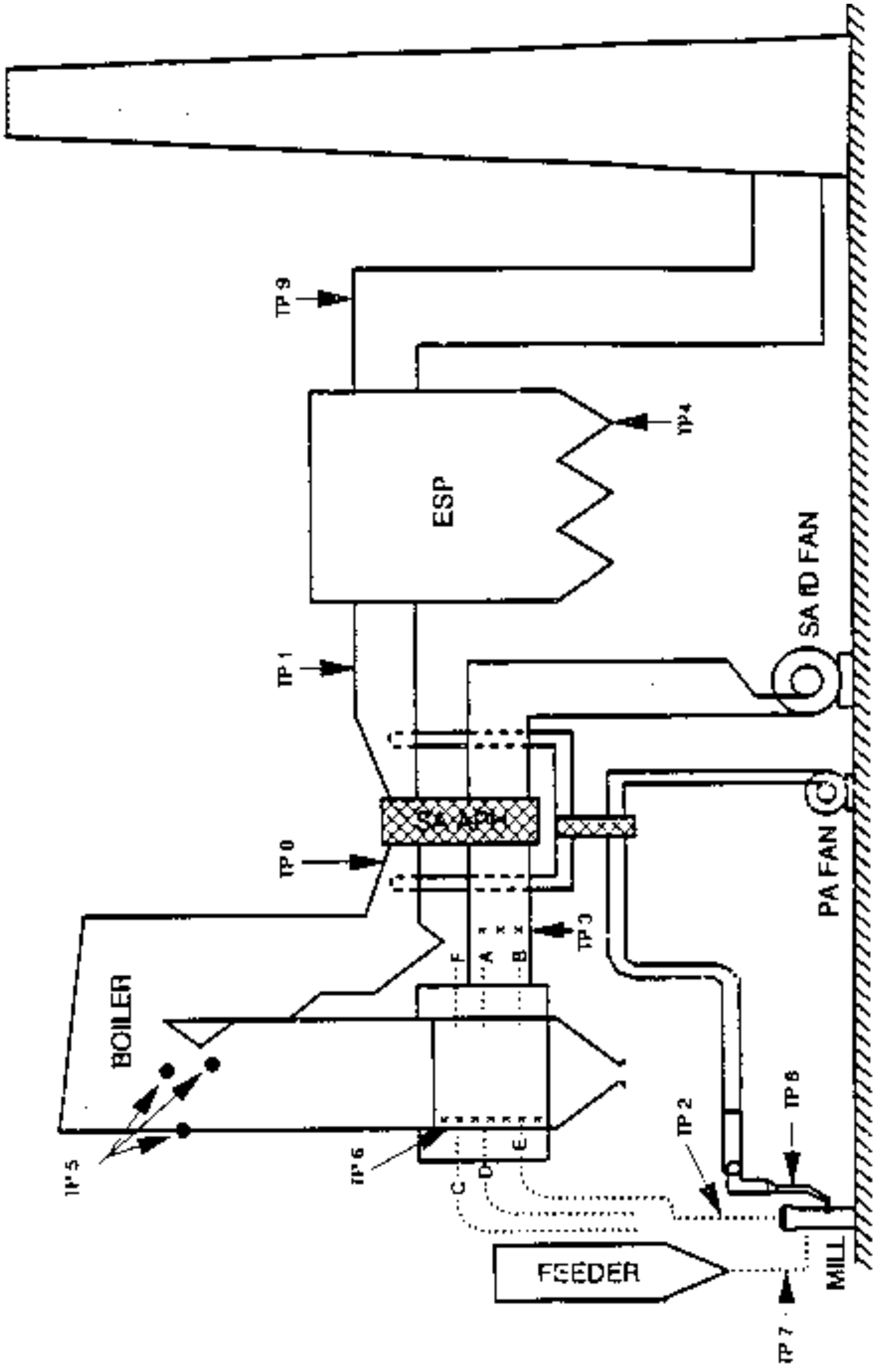


TABLE 1-2 HAMMOND UNIT 4 TEST POINT DESCRIPTION

SITE NO.	LOCATION	TESTS PERFORMED	RESPONSIBLE CONTRACTOR
TP0	Flue Gas Before APH	Gas Specie Temperature	Spectrum Systems
TP1	Flue Gas After APH	Resistivity SO_3,TPM,PSize	Southern Research
TP2	Pulverizer	CleanAir Velocity Dirty Air Velocity Particle Size Coal Flow Distribution	Flame Refractories
TP3	Secondary Air Venturi	Velocity	Flame Refractories
TP4	ESP Hopper	Resistivity LOI	Southern Research
TP5	Furnace Nose	Gas Specie HVT	Flame Refractories
TP6	Windbox Duct Turbine Side	Velocity	Flame Refractories
TP7	Coal Feeder Inlet	Coal Samples	Georgia Power
TP8	Primary Air Duct	Air Flow	Flame Refractories
TP9	Stack	Gas	Spectrum Systems

2.0 TEST PROGRAM DESCRIPTION

2.0 TEST PROGRAM DESCRIPTION

In the past, there have been a number of "demonstration" programs by various burner manufacturers for the purpose of evaluating the NOx reduction potential of their equipment. Without exception, these demonstrations have provided only minimal amounts of information which could be used to extrapolate to the gene--al population of utility boilers. All of these demonstrations provided only small amounts of short-term data (generally less than one day for each data point) in both pre- post-retrofit configurations. Very few of these demonstrations have provided long-term data (on the order of months of continuous data) in the post-retrofit configuration, and none have provided long-term data in the pre-retrofit configuration. The purpose of this DOE ICCT II program is to provide detailed short- and long-term pre- and post retrofit emission data on a number of low NOx combustion technologies applied to a wall-fired utility boiler.

The following paragraphs describe the technologies that are to be investigated during the four phases of this program, the general methodology used to obtain data and the schedule of events for Phase I.

2.1 Technology Background

At the completion of the DOE ICCT II program, three basic NOx control technologies will have been demonstrated and compared to the baseline configuration. The technologies that will eventually be investigated are:

1) Advanced Overfire Air Operation (AOFA),
2) Low NOx Burner Operation (LNB),
and 3) Combined LNB and AOFA Operation.

Each of the technologies (or combination of technologies) will eventually be compared to the baseline configuration to ascertain the NOx reduction effectiveness. Southern Company Services has contracted with Foster Wheeler Energy Corporation to provide the burner hardware which will be retrofit to the Hammond Unit 4 by Flame Refractories, Inc. (Flame).

The baseline configuration evaluation is the subject of this report and is defined as the "as found" configuration of the unit. The "as found" configuration is further defined as the configuration under which the unit has operated in the recent past. In the case of Hammond Unit 4, this consisted of operation with some existing burner related problems that will be detailed in Section 5.1. The results of this baseline effort will be compared to the results for subsequent Phases of the overall program. The following paragraphs provide an overview of AOFA and LNB retrofits as they will be subsequently incorporated into Unit 4.

2.1.1 Advance Overfire Air Ports

The standard offering of overfire air ports incorporates combustion air bypass from the main burner windbox through ports above the burners. This secondary combustion air is obtained from an extension of the burner windbox and is generally integral to the main burner windbox. The portion of the combustion air diverted away from the burners drives the primary combustion stoichiometry toward a fuel rich condition. The secondary combustion air diverted above the burners to the overfire air ports provides sufficient air to complete combustion before the products reach the convective pass. Because of the diversion of air, the primary coal combustion zone operates under a fuel rich condition, which facilitates reduction of NOx.

Studies by EPRI and boiler manufacturers have shown that the standard overfire air (OFA) offerings do not result in optimum NOx reduction due to inadequate mixing of the secondary air with the partially combusted products from the fuel rich burner zone. This inadequate mixing limits the effectiveness of the OFA technique. The Advanced Overfire Air Ports to be provided by Foster Wheeler incorporate separate (from the windbox) injection port and duct configurations that are designed to provide increased secondary air penetration. Typical standard offerings provide penetration velocities approximately two times the furnace flow velocity. The Advanced Overfire Air Ports designed by Foster Wheeler for this project will provide increased penetration velocities by supplying secondary air from completely separate aerodynamically designed ducts located above the existing burner windbox. A schematic of the design is shown in Figure 2-1. The ports themselves are also designed to provide increased penetration velocities. Elements of these designs have been incorporated into other recent Foster Wheeler projects. Evaluation of this low NOx combustion concept will be undertaken during Phase II of the project.

2.1.2 Low NOx Burners

Foster Wheeler will! supply their Controlled Flow-Split Flame (CFSF) burner for retrofit into the existing wall penetrations of the 24 Intervane burners. This burner was originally developed for use or. the San Juan Units of the Public Service Company of New Mexico in the mid-1970s. Subsequent to that development, modifications of the burner have been incorporated into new boilers and have been retrofitted to a number of existing utility boilers. Figure 2-2 illustrates the basic design features of the current FWEC offering of the CFSF burner.

As with all of the manufacturers of new low NOx burners, Foster Wheeler's burners utilize the principle of separating the fuel and air streams in the primary combustion zone. Unique design features of the burner allow low NOx operation with shorter flames than may result from other wall-fired burner

FIGURE 2-1 SCHEMATIC OF ADVANCED OFA

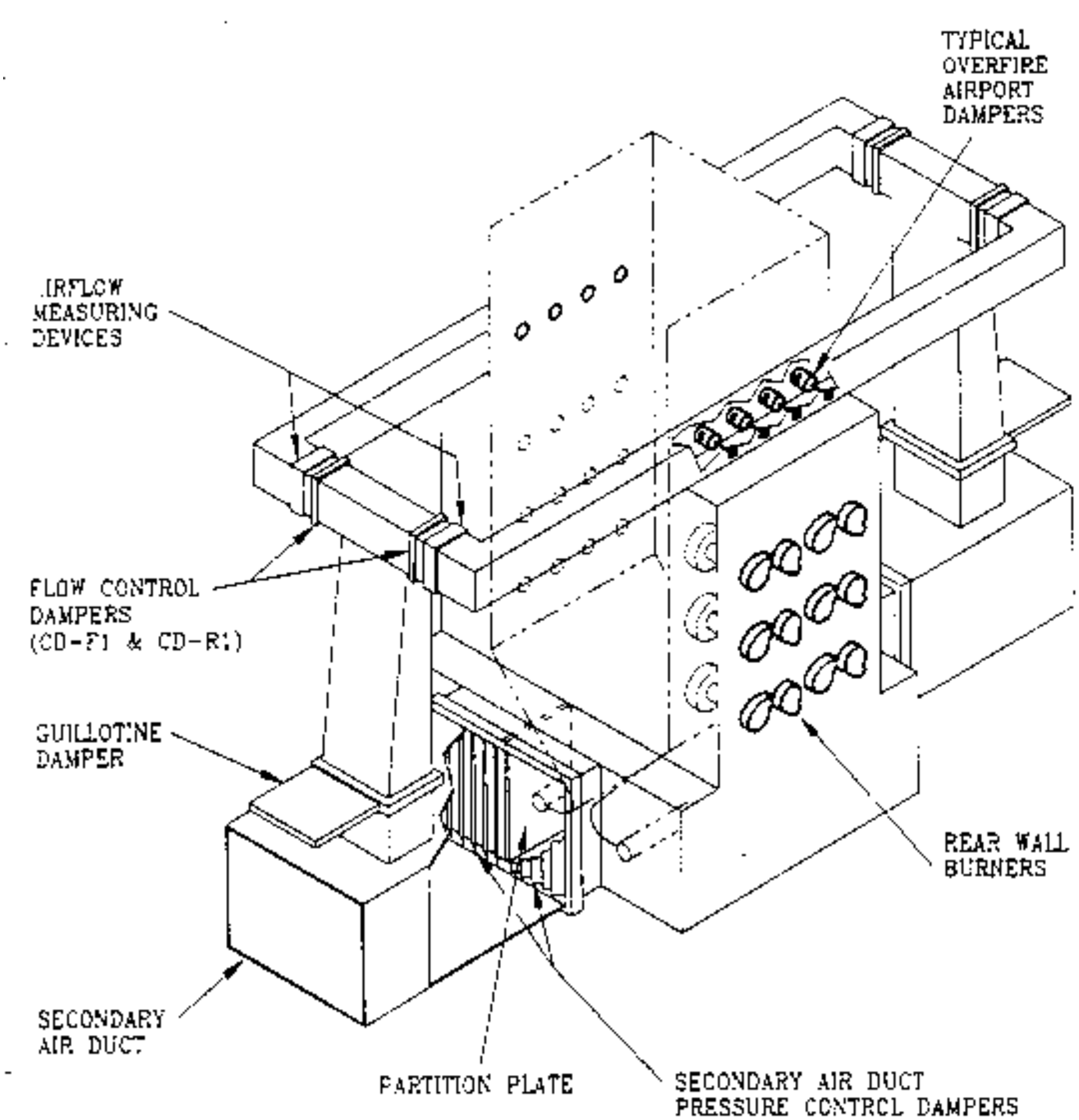
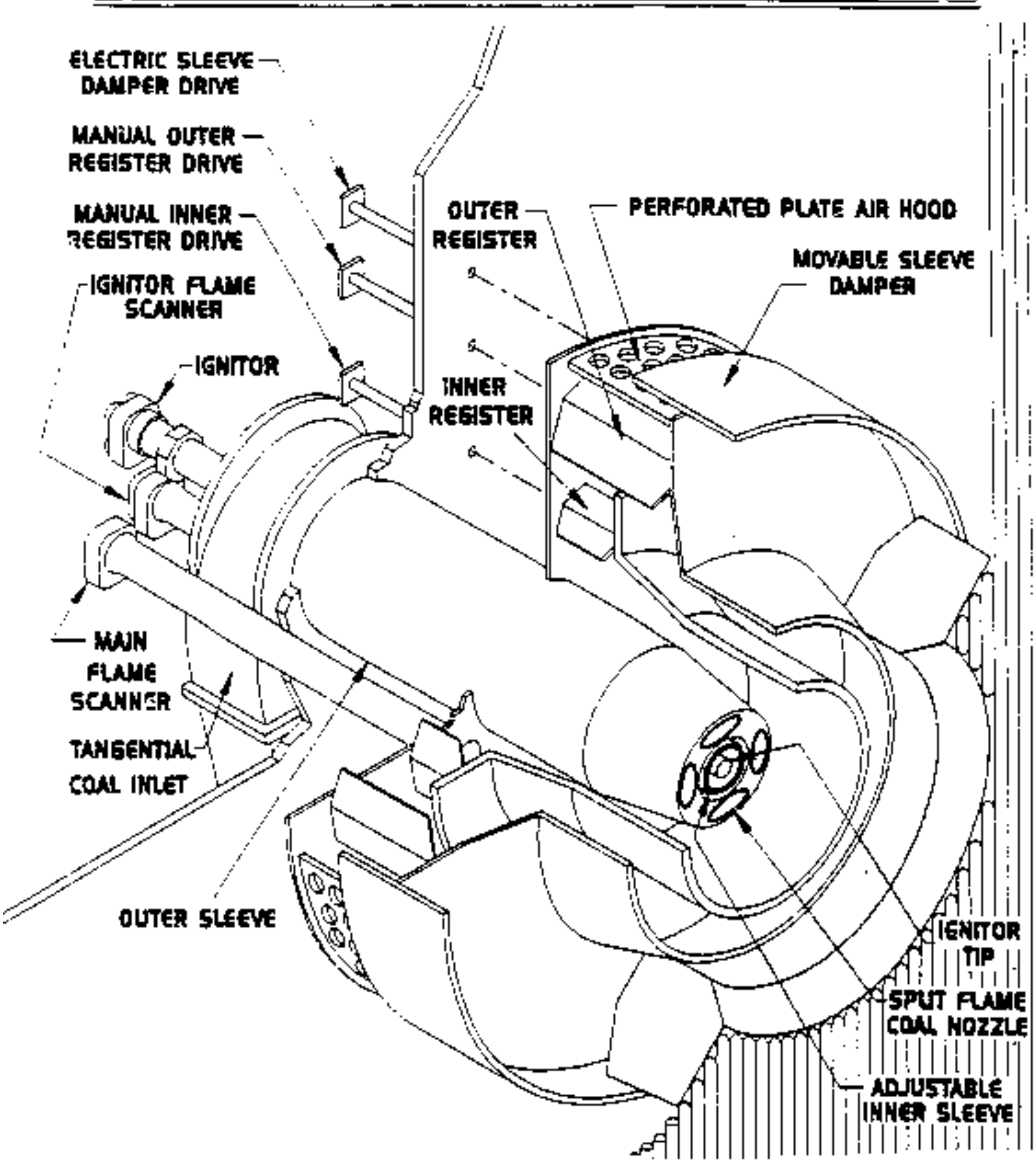


FIGURE 2-2 ILLUSTRATION OF CFSF BURNER



manufacturers' concepts. These "internally" staged burners accomplish NOx reduction in the similar manner as accomplished with overfire air, however, in a much more efficient manner. These "internally staged" burners result in significantly better mixed final products of combustion than do overfire air ports. This low NOx burner concept will be evaluated during Phase III of the project. Due to the unique design features of the burner the same burner can be operated with or without the Advanced Overfire Air Ports described above. The combination of the Foster Wheeler CFSF burner operation used in conjunction with Advanced Overfire Air Ports will be evaluated during Phase IIIb of the project.

2.2 Program Test Elements

One of the underlying premises for the structure of the testing efforts in all of the Phases of this DOE ICCT II project is that short-term tests cannot adequately characterize the true emissions of a utility boiler. As a consequence of this, the focal point of the test efforts during all Phases of this project is long-term testing. Short-term testing is used only to establish trends that may be used to extrapolate the results of this project to other similar boilers. During this program, the short-term test results are not intended to be used to determine the relative effectiveness of the retrofitted NOx control technologies. This will be accomplished by performing statistical analyses of the long-term data. A description of the purpose and sequence for each of three types of testing involved in all Phases of the project follows.

2.2.1 Short-term Characterization

Initial short-term testing is generally performed to establish the trends of NOx emissions under the most commonly used configurations. In addition, it is used to establish the performance of the boiler in these normal modes of operation. The characterization testing is divided into two elements - Diagnostic and Performance tests. Diagnostic testing is used to establish the gaseous emission trends while Performance testing is used to establish boiler efficiency and steaming capability as well as gaseous and particulate emissions. Both Diagnostic and Performance testing are conducted under conditions controlled by the wall-fired project test personnel. The results of analysis of the Short-Term Diagnostic and Performance data are presented in Sections 5.1 and 5.2.

Diagnostic testing involves characterizing the gaseous emissions under three to four load conditions over the range of operating parameters which might normally be encountered on Unit 4 as well as excursions about these normal conditions. The primary parameters that are used for characterization are excess oxygen, mill pattern and mill bias. Testing at each of the selected conditions is accomplished during a one to three hour period with the unit in a fixed configuration while it is off of

System Load Dispatch to better control the operation of the boiler.

Performance testing is accomplished at specified loads in configurations recommended by Plant Engineering and which were tested during the Diagnostic testing. These configurations represent one of the normal modes of operation for each load condition. Parametric Performance data are recorded during ten to twelve hour test periods with the unit off of System Load Dispatch to provide steady operating conditions.

Results from each of these tests will ultimately be used for comparison with results from similar testing of the various NOx control technologies undertaken in Phases II and III, i.e., AOFA, LNB and LNB + AOFA.

2.2.2 Long-Term Characterization

Long-term testing for each Phase is conducted under normal System Load Dispatch control conditions. Generally, no intervention with respect to specifying the operating configuration or conditions are imposed by test personnel. The long-term testing provides emission and operational results that include most if not all of the possible influencing parameters that can affect NOx emissions for a boiler over the long run. These parameters include coal variability, mill in-service patterns, mill bias ranges, excess oxygen excursions, equipment conditions as well as many as yet undetermined influencing parameters. Results from this long-term testing provide a true representation of the emissions from the unit. Data for the parameters of interest are recorded continuously (5 minute averages) for periods of as long as 80 days. The analysis of this long-term data will be discussed in Section 6.0 for this Phase 1

2.2.3 Short-Term Verification

Over the 70 to 80 day test period required for the Long-Term Characterization, changes in the unit condition and coal can occur. Verification testing is conducted at the end of all four phases for the purpose of quantifying some of the impacts of these potential changes on the Long-Term emission characterization. This Verification testing can assist in explaining potential anomalies in the Long-Term data statistical analysis. The verification tests are conducted in a similar manner to that of the Short-Term Characterization testing described above. Four to five basic test configurations (load and mill pattern) are tested during this short effort.

2.3 Phase I Test Plan

The Hammond Unit 4 Phase I testing effort was completed on April 5, 1990 after five months of uninterrupted testing. The following briefly describe the test sequence during this period.

2.3.1 Short-Term Characterization Testing

The test plan for Phase I Short-Term Characterization incorporated four load points ranging from 185 to 489 MWe which were initially identified as being representative of normal operation. It was subsequently discovered that loads below 400 MWe were rarely experienced in normal operation. The initial test plan for the Short-Term Characterization testing is shown in Table 2-1 Preliminary Phase I Short-Term Characterization Test Plan and includes the following Diagnostic tests:

LOAD	MILL PATTERN	NO. TESTS
489 Mwe	All Mills-in-Service	9
400	4 Mill-out-of-Service (MOOS) Patterns	14
300	4 MOOS Patterns	10
185	2 MOOS Patterns	8

The final Diagnostic test plan as performed on Unit 4 is shown in Table 2-2 and was performed over the period from November 2, 1989 to November 13, 1989. This revised Diagnostic Test plan included the following basic test conditions:

LOAD	MILL PATTERN	NO. TESTS
480 MWe	All Mills-in-Service	14
400	2 MOOS Patterns	11
300	3 MOOS Patterns	7
185	1 MOOS Patterns	2

Each of these tests was performed over a duration of from one to three hours. A discussion of the Diagnostic test results can be found in Section 5.1.

Table 2-1 includes the initial test plan for the Performance portion of the Short-Term Characterization tests. The Performance tests were executed as planned and no make-up testing was necessary. Due to scheduling problems, an extra day of testing at the nominal 480 MWe load point was performed and was used to obtain additional supporting data. A discussion of the Performance test results can be found in Section 5.2.

2.3.2 Long-Term Characterization Testing

Long-Term Characterization testing began in early January 1990 and was completed early in the month of April 1990. During

TABLE 2 - 1 PRELIMINARY PHASE 1 TEST MATRIX

	TEST DAY	TEST CONDITIONS	LOAD MWe	MOOS PATTERN	02 LEVEL
	1	OPERATIONAL RANGE	489	I	H-L
	1	“	400	II	H-L
	1	“	300	IV	H - L
	2	Hl LOAD O2 VARIATION	489	I	3.0
	2	“	489	I	4.0
	2	“	489	I	5.0
	3	MID LOAD 02 VARIATION	400	II	3.0
	3	“	4400	II	4.0
	3	“	400	II	5.0
	4	MID LOAD MILL VARIATION	400	III	3.0
CHARACTERIZE THE	4	“	400	III	4.0
EFFECTS OF VARIOUS	4	“	400	III	5.0
PARAMETERS ON	5	MID LOAD 02 VARIATION	300	IV	3.0
EMISSIONS AND	5	“	300	IV	4.0
OPERATION	5	“	300	IV	5.0
	6	MID LOAD MILL VARIATION	300	V	3.0
	6	“	300	V	4.0
	6	“	300	V	5.0
	7	LOW LOAD 02 VARIATION	185	VI	4.0
	7	“	185	VI	5.0
	7	“	185	VI	6.0
	7	“	185	VI	7.0
	8	LOW LOAD MILLVARIATION	185	VIII	4.0
	8	“	185	VIII	5.0
	8	“	185	VIII	6.0
	8	“	185	VIII	7.0
	9	Hl TO MID LOAD TESTS	489	I	4.0
	9	“	489	1	5.0
	9	“	400	II	5.0
	9	“	400	II	4.0
	9	“	300	IV	5.C
	9	“	300	IV	6.0
	10	MID LOAD MILL TESTS	400	II	4.0
	10	“	400	VIII	4.0
REPEAT TESTS TO	10	“	400	IX	4.0
CONFIRM AND	10	“	300	IV	4.0
SUPLIMENT DATA	10	“	300	X	4.0
	10	“	300	XI	4.0
	11	HI TO MID LOAD BIAS TESTS	489	I	4.0
	11	“	489	I-1	4.0
	11	“	489	I-2	4.0
	11	“	400	II	4.0
	11	“	400	II-1	4.0
	11	“	400	II-12	4.0

TABLE 2-1 PRELIMINARY PHASE 1 TEST MATRIX (Con't)

	TEST DAY	TEST CONDITIONS	LOAD MWe	MOOS PATTERN	O2 LEVEL
	12	ENVIR. & PERF CHARACTER	489	1	3.4
	13	ENVIR. & PERF CHARACTER	489	1	3.4
	14	ENVIR. & PERF CHARACTER	400	11	NORM
DOCUMENT BASELINE	15	ENVIR. & PERF CHARACTER	400	11	NORM
EMISSIONS AN	16	ENVIR. & PERF CHARACTER	300	IV	NORM
PERFORMANCE	17	ENVIR. & PERF CHARACTER	300	IV	NORM
	18	ENVIR & PERF MAKEUP	TBD	TBD	TBD
	18	ENVIR & PERF	TBD	TBD	TBD
	20	ENVIR 8 PERF	TBD	TBD	TBD

NOTE: ROMAN NUMERAL MILL PATTERNS REPRESENT DIFFERENT AS YET UNDETERMINED PATTERNS

TABLE 2 - 2 FINAL PHASE l TEST MATRIX

	TEST NO.	DATE	TEST CONDITIONS	LOAD MWe	MOOS PATTERN	DAS 02 LEVEL
DIAGNOSTIC TESTS	1-1	11/2	OPERATIONAL RANGE	480	NONE	HIGH
	1-2	11/2	OPERATIONAL RANGE	480	NONE	LOW
	1-3	11/2	Hl LOAD 02 VARIATION	480	NONE	3.1
	2-1	11/3	Hl LOAD 02 VARIATION	480	NONE	2.5
	2-2	11/3	Hl LOAD MILL BIAS	480	NONE	2.7
	2-3	11/3	MID LOAD 02 VARIATION	400	E	3.3
	3-1	11/4	LOW LOAD 02 VARIATION	185	B&E	7.2
	3-2	11/4	LOW LOAD 02 VARIATION	185	B&E	6.2
	4-1	11/5	Hl LOAD 02 VARIATION	480	NONE	2.5
	4-2	11/5	Hl LOAD 02 VARIATION	480	NONE	2.2
	5-1	11/6	Hl LOAD MILL BIAS	480	NONE	2.4
	5-2	11/6	MID LOAD 02 VARIATION	400	E	2.4
	6- l	11/7	MID LOAD 02 VARIATION	300	E	3.8
	6-2	11/7	MID LOAD 02 VARIATION	300	E	5.2
	6-3	11/7	MID LOAD MILLVARIATION	400	NONE	3.5
	7-1	11/8	MID LOAD 02 VARIATION	300	E	4.3
	7-2	11/8	MID LOAD MILLVARIATION	300	B	4.2
	7-3	11/8	MID LOAD 02 VARIATION	400	E	4.3
	7-4	11/8	MID LOAD 02 VARIATION	400	B	3.2
	7-5	11/8	Hl LOAD 02 VARIATION	480	NONE	2.9
	8-1	11/9	MID LOAD MILL VARIATION	300	B&E	4.0
	8-2	11/9	MID LOAD 02 VARIATION	479	NONE	3.0
	8-3	11/9	MID LOAD 02 VARIATION	478	NONE	2.7
	8-4	11/9	Hl LOAD 02 VARIATION	478	NONE	2.2
	9-1	11/10	MID LOAD 02 VARIATION	400	B	2.3
	9-2	11/10	MID LOAD 02 VARIATION	400	B	3.5
	9-3	11/10	MID LOAD 02 VARIATION	400	B	5.1
	9-4	11/10	HIG H LOAD 02 VARIATION	480	NONE	3.3
	9-5	11/10	HIG H LOAD 02 VARIATION	480	NONE	2.9
	10-1	11/11	MID LOAD 02 VARIATION	405	E	2.0
	10-2	11/11	MID LOAD02 VARIATION	403	E	3.1
	10-3	11/11	MID LOAD 02 VARIATION	400	E	4.5
	10-4	11/11	MID LOAD 02 VARIATION	305	E	2.8
	10-5	11/11	MID LOAD02 VARIATION	315	E	4.8
	11-1	11/13	HIG H LOAD 02 VARIATION	478	NONE	2.9
	11-2	11/13	HIG H LOAD02 VARIATION	480	NONE	2.9
PERFORMANCE TESTS	12-1	11/29	HIGH LOAD NORMAL OPERATION	472	NONE	2.6
	13- l	11/30	HIG H LOAD NORMAL OPERATION	475	NONE	2.6
	14- l	12/01	LOW LOAD NORMAL OPERATION	299	E	4.2
	l5- l	12/02	LOW LOAD NORMAL OPERATION	306	E	4.1
	16- l	12/03	MID LOAD NORMAL OPERATION	400	E	3.4
	17- l	12/04	HIG H LOAD NORMAL OPERATION	475	NONE	2.8
	18- l	10/05	MID LOAD NORMAL OPERATION	400	E	3.2

this period, a significant amount of continuous emission data was collected. During the over three month period the unit was online all but five days due to unscheduled outages. Due to difficulties with the Continuous Emission Monitoring systems, some information was lost, however, it did not compromise the statistical analysis of the data. A discussion of the results of the long-term data and the analyses can be found in Section 6.0 along with a comparison of the long- and short-term test results.

2.3.3 Verification Testing

Verification testing was completed during the week of April 2, 1990. Eleven tests were performed during this period - six at 400 MWe and five at 480 MWe. The trends exhibited by this data indicated that no significant changes occurred during the long-term test effort. A discussion of the results of the verification testing can be found in Section 5.5.

3.0 TEST PROCEDURES AND MEASUREMENTS

3.0 TEST PROCEDURES AND MEASUREMENTS

A wide variety of measurement apparatus and procedures were employed during the test program described in Section 2.0. The acquisition of data can be conveniently grouped into four broad categories relating to the equipment and procedures used. A brief description of each data category follows. A more complete description of each category is contained in Sections 3.1 through 3.4.

1) Manual Boiler Data Collection

   These data were recorded manually onto data forms based on readings from existing plant instruments and controls. The data were subsequently entered manually into a computer data management program. Coal, bottom ash and ESP hopper ash samples were collected regularly for subsequent laboratory analysis.

2) Automated Boiler Data Collection

   Two scanning data loggers (described below) were installed to record, at frequent intervals, the signals from both pre-existing plant instrumentation and instruments installed for this test program. The data loggers were monitored by a central computer (IBM PC compatible) which maintained permanent records of the data and also allowed instantaneous, real-time interface with the data acquisition equipment.

   Specialized instrumentation was also installed to measure some specific parameters related to the combustion and thermal performance of the boiler, as well as selected gaseous pollutant emissions. These included combustion gas analyzers, pollutant emissions analyzers, an acoustic pyrometer system, fluxdomes, and continuous ash samplers. The combustion gas and emissions analyzers and the acoustic pyrometer system were linked to the central computer for automated data recording.

3) Combustion System Tests

   At several specific operating conditions tests were performed by a team of engineers (Flame Refractories, Inc.) using specialized apparatus and procedures to measure parameters related to the combustion and thermal performance of the boiler.

4) Solid/Sulfur Emissions Tests

   During the performance tests, a team of scientists and technicians from Southern Research Institute made measurements of particulate and gaseous emissions exiting the boiler, using specialized equipment and procedures.

The manual data collection duplicated some of the operational parameters also measured by the automated boiler data collection system in order both to provide backup of important data and to permit assessment of the boiler operation during the test. period. The following sections describe the equipment and procedures used in each category and the way in which the data were reduced and analyzed.

3.1 Manual Boiler Data Collection

The manual boiler data comprised both operating data and material sample collection and analysis.

3.1.1 Boiler Operating Data

Detailed operational data were recorded from existing plant instrumentation for two principal reasons. First, the data were used to establish, maintain and document critical operating parameters at specified steady-state test conditions for comparison to subsequent post-retrofit testing. The second reason was to provide a broad range of operational data which might be useful in the analysis and interpretation of vital performance and emissions data related to combustion. The parameters recorded are listed in Table 3-1.

Short-term Diagnostic tests were performed to document the relationship of NOx emissions to various boiler operating parameters (load, excess O_2, mill operation, etc.) and to establish Baseline NOx emissions and boiler efficiency for later comparison to post-retrofit results. "Performance" tests were conducted to acquire some of the operational and emissions data which require longer times to complete, such as fuel/air flow distributions and solid/sulfur emission characteristics.

The Diagnostic, or parametric, tests were performed over periods of from l to 3 hours, beginning after the desired operating conditions had been established and the unit had been stabilized for up to an hour. Steady operating conditions were maintained to the extent possible during the test. Typically, data were recorded manually at the beginning and end of the total test duration and approximately one-hour intervals in between in the case of longer test durations. A single composite coal sample from all active mill feeders was taken on each day of testing.

Each Performance test series was run over a period of 10 to 12 hours on each of two days. After establishing the unit operation at the desired test conditions, the unit was allowed to establish steady state operation for up to one hour prior to the start of the test. During the full duration of each day's tests, slight adjustments were made periodically, as necessary, to maintain combustion conditions. These adjustments were made to maintain fuel and air flows, temperatures, steam conditions,

TABLE 3-1
Boiler Operational Data
Hammond Unit 4

Operating Parameters	Units
Gross Load	MW_e
Main Steam Flow	MMlb/hr
Throttle Pressure	psig
Main Steam SH & RH Temperatures	degrees F
SH Spray Flow (upper/lower)	lb/hr
Turbine Back Pressure	in. Hg
Coal Mills (A-F)	
Feeder Set Point	%
Feeder Coal Flow	Klb/hr
Supply Pressure	in. H_2O
Hill Differential Pressure	in. H_2O
Mill Motor Current	amp
Mill Outlet (PA) Temperature	degrees F
Combustion Air Flow	MMlb/hr
FD/ID Fan Currents	amp
Windbox Pressure (front/rear)	in. H_2O
Furnace Draft	in. H_2O
Boiler exit excess O2 (A/B)	%
Secondary APH Gas/Air, In/Out Temps (A/B)	degrees F
Primary APH Gas/Air, In/Out Temps (A/B)	degrees F
Stack Opacity	%

Boiler Controls	Position of Set Pt.
Boiler Master Set Pt.	%
Boiler Pressure Set Pt.	psig
Fuel Master Pos.	%
Combustion Air	
FD/ID Inlet Vane Pos	%
ID Bias Set Pt. (B/C)	%
Steam	
Main Steam Temp Set Pt.	degrees F
SH Spray Pos (upper/lower, right/left)	%
SH Damper Pos.	%
RH Temp. Set Pt.	degrees F
RH Spray Valve Pos.	%
RH Damper Pos.	%
Pulverizer Feeder Readings	
Change Over Measured Time	100 lb increments

excess O_2, opacity, etc., as constant as possible, notwithstanding uncontrollable variations in ambient temperature and humidity, fuel quality, etc. This was accomplished by setting the boiler Fuel and Air Masters on hand control and making slight adjustments gradually during the day to keep the firing rate, steam conditions, excess air, etc., relatively constant. Generally speaking it was possible to keep these parameters steady within ± 2% over the duration of the test period.

The greatest variation experienced during the tests was in excess O_2, as the FD fan output changed due to variations in ambient air temperature. For the most part the excess O_2 varied within ± 0.3% of the average for individual tests. In order to monitor the stability of the test parameters during the performance tests, readings of the parameters shown in Table 3-l were recorded at the beginning and end of the test period and at roughly 2-hour intervals in between.

The normal regimen for soot-blowing on the unit calls for IR and IK soot blowing (furnace walls and convective pass tubing, respectively), as needed to maintain proper steam temperature balances, and air heater (APH) blowing about once per shift to prevent pluggage of the APH baskets. During the performance and emissions sampling periods of each characterization test, no soot-blowing was allowed. Air preheaters were blown clean at times during mid-day breaks in the emissions sampling routine. APH blowing was stopped at least l/2 hour prior to resumption of emissions testing.

3.1.2 Material Samples

Batch samples of coal, bottom ash and ESP hopper fly ash were obtained by plant personnel at various times during the duration of each performance test. Table 3-2 shows the approximate sample times and locations.

TABLE 3-2 Material Sample Times

Sample	Source	Point in Test
Coal	Each mill inlet chute (sample mixed and crushed by plant personnel)	Start-mid-end
Bottom Ash	Combination of East and West bottom hoppers	Mid
ESP Ash	Separate samples from A-3, A-7, B-3, B-7 hoppers (A-inlet, B-outlet field; 3-east side, 7-west side)	Mid

During the performance testing, coal samples were acquired three times daily for all except one test day. The coal samples were obtained directly from the silo outlet chutes supplying each mill feeder. Care was taken to ensure that a representative sample of the coal entering each mill was obtained in approximately equal amounts. All samples taken at a specific time were mixed, quartered and divided, crushed to roughly 50 mesh and sealed in plastic bags of about 3-pound capacity. A tag identifying the date and time of sample was written on each bag.

The coal samples were analyzed in the Alabama Power General Test Laboratory in Birmingham. Ultimate and proximate analyses were performed on all samples. Ash fusion temperatures (initial deformation temperature, softening temperature, fluid temperature) were determined for all performance test samples.

Bottom ash samples were obtained once per day near the mid-point of the test. Early in each test the bottom ash was pulled to insure that in the ensuing several hours only ash deposited under known test conditions would accumulate in the hopper. For the desired sample, approximately 20 to 50 pounds of bottom ash was removed from one hopper and allowed to drain on a clean section of concrete floor. Approximately 10 pounds of moist ash was placed in a plastic bag. The process was repeated for the other bottom hopper, adding about 10 pounds of moist ash to the first sample. The bag of mixed ash was tagged to identify the date and time of sampling. Bottom ash samples from the performance tests were analyzed for Loss on Ignition (LOI) according to ASTM D3174-82.

The ESP hoppers are continuously emptied by a pneumatic conveying system. Thus, several hours into a test the ESP hoppers should contain only ash that represents the accumulation during the early test period. For each test day, four bags of ash (approximately 2 pounds each) were obtained, one each from four separate ESP hoppers representing inlet and outlet ESP fields and from both sides of the boiler exit (east and west). The ESP ash samples were kept separate in the event that it became necessary to assess the variation of ash characteristics spatially within the precipitator. Each ESP ash sample was divided in two parts; one portion was reserved for archive and the other was analyzed for LOI by Southern Research Institute.

3.2 Automated Boiler Data Collection

A Data Acquisition System (DAS) was designed and installed for the Hammond Unit 4 ICCT project. It 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 a relationship in common with either boiler performance or boiler exhaust gas properties.

3.2.1 Data Acquisition System Description

The DAS is divided into four subsystems: 1) Instrumentation and Process Inputs, 2) Data Acquisition Package, 3) Field Wiring and 4) Instrumentation Shack which are described in the following paragraphs.

Instrumentation and Process Inputs

The Instrumentation and Process Inputs (I&PI) subsystem is the collection of field instruments used to sense plant and process parameters. The instruments serve to make available plant process, combustion, and environmental data for the Data Acquisition Package. The I&PI consists of selected, existing plant data points and new instrument packages purchased for boiler emissions and combustion gas temperature monitoring. For the most part, very few plant instruments are appropriate for direct inputs to the Data Acquisition Package since many of the Plant's process transmitters are pneumatic. New electronic transmitters were installed on existing instrument taps to provide 4-20 ma signals for DAS pressure and flow data. Existing plant thermocouples were used as direct temperature data inputs for the Data Acquisition Package. The Plant Data List shown in Table 3-3 identifies the existing plant data points utilized in the DAS. This data is collected primarily for boiler performance analysis and comparisons before and after implementation of the various NOx control techniques.

TABLE 3-3 Automated Boiler Data List

Boiler Drum Pressure	Superheater Outlet Pressure
Cold Reheat Pressure	Hot Reheat Pressure
Turbine 1st Stg Pressure	Feed Water Pressure
Feed Water Flow	Reheater Spray Flow
Superheater Spray Flow	Secondary Air Flows
Primary Air Flows	Pri. Tempering Air Flows
Coal Flows (Feeder Speeds)	Unit Gross Generation (MWe)
Main Steam Temperatures	Economizer Inlet (F.W.)
Heater 8A/B Drain Temps	Pri. Superheater Outlet Temp
Sec. Superheater Outlet Temps	Superheater Spray Water Temp
Cold Reheat Temperature	Reheat Spray Water Temperature
Hot Reheat Temperature	Secondary Air Htr Air Out Temp
FD Fan Outlet Temps	Pulv. Mill Temperatures
Boiler Exit Gas Oxygen	Air Heater Exit Gas Oxygen

New instrumentation is incorporates into the DAS to provide specific data for the evaluation of the boiler's combustion process and for the monitoring of boiler exhaust gases being discharged to the atmosphere. The special data requirements for the ICCT project necessitated the installation of ;) Extractive

Continuous Emissions Monitor, 2) Acoustic Pyrometer, 3) Flux Domes and 4) Oxygen Monitor, which are described in greater detail below:

Data Acquisition Package

The Data Acquisition Package (DAP) is a general purpose, fully integrated system developed for IBM PC's and compatibles. The system currently collects approximately 150 analog inputs, a mixture of both high level (such as pressure transmitters) and low level (primarily thermocouple) signals. The analog inputs and another 100 calculated points are stored at 5 minute intervals for later analysis. The basic scan rate of the system is 5 seconds.

Hardware

The system uses a 16 MHz 80386 PC class computer. The PC is configured with a 80387 numeric co-processor, 4 MB of RAM, and 40 MB hard disk. An IBM ARTIC co-processor card is installed and is used to perform background scanning. The PC is located in the DAS instrument room. Data is collected by two local processing units (LPU) supplied by Kaye. One LPU, located in the instrument building, is currently configured to allow up to 96 analog inputs. Inputs include new instrumentation installed around the air heaters, the KVB Extractive Continuous Emissions Monitor (ECEM), flux domes and the acoustic pyrometers. The other LPU, located in the Unit 4 control room, has 64 analog input channels. Inputs to this LPU, primarily from the feedwater and steam paths, include both existing plant instrumentation and newly installed transmitters and thermocouples. There are no analog outputs or digital inputs or outputs in the system

Each LPU is a programmable data collection front end. Both can be configured to perform several functions including:

o Scaling
o Averaging
o Totalization
o General calculations
o Steam table calculations
o Remote logging

The analog scanners accept inputs from thermocouples, high-level signals (0-12 VDC) and current inputs (using a shunt resistor).

Software

The DAS system software is a fully integrated, control and data acquisition package for IBM PC's and compatibles. The package consists of a number of software modules that share a common database and that run under a DOS multi-tasking shell

A program called VIEW is the user's graphical window to the process values. It's capabilities include: free-form pixel graphics, 16 foreground and background colors, real time data trending, bar charts, and animation. These displays are set up in hierarchical structure with movement from one display to another using function keys.

A data tabulation program provides access to process data via a character oriented screen. Up to 30 variables can be viewed at one time in each of the several pre-formatted logs. Additional logs can also be defined.

Historical Trending

A historical trending package provides a method of storing process data for later analysis. Data points can be sampled or averaged and then stored to disk. The method of collection and the period at which the data is stored can be different for each point. Data can be stored at rates ranging from 2 seconds to 1 hour. Up to 300 different points can be stored. More than 60 days of data can be stored before having to archive the historical trend files to tape or diskette. Presently data is being stored to the disk every 5 minutes for approximately 250 points.

Points stored are viewed using the historical data display package (HDD). Up to eight points can be displayed at one time. This package allows panning, zooming and time-shifting of the displayed data. The time span of the data displayed can range from 2 seconds to 99 days.

Data collected by the trend package can be exported to a Lotus 123 compatible PRN file by two methods. HDD displayed data can be dumped to a PRN file directly but always contains the same number of entries per tag name; intermediate time and process values are interpolated. Single days can also be dumped using the historical trend file read program (HTFREAD). Only entries written to the disk are dumped by this program.

Reports

A report package allows the definition of up to eight concurrent reports. These reports are free format and contain up to 300 tag names per report. Reports can be initiated on time of day, time interval, process data values and alarm conditions.

Remote access is provided to the DAP subsystem using the general purpose, remote access package pcANYWHERE. The pcANYWHERE package makes it possible for a remote PC user with a MODEM to run a host IBM personal computer or compatible at another site (the host PC is the DAS computer). Both remote and host keyboards become active and drive the host application. All displays on the host display are echoed to the remote PC. A user must have a password to access this system.

Instrumentation Building

Much of the instrumentation is located in a temperature-controlled building on the 5th floor of the boiler house adjacent to the west wall of the Unit 4 boiler. This location was chosen to minimize *instrument* cable lengths. The building serves as the central test facility for this project. The following equipment is located inside this building:

1) Data acquisition computer and operator interface
2) One of the two data acquisition front ends
3) Acoustic pyrometer display
4) Extractive emission monitoring equipment
5) Weather station electronics.

3.2.2 Extractive Continuous Emissions Monitor (ECEM)

A principal objective of this ICCT project is to evaluate the long term effectiveness of the installation of low NOx burners and advanced overfire air with regards to the reduction of NOx pollutants in the boiler exhaust gas. The Extractive Continuous Emissions Monitor (ECEM) was purchased from KVB to aid in the evaluation of combustion modifications. The system provides the means of extracting gas samples for automatic chemical analysis from sample points at strategic locations in the boiler exhaust ducts. The ECEM is equipped with a manual valving system that permits the DAS technician to select the extraction of gas samples from any ECEM probe or combination of probes. The extraction points are in the following locations:

TABLE 3-4 Gaseous Sample Extraction Points

Location	No. of Extraction Points	Arrangement of Sample Probes
Economizer Outlet/ Secondary Air Heater Gas Inlet Ducts A & B	4 sets of 3 probe assemblies per duct (total 24)	4 across x 3 deep matrix
Economizer Outlet/ Primary Air Heater Gas Inlet Ducts A & B	2 sets of 2 probes per duct (total 8)	2 across x 2 deep matrix
Secondary Air Heater Gas Outlet/Precipitator Inlet Ducts A & B	4 sets of 2 probes per duct (total 16)	4 across x 2 deep matrix
Duct to Stack	1 probe	Single point

The system quantitatively analyzes gas samples for N0x, SO_2, CO, O_2, and Total Hydrocarbons (THC). The results of the five analyses are continuously transmitted from the ECEM to the Data Acquisition Package (DAP) computer where the data can be processed and stored.

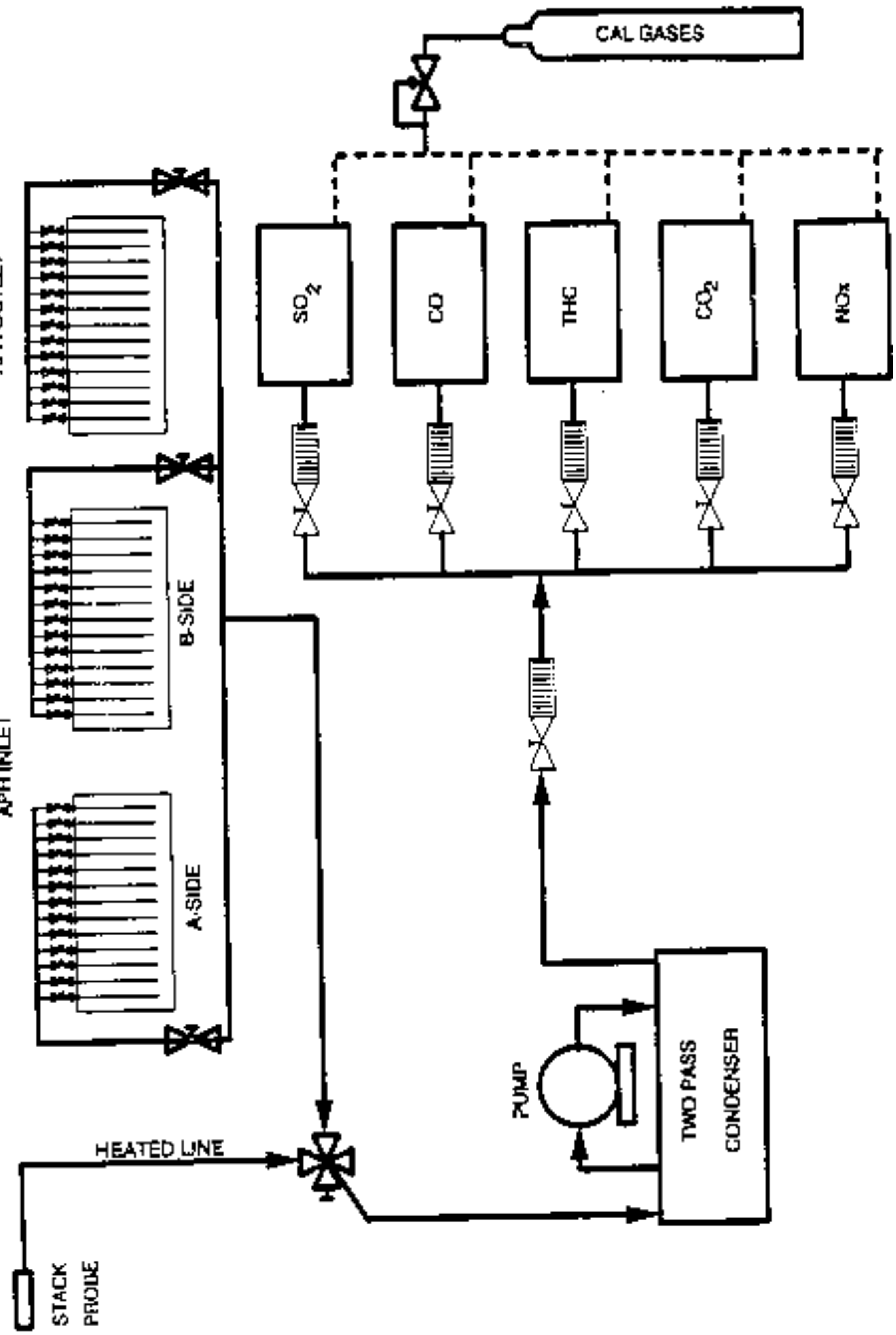
The ECEM comprises sample probes and lines, a sample control system consisting of valves and sample distribution manifolds, pumps, sample conditioning (filters, condenser/dryer, pressure regulation and a moisture detector), flowmeters, gas analyzers and an automatic calibration system. Figure 3-1 shows a schematic flow diagram of the ECEM. The sample probes consist of 1/2" Hastelloy C pipes fitted with sintered stainless steel filters to prevent fly ash from entering the probes. Where appropriate one, two or three probes penetrate a single port cap, extending vertically down into the duct to various depths. Polyethylene sample lines (3/8" OD) connect the probes to the ECEM sample selection valving. Exterior sample lines are heat traced and insulated for freeze protection. A Teflon sample line connected to a probe in the stack is heated to prevent moisture condensation. This line/probe is called the "continuous stack monitoring line."

With the exception of the continuous stack monitor probe line, all sample lines lead to individual flow control valves which are part of a sample distribution manifolding system, included in Figure 3-1. This arrangement allows the test personnel to sample selectively from any one probe, or any combination of probes, for analysis of the exhaust gases. The sample distribution bubblers act as simple flowmeters to ensure equal flow from each probe sampled. The use of the bubblers invalidates any SO2 or THC readings from the duct probes due to partial solubility in the bubbler water. The valid SO2 and THC data are acquired only through the heated stack probe/line.

The sample acquisition/conditioning system consists of dual diaphragm-type pumps, a refrigerated, water-bath moisture condenser, filters, valves and a back-pressure regulator. Moisture is removed from the sample gas within the condenser and drained automatically at set intervals. The back pressure regulator assures constant pressure supply to the analyzers to avoid measurement drifts associated with flow variations. The pumps draw roughly 1.0 cfm of sampled gas, of which a small portion is delivered to the analyzers and the remainder vented overboard. The high total sample rate is used to minimize the response time between the sample entering the probes and analysis.

Automatic (or manual) calibration is achieved by sequentially introducing certified gases of known zero and span value for each analyzer into the lines. The electric output of each analyzer for its respective zero or span gas is recorded by the control computer and translated into a linear calibration equation in engineering units. All of the analyzers have linear output response.

FIGURE 3-1 HAMMOND UNIT 4 ECEM FLOW SCHEMATIC



3.2.3 Acoustic Pyrometer

The reason for installation of the Acoustic Pyrometer system was to provide some measure of the heat distribution within the furnace combustion area during each phase of the retrofit program. It is hoped that a comparison of the pyrometer data from phase-to-phase will indicate whether any beneficial or deleterious effects on the furnace temperature conditions is caused by any phase of the retrofit.

The acoustic pyrometer package provides furnace gas temperature data for the analysis of variations in the combustion process. The Acoustic Pyrometer is a micro-computer controlled system that transmits and receives sonic signals through the hot furnace gas from multiple locations around the girth of the boiler furnace. The velocity of sonic pulses along multiple paths across the furnace can be computed and processed to provide an isothermal (contour) map of furnace temperatures at the level where the acoustic pyrometer transceivers are installed around the furnace. On Hammond 4, the horizontal plane that includes the transceivers is approximately 15 feet above the uppermost elevation of burners. The acoustic pyrometer's six furnace wall transceivers are located as described below.

Acoustic Pyrometer Transceivers are located as follows:

- 2 transceivers at equal thirds across the front wall on elevation 660",
- 2 transceivers at equal thirds across the rear wall on elevation 662',
- l transceiver on the left furnace wall, 15' from the rear wall corner on elevation 662',
- l transceiver on the right furnace wall, 15' from the front wall corner on elevation 662'.

The acoustic pyrometer provides average temperature data for straight line paths between any two transceivers not located on the same furnace wall. For the six transceiver configuration shown in Figure 3-2 a total of 12 paths are provided. The acoustic pyrometer computer provides eight 4 20 ma data channels for the DAP that can be programmed to represent any eight of the twelve temperature paths between transceivers. In addition, the acoustic pyrometer can display, on its color CRT, isothermal maps and three dimensional surface plots to allow engineers to evaluate heat profiles in the boiler. Print-outs of CRT displays can be generated on demand at the plant. The average path temperatures (13) are input to the DAP for inclusion in the Historical Data Record.

3.2.4 Fluxdome Heat Flux Sensors

The DAS instrumentation includes heat flux sensors (Fluxdomes, Land Combustion) that detect the heat absorption into the boiler's furnace wall tubes at strategic locations in the furnace. These flux measurement devices are intended to provide an indication of both the furnace combustion gas temperatures and the condition of wall ash deposits in the near-burner zone. Comparison of the flux measurements during the various phases of retrofit may indicate whether any beneficial or undesirable effects on the furnace wall tubing is associated with the low-NOx technologies.

The Fluxdome sensors consist of small metal cylinders welded to the fire side surface of a boiler tube. The shape, size and weld specifications of each cylinder are carefully controlled to assure exact dimensions in order to provide a specified heat path From the furnace/tube interface into the boiler tube. Two K type thermocouples are embedded in each cylinder at prescribed depths. The temperature gradient (typically 0-70 degrees C) detected by the thermocouples is proportional to the heat flux at the point of measurement.

The Fluxdomes are intended to provide comparative heat distribution and absorption data that may be used with other data to aid in the evaluation of the effects of low NOx burner and overfire air retrofits on combustion, heat distribution and wall deposits.

3.2.5 Special Flue Gas O_2 Instrumentation

In order to continuously monitor the excess oxygen levels at the economizer outlet and the air preheater outlet, in-situ monitors were installed in these locations. The purpose of these monitors was to allow detection of air preheater leakage through the seals and to provide accurate excess oxygen data for the long-term data collection effort.

The excess oxygen monitoring system uses zirconium oxide measuring cells located in the flue gas path. This in-situ method of measurement eliminates many of the maintenance problems associated with extractive systems. The zirconium oxide O_2 monitors used at the Hammond plant are commonly used in power plant applications and provide an accuracy of ± 0.25 percent O_2.

The Hammond Plant installation includes six monitors at the economizer outlet and six monitors at the air preheater outlet.

3.3 Combustion System Tests

These tests were performed by the Performance Subcontractor personnel (Flame Refractories, Inc.) under the supervision of ETEC, with assistance from Georgia Power. The tests were intended to provide measurements of a number of parameters specifically related to combustion performance. The tests can be grouped into the following categories for discussion purposes:

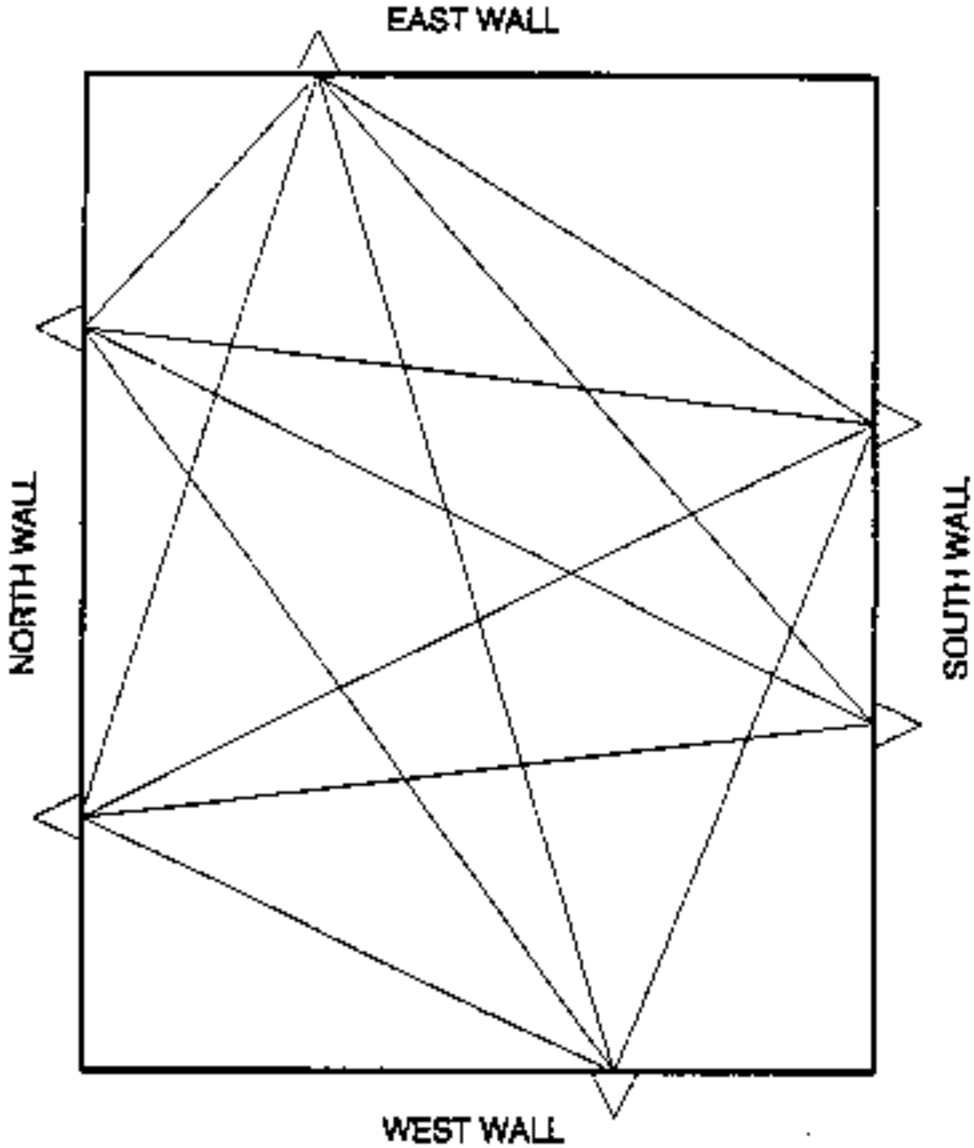


FIGURE 3-2 ACOUSTIC PYROMETER LOCATIONS AND PATHS

- Primary Air/Fuel Supply
  - Primary air/coal velocity to each burner
  - Coal flow rate to each burner
  - Coal particle size distribution to each burner
- Secondary Air Supply
  - Secondary air flow, east/west
  - Secondary air flow, front/rear windbox
- Furnace Combustion Gases
  - Gas temperatures near furnace exit
  - Gas species near furnace exit
- Boiler Efficiency
  - Exit gas temperatures
  - Exit gas excess O_2
  - Unburned carbon losses

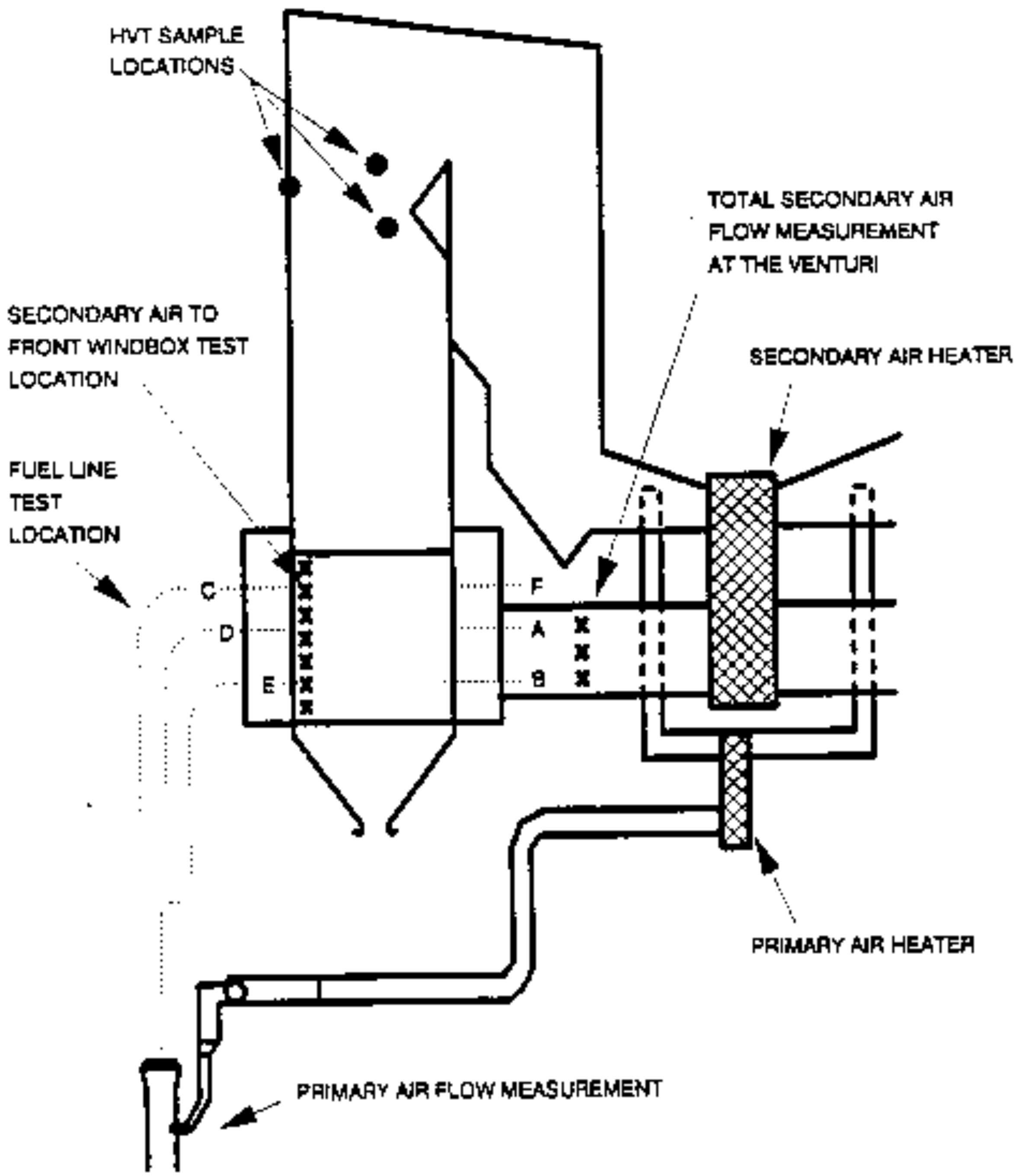
Figure 3-3 illustrates the locations at which the various measurements were made.

3.3.1 Primary Air/Fuel Supply Measurements

These tests were performed to characterize the quantity and properties of coal fuel and its transport air flow (primary air), supplied to each burner under several firing rates. The purpose of these tests is to correlate combustion conditions, boiler thermal performance, slagging/fouling characteristics and emissions (particulates, fly ash properties, NOx, etc.) with the fuel supply. In that way, the effects of the subsequent modifications to the burners and air supply (e.g. OFA) may be discriminated from effects due to any changes in the fuel supply characteristics. The principal fuel supply measurements were of the coal mass distribution to each burner and the particle size distribution within each burner supply pipe. Supporting measurements were made to determine the primary air/coal velocity profile in each supply pipe and the primary air flow provided at each mill inlet. Duplicates of each measurement were made on successive days at load levels of 300 and 480 MWe.

For each test condition the boiler was set to the desired firing rate (nominal MWe load) and the Fuel and Air Master controllers put on manual operation to prevent excessive fluctuations in the firing rate. To the extent possible, all active mill feeders were set to provide equal coal feed rates to their respective mills. The mill feeder, primary air and temperature controllers were left on automatic control to maintain the nominal air/coal ratios and mill outlet temperatures. Several times during each test the relevant mill parameters (coal feed rate, primary air differential, mill differential and mill outlet temperature) were recorded to ensure that nearly constant operation was maintained.

FIGURE 3-3 HAMOND UNIT 4 COMBUSTION SYSTEM TEST LOCATIONS



The initial measurements made for each test condition were of the "dirty air" (PA plus coal) velocity profiles in each burner supply pipe. This was done using a specialized type of pitot tube designed by Flame Refractories for use in particle-laden air. Figure 3-4 provides a depiction of the pitot device and an illustration of its use. The pitot total/static pressure differential was measured using a combination vertical/inclined water manometer. The temperature within the coal pipe was measured with a type K (chromel/alumel) thermocouple and a Fluke digital thermometer readout with a temperature compensating junction.

Measurements were made at 12 points along each of two perpendicular axes for each pipe. A dustless connection was used to prevent coal leakage around the velocity probe. The connection employs air aspiration to counteract the pipe internal pressure as the cock valve is opened and the velocity probe inserted. During velocity measurement the aspirating air is turned off to avoid undue influence on the velocity measurements.

Following determination of the dirty air velocity profile in each pipe a coal sampling device was inserted through the dustless connection and coal withdrawn over a measured time period. The device used for coal sampling is shown in Figure 3-5. It is based upon the recommended ASME design (PTC 4.2) but modified by Flame Refractories to include a filter, a flow measurement orifice, and a sampling aspirator with control valve.

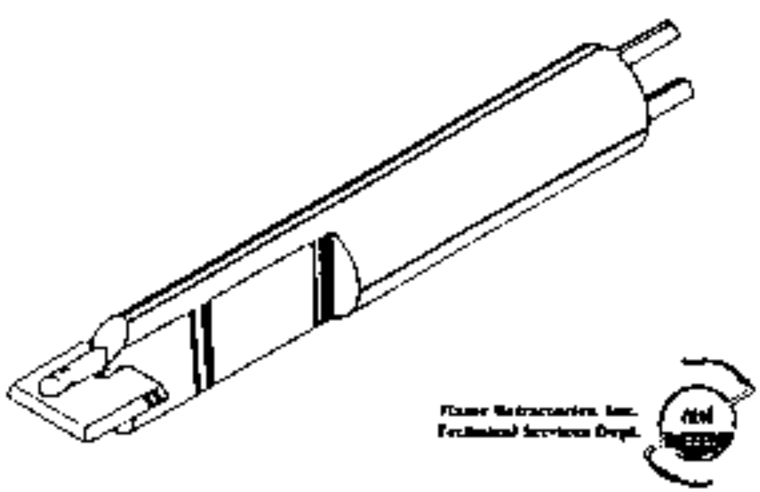
At each sample point (12 points on each of two diameters) the coal was sampled for a timed duration at an isokinetic rate consistent with the previously-determined velocity profile for the pipe. Each pipe was sampled for the same duration. Therefore the quantity of air/coal sampled for each pipe should be proportional to the total air flow rate in the pipe. Thus, it is assumed that the coal acquired from each pipe represents a reasonably accurate measure of the total coal distribution to the burners.

Each coal sample and filter was transferred to a plastic bag, sealed, and identified as to test condition, coal pipe, and the date and time of the sample. Each sample was subsequently weighed to determine the relative coal flow per unit time for each pipe.

Following the determination of total weight collected, each sample was sieved at the test site using a combination of 50, 100 and 200 mesh U.S. Standard sieves and a shaker machine. The weight percent remaining on each sieve, and passing the 200 mesh sieve, was determined and plotted on a Rosin and Rammler chart to depict the particle size distribution.

FIGURE 3-4 COAL PIPE VELOCITY APPARATUS

A. DIRTY AIR VELOCITY PROBE



B. DUSTLESS CONNECTION

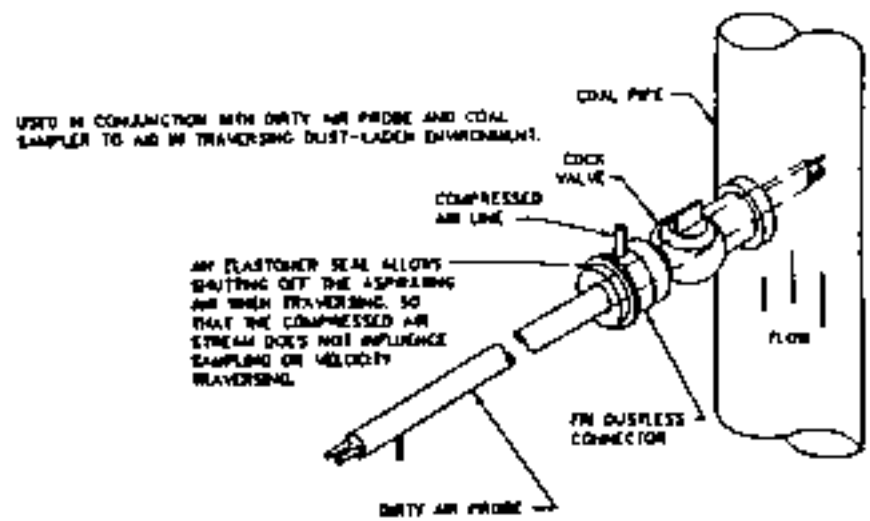
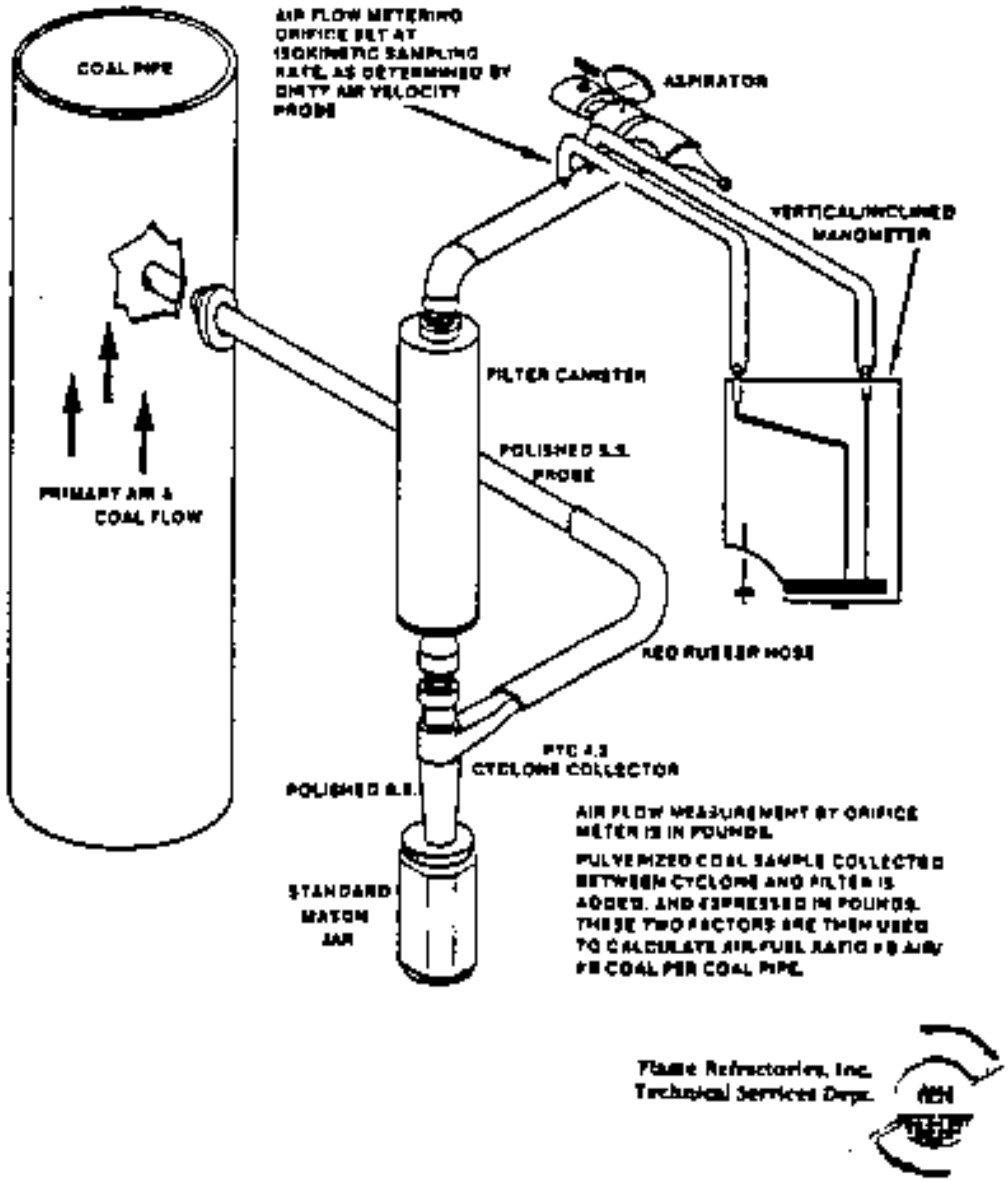


FIGURE 3-5 COAL PIPE SAMPLING APPARTUS



As a final documentation of mill performance, Flame Research measured the inlet primary air flow rate to each mill under several operating conditions (firing rate). The measurements were made at the rectangular ducts immediately at the mill inlet. Velocity head and temperature were measured in 40-point transverse (4 depths in each of 10 ports), using a standard type S pitot, a vertical/inclined Manometer, a type K Thermocouple and a Fluke digital thermometer.

Independently of the Performance Tests, Flame Research also measured the "clean air" velocities (no coal flow) in each coal pipe at 24 points. Each mill was shut off, with no coal flow, and primary air was provided at approximately the nominal, on-line flow rate and mill outlet temperature. This was done to provide an indication of the flow distribution to each pipe without coal. A standard type S pitot was used for these measurements.

3.3.2 Secondary Air Supply Measurements

Heated combustion air is supplied to the boiler through two ducts, one on either side of the boiler (east and west). Each supply duct contains a two- dimensional venturi section with pressure taps to measure air flow rate. Approximately at the midpoint of the east and west sides of the boiler, the air supply ducts connect to a windbox that encircles the boiler at the level of the burners. The FD fan controls can be used to balance the east/west air flows to some extent. There is no means to control the division of secondary air toward the front or rear burner areas, other than individual burner air register adjustments. No attempt was made to balance the air flows by this means, primarily because nearly half of the air registers were inoperable.

Secondary air flow rates (velocity) were measured at the east and west venturi throats and also in the east and west sides of the boiler windbox just before the front windbox area (see Figure 3-3). For all locations both modified Type S and Fecheimer pitot probes were used along with a vertical/inclined manometer and a type K thermocouple with a digital thermometer readout. At the venturi throat location, velocities were measured at 3 depths at four test ports. Velocities entering the front windbox (east and west) were measured at 8 horizontal insertion depths for each of 9 vertically aligned ports. The flow to the fear windbox we" inferred by subtracting the measured flow to the front windbox from the measured flow at the venturi throats.

Each of the secondary air flow measurements was made at least twice (on consecutive days) for each load condition (300, 400, 480 MWe). The modified type S pitot probe was used on all tests. For selected measurements, the Fecheimer velocity vector probe was also used to corroborate the type S pitot measurements.

3.3.3 Furnace Gas Measurements

Measurements were made of temperature and gas species within the furnace combustion zone above the burners to assess the potential effects of low-NOx retrofits on heat distributions and the completeness of combustion within the furnace.

A 20-foot long, water-cooled High Velocity Thermocouple (HVT) probe was used to measure both the temperature and gaseous species compositions of the combustion gases above the burner zone, near the entrance of the gas flow into the convective tube passages. The probe, shown in Figure 3-6, is a triple-tube design with the outer two tubes providing supply and return passages for the water coolant, and the innermost tube providing for aspiration of furnace gases to the boiler exterior. An enclosed thermocouple probe passes through the innermost tube and emerges at the insertion end to expose the measurement tip to the furnace gases. A radiation shield of stainless steel (or ceramic) is provided to prevent a false T/C reading due to radiation gain or loss from the surroundings. A type K (chromel/alumel) T/C was used along with a Fluke digital thermometer.

Furnace gases are aspirated through the innermost tube of the probe in order both to ensure constant exposure of the T/C tip to the hot furnace gases and to exhaust the furnace gases for analysis of their species composition. An air-driven aspirator exhausts gases through the probe and expels them to the atmosphere. A portable oxygen/CO analyzer with a self-contained sampling pump withdraws a small amount of the furnace gases from between the probe and the aspirator.

The probe was inserted through existing view ports at the 7th and 8th floor elevations, in the proximity of the furnace "nose." Figure 3-7 shows the plan view of the measurement locations, representing a total of 80 distinct points at the 8th Floor and 20 additional points at the 7th floor.

3.3.4 Boiler Efficiency

The purpose of the efficiency calculations is to determine whether the ensuing combustion modifications have any substantial effect on the boiler operating efficiency. Subsequent efficiency calculations will be compared to the present base-line reference, taking into account the effects of variations in parameters not related to the low-NOx retrofit modifications.

FIGURE 3-6 HVT PROBE

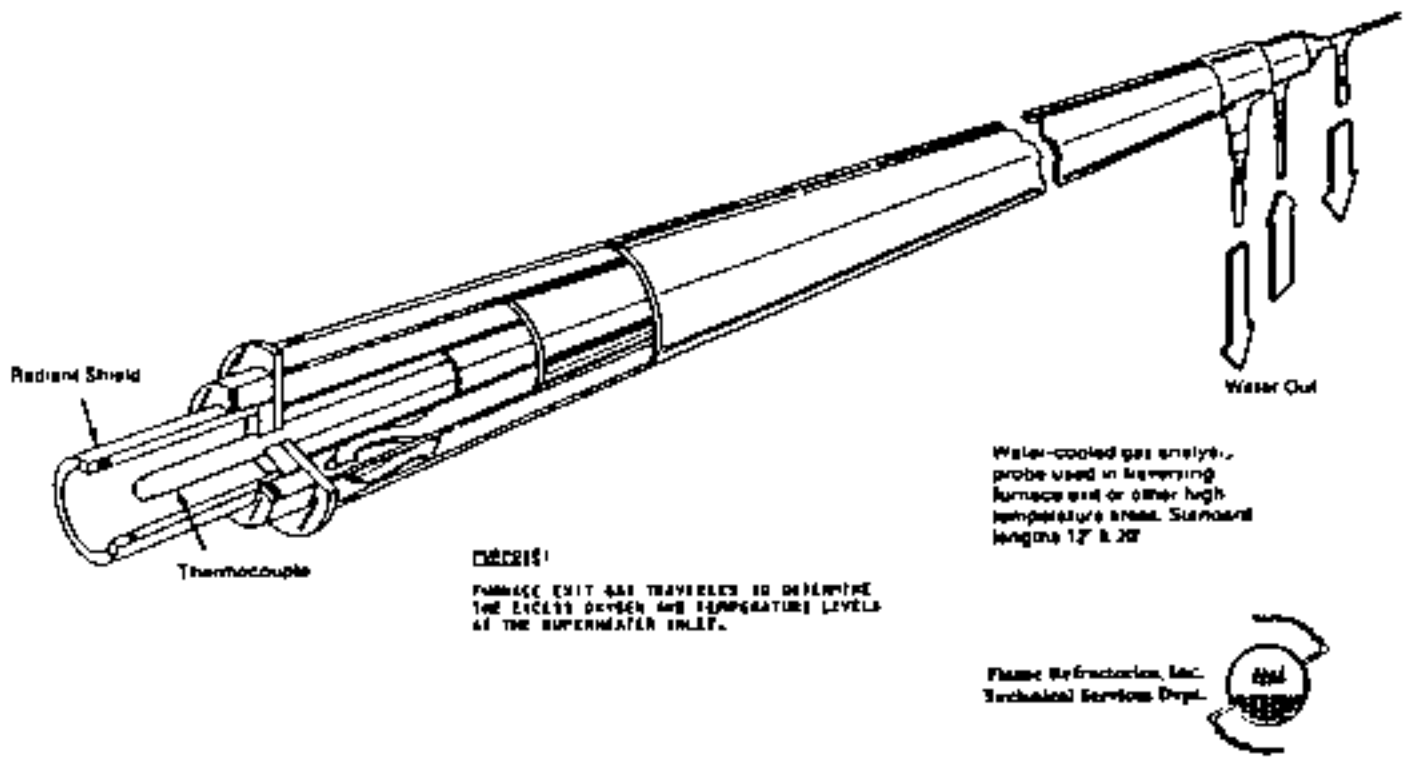
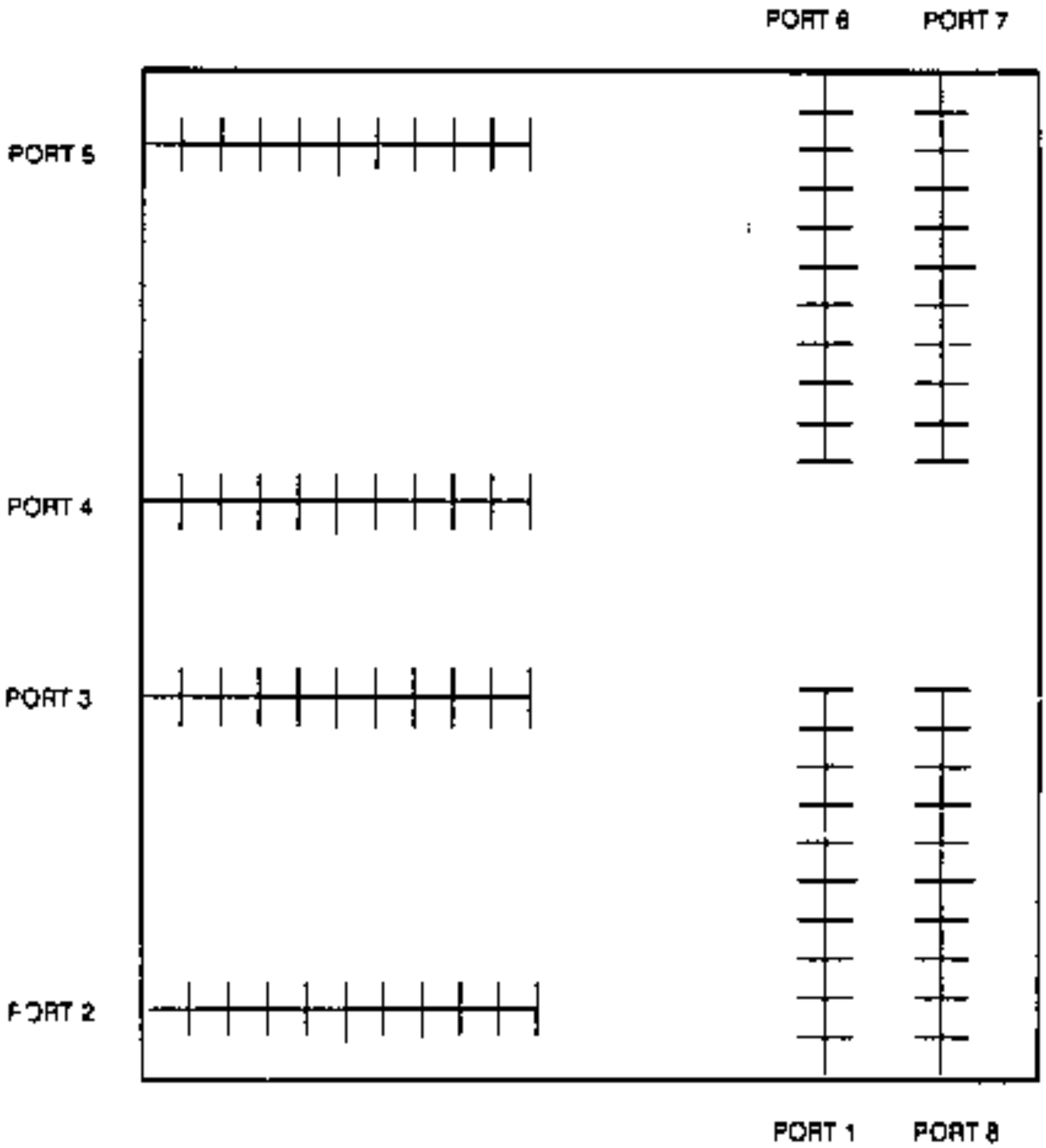


FIGURE 3-7 HVT TEST LOCATIONS

PLAN VIEW - 8 TH FLOOR



NOTE. PORTS 1B & 6B ARE ON 7 TH FLOOR BELOW PORTS 1 & 6

Calculations were made of the boiler thermal efficiency using the ASME PTC 4.1 Short Form Heat Loss Method. Flue gas exhaust flow was calculated based upon the fuel ultimate analysis and the measured excess oxygen and CO at the boiler exit. The boiler efficiency was calculated as 100% minus the percentage of fuel input energy discharged in the form of dry combustion gas heat content, combustion gas moisture heat content (latent and vaporization heat), energy lost through unburned carbon in the fly ash, carbon in bottom ash, blowdown heat loss, minor electrical power losses, soot blowing steam, etc.

Boiler exhaust gases were sampled through a matrix of 16 probes placed across the air preheater exit ducts, and analyzed with the Extractive Continuous Emission Monitoring system (see Section 3.2). Excess oxygen and carbon monoxide were measured and used in the Heat Loss Method efficiency calculations.

Energy lost through unburned carbon in the fly ash was calculated from the Loss On Ignition (LOI) analysis of the fly ash collected by the Engineering Emissions Test contractor (see Section 3.4).

3.4 SOLID/SULFUR EMISSIONS TESTS

The purpose of the Phase I test effort is to assist in determining whether the proposed retrofits can reduce nitrogen oxides emissions effectively. It is important, however, to ensure that NOx reduction is not achieved at the cost of an increase in other forms of pollutant emissions. Section 3.2 describes gaseous monitoring procedures and equipment which will document the effects of the retrofit technologies on CO, SO_2 and THC, as well as on NOx. Special test procedures were incorporated in the current program to assess the effects of the retrofit technologies on particulate emissions. These tests were performed during the Phase I baseline testing by personnel from Southern Research Institute (SoRI).

The solid/sulfur emissions tests were conducted to measure both the total mass emissions and the characteristics of the particulate matter as they might affect the ability of downstream control equipment to prevent emissions to the atmosphere. Tests were conducted at 480, 400 and 300 MWe load levels.

The SoRI testing was performed primarily at the boiler flue gas exhaust ducts between the air preheaters and the inlet to the electrostatic precipitator (ESP). SoRI also performed laboratory analyses on ash samples taken from the ESP hoppers. The tests were conducted simultaneously with the control room data recording (Sections. 3.1 and 3.2) and the Combustion System tests (Section. 3.3).

3.4.1 Total Particulate Emissions

Particulate mass emissions were measured using EPA Method 17 procedures and equipment. Triplicate samples were obtained for each test sequence. Two sequences were performed at 480 MWe and one each at 400 and 300 MWe. Prior to each sequence the velocity profile at the test points was determined and the sampling conditions established (nozzle size and sampling rate). The sample probe with in-stack filter was suspended vertically during the sampling. A total of 24 discrete sample points were used, in a matrix of 4 depths at each of 6 test ports (2, 4, 6, 9, 11 & 13) across the width of the flue gas ducts, as shown in Figure 3-8.

3.4.2 Particle Size

An important factor affecting the efficiency of particulate control equipment is the distribution of particle sizes present. Very small particles (less than 2 micron) are difficult to capture, especially in a device such as an ESP. It is important to document whether the retrofit NOx control technologies employed have a net positive or negative effect on the fly ash particle size, with respect to its ease of control by standard control devices, in this case an ESP.

The apparatus chosen for the current program to collect and analyze the fly ash particles is a Brink cascade impactor with a pre-cut cyclone provided to remove the majority of large particles (over lOO micron). The purpose of the pre-cut cyclone is to improve the performance of the Brink impactor with respect to small particle collection and discrimination by preventing overloading of the impactor stages with large quantities of big particles. Figures 3-9 and 3-10 illustrate the general testing apparatus and the configuration of the Brink Impactor, respectively.

Six impactor runs were obtained for each of the 3 test conditions (480, 400 and 300 MWe) during the baseline test series. For each sample, the impactor was inserted at four depths in a single port and flue as drawn at the rate of 0.03 acfm. Glass fiber substrates were used in each impactor stage to minimize particle bounce. The substrate material was pre-washed with sulfuric acid to reduce interaction with flue gases and particulates. Six separate impactors were used each day plus a seventh blank impactor subjected to conditions identical to the sampling impactors. Each of the six impactor runs for each test was made in a different port and the results were averaged. Data were obtained in ports 2, 4, 6, 9, 11 & 13 (Figure 3-8). The impactor data were reduced using a computer program developed at SoRI under EPA sponsorship and described in the publication "A Computer-Based Cascade Impactor Data Reduction System", EPA-600/7-78-042, March, 1978.

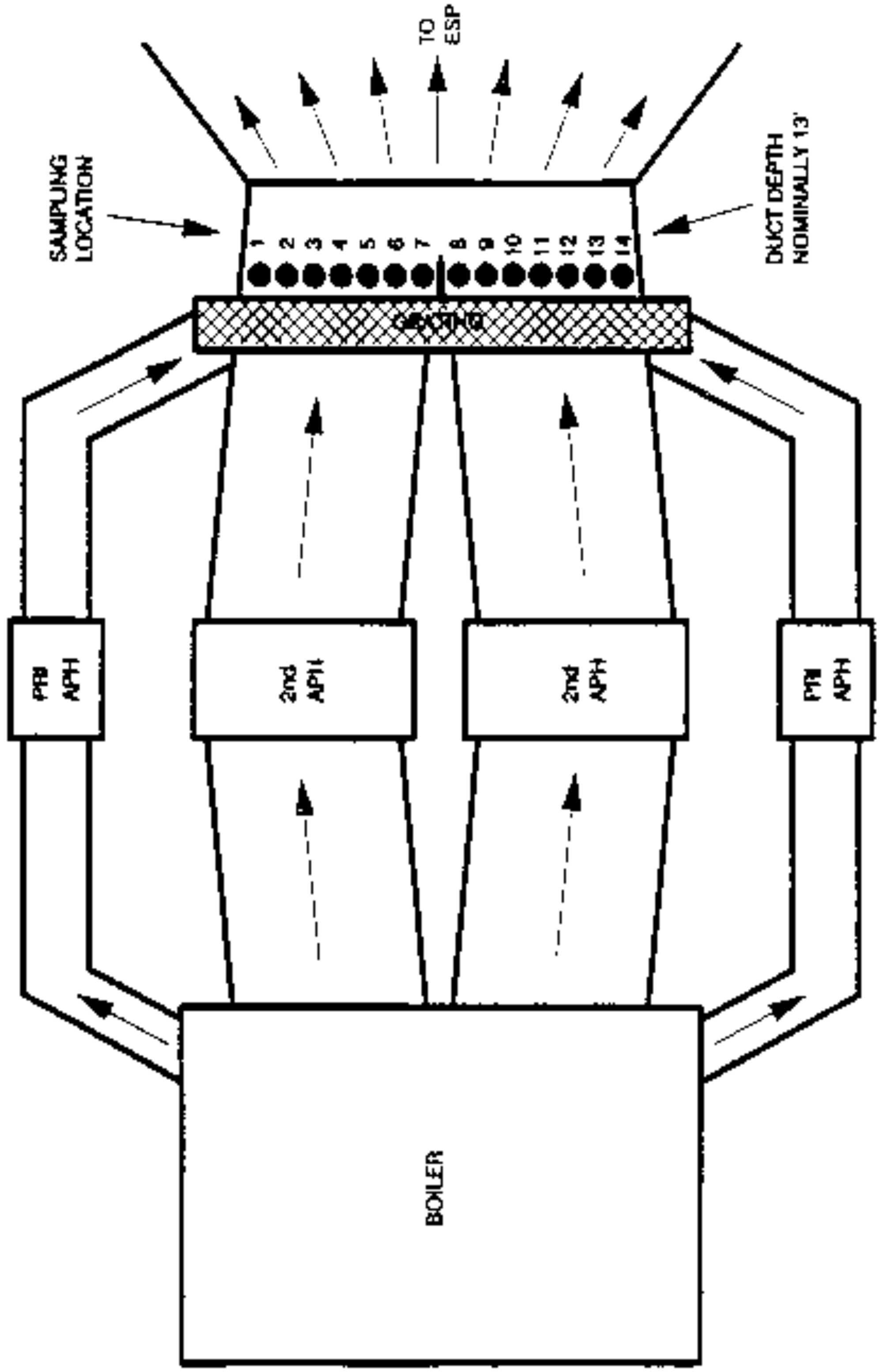


FIGURE 3-8 SOLID EMISSIONS TEST LOCATIONS

FIGURE 3-9 CASCADE IMPACTOR SAMPLE APPARATUS

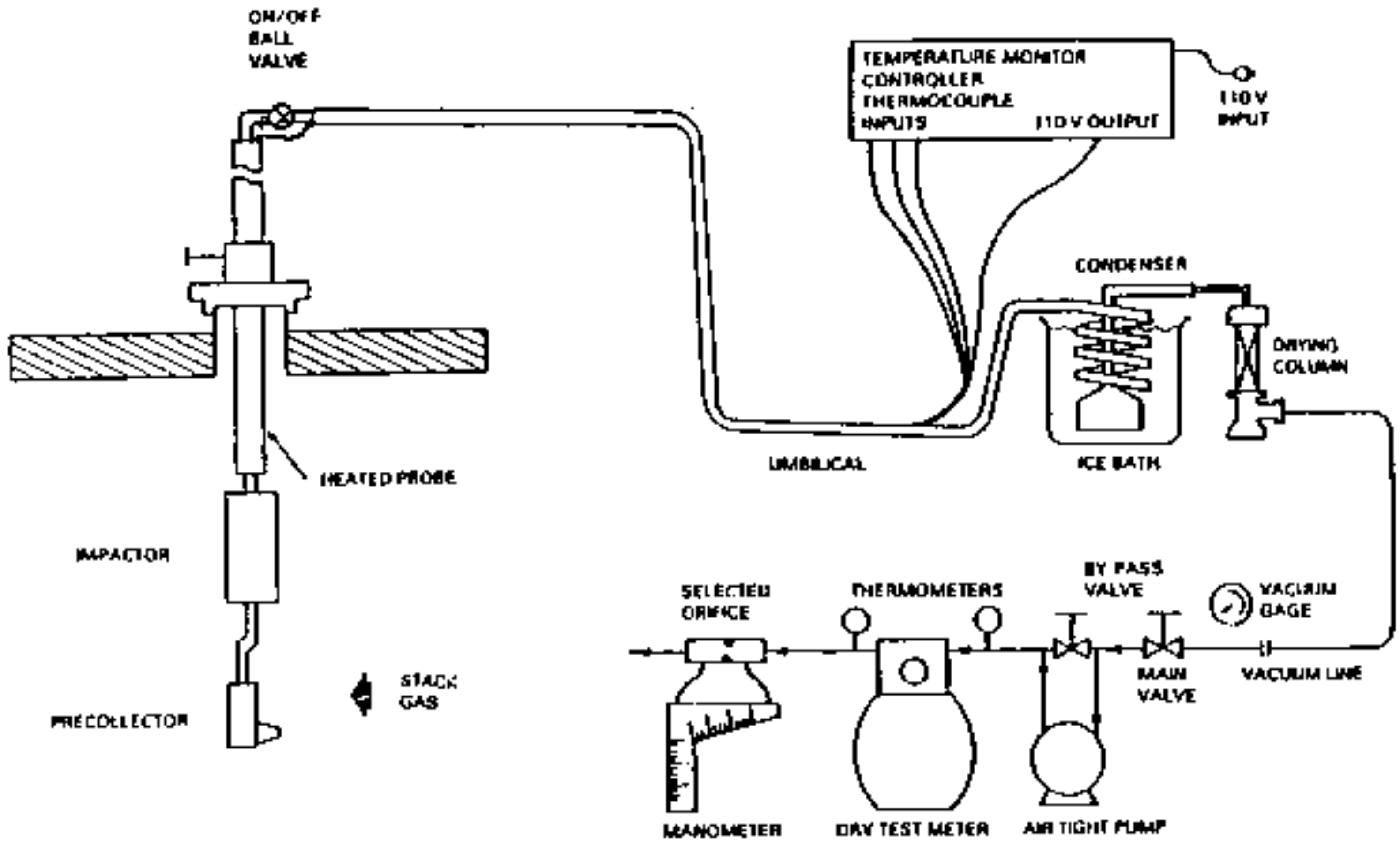
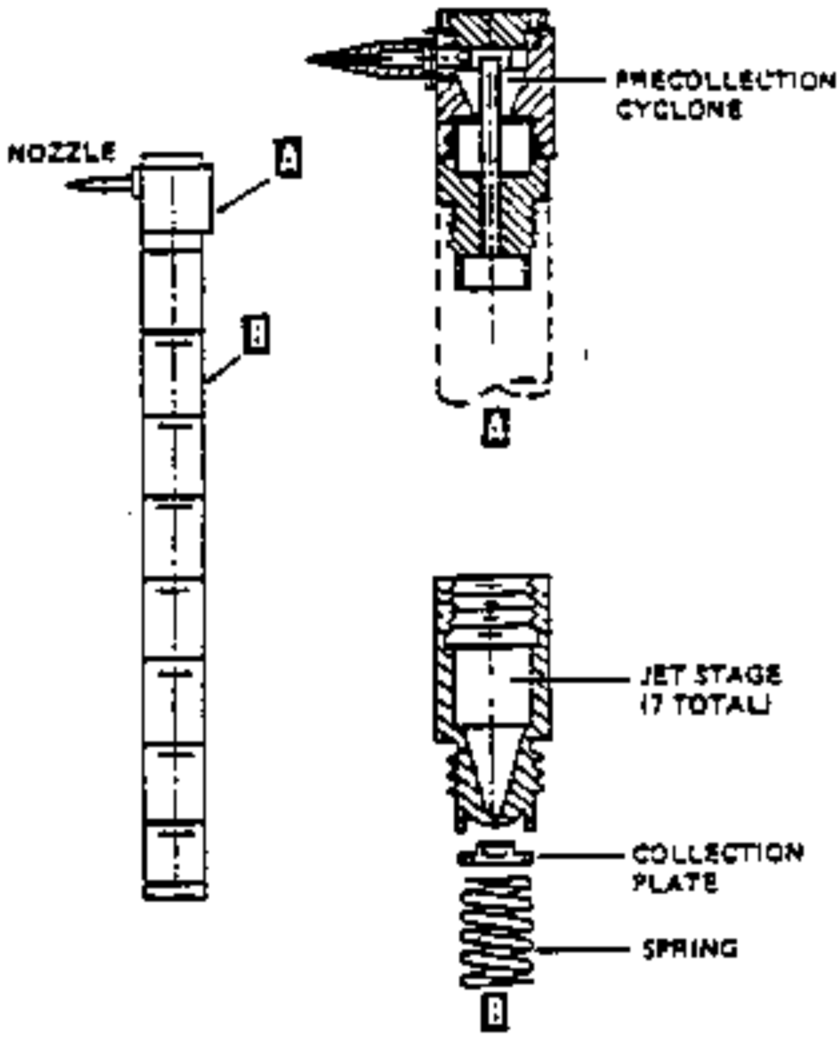


FIGURE 3-10 BRINK MODEL C IMPACTOR



3.4.3 Ash Resistivity

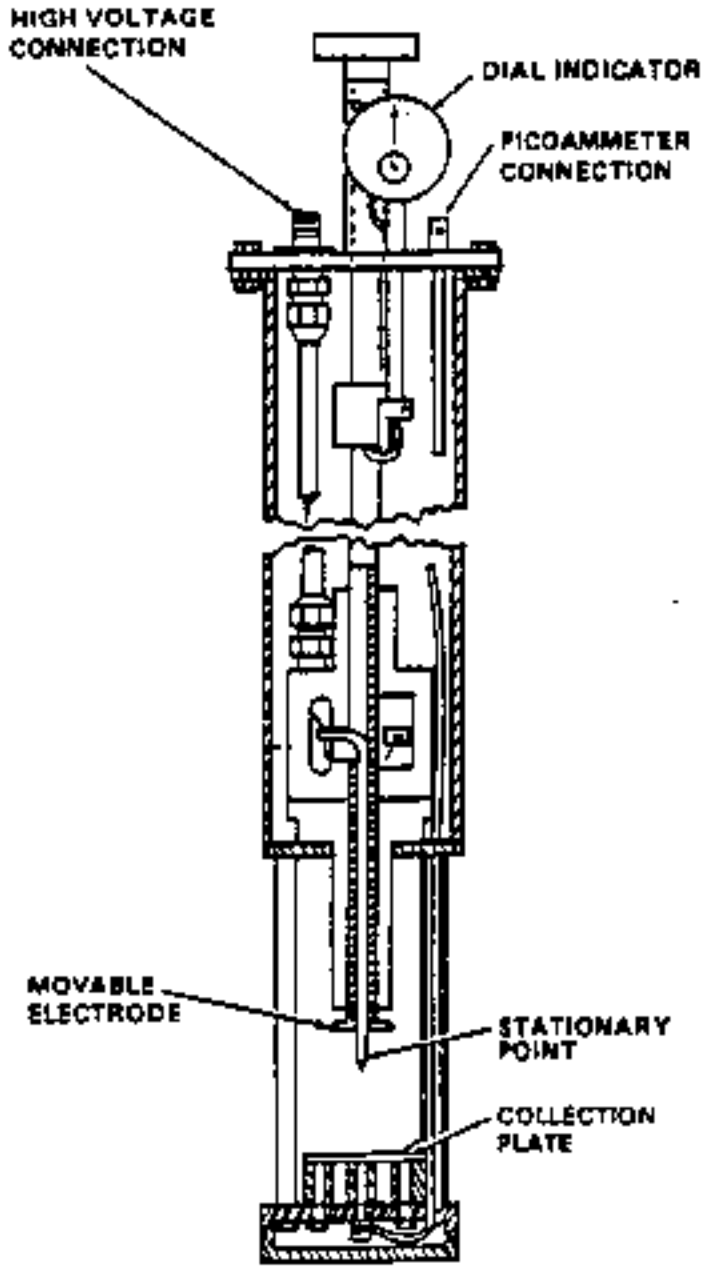
Measurements of the electrical resistivity of the dust entering the Hammond ESP were made in-situ with a point-to-plane resistivity probe. The point-to-plane probe has been used to measure resistivity since the early 1940's. The SoRI-designed version of this device is shown in Figure 3-11. The probe was inserted vertically down into the dust laden gas stream and allowed to come to thermal equilibrium. The particles passing through the measurement cell are electrically charged by a high-voltage corona discharge from the stationary point electrode. A dust layer is formed on the collection plate through the interaction of the charged particles with the electrostatic field adjacent to the plate. Thus, this device is intended to simulate the behavior of a full-scale precipitator and to provide a realistic value for the resistivity of the dust that should be comparable to that in an actual precipitator.

Following sample collection, two methods of measuring resistivity on the same sample were used. In the V-I method, a voltage-current curve is obtained before the electrostatic deposition of the dust, while the collecting disk is clean. A second voltage-current curve is obtained after the dust layer has been collected. The voltage drop across the dust layer for a given current is then determined by the shift in the voltage-vs-current characteristics along the voltage axis. After the clean and dirty voltage-current curves have been established, the spark method is employed. In this method, a disk electrode is lowered onto the collected sample. Increasing voltages are applied to the dust layer and the resulting current is recorded until the dust layer breaks down electrically and a sparkover occurs. The resistivity is calculated for the voltage and current at the point just prior to sparkover.

The two measurement methods each has its own strong and weak points. The V-I method attempts to measure the voltage drop across the dust layer without contacting the sample. In the range of resistivity between 10^{10} and 10^{12} ohm-centimeters the V-I method provides data which is fairly accurate and insensitive to the presence of large conductive carbon particles. The spark method is generally the more reliable, however, and is often the only value reported. Nevertheless, problems with this measurement can be encountered due to the similarity between the thickness of the collected dust layer and the size of unburned coal and carbon particles emitted from boilers (ca 1 mm). Large conductive particles can produce premature sparkover resulting in erratic data.

During the Phase I baseline testing, resistivity measurements were made on both ducts leading to the ESP. For each test condition, data were collected in ports 5 and 10 (Figure 3-8).

FIGURE 3-11 IN-SITU RESISTIVITY PROBE



Laboratory measurements were made of ash resistivity using ash samples from the on-site testing and a basic laboratory resistivity cell as defined by ASME PTC 28 (1965). The test environment was controlled to approximate the important components and conditions of the flue gas stream. A descending temperature test (IEEE 548, 1981) was performed on all samples over the range from 460 to 84 C.

3.4.4 SO_3/SO_2 Tests

Sulfur trioxide is a vapor/solid depending upon temperature. It has electrical properties that can substantially affect the net average resistivity of the fly ash, and therefore the collection efficiency of ESP's. The degree to which sulfur is oxidized to SO_3 or to SO_2 is dependent upon many combustion factors, including stoichiometry and temperature histories in the boiler. Tests were performed by SoRI to determine the emissions of SO_3 and SO_2 for the three load conditions (300, 400, and 480 MWe) .

The procedure selected for the tests was the Cheney-Homolya method which consists of: 1) extracting gas through a probe which has a filter at its tip to exclude fly ash; 2) maintaining the extracted gas at a 'temperature above the condensation points of SO_3, H_2SO_4 and water; 3) condensing out the SO_3 in a helical glass coil controlled to cat 150 degrees F (between the dew points of SO_3 and H_2SO_4) and; 4) condensing SO_2 in a cooled impinger train containing water and hydrogen peroxide. The helical coil was washed with distilled water and the catch titrated for sulfur content. The impinger catch was similarly analyzed for total sulfur.

3.4.5. ESP Performance Prediction

Based upon the values of ash resistivity, ash chemical composition, SO_2/SO_3 concentrations, mass emissions and particle size, SoRI made calculations to estimate the performance of a generic ESP representative of large utility installations. The mathematical model used in the calculations is documented in "A Mathematical Model of Electrostatic Precipitation, Rev 3, Faulkner & Dubard, EPA-600/7-84-069a,b,c, June, 1984. The ESP performance predictions based on the Phase 1 Baseline test data will be used for comparison to similar predictions to be made based upon the results of subsequent test phases after retrofit of the low-NOx technologies. These comparisons will provide a valuable means of assessing any potential benefit or degradation to particulate emissions attributable to the retrofit technologies.

4.0 DATA ANALYSIS METHODOLOGY

4.0 DATA ANALYSIS METHODOLOGY

Two distinctly different types of data analyses are utilized to characterize the data obtained for the Phase I test effort: discrete analyses for short-term data and statistical analysis for long-term data. The short-term data are used to establish emission trends, provide information for engineering assessments and provide data for evaluating guarantees or goals established with the equipment vendors. Long-term data are used to statistically establish the long term emission trends and regulatory assessments when the unit is operated in a normal System Load Dispatch mode.

4.1 Short-Term Characterization Data Analysis

The short-term data collection portion of the project is divided into two elements: Diagnostic and Performance test efforts. The diagnostic data collection effort is used to establish the trends of NOx versus load, mill patterns and excess oxygen. The Performance data collection effort is used to establish input/output characterizations of fuel, air, flue gas effluent and boiler efficiency. Both the Diagnostic and Performance efforts are performed under well controlled conditions with the unit off of System Load Dispatch. Each data point from these efforts is for a single operating condition. Unlike the data collected in the Long-term effort discussed in Section 4.2, the data collected during the Short-term effort is generally not of sufficient quantity to apply advanced statistical analyses or for that matter any sophisticated mathematical analysis. Most of the analysis of the short-term emission data is graphical while the analysis of the coal and ash samples is by chemical analyses.

4.1.1 Diagnostic Data

The emphasis of the Diagnostic testing was to determine the NOx characteristics, although much more information was obtained for use during other Phases of the project. As explained in Section 3.2.2, the NOx, O_2, CO, THC and SO_2 are automatically recorded every five seconds and stored in the historic files on an IBM PC-compatible computer located in the Instrumentation Room. The NOx measurements of interest during this element of the short-term testing are those obtained from the Sample Flow Distribution Manifold (See Figure 3-1, Section 3.2.2). The manifold allows sampling from individual probes or combinations of probes located in the economizer exit prior to the primary and secondary air preheaters. Depending upon the probe groupings, the composite emission measurements over the entire economizer exit (average of 28 probes) for the period of a Diagnostic test represents a single data point for one configuration.

A single data point is obtained by selecting a probe group and obtaining numerous one minute averages of the five second data over the one to three hour period of the test for each test condition. Sampling on one of the groupings is made for a sufficient time to insure that the readings are steady. The DAS is then prompted to gather data for one minute (12 five-second readings) and to obtain the statistics for that period. Table 4-1 illustrates the type of results obtained for one reading (one minute average) on the A- and B-sides of the economizer exit. If the standard deviation is large, the reading is discarded. The average of all of the one minute average measurements over the test duration constitutes a single data point for NOx for the condition under which the test was performed.

TABLE 4-1 TYPICAL ONE MINUTE AVERAGE EMISSION MEASUREMENTS

VALUE	A-SIDE OUTLET	B-SIDE OUTLET
CO EMISSIONS		
Current	11.0	6.3
Average	10.9	7.3
Maximum	11.8	8.0
Minimum	9.6	6.2
Std. Dev.	0.8	0.7
NOx EMISSIONS		
Current	937.0	953.7
Average	935.6	956.4
Maximum	937.0	960.3
Minimum	933.1	952.7
Std. Dev.	1.5	2.8
O_2 EMISSIONS		
Current	3.4	2.8
Average	3.5	2.8
Maximum	3.5	2.9
Minimum	3.4	2.7
Std. Dev.	0.0	0.1

Other information such as coal samples, ash samples and air preheater exit measurements are recorded and stored for future use in the historic files on the IBM compatible PC. This information may become valuable for comparison purposes with results from other Phases. These additional data were not used in analyses of the Diagnostic tests for the Phase 1 effort.

A matrix of tests was established to allow trending and engineering evaluations of the Short-term NOx emissions data utilizing the "Experimental Design" approach. The project statisticians advised the use of the Experimental Design approach to minimize the introduction of potential bias into the trending.

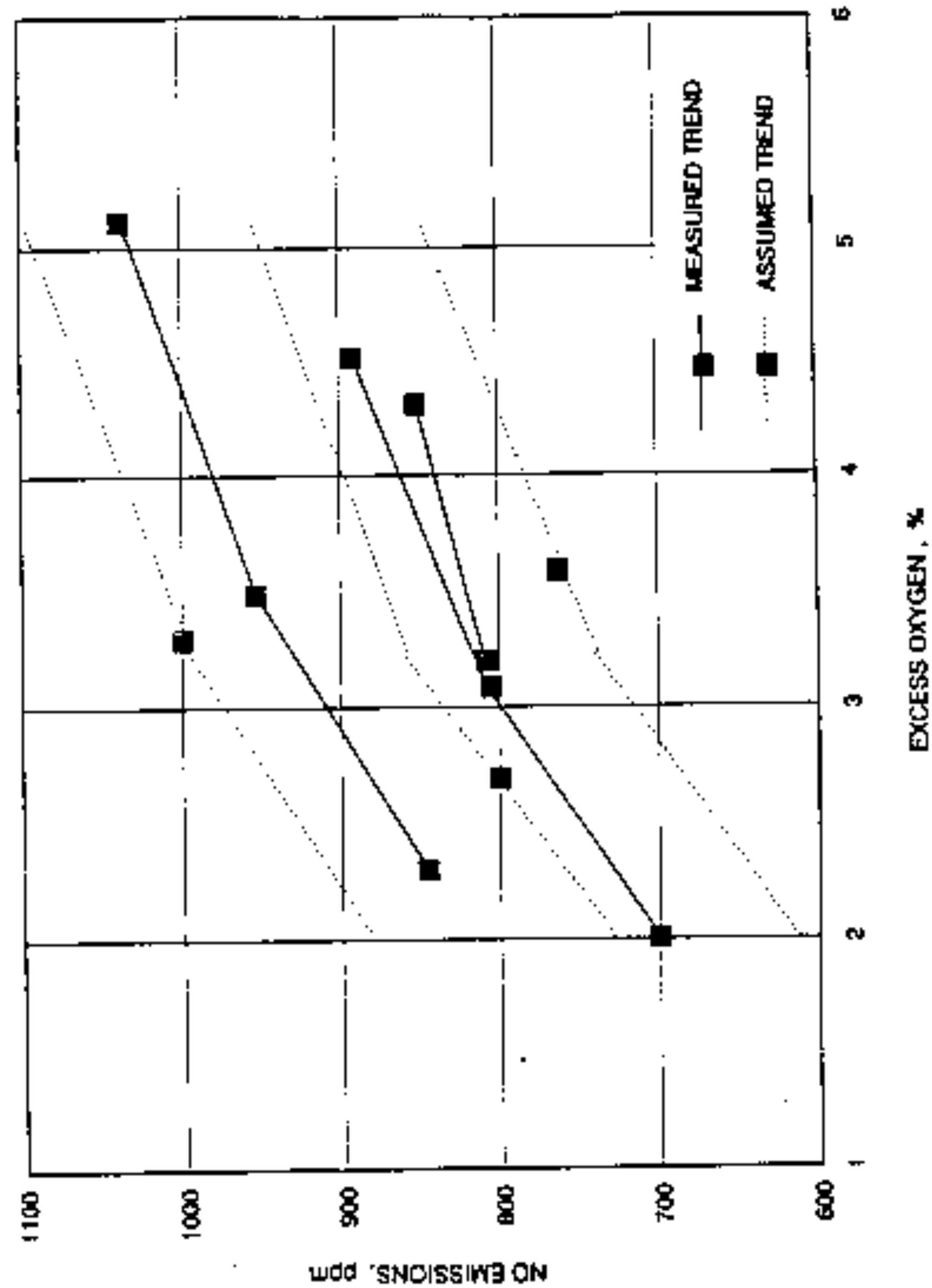
Based upon the hypothesis that the Experimental Design process was appropriate for the Diagnostic testing, a suitable test matrix was developed utilizing statistical criteria. However, the criteria could not be entirely satisfied due to the nature of utility boiler operation and the time required to establish the range of conditions on any given test day.

Experimental Design introduces a randomizing element into the test matrix to eliminate some of the bias that may be introduced by sequentially testing specified parameters. The original matrix (Table 2-1) utilized tests at one load at various excess oxygen levels during a one day test period. It was hypothesized that this could introduce bias simply due to the fact that on another day, other influencing parameters could slightly change the result. Consequently, the results obtained simply from the one day tests at one specific load could potentially be misleading or biased. The presumption with Experimental Design is that sufficient data will be taken to allow a statistical regression that will indicate the "true" trend which includes most of the influencing parameters.

Early Diagnostic test efforts showed that the variability of the NOx emissions was significant for seemingly identical conditions, i.e., load, O_2 and mill pattern. Since only a limited amount of short-term data were to be collected in the Diagnostic effort, the high variability potentially jeopardized the ability to adequately trend the emissions data. If the Diagnostic test effort had included many more data points (requiring significantly more test days), the approach may have provided sufficient information to perform the Experimental Design regression analyses. As a result of the NOx variability, the test Plan reverted to a more or less sequential approach to collecting emission data, i.e., one ;load and mill pattern per day with a range of excess oxygen levels measured during steady-state conditions. Table 2-2 (Section 2.3.1) shows the final test matrix used for the Phase I Diagnostic test effort.

During the Diagnostic testing attempts were made to gather three sequential data points (either increasing or decreasing excess oxygen level) at each load level (or mill pattern). With three data points on one day with a minimum variation of the other influencing parameters, the general trend of NOx versus load (or mill pattern) could be determined. Test points which were not sequential (different loads or mill patterns on the same day) were used to indicate the potential variability about the trend lines. It is assumed that the trends for these single, non-sequential data points is similar to that determined for sequential data and that families of curves exist. This assumption was tested and found to be true by obtaining several days of sequential data at the same operating conditions. Figure 4-1 illustrates the type of trending that was obtained using this methodology. All NOx trend data are presented in ppm as dry corrected to 3% O_2 to correct for dilution. Where possible,

FIGURE 4-1 TYPICAL TRENDING CURVES



general equations that represent the trend are developed. It should be pointed out, however, that in most cases, only three points were available to describe the trend. As was mentioned above, insufficient data at each condition was available to perform meaningful statistical analyses of these data.

4.1.2 Performance Data

One purpose of Performance tests was to establish baseline evaluation criteria for Foster Wheeler's Advanced Overfire Air Port and Low NOx Burner retrofits. These criteria are related to the impact of the retrofits on the boiler efficiency, particle matter changes (size, amount and resistivity) and the retrofit NO reduction effectiveness. Another equally important purpose of these Performance tests was to quantify the boiler characteristics for comparison with other phases of the program and for comparison with the population of similar utility boilers. In addition, the Performance NOx emission data was used for comparison against the results of the Phase 1 Diagnostic trends.

Analysis of the data gathered from the Performance tests was different from that for the Diagnostic test effort. During Diagnostic testing, data were gathered over a range of mill patterns and excess oxygen levels. Since the Diagnostic test periods were one to three hours in length, it was not possible to obtain information on the inlet and outlet characteristics of the mill, primary air, secondary air, total particulates and particulate sizing. These characterizations and the determination of the boiler efficiency require considerably longer periods of stable conditions. During the Performance tests, the boiler condition was fixed at one load with a specified mill pattern and excess oxygen level that was most representative of the normal operating configuration. Repetitions of this condition were made thus providing data for essentially only one configuration per load. Consequently, the emphasis for the Performance tests was on the analysis of the flows, solids and boiler efficiency rather than the NOx trends. As with the Diagnostic test data, insufficient data were available to perform meaningful advanced statistics.

The boiler efficiency was determined utilizing the Short Form PTC 4.1 methodology described in the ASME Power Test Codes for Steam Generators. Section 5.2.8 provides a discussion of these efficiency calculations. Data for these calculations were obtained utilizing the gaseous samples from the Sample Flow Distribution Manifold (Figure 3-1) along with other logged information on the DAS. Air preheater leakage was also calculated using these data. The Performance tests were segregated into inlet (fuel and air) and outlet (solids and gaseous) measurements. Generally two sets of solid emission tests could be performed for the test configuration while only one fuel/air test could be performed during the 10 to 12 hour test period for one configuration (load, O_2 and mill pattern). While gaseous measurements (NOx, O_2 etc.) could be made much more frequently than inlet and solids matter measurements, the outlet gaseous test duration was arbitrarily made equivalent to the duration for the solids emission tests. Consequently, for each Performance configuration, two PTC 4.1 determinations were made. Data from the following sources were used to calculate the ASME PTC 4.1 boiler efficiency and air preheater leakage:

1) Air preheater inlet gas temperatures, CO emissions and excess oxygen level from the DAS,

2) Air preheater outlet gas temperatures, CO emissions and excess oxygen level from the DAS,

3) ESP inlet Method 17 flyash catch LOI,

4) Fuel ultimate analysis from grab samples,

5) Ambient moisture content.

For each Performance configuration (test day), the following types of data were obtained:

1) Two gaseous emission measurements of NOx, O_2, SO_2, CO and THC each composed of at least 10 one-minute Sample Distribution Manifold composite flue gas measurements,

2) Two PTC 4.1 boiler efficiency determinations and two air preheater leakage determinations,

3) A minimum of three repetitions of specific flue gas solids emission parameters (total particulate emissions, SO_3, resistivity, LOI, or particle size)

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

4.2 Long-Term Characterization Data Analysis

During this portion of the test program, the emission and plant operating data input was automatically recorded on the DAS and archived. The emission input was handled automatically by the KVB CEM. A single emission measurement point in the ductwork just prior to the stack breaching was monitored 24 hours per day during the entire Long-term effort. The emission sample was brought to the CEM through heated lines to preclude condensation of $S0_2$ in the lines. Prior to the start of the Long-term test effort, the CEM was certified by Spectrum Systems.

The primary focus of the long-term test effort was to capture the natural variation of the data in the normal mode of operation. During the entire long-term effort, no operational intervention by the SCS test team members (SCS Research or ETEC) occurred or was for that matter allowed. This was to insure that the long term data would not be biased by this type of input. For all practical purposes, the boiler was operated in it's normal day-to-day configuration under control of the Load Dispatcher.

The thrust of the analysis of the long-term data is it's interpretation primarily by statistical methods. The specific types of analyses used are related to regulatory issues and the engineering interpretation of Phase 1 Long-term results compared to Short-term diagnostics results. The analyses related to the regulatory issues were associated with the determination of the 30-day rolling average emissions and the estimation of an achievable emission level that the data support. The analyses related to the engineering interpretations were associated with the determination of the best statistical estimates of the operating characteristics, i.e., NOx versus load, mill pattern, etc.

The following paragraphs provide information related to the manner in which the raw long-term data are processed to produce a valid emission data set and the fundamentals of the data specific analytic techniques.

4.2.1 Data Set Construction

<u>Five minute average emission</u>

The data collected during the long-term test program consisted of 5-minute averages of parameters related to boiler operating conditions and emissions. These 5-minute data form the basis for analyses that describe the general emission profiles, the impact of boiler load, mill pattern and O_2 on NOx formation, and the achievable NOx emission limit. The procedures by which the 5-minute average data were used is presented below. The results of the analyses are presented in Section 6.0 along with a comparison of long- and short-term results.

The data pertinent to the analysis of the long-term 5-minute data consist of parameters describing boiler load, boiler emissions (NOx, O_2, and SO_2), and the coal flow to each of the mills that are in service during any particular 5-minute period. These data and their source are presented in Table 4-2.

The intent of all analyses conducted during the long-term test period is to depict boiler operation during normal operating conditions. Under this premise, data collected when the boiler is in the process of undergoing startup and shutdown is not considered valid for the purpose of this characterization. Startup and shutdown periods reflect transient times when the unit is either coming on-line or going off-line. This also includes the transient period during which short-term unit trips occur. Therefore, data collected during these periods were excluded from the analyses. The instances in which data are deleted are provided in Table 4-3. Several parameters were computed from the edited 5-minute data set. These computed parameters included 1) NOx emissions, in lb/MMBtu, 2) mills in service, and 3) coal flow. The procedures used for these computations are described below.

TABLE 4-2 FIVE-MINUTE HOURLY AVERAGE DATA

PARAMETER	SOURCE
Load, MWe	Wattmeter
Coal Flow (A to F mills), lb/Hr	Totalizer
NO, ppm	KVB CEM
$S0_2$, ppm	KVB CEM
0_2, %	KVB CEM
0_2 (A & B economizer), %	DAS

TABLE 4-3 START UP, SHUTDOWN AND UNIT TRIP PERIODS

START		STOP		REASON
DATE	TIME	DATE	TIME	
12/30/89	00:00	01/02/90	03:35	Unit shutdown
01/16/90	09:00	01/18/90	06:25	Unit shutdown
02/17/90	02:30	02/17/90	04:00	Unit Trip
02/22/90	08:30	02/23/90	20:40	Unit shutdown
04/05/90	08:00	-	-	AOFA retrofit shutdown

As indicated in Table 4-2, NOx (ppm) and 02 (%) were measured using the KVB extractive monitoring system. The KVB system extracts a sample of gas from the stack, removes moisture and particulate, and then determines the NOx and 02 concentrations. The KVB system experienced operational difficulties during the Phase 1 long-term test period, however, the difficulties were easily overcome.

The NOx emissions (lb NOx/MMBtu) were computed using the EPA "F" factor method. This method computes the NOx emission rate (lb NOx/MMBtu) from the stack gas NOx (ppm) and O_2 content. Both values were obtained from the KVB CEM.

Coal flow to each of the six mills was available on a 5-minute average basis. Each of the mills is capable of sustaining a maximum coal flow of approximately 80,000 pounds of coal per hour. The mills are generally not continuously operated below approximately 20,000 pounds coal per hour. The coal flow to each mill is used to determine if it is in full operation or was in a transient condition during shutdown or startup. This information was used to assess the periods during which the mills were either in- or out-of-service. The total coal flow to the boiler was computed using the flow data to each mill determined to be in service. This 5-minute mill pattern dataset was used to evaluate specific operating characteristics of the boiler discussed in Sections 6.1 and 6.2.

The 5-minute average data are also used to compute hourly average load, NOx and 02. These hourly averages are used to depict the hour-to-hour variations in boiler performance and emissions. The hourly values were also used to compute daily average NOx emissions while the daily average emissions were used primarily to estimate the achievable NOx emission limit.

Hourly Average Emissions

The loss of 5-minute data due to CEMS failure impacts the calculation of hourly averages. Clearly, one 5-minute value does not adequately depict an hourly average. The EPA has guidelines for determining how much data is sufficient to compute an hourly average for emissions monitoring purposes. It is recognized that the EPA guideline criteria are not strictly relevant to an R&D project, nevertheless, they serve as an reasonable methodology for evaluation of the data. These EPA guidelines, set forth in the Code of Federal Regulations for New Source Performance Standards (NSPS) 40 CFR 60, first require that CEMS measure the pollutant emission rate at least once during each 15-minute period in an hour [40 CFR 60.13(b)]. In addition, sources subject to NSPS Subpart Da must obtain at least two 15-minute readings per hour in order for the hour to meet the minimum data capture requirements [40 CFR 60.47a(g)].

The Hammond Project CEMS data acquisition system (DAS) generally provided 12 5-minute averages per hour. However, occasionally only 11 readings per hour were recorded. In order for an hourly average to be considered valid, one of two things must occur. If twelve 5-minute periods in an hour are available, then at least six of the periods must contain complete load and emissions data. If eleven or less 5-minute periods are available or less, then that hour must contain five or more periods of complete load and emissions data. Approximately 1500 valid hours of data were collected during the Phase I long-term test program.

Daily Average Emissions

The valid hourly averages discussed above were used to compute daily averages. The daily averages form the basis for the determination of the achievable emission limit discussed in paragraph 4.2.2 below.

Missing or invalid hourly data not only affects the hourly average computations it also affects the computation of daily averages. The EPA NSPS Subpart Da data capture criteria were used to define the valid daily average emission data for the Phase 1 data. The EPA criteria requires that at least 18 hours of valid hourly data must collected, for emission monitoring purposes. As was stated above, this may not be relevant for an R&D project, however, it serves as an reasonable established methodology for evaluation of the daily data.

4.2.2 Data Analysis Procedures

Five-minute Average Emission Data

The edited 5-minute average data were subjected to a series of analyses. These analyses included (1) the determination of the NOx versus load relationship and (2) the NOx versus O_2 response for various load levels. These graphical and analytic data were primarily used to make engineering assessments and comparisons with the short-term data. The results of these analyses are discussed in Section 6.1.

Hourly Average Emission Data

The purpose of hourly average emission analyses was to assess the hour-to-hour variation in NOx, 02, and load during the long-term test period, and the within-day variation of NOx, 02, and load. The hour-to-hour variation in NOx, 02, and load are simply time ordered graphical presentations of the hourly averages. These graphical presentations are used to establish general trends The within-day data analyses are performed by sorting the hourly averages by hour of the day (01:00, 02:00, ..., 24:00) and computing the average NOx, 02, and load for these periods. The statistical properties for these hourly periods and the 95 percentile uncertainty band was computed for each hourly data subset.

Daily Average Emission Data

The daily average emission data are used primarily to establish the trends in NOx, O_2 and load, and to calculate the 30-day rolling NOx emission levels for the entire Long-term period. The daily average emissions data were analyzed both graphically and statistically. The graphical analyses consist of a series of plots to depict the daily variations in NOx, 02, and load to establish trends. The purpose of the statistical analyses was to determine the population mean, variability (standard deviation), distributional form (normal, lognormal), and time series (autocorrelation) properties of the 24-hour average NOx emissions. The SAS Institute statistical analysis package (UNIVARIATE and AUTOREG) procedures were used to perform the statistical analyses.

Achievable Emission Rate

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

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

$$Z = \frac{L - X}{S30}$$

where: Z is the standard normal deviate
L is the emission limit
X is the long-term mean

S30 is the standard deviation of 30-day averages. S30 is computed using the estimated standard deviation S24 and autocorrelation (ρ) level for daily averages.

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

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

It should be noted that the mean (X), and standard deviation (S30) are estimated from sample data. There is an uncertainty level inherent in these estimates. The estimate of S30 is also affected by the level of autocorrelation present in the data. The determination of the achievable emission limit is further complicated by the fact that the autocorrelation level is also estimated. Methods are available for introducing the uncertainty levels in the mean, variability, and autocorrelation into the determination of the achievable emission limit. This procedure is parameterized in terms of the autocorrelation level. Once the autocorrelation level is determined, the procedure uses the estimated mean and variability to determine the achievable emission limit. Typically, this process is first applied using the central estimate of the autocorrelation level determined using the SAS AUTOREG procedure. The procedure is then applied after incorporating the uncertainty level in the estimated autocorrelation. An achievable emission limit estimated in this manner represents an approximate 95 percent upper confidence limit on the true achievable emission limit.

5.0 SHORT-TERM TEST RESULTS

5.0 SHORT-TERM TEST RESULTS

The short-term testing consisted of first performing Diagnostic testing to establish the general NO 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. All tests during both the Diagnostic and Performance 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 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 I short-term program was from the normal supply source and was handled according to common plant practice. No special efforts were taken to maintain a consistent coal source for these tests. Subsequent to the completion of the long-term testing (Section 6.0) a short verification test effort was undertaken to determine if significant changes occurred during the long-term test effort.

The Phase 1 Short-Term Characterization testing was conducted from November 2 through December 5, 1989. A total of 36 tests were performed during this period. An additional eleven tests were performed during the verification test effort. During the entire Phase 1 effort, 47 short-term tests were performed. The following paragraphs describe both the Diagnostic, Performance and Verification testing performed during the Phase effort.

5.1 Diagnostic Tests

The Phase 1 Diagnostic effort consisted of characterizing emissions under "as found" conditions before any subsequent repairs or retrofits had been implemented. Thirty-six tests were performed at nominal loads of 185, 300, 400 and 480 MWe during the period from November 2 through November 13, 1989. Immediately before the start of the Diagnostic testing effort began, exploratory tests were performed to establish the general boiler operating characteristics and to establish steam, fuel and air condition stabilization times. Generally, changes between test conditions took from one to three hours to insure stable steam temperature and pressure conditions. Each test condition (load, excess oxygen 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, furnace backpass ash grab samples were collected from the Cegrit Ash Samplers, coal samples were collected from the individual mills and economizer exit and air preheater exit species and temperatures were recorded utilizing the Sample Distribution Manifold and were recorded on the DAS.

5.1.1 Unit Operating Condition

This "as-found" unit condition presented some limitations to completing the test matrix developed to include the "Experimental Design" criteria (Table 4-1, Section 4.1.1) prepared immediately prior to beginning Diagnostic testing. Attempts were initially made to satisfy "Experimental Test Design" criteria, however, the test matrix was too small to adequately utilize this technique taking in to account the mill and secondary air register condition discussed in the following sections.

Several limitations to completely satisfying the planned test matrix existed. These limitations did not, however, compromise the characterization of the NO emissions, i.e., comparison of Short-term and Long-term emissions. The limitations were associated with the high load O2 test range and register adjustment capability, and System Load Dispatch considerations.

The potential for opacity excursions (opacity > 40%) under certain high O_2 operating conditions as well as other minimum low O_2 operating conditions dictated by unit safety considerations affected the ability to test over a wide range of O_2 levels at loads near 480 MWe.

As with most boilers of this vintage, burner register drives are either not operable or their position is not accurately known. This operational condition was present on nearly half of the burners as illustrated in Figure 5-1.

As a result of normal Southern Electric System requirements during the period of testing, it was difficult to obtain low load operating conditions (185 to 300 MWe). This significantly reduced the amount of data that could be obtained at these loads. This is not unusual for a low heat rate, base loaded unit. Thorough characterization at these low loads was, consequently, felt to be inappropriate for this Phase of the program since they would not be experienced to any great extent during the Long-Term Characterization portion of the Phase I effort. Without the Long-term data at these low loads no comparison could be made to assess the representativeness of the Short-term characteristics.

Table 5-1 presents the "as tested" conditions during the Diagnostic portion of the testing. Eleven days of testing were planned and executed comprising 36 individual tests at various excess oxygen, mill pattern and load conditions. Since high load is the normal Unit 4 mode of operation (approximately constant 480 MWe base-loaded operation), most of the testing (14 out of 36) was at or near 480 MWe with a slightly reduced amount (11) of testing at 400 MWe. The testing between 185 and 300 MWe consisted of nine individual tests.

FIGURE 5-1 HAMMOND UNIT 4 BURNER REGISTER CONDITION

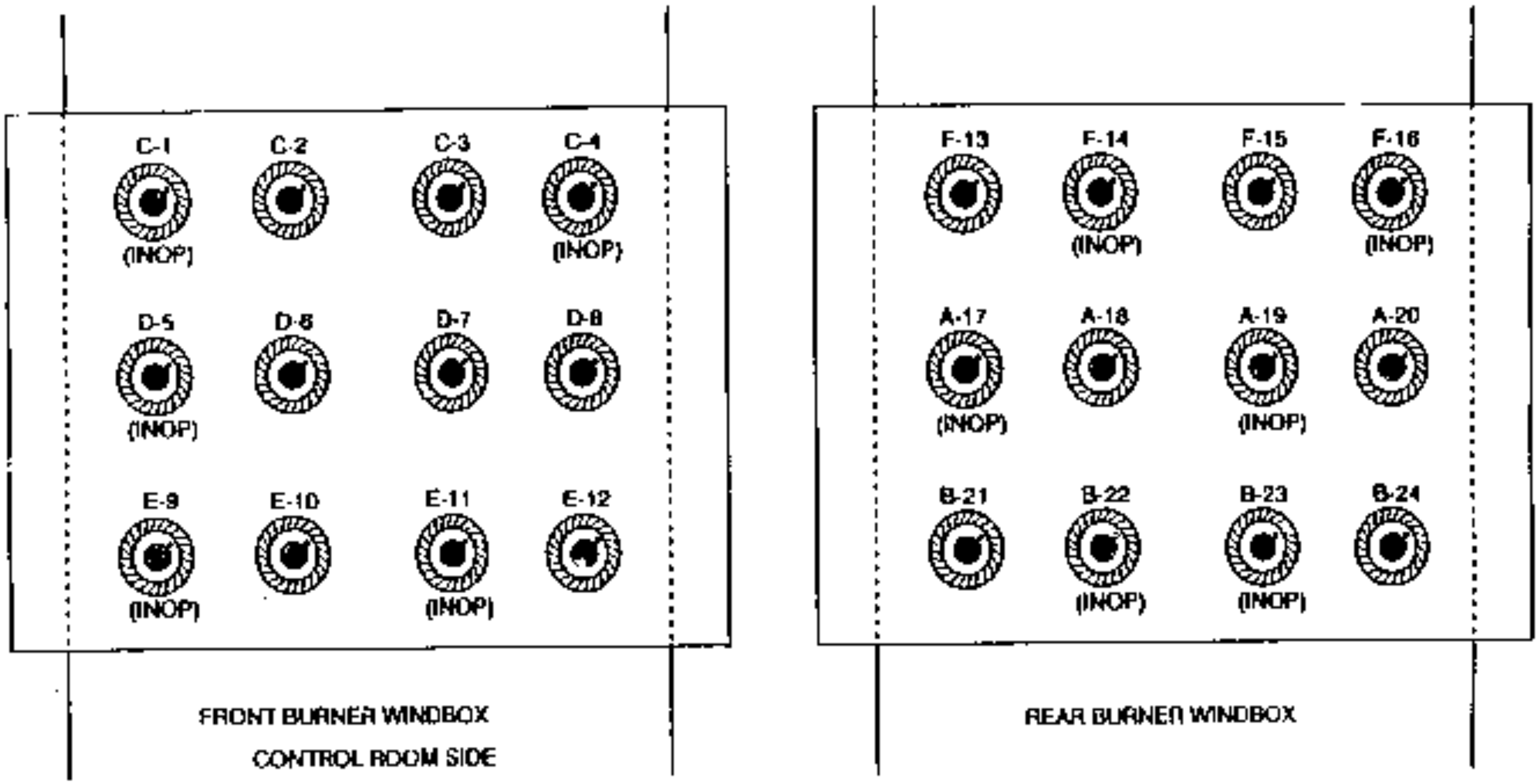


TABLE 5- 1 PHASE l DIAGNOSTIC TEST RESULTS

TEST NO.	DATE	TEST CONDITIONS	LOAD MWe	MOOS PATTERN	DAS 02 %	DAS NO ppm
1-1	11/2	OPERATIONAL RANGE	480	NONE	HIGH	-
1-2	1112	OPERATIONAL RANGE	480	NONE	LOW	-
1-3	11/2	Hl LOAD 02 VARIATION	480	NONE	3.1	999
2-1	11/3	Hl LOAD 02 VARIATION	480	NONE	2.5	933
2-2	11/3	Hl LCAD MILL BIAS	480	NONE	2.7	1000
2-3	11/3	MID LOAD 02 VARIATION	400	E	3.3	992
3-1	11/4	LOW LOAD 02 VARIATION	185	B& E	7.2	872
3-2	11/4	'	185	B& E	6.2	786
4-1	11/5	Hl LOAD O2 VARIATION	480	NONE	2.5	917
4-2	11/5	'	480	NONE	2.2	876
5-1	11/6	Hl LOAD MILL BIAS	489	NONE	2.4	858
5-2	11/6	MID LOAD O2 VARIATION	400	E	2.4	803
6-1	11/7	MID L OAD 02 VARIATION	300	E	3.8	694
6-2	11/7	'	300	E	5.2	780
6-3	11/7	MID LOAD MILL VARIATION	400	NONE	3.5	764
7-1	11/8	MID LOAD 02 VARIATION	300	E	4.3	799
7-2	11/8	MID LOAD MILL VARIATION	300	B	4.2	752
7-3	11/8	MID LOAD 02 VARIATION	400	E	4.3	853
7-4	11/8	'	400	B	3.2	808
7-5	11/8	Hl LOAD O2 VARIATION	480	NONE	2.9	885
8-1	11/9	MID LOAD MILL VARIATION	300	B&E	4.0	713
8-2	11/9	MID LOAD 02 VARIATION	479	NONE	3.0	970
8-3	11/9	'	478	NONE	2.7	974
8-4	11/9	Hl LOAD 02 VARIATION	478	NONE	2.2	957
9-1	11/10	MID LOAD 02 VARIATION	400	B	2.3	842
9-2	11/10	'	400	B	3.5	954
9-3	11/10	'	400	B	5.1	1041
9-4	11/10	HIGH LOAD 02 VARIATION	480	NONE	3.3	1072
9-5	11/10	'	480	NONE	2.9	1042
10-1	11/11	MID LOAD O2VARIATION	405	E	2.0	701
10-2	11/11	'	403	E	3.1	805
10-3	11/11	'	400	E	4.5	888
10-4	11/11	'	305	E	2.8	714
10-5	11/11	'	315	E	4.8	838
11-1	11/13	HIGH LOAD 02 VARIATION	478	NONE	2.9	953
11-2	11/13	'	480	NONE	2.9	970

5.1.2 Gaseous Emissions

During both the Diagnostic and Performance test efforts, flue gas data and boiler operating data were collected on the Data Acquisition System (DAS). The Gas Analysis System (GAS) allowed measurement of NO, CO, O_2, SO_2 and total hydrocarbons (THC) from 48 probe locations within the flue gas stream both upstream and downstream of the air preheater. Two basic types of tests were performed - overall NO characterization and economizer exit plane species distribution characterization. The overall NO characterization tests were performed over a period of approximately one hour and was used to obtain composite average specie concentrations from the individual probes in a duct sampled as a group. In general, the groups were 1) A-side economizer outlet, 2) Beside economizer outlet, 3) A-side APH outlet and 4) Beside APH outlet composite concentrations. The economizer exit plane species distribution characterizations were performed over a period of approximately two to three hours. These tests used data from the individual probe species concentrations in the A- and Beside economizer exit planes to establish the extent of maldistribution of combustion products emanating from the boiler. These maldistributions are an indication of the uniformity of combustion due either to fuel and/or air non-uniformities. Data from this type of test will be presented in Section 5.2.2.

Table 5-2 presents a summary of important emission and operating parameters recorded on the DAS during the Diagnostic test effort. These operating parameters provide information on the steaming conditions and the fuel supply configuration. The range of excess oxygen and resulting NO emissions for the four nominal load levels tested during the Diagnostic portion of the Phase I effort are shown in Figures 5-2 and 5-3. The conditions represented in these figures include excess oxygen variation, mill-out-of-service variation and mill biasing.

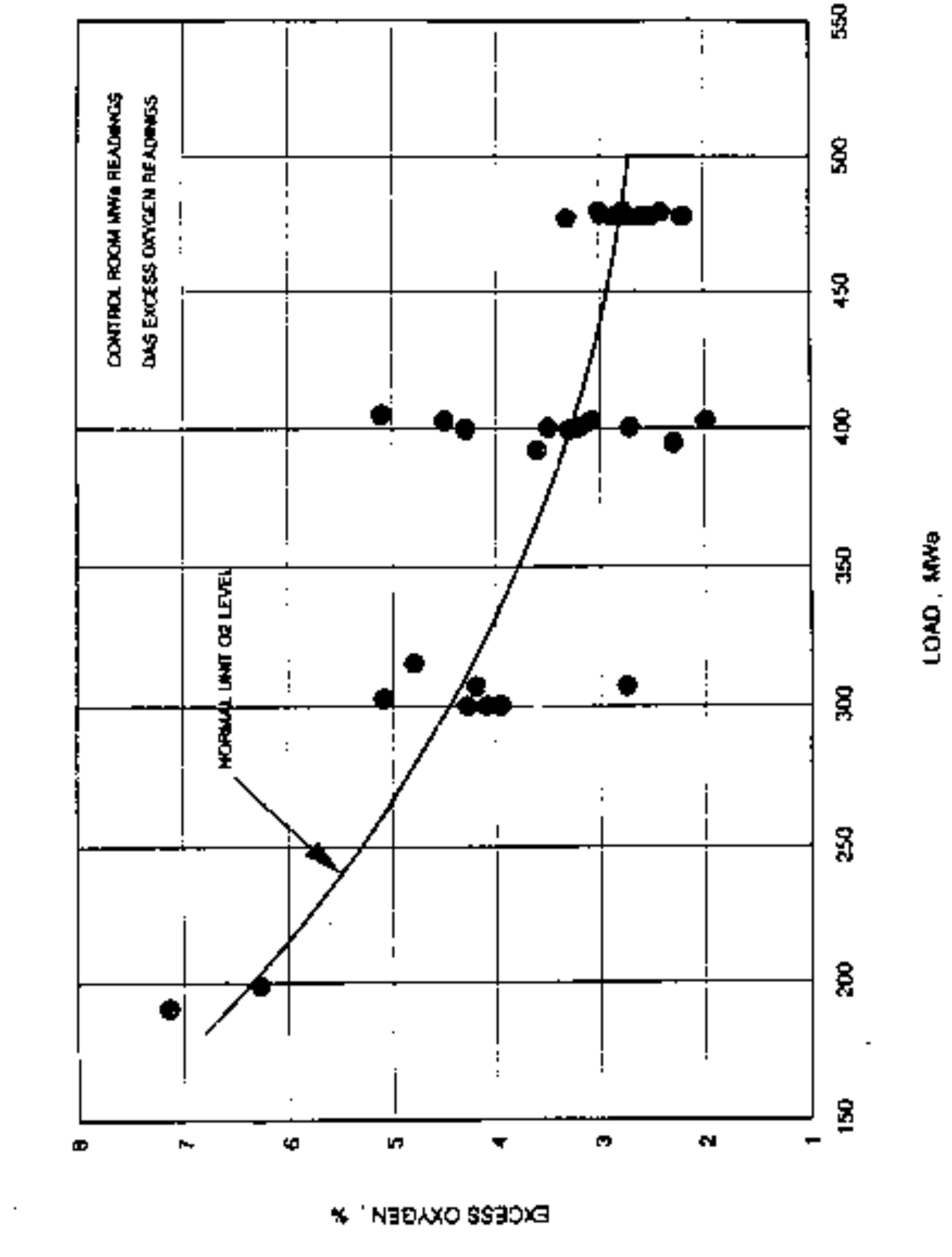
Figure 5-2 serves to illustrate that the testing was performed over a range of excess oxygen levels that were both below and above the levels recommended for this unit. The solid curve represents the manufacturer/Plant engineering recommended operating level. During System Dispatch control of the unit, excursions to these levels are frequently experienced during transient load conditions. In order to properly compare the Short-term and Long-term characteristics, this O_2 excursion testing during the short-term diagnostic effort was required.

It was evident as Diagnostic testing progressed that other variables potentially were greatly influencing the NO emissions, however, their influence could not be quantified. These influencing factors are preliminarily believed to be due to mill operating conditions (flows, grind and condition) and secondary air non-uniformity (air register settings). As discussed above, the secondary air registers on almost half of the burners were either inoperative or their position could not be accurately determined. It is believed that these combined factors made it

TABLE 5-2 SUMMARY OF PHASE 1 DIAGNOSTIC TESTS
OPERATING AND EMISSION DATA

Table not legible for scanning

FIGURE 5-2 HAMMOND UNIT 4 OXYGEN LEVELS TESTED



virtually impossible to repeat test conditions on different days and was the primary reason that the Experimental Design approach (See Section 4.1.1) was abandoned.

Figure 5-3 is a summary of all of the NO 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 that different configurations are represented and also due to the lack of data repeatability discussed above. It is not mathematically appropriate to attempt to statistically characterize these data due to the small population within each load category and the number of variables imbedded in the data. For engineering purposes it is helpful to place a band of confidence about the data to illustrate the general trend of NO versus load. At loads below 300 MWe insufficient data was available even for that purpose. The band (lo standard deviation [STD]) and the mean NO line shown in Figure 5-3 for loads from 480 to 300 MWe indicate that, at least for this set of data, the trend is increasing NO with increasing load. It should be pointed out that with more NO data the slope of the trend may change. Analyses performed for data gathered during the Long-term testing (Section 6.1) where virtually thousands of data points were used for the characterization provide a more statistically appropriate NO trend.

On Hammond Unit 4, short-term characterizations of the NO emissions could only be made for trends determined on the same day of testing for a particular configuration. This is believed to be due to the influence of the uncontrollable parameters described above. Figures 5-4 through 5-7 show the Diagnostic test results for the four nominal loads tested - 480, 400, 300 and 180 MWe. The legend for each data point indicates the mill configuration (where appropriate) and the test day for the particular data point. In some instances, the mill flows were biased (to nominally equal flows) from the settings normally used by the operators in order to determine the influence on NO emissions. Since the variability of the NO emissions for seemingly similar configurations was relatively large, this biasing influence could not be discerned.

Figure 5-4 shows the NO data for the 480 MWe test point. At this load, the only operational mill pattern is with all mills-in service (AMIS). As explained above, due to opacity and safety considerations, the excess oxygen range that could be tested was relatively small (approximately one percent). Over this range it is difficult to obtain a definitive trend for the NO versus O_2. It is evident from the figure that the slope for the three characteristic curves varies greatly (17, 75 and 136 ppm/% O_2). Over this small range of O_2 the most that can be said is that the NO increases with increasing excess oxygen. It is also evident that for seemingly identical test conditions the NO varied by as 6 percent (160 ppm) for tests conducted on different days.

FIGURE 5-3 HAMMOND UNIT 4 NITRIC OXIDE MEASUREMENTS

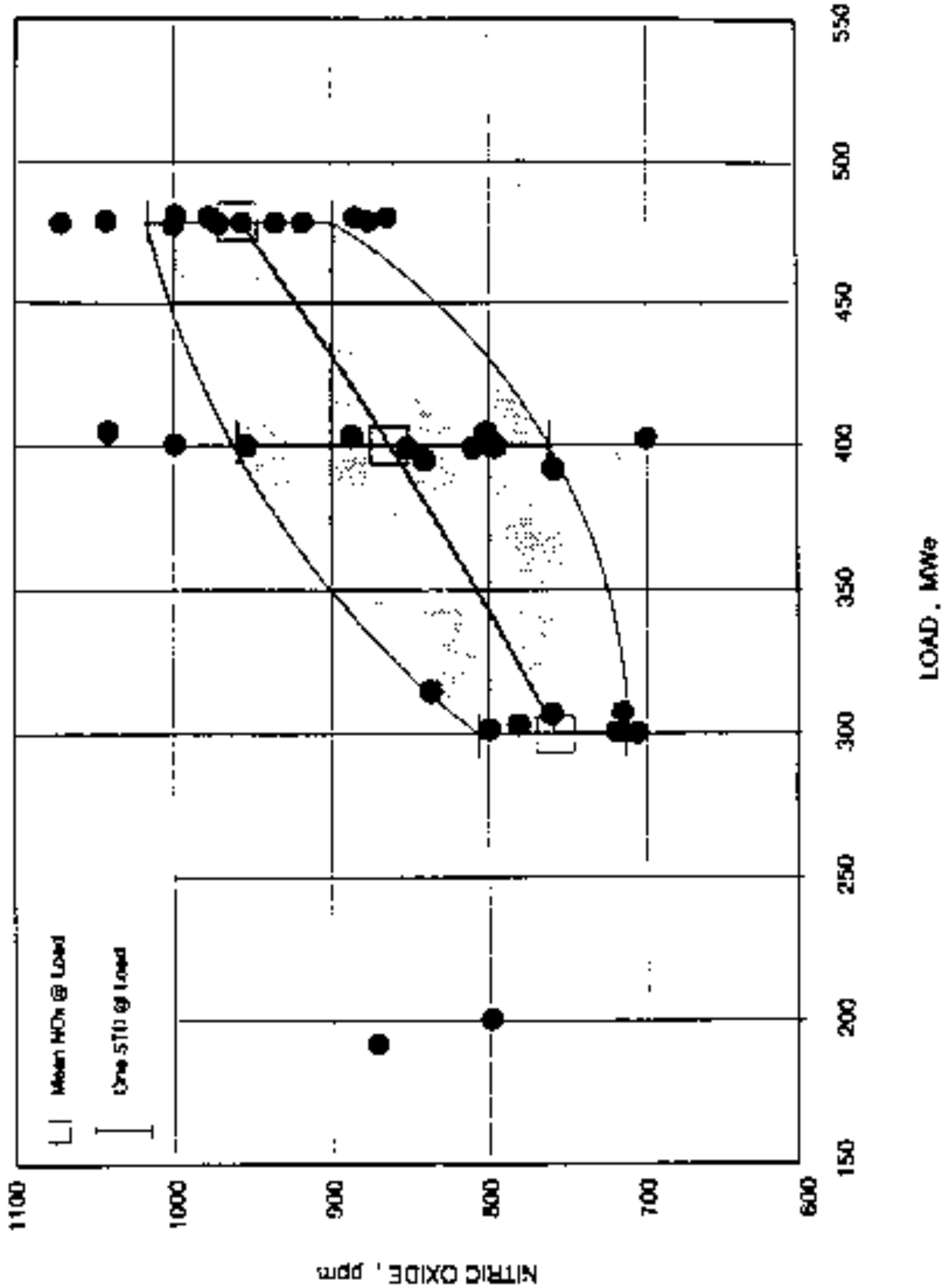


FIGURE 5-4 NOx CHARACTERIZATION @ 480 MWe NOMINAL LOAD

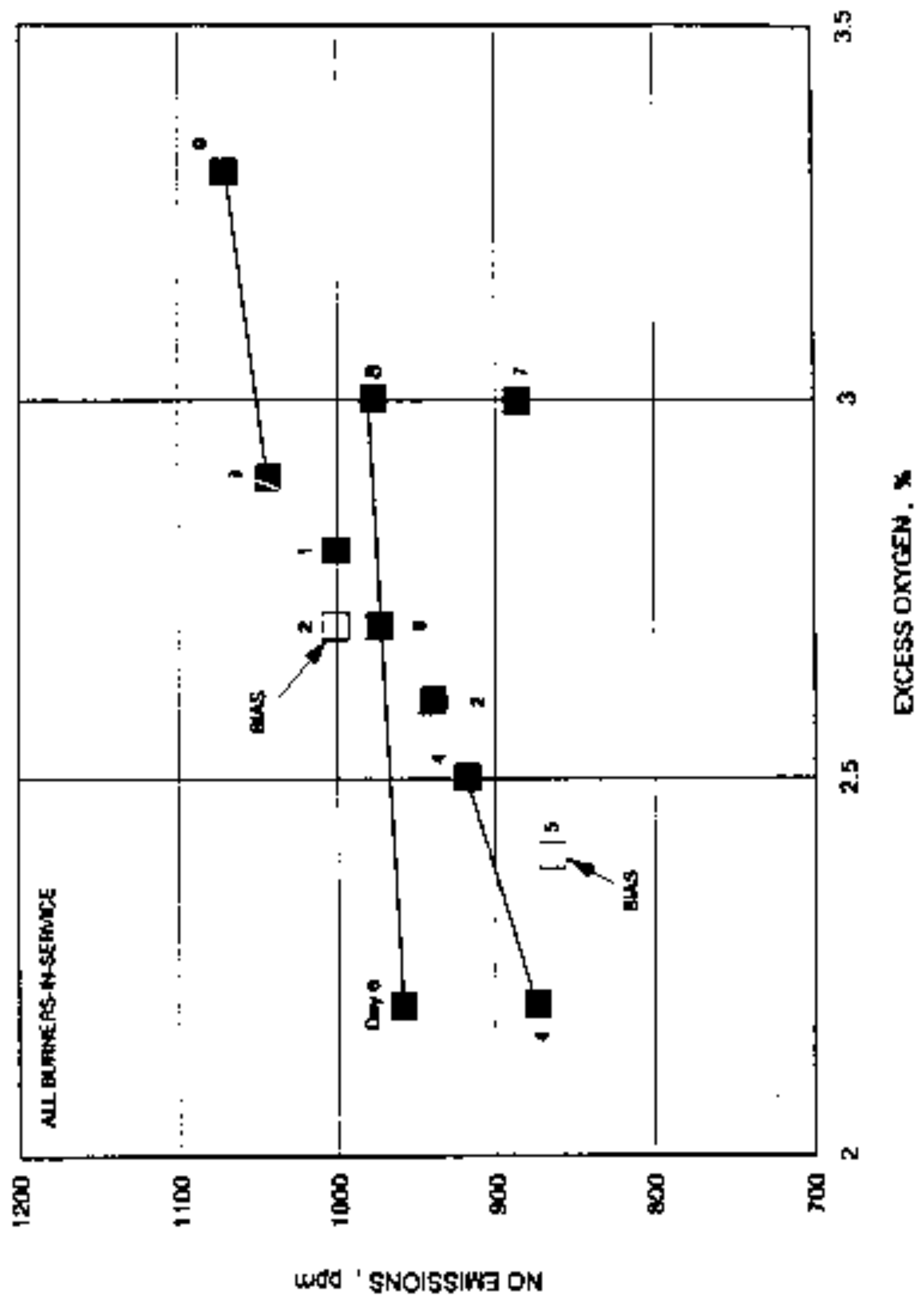


FIGURE 5-5 NOx CHARACTERIZATION @ 400 MWe NOMINAL LOAD

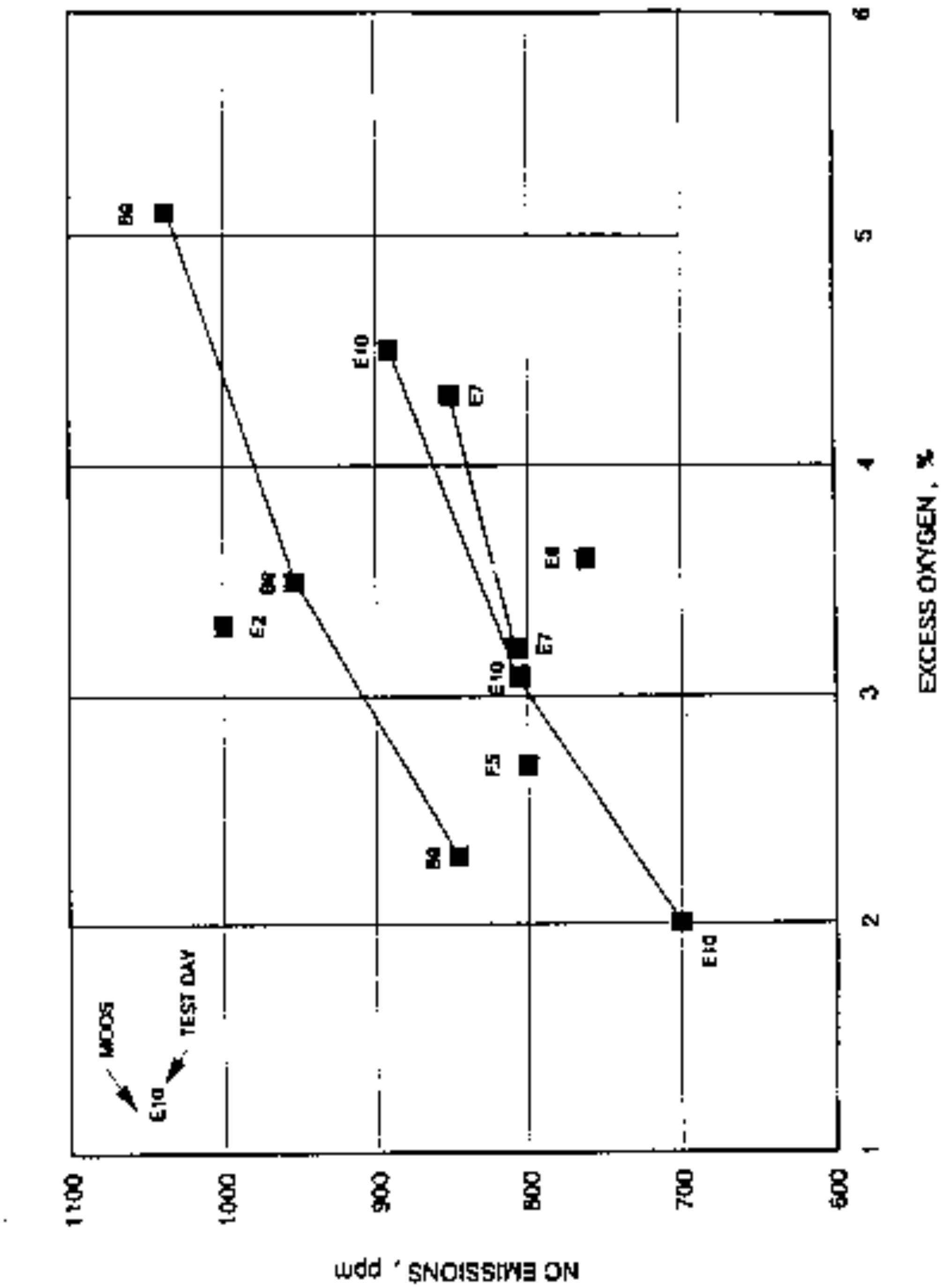


FIGURE 5-6 NOx CHARACTERIZATION @ 300 MWe NOMINAL LOAD

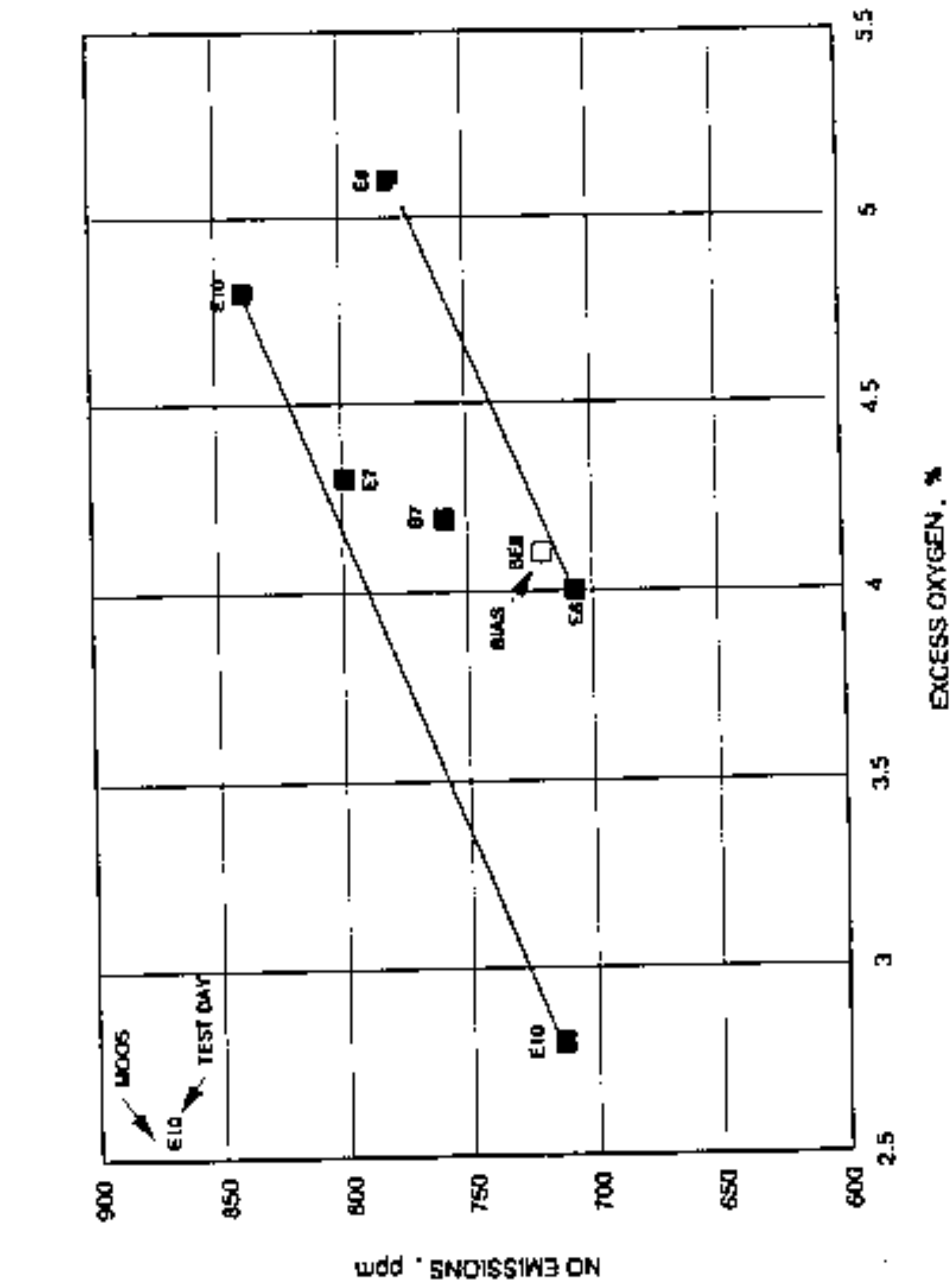
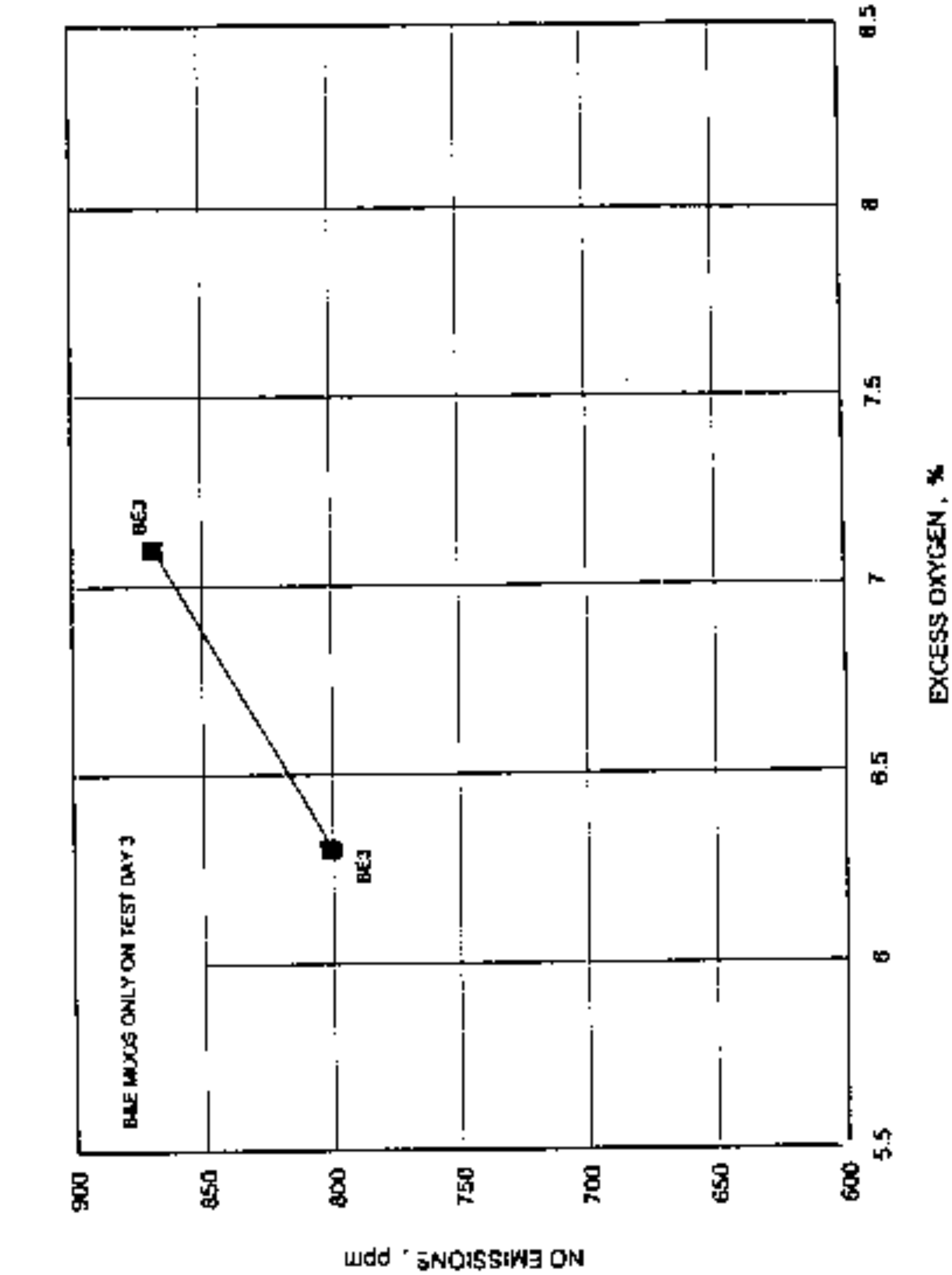


FIGURE 5-7 NOx CHARACTERIZATION @ 185 MWe NOMINAL LOAD



NO data for the 400 MWe test point is shown in Figure 5-5 primarily for two mill patterns - B-MOOS and E-MOOS. According to plant personnel these were the most commonly used mill patterns at this load. One data point with AMIS was tested as well. The opacity and safety limitations for the 480 MWe testing - were not factors at the 400 MWe test point and below, consequently, a wider range of conditions could be tested.

At 400 MWe, a considerably wider excess oxygen range could be tested (approximately three percent) and the opacity was not a problem at high O_2 levels. For all mill patterns, the NO trends appeared to be similar, however, they were offset from one another. With this small amount of data and the variability exhibited for all of the data taken during this Diagnostic test phase, it is not possible to determine if this offset is a trend. It is evident, however, that the NO versus O_2 characteristic do exhibit a definite repeatable trend based upon this data. On average the NO varied approximately 73 ppm/percent O_2 over the three percent excess oxygen excursion. Due in part to the fact that three mill patterns were tested, the NO varied by as much as 25 percent (228 ppm) for tests conducted on different days.

Due to the fact that the 300 MWe test point is not a common load point for this unit, a relatively small amount of NO data was obtained compared to that obtained at the higher load test points. Figure 5-6 shows the data for three mill patterns (B-, E- and B&E-MOOS). Sufficient data were available only for the EMOOS pattern to assess the NO versus O_2 characteristics. For the two days when the E-MOOS pattern was tested, the trend characteristics agreed quite well. Both days exhibited a 62 ppm/percent 02 slope illustrating that the repeatability of the trend. It should be pointed out, however, that as with the high load points, the data scatter resulted in an offset between the absolute NO emissions for the two days. The data scatter amounted to approximately 11 percent for the small amount of data collected. With more data it likely would have been greater based upon data obtained at the higher loads.

Only two data points were obtained at the 180 MWe load point. This load point is used infrequently when the unit is either coming up from and outage or when the load is required to perform maintenance that can not otherwise be performed at higher loads. This condition amounts to less than ten percent of the operating time. Figure 5-7 shows the trend for one mill pattern (B&E MOOS). For this one day of testing the data exhibits an 86 ppm/percent O_2 NO characteristic near the normal operating excess oxygen level. This is consistent with the data obtained at the 400 and 300 MWe test points, i.e., 73 and 62 ppm/percent O_2, respectively.

From these figures it is evident that while trends (NO vs O_2) determined on the same day are similar, the day-to-day variation can be larger than the effect of excess oxygen on NO for seemingly identical conditions. Even when mill biasing was introduced as a variable, the effect was within the normal scatter caused by other influencing variables.

5.1.3 Coal and Ash Analyses

Coal samples were taken each day of the Diagnostic testing near the end of the test day. Table 5-3 lists the analysis results for the 12 samples. Figure 5-8 illustrates the general variability of the coal from day to day. The properties that affect the NO emissions (fuel Nitrogen (N), volatile matter (VM) and HHV) were all relatively constant during the Diagnostic testing. Relative standard deviations (100*STD/Mean) for these properties ranged for 0.7 to 5.2 percent. The mean values for the N, VM and HHV were 1.5 percent, 33.5 percent and 12550 Btu/lb, respectively. The highest RSD was for the fuel Nitrogen (5.2 percent), however, this is within the accuracy of the measurement technique and consequently the fuel Nitrogen level is assumed to be constant at 1.5 percent during the tests.

Grab samples of the flyash in the backpass were collected using the on-line Cegrit Samplers. The grab samples were collected for a limited number of tests during the Diagnostic portion of the Phase I effort. Table 5-4 lists the results or analyses to determine the loss on ignition (LOI) for the east and west duct samplers. Figure 5-9 presents the LOI results plotted against the ECEM economizer exit excess oxygen level.

Least squares linear curves were fitted to the Cegrit LOI data for each of the three load points (480, 400 and 300 MWe). Sufficient data was available for the 400 MWe data to characterize LOI for the B- and E-MOOS patterns. It should be pointed out that the fitted lines are only for the purpose of discerning the general trend and not meant to be used to extract absolute LOI values at specific O_2 levels. Insufficient data were available for that purpose. The trends are the expected trends in that the LOI increases with decreases in excess oxygen. One specific observation that can be made for this limited data is that the LOI at 400 MWe with the E-MOOS is significantly higher than that for the B-MOOS. This is consistent with the NO data shown in Figure 5-5 in that the NO emissions for these configurations are the inverse of this trend, i.e., NO is higher for the B-MOOS pattern while the LOI is lower. Since NO production is a good measure of the combustion efficiency (high NO with high efficiency), this trend at the 400 MWe load point agrees with theoretical and empirical observations.

5.2 Performance Tests

Seven Performance tests were conducted at nominal gross loads of 300, 400 and 480 MWe. At each nominal load the coal firing rate was kept as constant as possible and the electric

TABLE 5-3 DIAGNOSTIC TEST COAL ANALYSIS

	Ultimate Analyses, (%)									HHV	VM	FIXED CARBON
Date	H20	C	H	N	Cl	S	Ash	O	TOTAL	BTU/lb	%	C,%
11/02	5.36	70.33	4.51	1.41	0.034	1.71	10.1	6.57	100.03	12489	33.1	51.4
11/03	4.75	71.14	4.82	1.60	0.029	1.72	10.3	6.00	100.36	12708	33.6	51.7
11/04	5.58	70.2	4.55	1.57	0.031	1.73	9.4	6.96	100.03	12S24	33.2	51.8
11/05	5.80	69.7	4.53	1.43	0.031	l.72	9.8	7.00	100.02	12561	33.5	50.9
11/06	5.85	70.2	4.53	1.55	0.008	1.80	9.6	6.27	100.01	12S18	34.0	50.3
11/07	5.56	70.3	4.52	1.38	0.034	1.68	10.3	6.26	100.03	12497	33.0	51.2
11/08	4.86	70.2	4.58	1.45	0.029	1.76	11.0	6.16	100.01	12540	32.9	51.2
11/09	4.39	71.3	4.71	1.39	0.028	1.77	9.8	6.61	100.03	12748	35.0	50.8
11/10	6.42	69.4	4.51	1.43	0.032	1.74	10.2	6.23	100.03	12403	33.3	50.0
11/11	6.01	70.5	4.60	1.49	0.027	1. 72	9.3	6.45	100.04	12566	34.0	50.8
11/13	5.95	69.8	4.64	1.57	0.032	1.83	10.0	6.25	100.03	1249S	33.3	50.8
Avera	5.50	70.3	4.59	1.48	0.029	1.74	10.0	6.43	100.06	12S50	33.5	51.0
STD	0 58	0.5	0. 09	0.08	0.007	0 04	0.5	0.31	0.09	94	0.6	0.5
RSD	10 62	0.8	2 04	5.18	24.02	2 36	4.6	4.79	0.09	1	1.7	1.0

STD = Standard Deviation
RSD = Relative Standard Deviation

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FIGURE 5-8 HAMMOND UNIT 4 COAL VARIABILITY

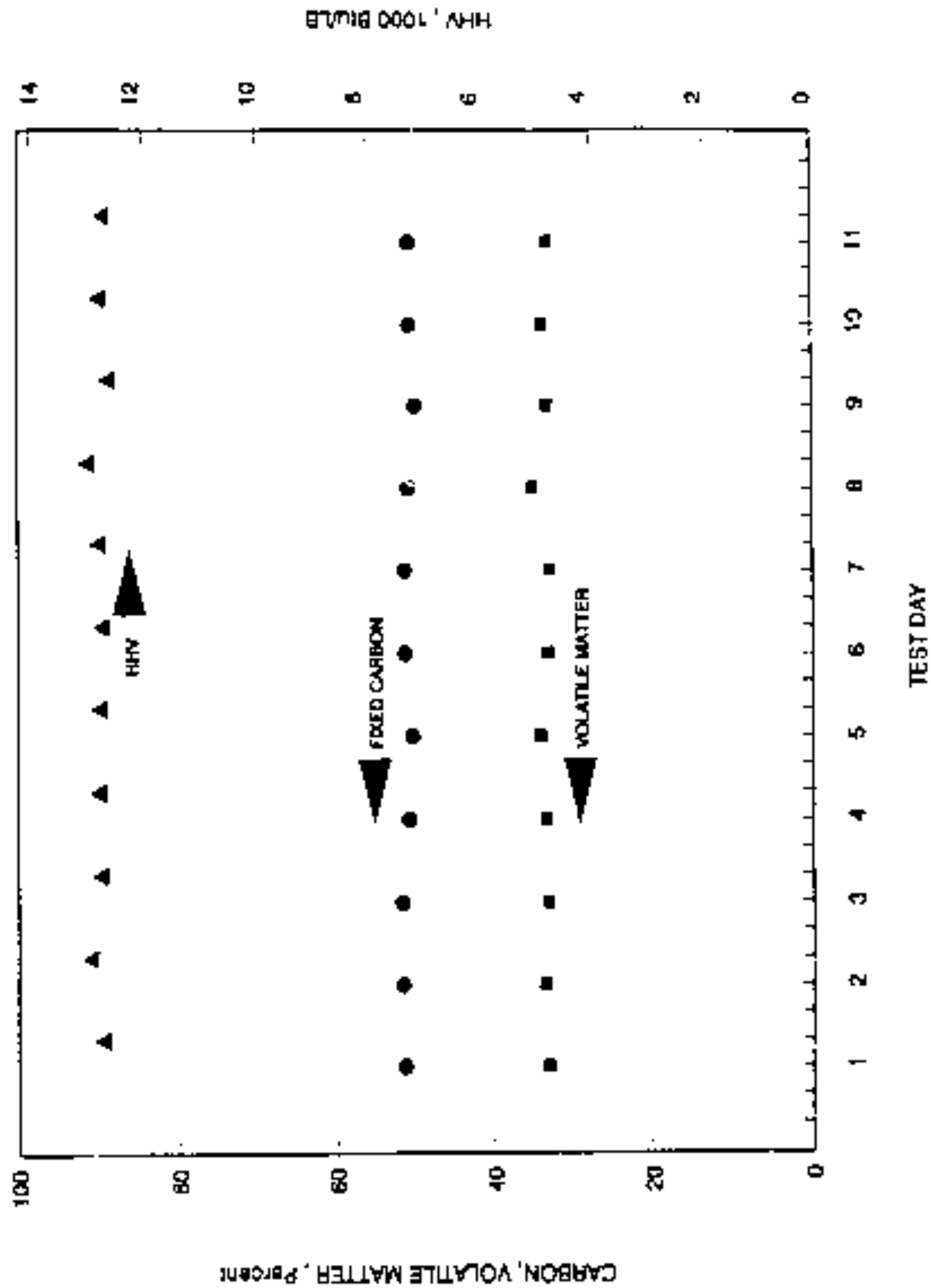
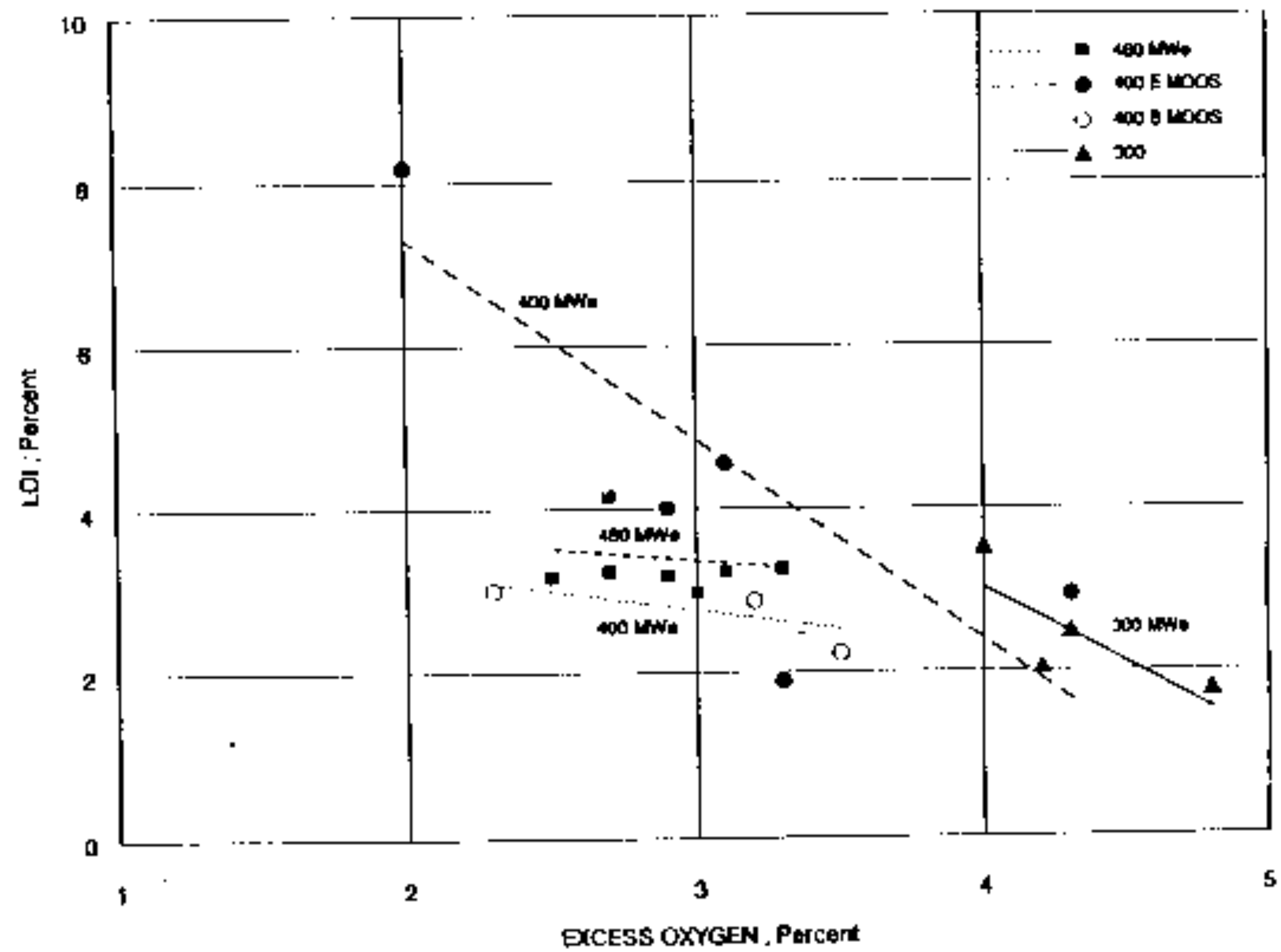


TABLE 5-4

HAMMOND UNIT 4 DIAGNOSTIC TEST CEGRIT ASH ANALYSIS

Test Number	Date	Nominal Load Mwe	Excess Oxygen %	A-Side LOI %	B-Side LOI %	Average LOI %
1-3	11/02	480	3.1	3.87	2.59	3.23
2-1	11/03	480	2.5	4.00	2.33	3.17
2-2	11/03	480	2.7	4.73	1.74	3.24
2-3	11/03	400	3.3	1.72	2.06	1.89
7-1	11/08	300	4.3	2.75	2.14	2.45
7-2	11/08	300	4.2	2.33	1.70	2.01
7-3	11/08	400	4.2	2.64	3.22	2.93
7-4	11/08	400	3.2	2.23	3.51	2.87
8-1	11/09	300	4.0	4.86	2.12	3.49
8-2	11/09	480	3.0	3.36	2.60	2.98
8-3	11/09	480	2.7	4.34	3.97	4.16
9-1	11/10	400	2.3	3.51	2.49	3.00
9-2	11/10	400	3.5	2.11	2.34	2.22
9-4	11/10	480	3.3	3.46	3.07	3.27
9-5	11/10	480	2.9	3.79	4.23	4.01
10-1	11/11	400	2.0	9.79	6.58	8.18
10-2	11/11	400	3.1	5.93	3.18	4.55
10-5	11/11	300	4.8	2.02	1.48	1.75
11-1	11/13	480	2.9	3.43	2.95	3.19

FIGURE 5-9 HAMMOND UNIT 4 DIAGNOSTIC TEST LOI



load allowed to swing slightly as affected by coal variations, boiler ash deposits, ambient temperature, etc. The maximum load swing recorded during any test was 6 MWe (< 2 percent). Each test covered a period of 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 and the engineering performance tests conducted.

5.2.1 Unit Operating Data

For each Performance test, the desired test conditions were established and allowed to stabilize at least one hour prior to commencement of testing. To the extent possible the active coal mills were balanced with respect to coal feed rate. Normal primary air/coal ratios and mill outlet temperatures were maintained, within the capacity of the existing primary air system. When the desired operating conditions were established the fuel and air masters were placed on manual control to minimize fluctuations in the fuel or air firing rate. This technique resulted in extremely stable operation over the test duration with only minor adjustments to the air flow over the day.

Because a portion of the testing was concerned with measurement of various particulate emission characteristics, it was decided that soot blowing (both furnace and air preheaters) should be suspended during the particulate sampling periods, so that the test measurements would include only particulate matter actually generated by the coal combustion at the time of testing (plus any normal attrition of wall or APH deposits) and not periodic portions of ash loosened by soot blowing. When necessary for proper unit operation, air preheaters were blown between repetitions in the solids emissions testing.

At each nominal load level, at least two tests were performed over a two- day period to accommodate all of the specific test measurements desired. A third test at 475 MWe was performed as a result of System demand requirements on December 4 which precluded testing at the scheduled 400 MW test. Table 5-5 summarizes the conditions of each of the seven performance tests

TABLE 5-5

SUMMARY OF PERFORMANCE TESTS

Test No.	Date	Gross Load MWe	Coal MOOS	Excess O_2 %
12	11/29	477	None	3.0
13	11/30	476	None	3.3
17	12/04	469	None	2.5
14	12/01	298	E	4.7
15	12/02	301	E	4.5
16	12/03	389	E	3.7
18	12/05	390	E	3.3

for ease of reference. Table 5-6 presents a summary of important operating parameters recorded on the DAS during this test series. The values shown in this table represent average over the duration of the test segment during the day.

5.2.2 Gaseous Emissions

During the Performance tests (tests 12 through 18) gaseous emissions were measured with the ECEM 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 are used to establish the overall emission characteristics while the individual probe measurements are used to establish spatial distributions of emission species.

Composite samples were acquired from all of the east duct probes and the west duct probes at the secondary APH inlet to represent the stoichiometric conditions in each half of the furnace. The ECEM excess O_2 values were used for the composite readings rather than the six existing plant O_2 analyzers since the ECEM obtains samples from 24 individual points in the two ducts. Table 5-7 lists the composite average values of O_2, CO and NO measured over a several hour period for each test condition. Each complete Performance test consisted of two separate but nearly equal conditions for a given load, e.g., conditions for test 12-1 or 12-2. The composite values recorded are the average of the east and west duct composites, each consisting of simultaneous sampling from 12 probes per duct for the two test conditions. Each value of O_2, Co and NO represent at least two sets of ten readings per duct over the full 10 to 12 hour Performance test duration.

TABLE 5-6 SUMMARY OF PHASE 1 PERFORMANCE TESTS
OPERATING AND EMISSION DATA

Table not legible for scanning

TABLE 5-7
SUMMARY OF GASEOUS EMISSIONS TEST DATA

Test No.	Gross Load MWe	Excess O_2 %	CO ppm	NO ppm
12	477	3.0	18	973
13	476	3.3	11	1117
l7	469	2.5	14	1070
16	389	3.7	12	949
18	390	3.3	12	1049
14	298	4.7	9	839
15	301	4.5	9	801

Although the presence of visible smoke (opacity) is frequently of more value than CO measurement as an indicator of undesirable coal combustion conditions, the presence of a ESP on this unit precluded the use of this tool. CO can be a useful tool in diagnosing combustion anomalies and is e measure of the quality of combustion. The low levels of CO measured during the present tests are in the instrument background noise level and are therefore not indicative of any combustion irregularities. The low levels of LOI (Section 5.2.3) during these tests, however, indicates that there were in fact no major combustion irregularities.

From Table 5-7 it can be seen that the NO emissions vary for seemingly identical test conditions. There is considerable variability in NO emissions, at the mid and high load levels. The data scatter of 10 to 15% from nominal reflects the influence on NO emissions of combustion variables which could not be controlled or measured adequately as was pointed out in Section 5.1.2. Variations in coal nitrogen content, fuel/air distributions, coal fineness, furnace wall cleanliness, etc., could all contribute to variability in the measured NO emissions. As will be discussed in later paragraphs, the exact reason for this variablity could not be ascertained with the available data.

Comparing these Performance data with the Diagnostic test data shows that the variability is similar for these two test elements (See Figures 5-4 and 5-5). It should be noted that the measurement of NO levels of 1117 and 1049 ppm for the 480 and 400 MWe Performance tests, respectively, are higher than any measured during the Diagnostic testing. This supports the contention made in Section 5.1.2 that additional Short-term data could exhibit even greater variability if more data were available.

Some indication of the spatial variation in combustion stoichiometry in the furnace can be inferred by measurement of the distributions of O_2 and NO concentrations in the furnace exit gases. For each load level, at least one measurement was made of each of the 24 probes in the economizer exit outlet ducts. Experience has shown that the distribution of critical gaseous species (notably O_2, NO and CO) at this location can provide a relatively accurate representation of the stoichiometric distributions within the furnace combustion zone. Figures 5-10 through 5-10 provide graphical representations of the O_2 and NO distributions at the economizer outlet exit plane. The CO levels were low for all of the Short-term testing and do not provide any insight for evaluation of combustion non-uniformities. In the figures the x-y base plane represents the cross-section of the ducts and the Z-axes represent the value of O_2 or NO existing at each point in the cross-section. The figures depict surfaces of O_2 and NO levels including a number of values interpolated between the actual sample data points. From Figures 5-10 and 5-15 it can be seen that there is considerable variation in both O2 and NO concentrations across the ducts. It can also be seen that the distributions vary from test to test, and even at nominally constant test conditions.

Two spatial distributions at each of the nominal load test points are available for direct comparison. Comparing Figures 5-10 and 5-11 for the nominal 480 MWe tests it can be seen that both exhibit slightly different NO and O_2 characteristics. Figure 5-10 illustrates that regions with high O_2 generally have high NO levels as would be expected. Figure 5-11 exhibits an entirely different characteristic. Regions of high O_2 correspond to regions of low NO. This is contrary to theory if one assumes that the flames are well established and are not detached from the burners. This could not be verified visually. It should be noted that the two tests illustrated were at different excess oxygen levels - 3 % for test 12 and 2.4 percent for test 17. It would be assumed that the low O_2 test would exhibit lower NO, however, the reverse was the case. The explanation for this anomaly is uncertain. The average NO across the ducts for the two tests differs by 100 ppm.

Comparing Figures 5-12 and 5-13, The same type of anomaly exists but is less dramatic. The major differences between the two figures is in the NO distributions. The NO measurements for Test 16-2 shown in Figure 5-12 exhibit a significant variation of NO across the furnace for only slight changes in O_2. In general the NO increases for east to west. Test 18-1 shown in Figure 513 exhibits the characteristic of low NO in regions of high O_2 as was experienced for one of the 480 MWe load tests. The average NO across the ducts for these two tests also differs by 100 ppm.

FIGURE 5-10 HAMMOND UNIT 4 FLUE GAS DISTRIBUTION
TEST 12-1 475 MWe

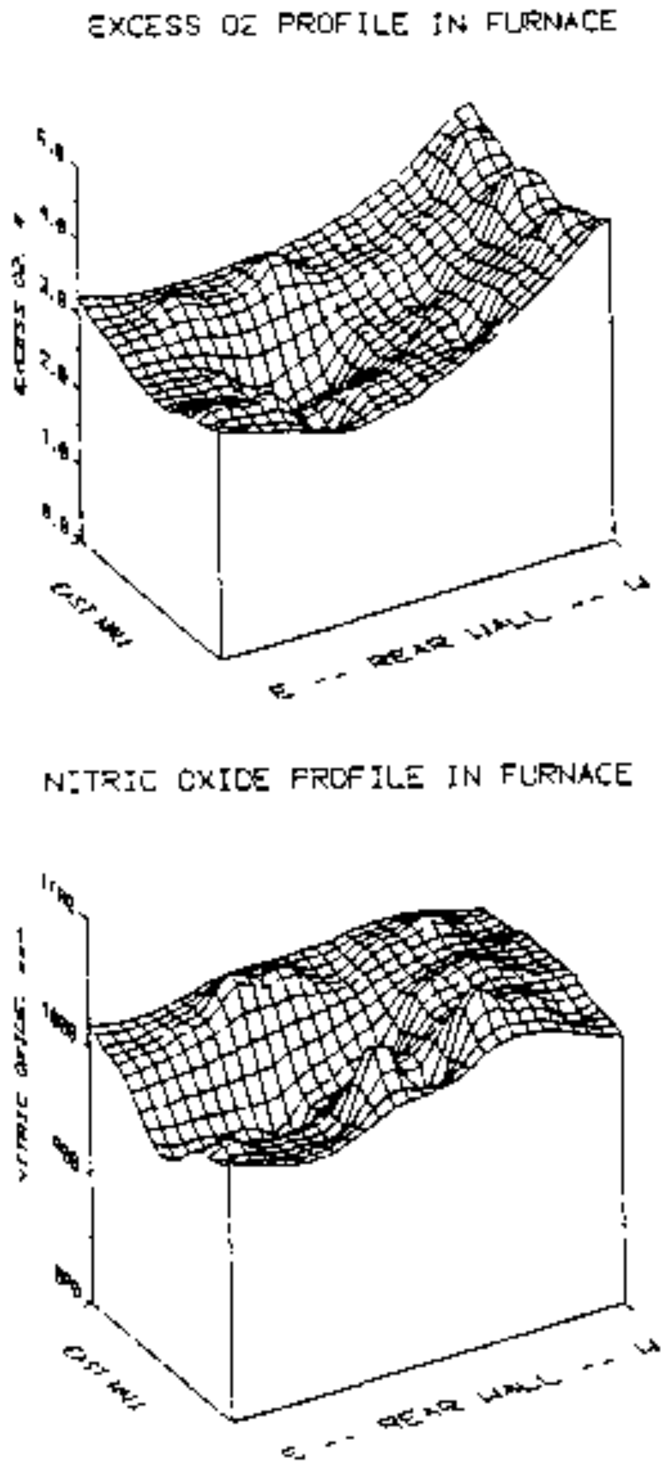
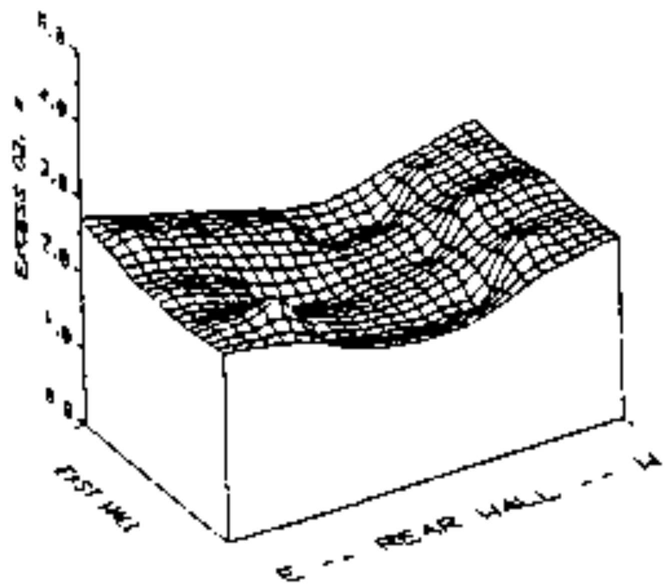


FIGURE 5-11 HAMMOND UNIT 4 FLUE GAS DISTRIBUTION

TEST 17-2 469 MWe

EXCESS O2 PROFILE IN FURNACE



NITRIC OXIDE PROFILE IN FURNACE

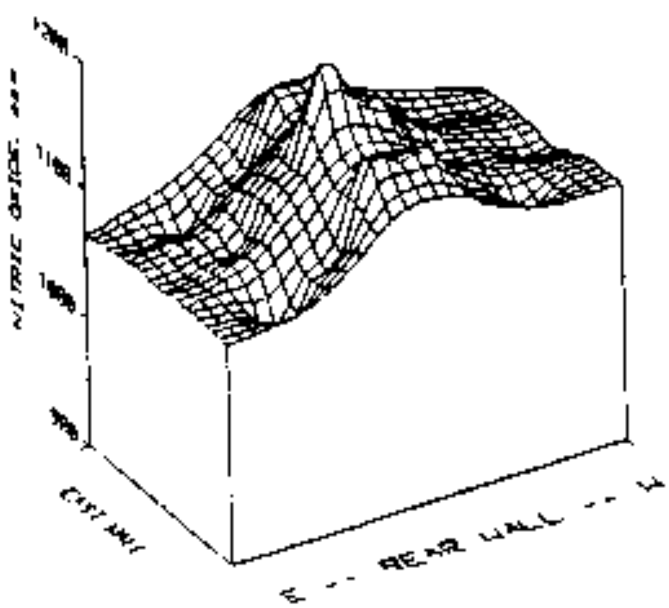
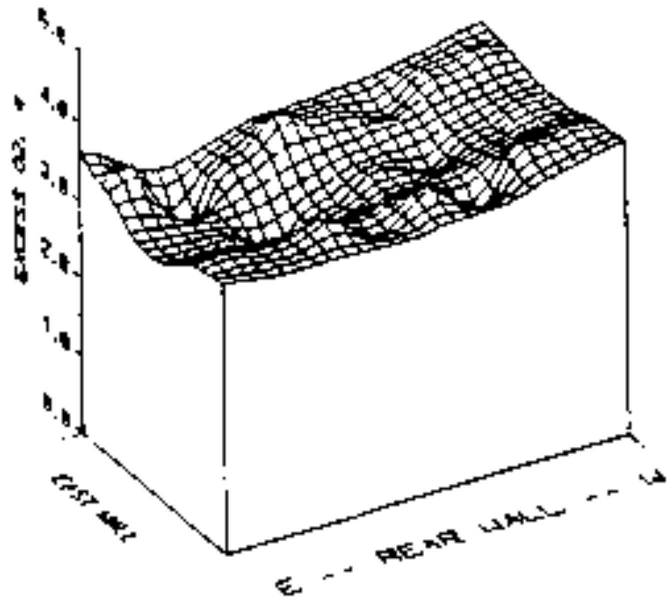


FIGURE 5-12 HAMMOND UNIT 4 FLUE GAS DISTRIBUTION
TEST 16-2 368 MWe

EXCESS O2 PROFILE IN FURNACE



NITRIC OXIDE PROFILE IN FURNACE

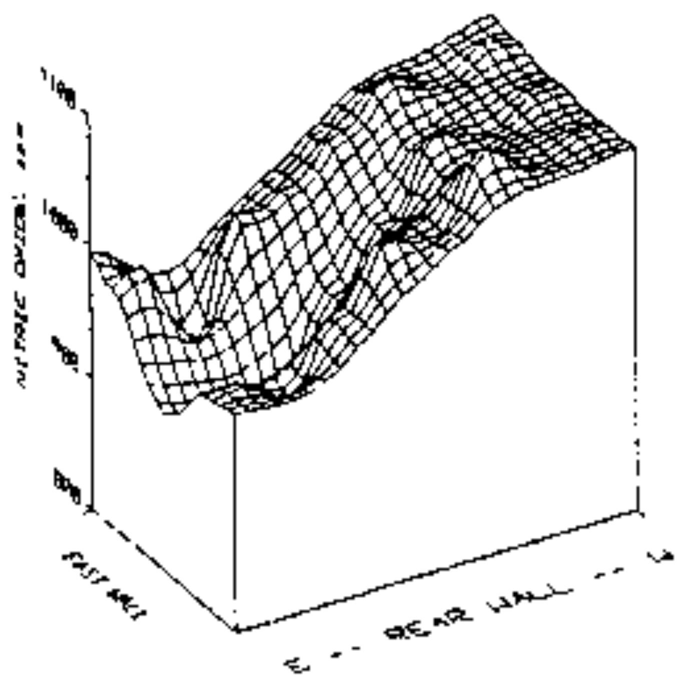
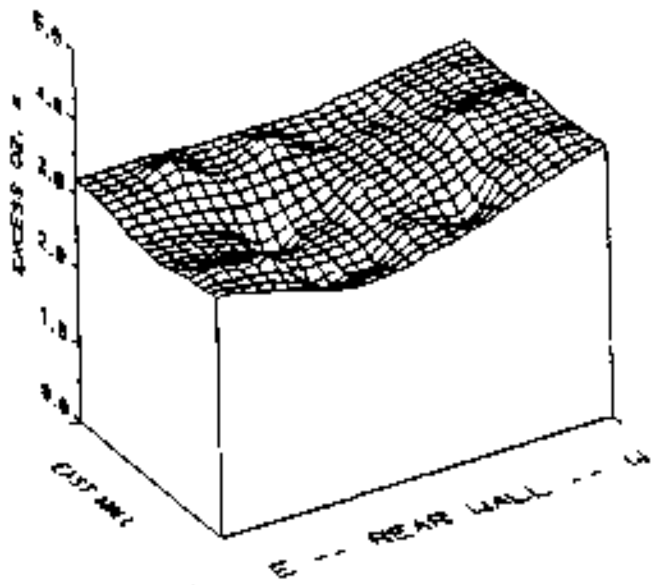


FIGURE 5-13 HAMMOND UNIT 4 FLUE GAS DISTRIBUTION

TEST 18-1 390 MWe

EXCESS O2 PROFILE IN FURNACE



NITRIC OXIDE PROFILE IN FURNACE

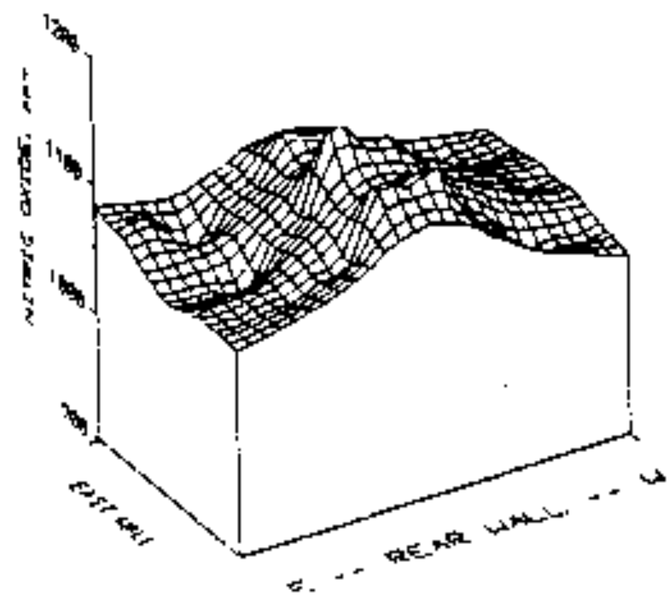
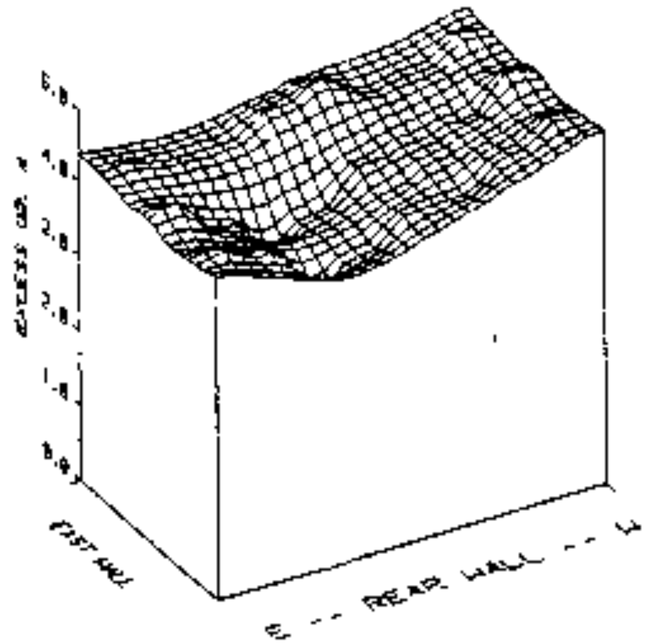


FIGURE 5-14 HAMMOND UNIT 4 FLUE GAS DISTRIBUTION

TEST 14-2 297 MWe

EXCESS O2 PROFILE IN FURNACE



NITRIC OXIDE PROFILE IN FURNACE

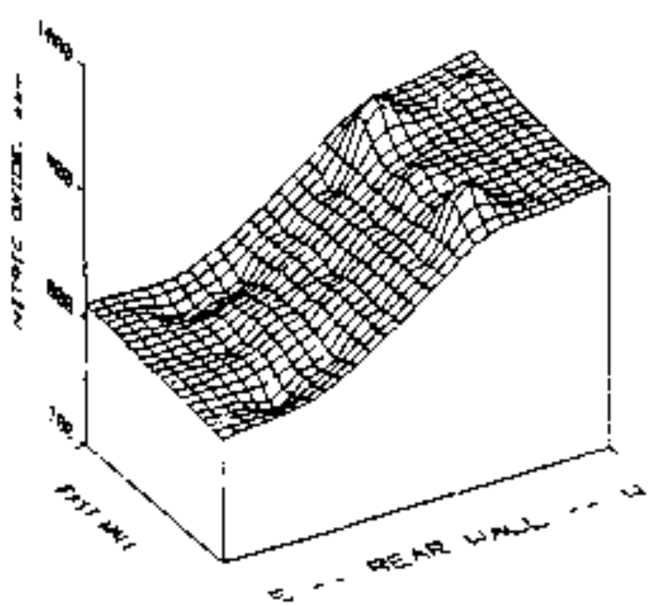
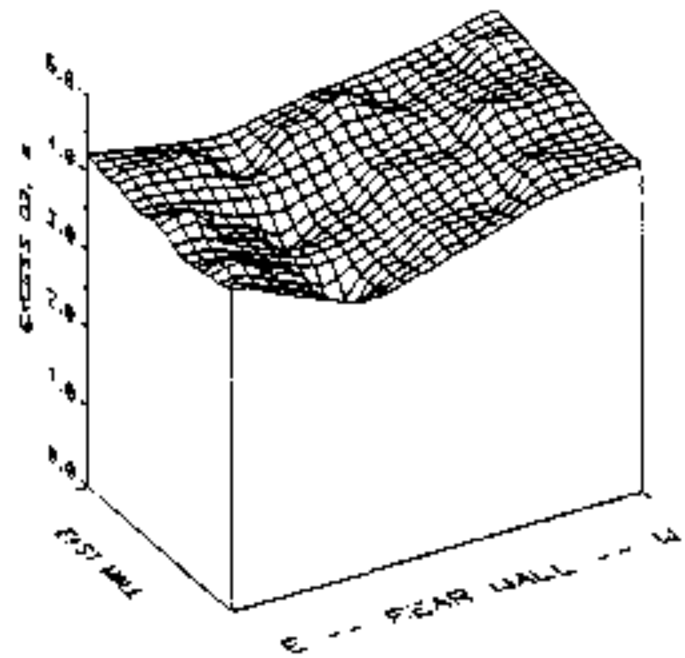
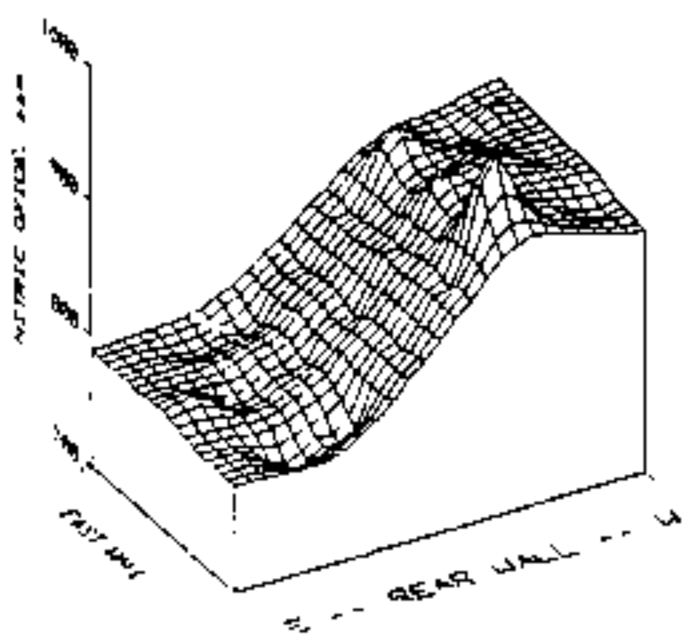


FIGURE 5-15 HAMMOND UNIT 4 FLUE GAS DISTRIBUTION
TEST 15-2 300 MWe

EXCESS O2 PROFILE IN FURNACE



NITRIC OXIDE PROFILE IN FURNACE



The tests at the 300 MWe test point exhibited almost identical O_2 and NO distributions although there was a significant gradient in NO from east to west for both tests. The difference in average NO across the ducts was only 38 ppm compared to 100 ppm for the higher load tests.

The cause of the large spatial variations in O_2 and NO species in the economizer exhaust ducts is most probably a non-uniform delivery of air and/or fuel to the individual burners. As noted previously, a large number of the burner air registers were either inoperable or their true positions could not be determined. In addition, as will be discussed below in Section 5.2.4, the secondary air flow was biased toward the front windbox and both the primary air and coal flows were unevenly distributed to the burners. The range of excess O_2 values in the ducts at 480 MWe suggests a variation of about 15 percent in the total air/fuel ratio among the burners.

5.2.3 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 and 4) ash resistivity. These measurements were made immediately after the air preheater (See Figure 3-8). The following paragraphs describe the results from these measurements.

Total Mass Emissions Total mass emissions reflect both a fraction of the total coal ash injected into the furnace (100% minus the ash which drops into the furnace bottom hopper or the economizer hopper), plus most, if not all, of any unburned carbon leaving the flame zone. Table 5-8 presents the results of the Method 17 tests performed (see Section 3.4) at each load level. For all tests the sampling rate was within 3.6% of isokinetic. The results shown for each load level represent the average of three replicate tests. For all tests, the data were remarkably consistent. Within each replicate series the standard deviation of mass loading was less than 3% of the mean value. At the 480 MWe (nominal) load, the two test series conducted 5 days apart resulted in measured mass loadings within 8% of their mean value. The within test repeatability as well as the test to test repeatability was surprisingly good during this Performance test series.

TABLE 5-8

SUMMARY OF SOLID MASS EMISSIONS TESTS

TEST No	LOAD MWe	O_2 2%	LOADING gr/dscf	GAS FLOW dsofm	LOADING lb/MMbtu	CARBON %	LOI %
12	480	3.0	2.63	1,229,667	3.69	4.9	5.4
17	480	2.5	2.42	1,252,000	3.39	4.5	4.9
16	400	3.7	2.23	1,112,667	3.13	4.1	4.7
14	300	4.7	2.60	913,333	3.64	1.9	2.3

As a measure of the degree of completeness of combustion, the ash collected in the cyclone portion of the Method 17 train for each test was analyzed by two separate methods for carbon content and Loss On Ignition (LOI). The LOI is considered to represent carbon content along with volatile solids (sulfates, chlorides, etc.) driven off in the analysis procedure. The close agreement between the carbon and LOI analyses for all samples provides a measure of confidence in the reliability of the results.

Referring to Figure 5-9, it can be seen that the LOIs using Method 17 are generally higher than those determined from the Cegrit samplers for the high load points. There is good agreement between the two methods at the 300 MWe load point. The lack of good agreement between the two methods is not surprising since the Cegret sampling is from two locations along the furnace walls while the Method 17 sampling is from 24 equally spaced points at the air preheater exit plane. The principal use of the Phase 1 Performance carbon and LOI analyses is as a reference for comparison with ash samples acquired during subsequent phases of the program. The Cegret carbon and LOI determinations are used to establish the general trend of these as a function of excess oxygen since method 17 measurements are made only at one condition.

Particle Size The particle size distribution of ash exiting the secondary air preheaters was determined using a cascade impactor. Six samples were obtained for each test condition. Figure 5-16 shows the particle size distributions for all test conditions as the total percentage of cumulative mass (4-axis comprising particles smaller than the aerodynamic diameter D50). The vertical bars visible to the upper right show the 90% confidence level for the mass values determined at the indicated particle diameter while the symbols show the average of the replicate samples for each load. For most of the data the 90% confidence interval is smaller than the plotting symbols. For large particle sizes the confidence band is exaggerated due to the exponential scale. The confidence interval for these points is still in the one percent range.

The very close overlapping of all of the data indicates both excellent replication of tests under common conditions and also the relatively minor effect of load on the ash particle size distribution. From Fig. 5-16 the mass-median diameter is about 18 microns for all tests. The geometric standard deviation (assuming log-normal distribution) is 2.3 microns for all data. These results compare closely with EPRI data base predictions of 16 micron, 3.4 std. dev. (J.L. DuBard and R.S. Dahlin, Precipitator Performance Estimation Procedure, EPRI CS-5040, Feb. 1987). The slightly larger median size of the present baseline tests is conducive to a slightly better than average ESP performance.

The derivative of cumulative mass with respect to diameter is presented in Figure 5-17. This type of presentation emphasizes the predominant concentration of mass vs. particle size. This format facilitates comparison of test data from subsequent phases of the program with these Phase 1 data and will highlight any significant changes in particle size distribution and potential effects on ESP performance due to the Low NO retrofits.

Chemical Compositions Samples of fly ash collected both from the Method 17 test samples and from selected ESP hoppers were analyzed for loss on ignition (LOI). The Method 17 samples were also analyzed separately for carbon content (Table 5-8). The ESP hopper samples (east and west composites separately) were analyzed for mineral composition. Table 5-9 presents these data and allow a comparison of carbon and LOI between the economizer exit (Method 17) and the ESP hopper chemical analysis.

The good agreement between the ESP hopper and Method 17 LOI values (with the exception of one spurious ESP sample) and between the Method 17 LOI and carbon analyses indicate that the small portion of ash passing through the ESP is not due to high carbon or LOI content. Also it appears that carbon constitutes roughly 90% of the material driven off in the LOI analysis.

FIGURE 5-16 HAMMOND UNIT 4 FLY ASH PARTICULATE SIZE CUMULATIVE PERCENT MASS

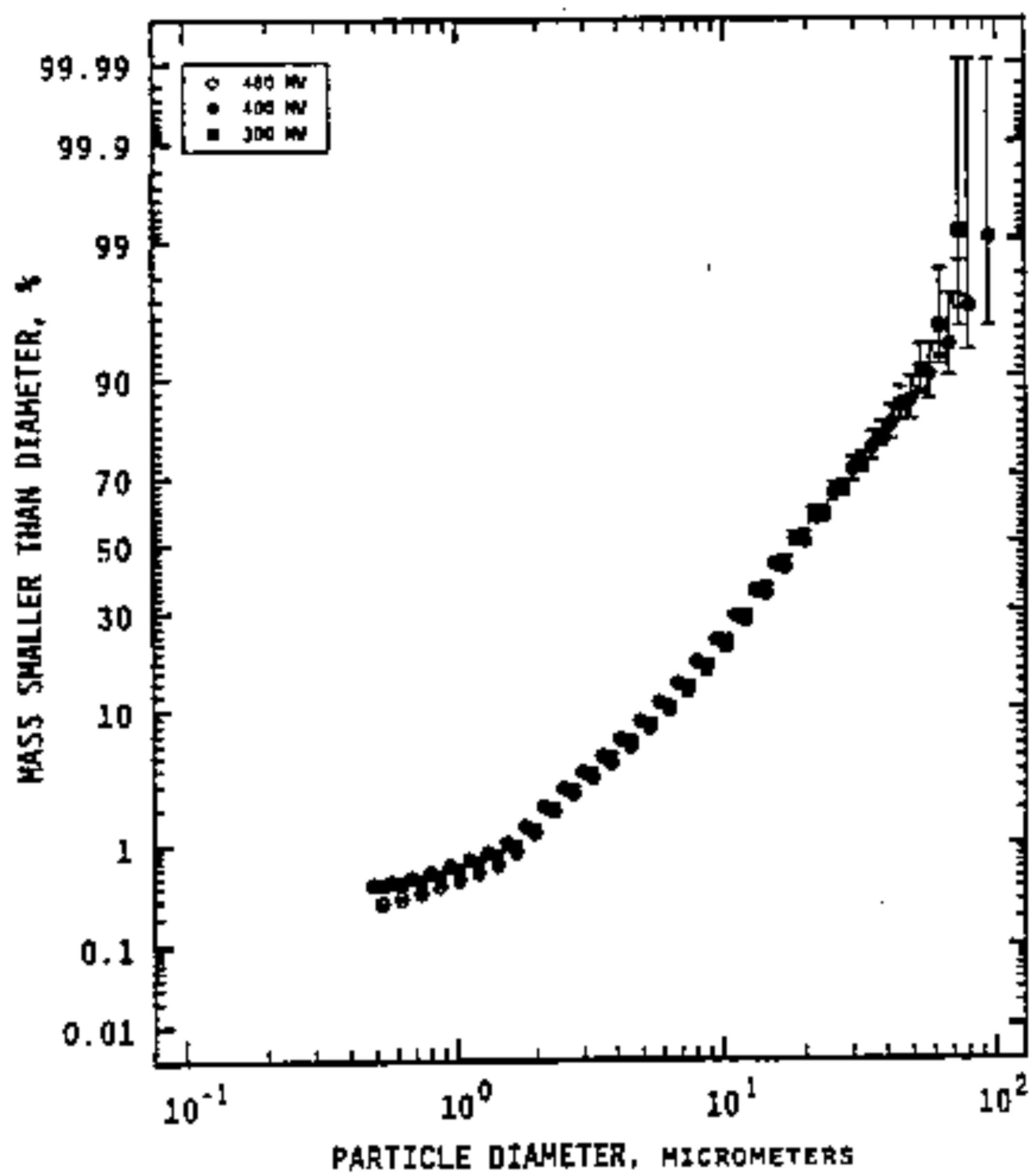


FIGURE 5-17 HAMMOND UNIT 4 FLY ASH PARTICULATE SIZE DIFFERENTIAL MASS

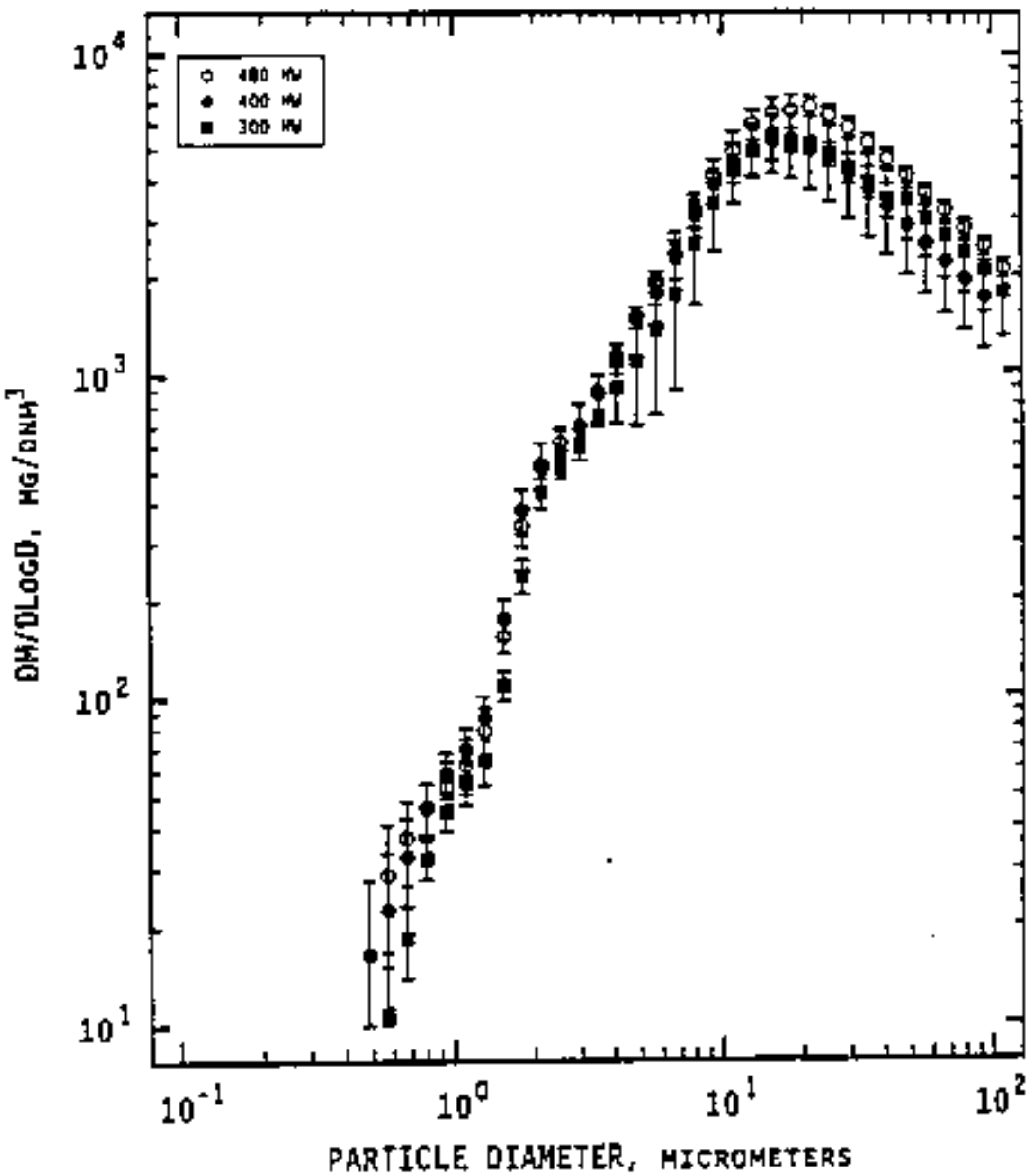


TABLE 5-9

HAMMOND UNIT 4 FLYASH CHEMICAL ANALYSIS

WEIGHT PERCENT

	480 MW EastDuct 11/29/89	480 MW WestDuct 11/29/89	480 MW EastDuct 12/04/89	480 MW EastDuct 12/04/89	400 MW EastDuct 12/03/89	400 MW WestDuct 12/03/89	300 MW EastDuct 12/01/89	300 MW WestDuct 12/01/89
ESP HOOPER								
Li_2O	0.05	0.05	0.06	0.06	0.04	0.04	0.05	0.05
Na_2O	0.49	0.47	0.56	0.52	0.42	0.42	0.44	0.44
K_2O	2.8	2.8	3.0	3.1	3.1	3.3	2.9	2.9
MgO	1.2	1.1	1.4	1.3	1.2	1.2	1.1	1.1
CaO	2.4	1.8	3.7	2.9	1.2	1.0	2.0	1.7
Fe_2O_3	17.1	17.1	16.1	16.1	15.0	15.0	15.7	15.0
Al_2O_3	26.5	26.7	27.90	27.2	27.2	27.0	26.7	26.8
SiO_2	47.7	48.0	45.7	47.3	49.6	50.5	48.9	49.5
TiO_2	1.2	1.3	1.1	1.1	1.2	1.1	1.2	1.2
P_2O_5	0.48	0.39	0.48	0.41	0.28	0.25	0.39	0.39
SO_3	0.14	0.12	0.17	0.14	0.06	0.05	0.14	0.07
LOI	8.1	5.1	6.7	3.8	4.8	14.9	5.5	2.3
AVG LOI	6.6		5.3		(?)		3.9	
FLY ASH								
LOI	5.4		4.9		4.7		2.3	
CARBON	4.92		4.53		4.11		1.92	

As mentioned above, the carbon and LOI data are useful primarily to establish a reference level to which post-retrofit results can be compared. The precise relation of carbon or LOI content of ash on ESP performance is not well understood and no current algorithms can confidently predict the effect of changes in their values on ESP performance. These data were collected not only to establish the relationship between the ESP and Method 17 results but also to archive for future use if an algorithm is developed in the future.

Ash Resistivity One of the most important properties affecting ESP performance is the resistivity of the ash particles. Ash resistivity is a measure of the ash's ability to retain an electrical charge which allows it to migrate and adhere to the ESP plates. Twenty-six measurements of ash resistivity were made using in-situ probes employing two different measurement techniques, i.e., the spark and voltage/current (V-I) methods. The results of those measurements are presented in Table 5-10. Laboratory measurements of the resistivity of ESP hopper samples from the different test conditions are shown in Figures 5-18 and 5-19. Isothermal measurements of resistivity with 1 and 3 ppm SO_3 present in the simulated environment are also shown on the figures, respectively.

The resistivity of the ESP hopper samples was calculated using their chemical compositions (Table 5-9) and a mathematical model of fly ash resistivity (Bickelhaupt, "A Study to Improve a Technique for Predicting Fly Ash Resistivity with Emphasis on the Effect of Sulfur Trioxide", EPS-600/7-86-010, 1985). Superimposed on Figures 5-18 and 5-19 are curves showing these calculated resistivities for typical ash compositions during the Hammond tests both without an SO_3 component and with the SO_3 level indicated.

All measurement techniques indicate that during low boiler load (400 and 300 MWe), the electrical operating conditions and resulting performance of the ESP would not be limited by resistivity of the collected dust layer. In the absence of other problems, resistivity values below 2×10^{10} ohm-cm should not have any effect on ESP electrical conditions. During two days of high load tests (Tests 12 and 13), the spark resistivity data disagreed with the low indications by the other techniques by indicating mid-10 ohm-cm values. On the last day of high load tests (Test 17), all techniques once again agreed that resistivity was low. No changes in dust chemistry, flue gas composition, or temperature can be identified which should have produced a real change in resistivity. Therefore, the spark data for tests 12 and 13 are believed to have been invalidated by carbon in the ash, to which this measurement is particularly susceptible. As discussed previously, the LOI and carbon values were the highest measured for the test program during the period that spark measurement problems were encountered (see Table 5-8).

TABLE 5-10 IN-SITU ASH RESISTIVITY

DATE	TEST NUMBER	GROSS Mwe	DUCT LOCATION	APH GAS TEMPERATURE	DUST LAYER	SPARK METHOD FIELD	RESISITIVITY	V-I METHOD FIELD	RESISITIVITY
11/29	12	480	EAST	277	0.92	13.0	5.0E+11	6.6	3.3E+10
				270	1.6	14.1	7.9E+10	2.6	1.3E+10
			WEST	296	1.26	17.9	3.1E+11	3.2	1.6E+10
				296	1.29	17.4	5.8E+11	5.8	2.9E+10
11/30	13	480	EAST	285	1.19	15.0	2.1E+12	5.4	2.7E+10
				289	1.66	16.3	4.1E+11	5.2	2.6E+10
				189	1.42	15.8	6.9E+10	13.6	6.8E+10
			AVERAGE	287		AVERAGE	2.7E+10	AVERAGE	3.0E+10
12/04	17	480	WEST	300	0.99	20.3	1.8E+10	20	1.0E+11
				304	0.99	21.2	6.6E+10	16.4	8.2E+10
			EAST	269	1.52	16.8	1.2E+10	4.6	2.3E+10
				272	1.85	13.8	1.3E+10	5.4	2.7E+10
			AVERAGE	286		AVERAGE	2.7E+10	AVERAGE	5.8E+10
12/03	16	400	EAST	244	0.53	17. 0	1.6E+09	8.6	4.3E+10
				247	0.55	19.1	1.2E+09	9.2	4.6E+10
			WEST	288	0.71	23.2	9.4E+09	15.6	7.8E+10
				289	1.02	17.6	1.9E+10	15.2	7.6E+10
12/05	18	400	EAST	257	1.89	12.7	8.7E+09	2.2	1.1E+10
				263	2.04	14.7	9.9E+09	1.2	6.1E+09
				266	1.64	15.5	7.6E+09	0.6	3.0E+09
			AVERAGE	265			8.2E+09		3.8E+10
12/01	14	300	EAST	260	1.34	16.8	2.6E+09	0.7	3.7E+09
				266	1.36	16.5	3.1E+09	1.1	5.5E+09
			WEST	268	0.82	22.0	4.3E+09	6.2	3.2E+10
				268	0.87	19.0	5.6E+09	8.4	4.2E+10
				272	0.74	18.2	7.3E+09	14.8	7.4E+10
				279	0.92	19.6	7.1E+09	12.6	6.3E+10
12/02	15	300	EAST	264	1.38	17.4	3.0E+09	2.2	1.1E+10
				265	1.19	16.4	2.4E+09	1.3	6.3E+09
			AVERAGE	268			4.4E+09		3.0E+10

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FIGURE 5-18 HAMMOND UNIT 4 VAPOR PHASE SO3 CONCENTRATION

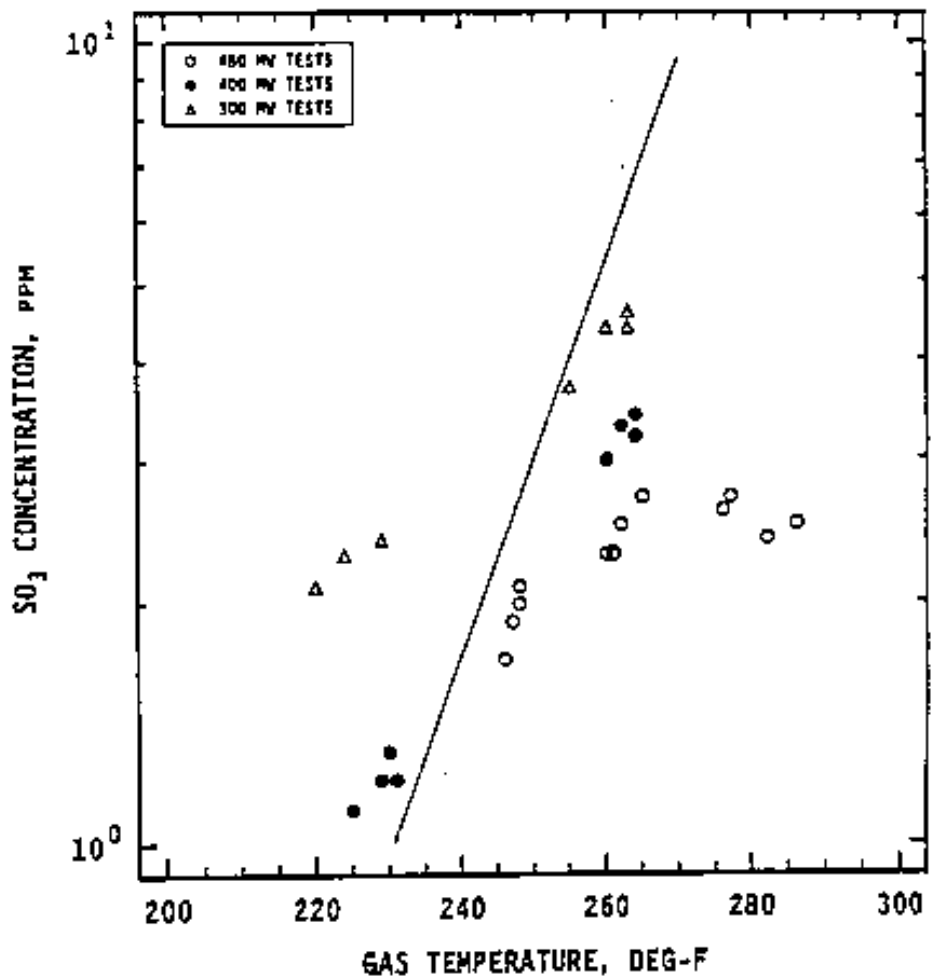
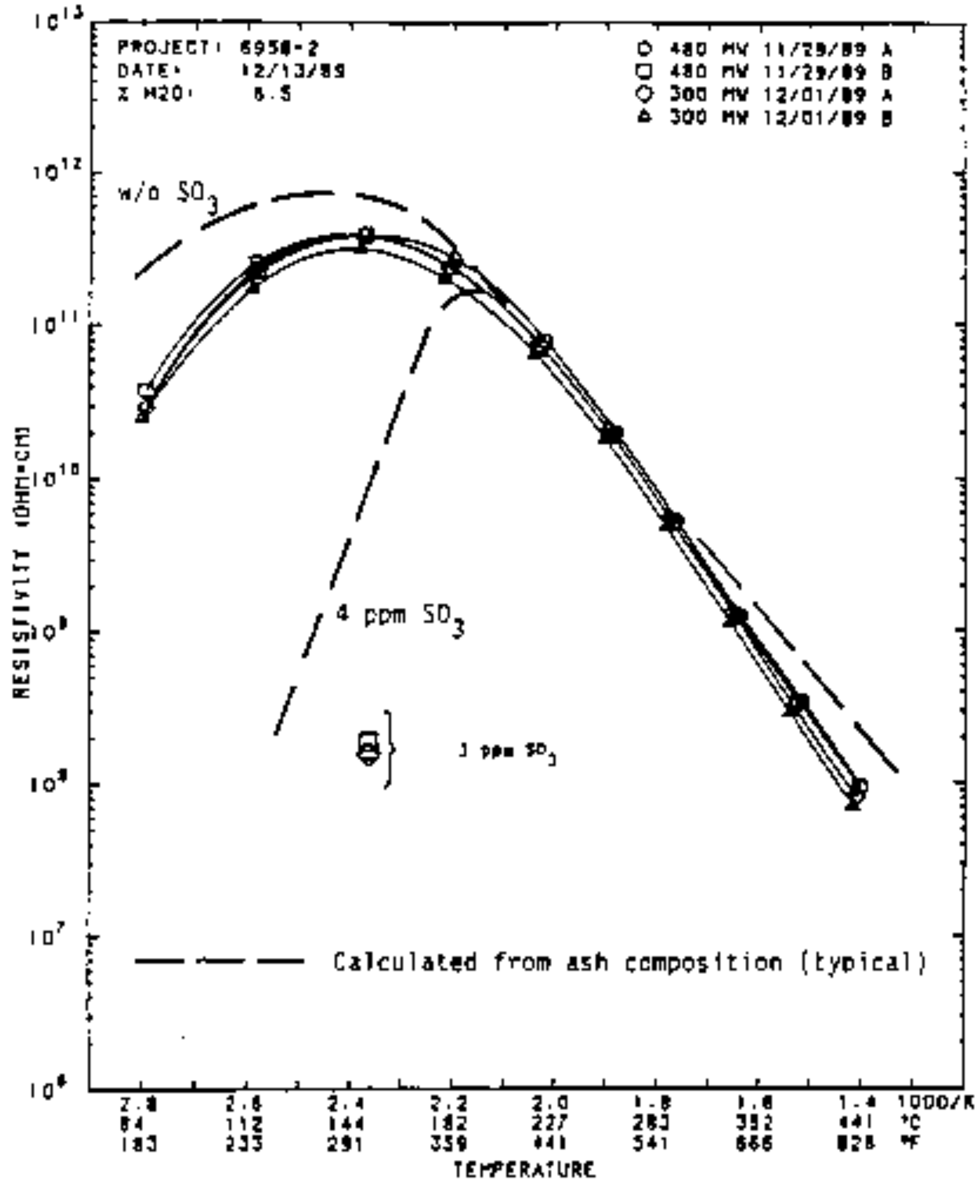


FIGURE 5-19 HAMMOND UNIT 4 ESP HOPPER ASH RESISTIVITY



5.2.4 SO_2/SO_3 Tests

The concentration of SO_2 and SO_3 (as separate species) was measured in both the east and west ducts at the air preheater exit for every load condition. Table 5-11 presents the results of the tests for the three load points. Figure 5-20 graphically depicts the SO_3 concentration as a function of the flue gas temperature at the sample point. From the table and figure some important observations related to the SO_2 can be made. First, the SO_2 value is relatively constant for any particular test sequence (e.g., Test 12 or 13) which indicates good repeatability. Second, the SO_2 varies considerably between sampling periods (e.g., between Tests 12 and 13). This variation was also exhibited in the ECEM data collected during these test periods. This phenomenon could potentially be due to short-time variations in fuel sulfur content or by the non-uniform distribution of various sulfur-level coal batches to the east or west side burner groups. The measured SO_2 variations, however, do not correlate with the average coal sulfur values (average of 2 to 5 samples) for the corresponding test day. Since the coal samples were acquired during the testing period from the mill inlet chutes, very little time delay should have passed between coal sampling and combustion in the furnace (via, a few minutes at most). The exact reason for the variation is unexplained at this time, however, the fact that SO_2 measurements were made at only a single point in one duct tends to favor the conclusion that SO_2 was stratified within the boiler.

From Figure 5-20 and Table 5-11 it can be seen that some of the east duct temperatures at the sample points were below the dew point of sulfuric acid at 300 and 400 MWe, i.e., Tests 14 and 18, respectively. At temperatures below the dew point the measured SO_3 concentration is invalid since some SO_3 could precipitate out as sulfuric acid. This precipitation is evident by comparing tests 14 and 18 with 15 and 16. it can be seen that the latter test group (above the dew point) is higher that the former test group. The data for test 14 and 18 are therefore invalid. From the data above for the test with the gas temperature above the dew point temperature, the SO_3 concentration varies inversely with load, due to the higher excess O_2 and lower furnace temperatures associated with low load operation.

5.2.5 Combustion System Tests

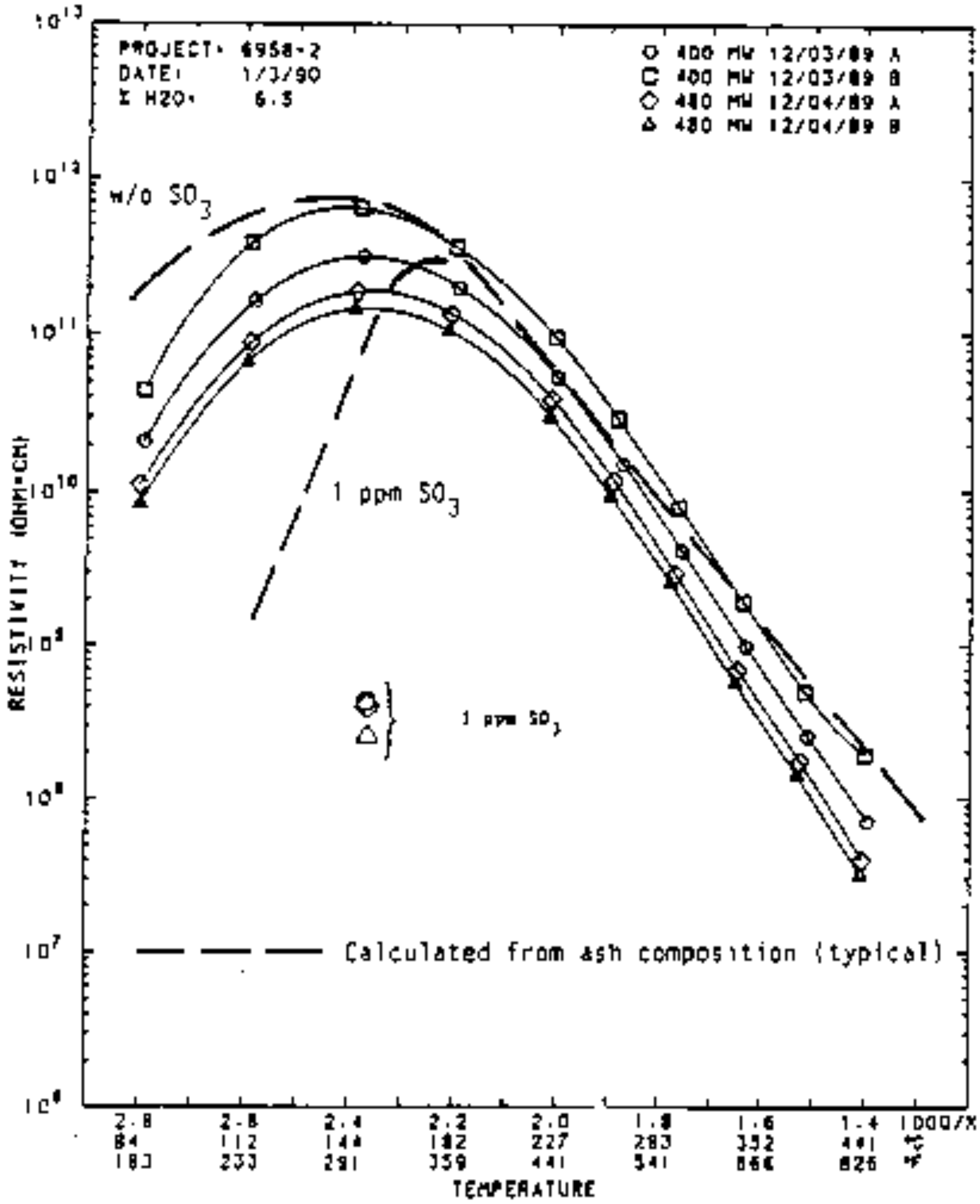
These tests were performed at each of the three load levels (Tests 13, 15 and 16) to document the specific performance parameters related to the fuel and air combustion systems. During subsequent phases of the program that involve changes to the air supply system, comparisons will be made to ascertain potential influences of these changes on the NO emissions.

<u>Mill Performance</u> The air flow to each mill and the particle size and mass flow distributions of coal to each burner were measured as described in Section 3.3. Duplicate tests were performed at 480 MW and 300 MW nominal load levels. Only

TABLE 5-11 SULFUR OXIDE EMISSION RESULTS

DATE	TEST NUMBER	GROSS LOAD MWe	DUCT LOCATION	APH GAS TEMPERATURE deg F	SULFUR TRIOXIDE ppm	SULFUR DIOXIDE ppm
11/29	12	480	EAST	246	1.7	1347
				247	1.9	1337
				248	2.1	1349
				248	2.0	1362
11/30	13	480	EAST	265	2.7	1025
				262	2.5	1031
				260	2.3	1042
				261	2.3	1048
12/04	17	480	WEST	276	2.6	1073
				277	2.7	1092
				282	2.4	1108
				286	2.5	1131
	480 MWe AVERAGES			263	2.3	1162
12/03	16	400	WEST	260	3.0	889
				262	3.3	886
				264	3.2	890
				264	3.4	891
12/05	18	400	EAST	225	1.1	1005
				229	1.2	1008
				230	1.3	999
				231	1.2	1008
	400 MWe AVERAGES			246	2.2	948
12/01	14	300	EAST	220	2.1	960
				224	2.3	947
				229	2.4	971
				229	2.4	978
12/02	15	300		255	3.7	902
				260	4.4	915
				263	4.4	921
				263	4.6	929
	400 MWe AVERAGES			243	3.3	940

FIGURE 5-20 HAMMOND UNIT 4 ESP HOPPER ASH RESISTIVITY



selected mill and coal pipe measurements were made at 400 MW. Table 5-12 summarizes the results of these tests. From Table 5-12 it can be seen that despite the mills being set to approximately equal coal flows with the boiler controls, the measured coal flows varied +/- eleven percent from mill to mill . Also evident is the variation in coal flow from pipe to pipe. For test 13-1 the standard deviation in pipe to pipe coal flow was 21% of the mean flow. This variation coupled with potential secondary air flow variations could partially explain the NO distributions illustrated in Figures S-10 through 5-15. It could also affect the LOI and SO2 measurements discussed previously.

The measured ratio of primary air to coal flow varied from approximately 2.5 at 475 MW to 3.5 at 306 MW. The range was required to maintain the desired mill outlet coal/air temperature of approximately 170°F. A potential impact of these levels of primary air flow could be high NO emissions.

During these mill tests the coal fineness was found to be below 70 percent through 200 mesh (except for mills C and F at 300 MW). This could potentially cause the NO emissions to be lower than for a condition with 70 percent through a 200 mesh screen. This condition (lower fine particle through 200 mesh) could be partially attributable to the low Hargrove Grindability Index of the coal tested. The Index was about 44 which is low compared to more common values of eastern bituminous coal of around 55.

It should be noted that the results of the mill performance were those obtained by Flame Methodologies. Foster Wheeler has taken exception to some of these methodologies. Subsequent testing during the Hammond Program will be designed to rectify these exceptions and determine the most appropriate methodologies.

<u>Secondary Air Supply</u> The secondary combustion air flow was measured at four locations as described in Section 3.3. Table 5-13 presents the results of the flow measurements for tests 13 through 18. From the table it can be seen that the indicated air flow is consistently biased to the front windbox. The airflow is distributed evenly between the right and left sides of the furnace based upon the measurements indicated in Table 5-13

TABLE 5-13
SECONDARY AIR DISTRIBUTION

TEST No.	LOAD MWe	O2 %	SECONDARY AIRFLOW lb/Hr	SECONDARY AIRFLOW REAR Rt	SECONDARY AIRFLOW FRONT Lt	DISTRIBUTION REAR Rt	DISTRIBUTION FRONT Lt
13	480	3.5	2,988,424	10.75%	40.54	11.57	37.13
17	480	2.5	2,661,583	18.61	32.60	14.86	33.93
16	400	3.7	2,385,146	22.93	27.62	23.73	25.71
18	400	3.3	2,218,796	17.53	33.39	13.96	35.12
14	300	5.1	1,822,025	14.71	34.76	24.38	26.15
15	300	4.7	1,528,560	14.22	32.62	19.62	33.54

TABLE 5-12

HAMMOND UNIT 4 SUMMARY OF MILL PERFORMANCE TESTS

TEST No.	UNIT LOAD GMWe	PARAMETER	MILLS A	B	C	D	E	F
13-1	475	Measured Coal Flow, Klb/hr	59.0	63.8	53.3	61.8	56.6	66.6
		Measured PA Flow, Klb/hr	153.9	149.3	146.5	148.8	159.9	141.9
		A/F Ratio	2.7	2.4	2.7	2.4	2.7	2.1
		Avg. Burner Pipe Velocity, FPM	8309	7928	7488	7482	7766	7244
		High Pipe Coal Flow, Klb/hr	22.8	16.7	12.4	19.0	17.5	15.3
		Low Pipe Coal Flow, Klb/hr	12.8	13.0	9.7	13.2	13.9	8.7
		Avg. Passing 200 mesh, PCT	61.7	58.7	66.9	63.0	67.8	65.9
15-1	306	Measured Coal Flow, Klb/hr	43.9	41.5	37.7	45.8	0.0	37..9
		Measured PA Flow, Klb/hr	156.1	136.7	146.5	145.5	0.0	141.0
		A/F Ratio	3.5	3.4	3.6	3.0		3.6
		Avg. Burner Pipe Velocity, FPM	7837	7132	6956	7101		6892
		High Pipe Coal Flow, Klb/hr	14.0	11.3	11.5	13.3		10.8
		Low Pipe Coal Flow, Klb/hr	9.7	8.4	8.4	9.2		8.4
		Avg. Passing 200 mesh, PCT	68.4	67.8	72.7	68.9		74.9
16-1	400	Measured Coal Flow, Klb/hr			53.7	60.5		
		Measured PA Flow, Klb/hr	153.4	136.6	156.8	148.7	0.0	138.1
		A/F Ratio			2.7	2.4		
		Avg. Burner Pipe Velocity, FPM			7454	7519		
		High Pipe Coal Flow, Klb/hr			14.4	20.0		
		Low Pipe Coal Flow, Klb/hr			11.9	12.3		
		Avg. Passing 200 mesh, PCT						

At the three load test points, the airflow distribution ranged from 80/20 to 66/34 percent, front to rear, except for one 400 MWe test (Test 16) which showed a remarkably uniform distribution. These results are in question due to the difficulty in obtaining accurate flow measurements within the windbox. The front windbox sample test ports are located in the side ducts in close proximity to the so degree turn prior to the entrance to the windbox (see Section 3.3). There was considerable turbulence and a large velocity gradient at this measurement location, however, no other adequate location was available. In order to better define the flow in this region, separate measurements were made with a Fecheimer velocity probe (which can measure the angle of the velocity vector in a plane perpendicular to the probe axis). These measurements produced essentially the same results as the standard Type S pilot probe measurements. An independent measurement could not be made of the flow to the rear windbox due to the lack of access for a velocity probe in that location. The calculated flow to the rear windbox was determined by subtracting the measured flow to the front windbox from the measured total flow. The large indicated imbalance in flow to the front and rear windboxes could be due to the combined effects of the air duct geometry and the inability to adjust a substantial portion of the individual burner air registers. At this point the measurements should only be used as qualitative assessments of the flow distribution rather than as accurate quantitative measurements.

The measurements made at the venturi throats in the secondary air supply ducts were very repeatable. The measurements taken at this location did not suffer from the inadequacies of the windbox flow locations. Thus, there is a high level of confidence in the total air flow measurements based upon the location and the repeatability.

Furnace Measurements Measurements were made of combustion gas temperatures and species concentrations (O_2 and CO) at eight locations within the boiler furnace at the 7th and 8th floor levels (See Figure 3-7). At each port approximately 10 measurements were made. Figures 5-21 and 5-22 show the distribution of temperature measurements made at the 480 and 300 MWe nominal load points, respectively. No measurements were made at the 400 MWe load point.

As expected the measured temperatures close to the side walls and the rear wall or nose tubes are lower in temperature than those measurements made away from these points (ports 3 & 4). This is evident at both the high and low load points. The high mid-furnace temperatures leaving the furnace (2300-2400 F) could be due to primary combustion extending upward from the burner zone. One potential reason for this could be due to the coal fineness distribution (< 70 percent through 200 mesh) and the non-uniformity of coal and air distributions to the burners which are discussed in the paragraphs above.

FIGURE 5-21 HAMMOND UNIT 4 8th FLOOR HVT PROFILES

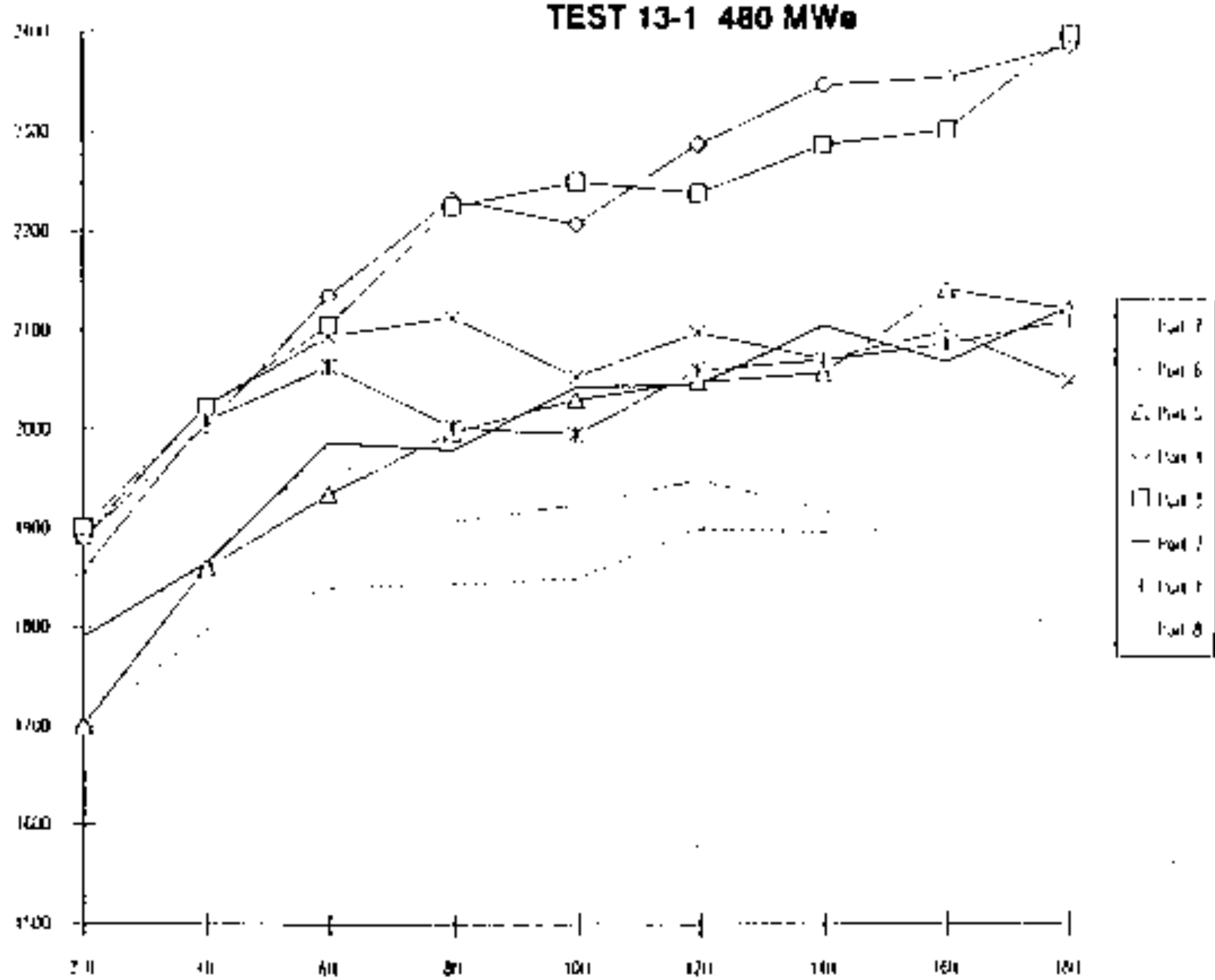
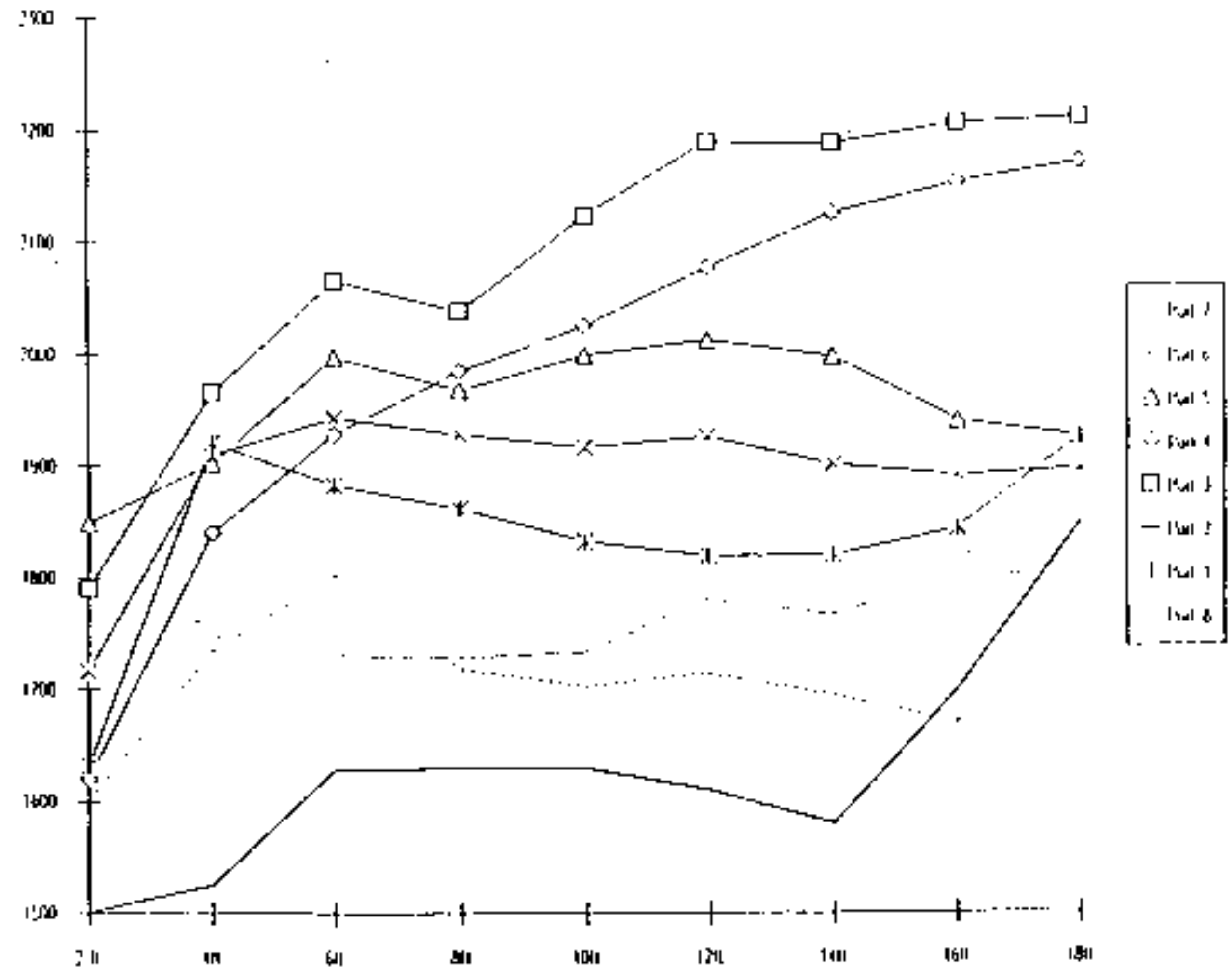


FIGURE 5-22 HAMMOND UNIT 4 8th FLOOR HVT PROFILES

TEST 15-1 300 MWe



Temperature Measurements attempted through the front wall ports at the 7th floor were aborted due to melting of the probe's stainless steel radiation shield. This indicates a temperature in excess of 2600 F in this region.

Species concentrations of O_2 and CO made simultaneously with the temperatures measurements indicate a significant stoichiometry non-uniformity within the furnace. Generally speaking the excess O_2 level was low (0 to 1%) and the Co concentration high (500 to 1000+ ppm) near the center of the furnace, and along the front wall. Oxygen levels were higher (and CO lower) toward the rear and side walls.

Figures 5-23 and 5-24 depict the temperature and oxygen profiles at the 8th floor level for the nominal 480 MWe test point (Test 17). The x-y plane in these figures represents the horizontal cross-section of the furnace at the 8th floor and the y-axis represents the magnitude of the measured variable (temperature or O_2). These 3-dimensional plots clearly illustrate the non-uniformity at the 7th floor sample plane which could be due the fuel and air maldistribution discussed previously. Similar results to those shown in Figures 5-23 and 5-24 were obtained at the 300 and 400 MWe test points. The extremes (high to low measurements) in both O_2 (stoichiometry) and temperature were, however, significantly less than for the 480 MWe test. This could be due to the reduced gas velocities providing longer residence times for completion of combustion within the furnace at these lower loads.

5.2.6 Coal and Ash Analyses

During each of the six days of Phase 1 Performance testing, samples were obtained of coal entering the active mills, fly ash exiting the furnace (east and west sides) and bottom ash collected in the furnace ash pit.

The coal samples were analyzed for proximate and ultimate composition, colorific value, grindability and ash fusion properties. Table 5-14 presents the results of these analyses. These analyses show that the coal properties remained very consistent over the duration of the testing and is consistent with the analyses obtained during the Diagnostic test effort (Table 5-3).

The results of the Cegrit furnace ash and the furnace bottom ash analyses are shown in Table 5-15. A fairly wide variation in LOI is indicated for the Cegret ash samples (ranging from 0.073 to 5.15 percent). Excluding the Cegret LOI measurements for the last test on December 1 the LOI are reasonably consistent with those obtained during the Diagnostic testing for the first five days of Performance testing. The final two days of testing resulting in LOIs approximately half of those measured during the Diagnostic testing. Nevertheless, even the highest levels of LOI are within the range for typical bituminous coal boilers.

FIGURE 5-23 HAMMOND UNIT 4 HVT TEMPERATURE DISTRIBUTION

TEST 17-1 480 MWe

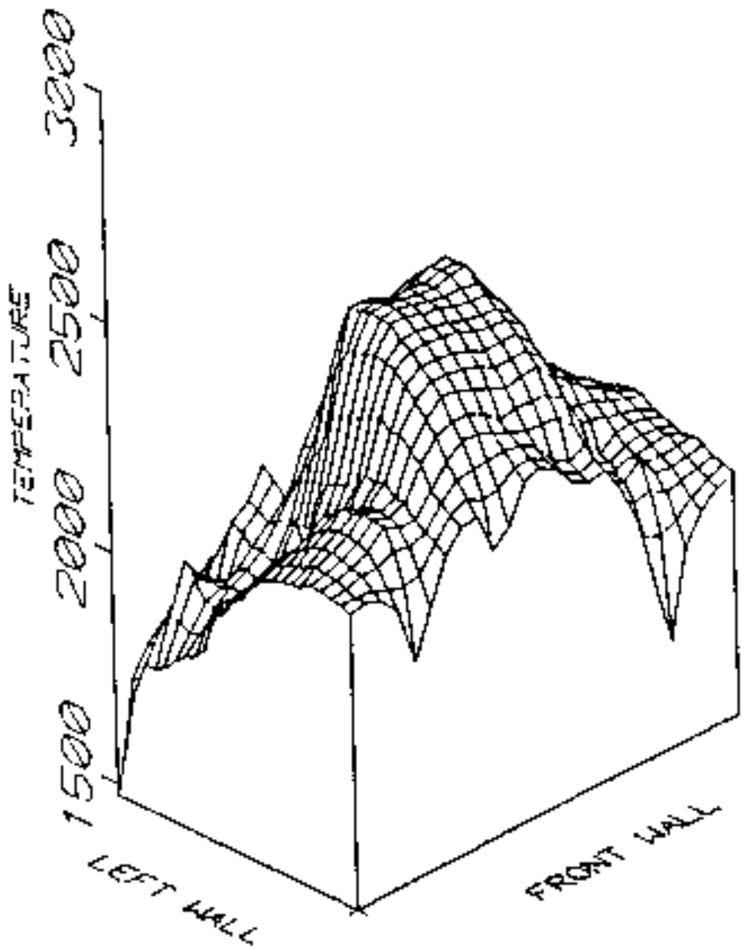


FIGURE 5-24 HAMMOND UNIT 4 HVT OXYGEN DISTRIBUTION

TEST 17-1 480 MWe

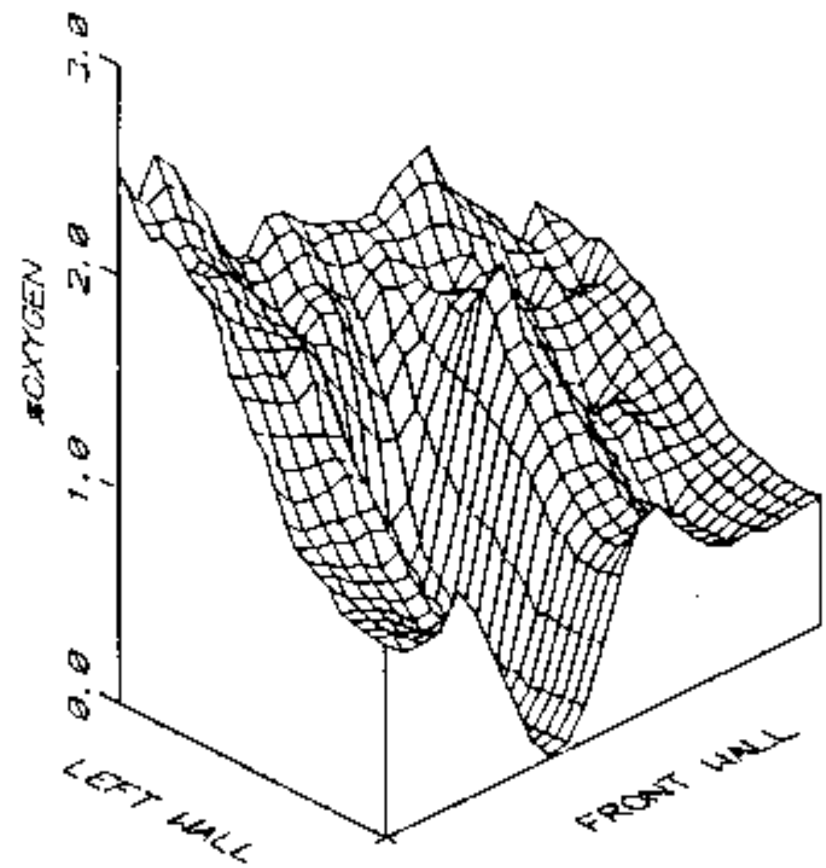


TABLE 5-14 PERFORMANCE TESTS COAL ANALYSIS

		|--------------------------Ultimate Analyses, (%)								-------------------------------|	HHV	VM	Fixed CARBON
Date	Time	H2O	C	H	N	Cl	S	Ash	O	TOTAL	BTU/lb	%	C,%
11/29	0900	3.70	71.0	4.63	1.53	0.030	1.82	10.8	6.53	100.03	12693	34.2	51.3
11/29	0900	3.48	72.4	4.68	1.56	0.020	1.77	9.9	6.19	100.00	12930	34.3	52.3
11/29	1300	4.18	72.2	4.77	1.49	0.031	1.78	9.9	5.67	100.02	12847	34.0	54.1
11/29	1700	4.49	71.4	4.57	1.50	0.031	1.75	10.0	6.34	100.02	12827	34.1	51.5
11/30	1200	5.42	71.2	4.72	1.47	0.027	1.79	9.9	5.50	100.03	12706	33.6	54.0
11/30	1515	4.55	72.1	4.61	1.44	0.031	1.69	10.1	5.57	100.03	12933	33.9	51.5
11/30	1800	3.95	72.9	4.73	1.29	0.032	1.58	10.4	5.11	100.03	12963	33.1	52.5
12/01	0900	3.22	73.2	4.70	1.39	0.037	1.70	10.1	5.68	100.03	13137	33.4	53.3
12/01	1530	3.12	74.2	4.76	1.52	0.030	1.65	10.2	4.58	100.03	13210	33.6	53.1
12/01	1745	3.77	73.3	4.75	1.40	0.031	1.66	9.9	5.21	100.02	13043	34.1	52.2
12/01	1745	3.98	72.9	4.80	1.38	0.033	2.01	9.7	5.77	100.03	12986	33.8	52.6
12/01	1745	3.96	72.2	4.64	1.45	0.020	1.96	10.0	5.79	100.00	12988	33.6	52.5
12/02	0900	4.37	71.9	4.71	1.44	0.035	1.66	9.8	6.15	100.03	12865	33.9	52.0
12/02	1300	3.89	72.5	4.82	1.40	0.033	1.73	9.9	5.77	100.03	12934	33.7	52.5
12/02	1600	4.18	72.7	4.66	1.38	0.031	1.72	9.7	5.72	100.03	12942	32.6	55.9
12/03	0830	4.83	71.4	4.54	1.38	0.033	1.77	10.0	6.02	100.03	12793	32.7	52.4
12/03	1200	5.58	72.0	4.63	1.29	0.030	1.51	9.1	5.91	100.03	12793	32.7	52.6
12/03	1500	4.94	72.8	4.66	1.43	0.030	1.62	9.4	5.21	100.04	12975	33.2	52.5
12/04	0915	5.03	72.9	4.74	1.42	0.031	1.61	9.6	4.73	100.02	12925	33.1	52.3
12/04	1300	5.07	72.6	4.77	1.42	0.031	1.76	9.0	5.41	100.02	12946	33.8	52.2
12/05	1200	4.62	71.6	4.68	1.48	0.030	1.83	9.9	5.93	100.02	12810	32.8	52.7
12/05	1430	4.14	72.7	4.77	1.47	0.034	1.64	9.4	5.89	100.03	12978	33.9	52.6
12/05	1430	4.23	72.3	4.60	1.48	0.034	1.60	9.5	6.23	100.00	12989	33.0	53.3
12/05	1700	4.04	72.7	4.68	1.39	0.031	1.76	10.1	5.30	100.03	12900	33.1	52.7
AVERAGE		4.28	72.4	4.69	1.43	0.030	1.72	9.8	5.65	100.02	12921	33.5	52.7
STD DE		0.63	0.7	0.07	0.07	0.004	0.11	0.4	0.48	0.01	117	0.5	0.9
VARIAN		0.39	0.5	0.01	0.00	0.000	0.01	0.1	0.23	0.00	13708	0.3	0.9

TABLE 5-15 HAMMOND UNIT 4 CEGRIT AND BOTTOM ASH LOI ANALYSIS

			|-----------------CEGRIT-----------------|			|-----BOTTOM ASH---|	
Date	Load Mwe	Excess Oxygen %	Sample Time Hrs	A-Side LOI %	B-Side LOI %	Sample Time Hrs	Composite LOI %
11/29	476	3.0	0820-1029	4.74	2.38		
11/29	476	3.0	1055-1220	4.43	2.09		
11/29	476	3.0	1330-1610	4.89	3.13	1430	17.33
11/30	476	3.3	1045-1600	3.98	3.61	1600	0.07
12/01	298	4.9	0915-1030	2.12	1.13		
12/01	298	4.9	103-1130	1.86	1.21		
12/01	298	4.9	1333-1450	1.90	.07	1630	0.00
12/02	301	4.5	0800-1300	2.43	1.22	1500	0.00
12/03	399	3.7	0800-0955	4.55	2.69		
12/03	399	3.7	1115-1320	5.00	3.13	1200	0.02
12/03	399	3.7	1418-1600	5.15	3.06		
12/04	469	2.5	0820-1007	2.66	1.75		
12/04	469	2.5	1010-1240	2.66	1.67	1330	0.23
12/04	469	2.5	1430-1540	2.72	1.80		
12/05	389	3.3	1015-1810	2.73	2.10	1500	0.24

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The bottom ash samples showed virtually no LOI except for the first sample on 11/29/89 which is felt to be an invalid measurement or analysis. Since no indication of combustion upset occurred for this test at the 480 MWe load point and no high fly ash LOI, high opacity or low furnace O_2 were observed, the single high button ash LOI can justifiably be dismissed as anomalous. It can therefore be concluded that all of the ash deposited from the furnace in the bottom ash pits has been completely combusted.

5.2.7 Acoustic Pyrometer Data

The Acoustic Pyrometer system can provide data in two formats; 1) average temperature between each pair of transmitter/receiver units, and (2) a computed isothermal may of the horizontal cross-section of the furnace at the 7th floor level. The first format was input to the DAS, read at 5- second intervals and stored as 5-minute averages in the historical data files. The second format can be displayed on-line on a high resolution color monitor and printed on demand on a dot matrix graphic printer.

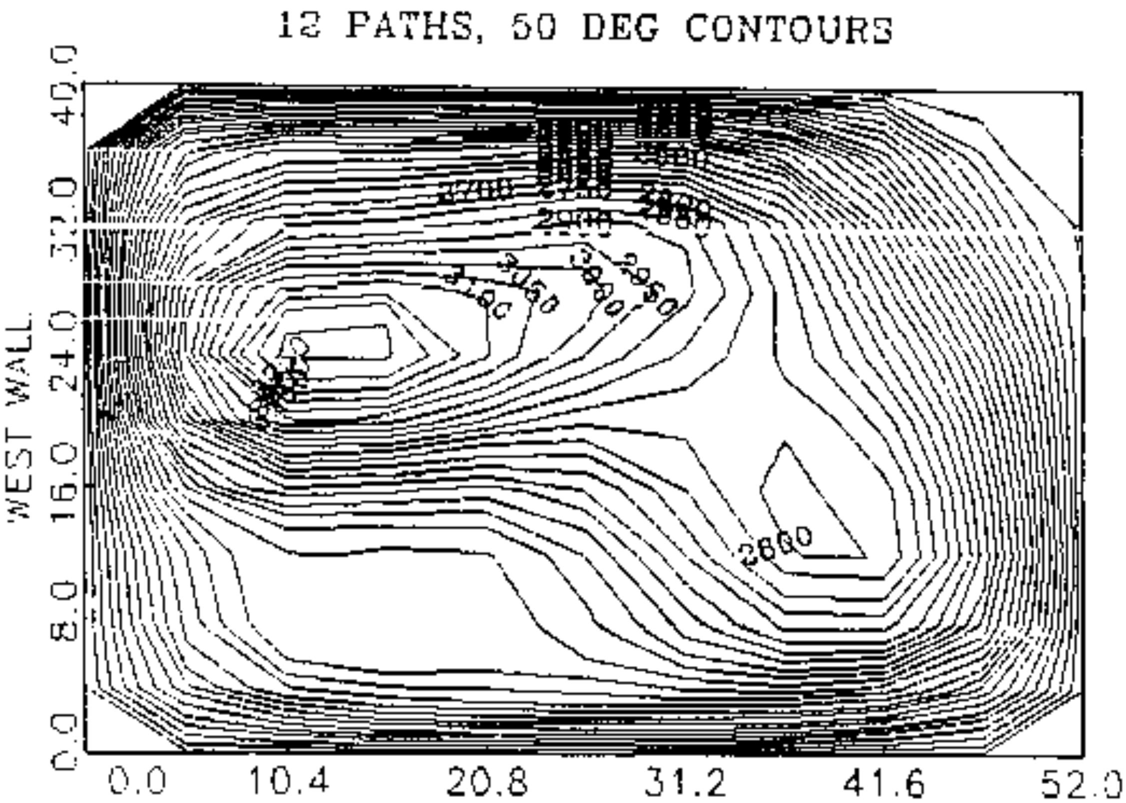
Figure 3-2 shows the locations of the acoustic transmitter/receivers and the 13 discrete acoustic paths. Figure 5-25 is a typical example of the isothermal map generated by the pyrometer computer algorithm. While the actual level and pattern of furnace gas temperatures is of some interest, the most valuable use of the acoustic pyrometer data will be in assessing the effects of subsequent retrofits on the magnitude and pattern of gas temperatures within the furnace. The historical record of the acoustic temperature measurements was maintained for each Performance Test (Tests 12 through 18). Analysis of the data will await the collection of similar data during the Phase 2,AOFA, post-retrofit testing. At present time no computer algorithm is available to either reproduce the Acoustic Pyrometer isothermal plots from historical sonic path temperature data or to manipulate the data in any other manner. Analysis of the historical data accumulated during the Performance Tests will require development of a suitable algorithm to allow averaging of the individual one-minute profiles over more characteristic time period representative of the boiler time constants.

During the Phase I testing program, it was necessary to expend effort to maintain the acoustic pyrometers in working order. The principal difficulty was with ash deposits forming over the furnace wall ports and disrupting the acoustic transmission. Typically, from one to three of the 13 paths were not functional. Nevertheless, it is believed that considerable data were accumulated that can be used for later analysis and comparisons with subsequent program phases.

5.2.8 Fluxdome Data

The temperature readings (2) from each Fluxdome were measured every 5 seconds by the DAP and recorded as 5-minute

FIGURE 5-25 HAMMOND UNIT 4 EXAMPLE ACOUSTIC PYROMETER ISOTHERMAL DISPLAY



averages in the historical data logs. No significant data analysis is planned until the comparative data are acquired in Phase II.

5.2.9 Boiler Efficiency

During each Performance Test, measurements were recorded of the flue gas temperatures and gaseous species, both upstream and downstream of the Air Preheaters, using the DAP and the ECEM. Over several hours of each test the ECEM probes in the relevant composite groupings, (e.g. East APH inlet, etc.) were sampled in a round-robin fashion to provide at least 10 readings of each duct composite gas sample. Gas temperatures in each duct were measured continuously to every 5 seconds - compiled into 5-minute averages) over the entire test duration.

ASME PTC 4.1 Heat Loss Method calculations were made of boiler efficiency losses for dry flue gas, moisture in flue gas (humidity plus moisture in fuel plus hydrogen combustion product), LOI in fly ash, LOI in bottom ash (negligible), and radiation loss (std. ASME curves). These calculations utilized data discussed in the previous paragraphs. The results of the efficiency calculations are presented in Table 5-16.

The purpose of the Boiler Efficiency calculations is to document the Phase 1 boiler efficiencies at specific operating conditions for comparison the subsequent efficiencies subsequent to the Low NO retrofits. Thus, the important parameter is any <u>change</u> in efficiency attributable to the retrofit, rather than the absolute value of efficiency measured. For this reason some efficiency loss components not related to combustion (e.g. blowdown, steam properties, etc.) were not considered. However, the Heat Loss calculations were done based upon the measured calorific value, moisture and chemical composition of the as-fired fuel samples taken during each test. Figure 5-26 shows resultant boiler efficiency values vs gross generator load for the seven performance tests.

5.3 Verification Tests

Subsequent to the Long-term testing, testing was performed to ascertain if significant changes in the NO characteristics had occurred during the Long-term test period. These test were performed during the week of April 4, 1990. During this period, eleven tests were performed at high loads. During the Verification test period, the System Load was such that it was not possible to obtain low load data (300 and 185 MWe loads).

Table 5-17 presents a summary of the data taken during the verification testing. Five tests were performed at the 480 MWe load point and six were performed at the 400 MWe load point. Testing at the 480 MWe load was with all mills in service while testing at the 400 MWe load was for the condition with E-mill and B-mills out of service. At the high load test point, only the first three tests were valid for comparison with the Diagnostic

TABLE 5-16

HAMMOND UNIT 4 ASME PTC 4.1 BOILER EFFICIENCY

Test No.	Date	Average Load	Start Time	Stop Time	As Measured Efficiency	Normalized Efficiency
12-1	11/29/89	470.7	8:13	12.30	89.84	89.99
12-2	11/29/89	482.0	13:34	16:40	89.95	90.10
13-1 (ABC)	11/30/89	474.3	10:55	16:00	89.38	89.56
13-2	11/30/89	477.9	16:38	18:23	89.55	89.73
14-1	12/01/89	295.7	8:34	12:18	90.08	90.27
14-2	12/01/89	299.7	14:20	16:53	90.13	90.22
15-1 (AB)	12/02/89	299.7	8:45	12:55	89.71	89.89
15-2	12/02/89	303.0	1.:44	16:00	90.02	90.06
16-1 (AB)	12/03/89	389.8	8:35	12:31	89.54	89.90
16-2	12/03/89	387.6	13:25	15:29	89.47	89.80
17-1 (AB)	12/04/89	470.0	8:37	13:44	89.27	89.61
17-2	12/04/89	468.2	14:34	16:41	89.46	89.68
18-1	12/05/89	388.7	10:48	13:07	89.65	89.82
18-2	12/05/89	390.8	14.22	15:46	89.74	89.83
18-3	12/05/89	389.9	16:09	18:12	89.60	89.75

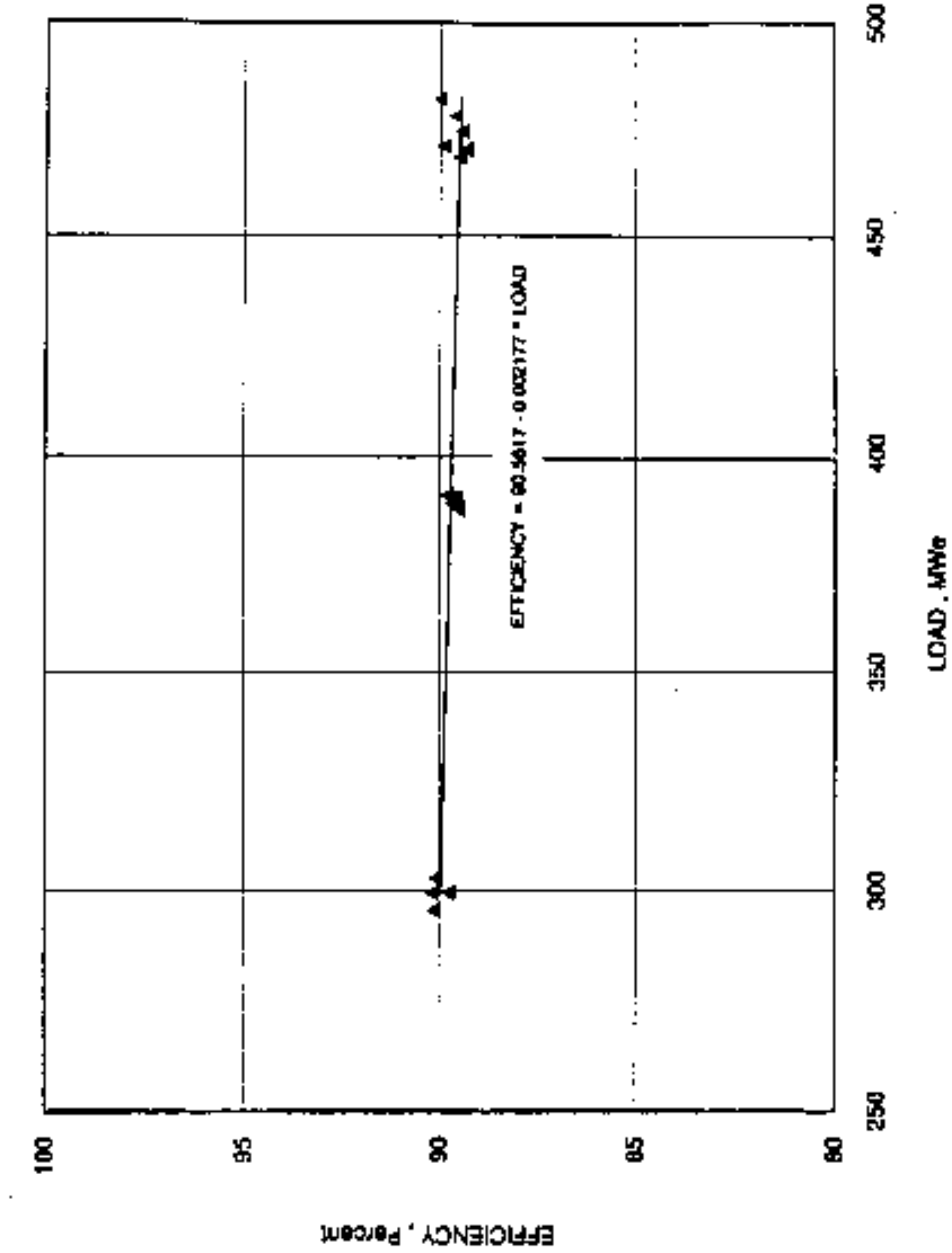


FIGURE 5-26 HAMMOND UNIT 4 MEASURED BOILER EFFICIENCY

TABLE 5-17 PHASE 1 VERIFICATION TEST RESULTS

TEST NO.	DATE	TEST CONDITIONS	LOAD Mwe	MOOS PATTERN	DAS O2 %	DAS NO ppm
19-1	4/02	HI LOAD O2 VARIATION	470	NONE	2.3	863
19-2	4/02	“	470	“	2.6	939
19-3	4/02	“	475	“	3.7	1063
20-1	4/03	MID LOAD O2 VARIATION	404	E	2.4	734
20-2	4/03	“	403	E	3.5	876
20-3	4/03	“	403	E	4.8	960
21-1	4/04	MID LOAD 02 VARIATION	400	B	2.3	785
21-2	4/04	“	402	B	3.1	921
21-3	4/04	“	402	B	4.3	974
22-1	4/05	HI LOAD O2 VARIATION	475	NONE	2.8	950
22-2	4/05	“	475	“	2.4	961

data due to problems with one of the burners. This problem resulted in operation in a non-standard configuration.

Figure 5-27 presents a comparison of the Verification test results with those for the Diagnostic testing (see Figure 5-4) for the 480 MWe load point. From Figure 5-27 it can be seen that for all practical purposes, the data for the two periods are the same and exhibit the same trend. The NO data fit within the data scatter for the Diagnostic tests. Based upon this it can be concluded that the full load NO characteristics did not significantly change during the Long-term test period.

Figure 5-28 presents a comparison of the Verification test results with those for the Diagnostic testing (See Figure 5-5) for the 400 MWe load point. Testing at the 400 MWe load point was with the two mill patterns used during the Diagnostic testing (e- and B-MOOS). From figure 5-28 it is evident that the Verification trends and the absolute levels of NO were remarkably similar to those for the Diagnostic test results. In both test series, the B-mill NO levels were higher than those for the E mill operation. As with the 480 MWe comparison, it can be concluded that no significant changes occurred during the Long-term test period for the 400 MWe test configuration.

Since no Verification testing was performed at the 300 and 185 MWe load points it is not possible to ascertain if changes occurred during the Long-term testing that would affect the NO emission characteristics. Based upon the results for the 480 and 400 MWe load points, it is likely that significant changes did not occur and that the Long-term results present in Section 6.0 are compatible with the Short-term test results.

FIGURE 5-27 VERIFICATION NOx CHARACTERIZATION

480 MWe NOMINAL LOAD

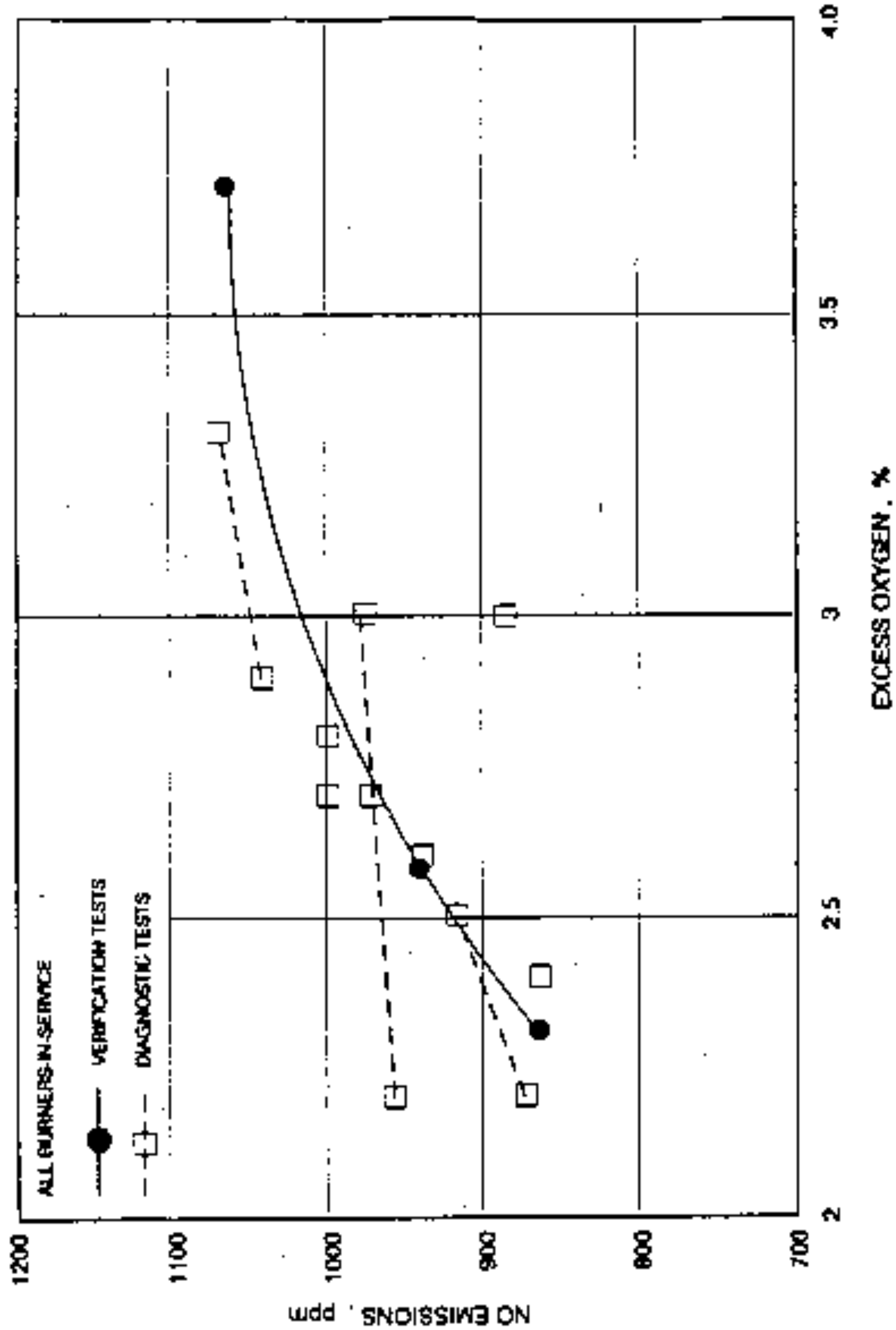
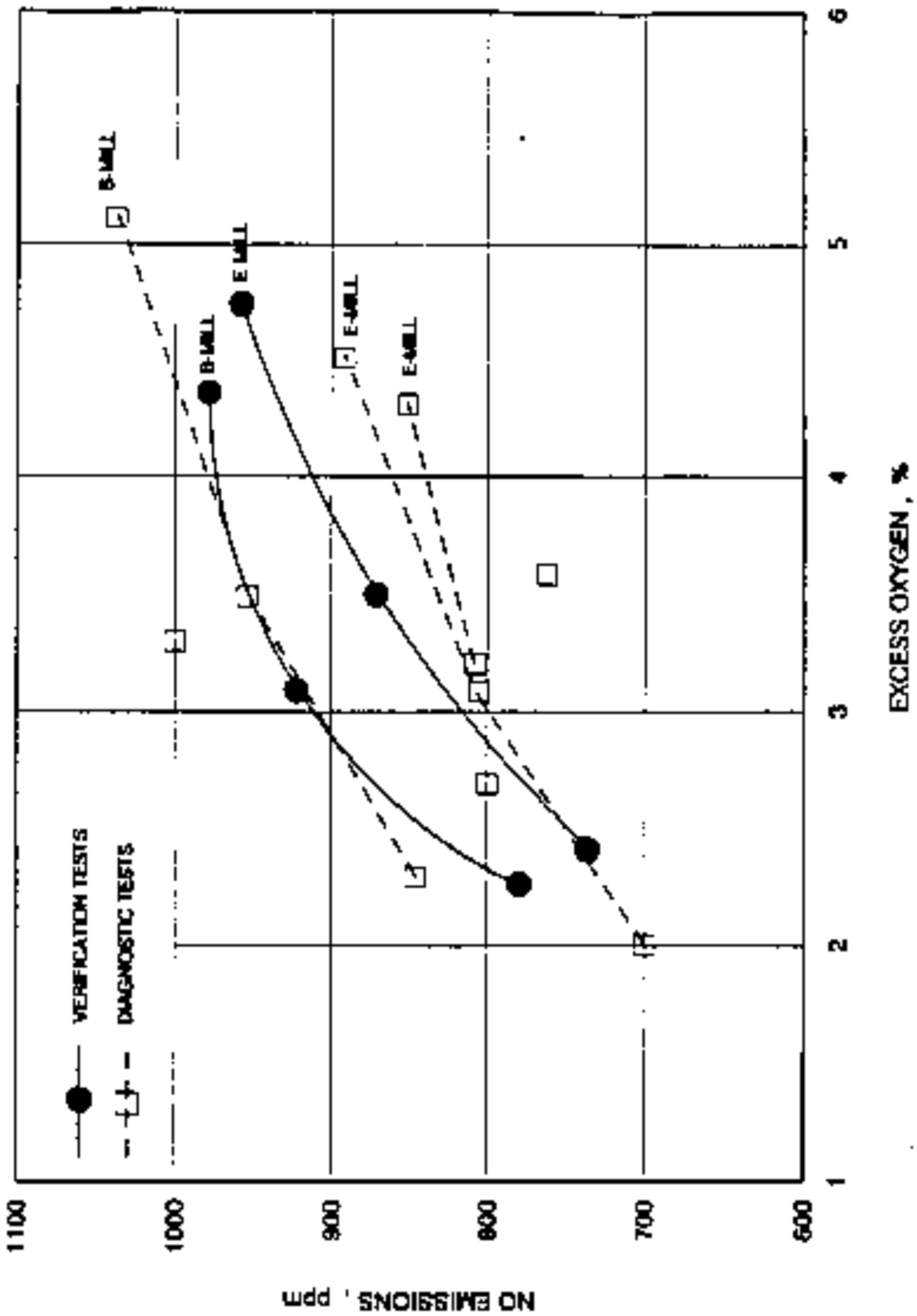


FIGURE 5-28 VERIFICATION NOx CHARACTERIZATION

400 MWe NOMINAL LOAD



6.0 LONG-TERM DATA ANALYSIS

6.0 LONG-TERM DATA ANALYSIS

The Long-term testing consisted of continuous measurement of operating parameters while the unit was under Load Dispatch Control. This Long-term testing was performed from late December, 1989 through early April, 1990. During this period three unit outages were experienced. In addition, the KVB ECEM experienced difficulties that resulted in lost days of data capture. The data capture was, however, sufficient to fully characterized the unit both from an engineering perspective as well as a regulatory point of view.

The focus of the analysis of this long-term data was;

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

2) Characterization of the NOx emissions as a function of the O2 and mill patterns for all five-minute ECEM data,

3) Determination of the thirty-day rolling average NOx emissions based upon valid days and hours of ECEM data,

4) Determination of the achievable NOx emission level based upon valid days of ECEM data.

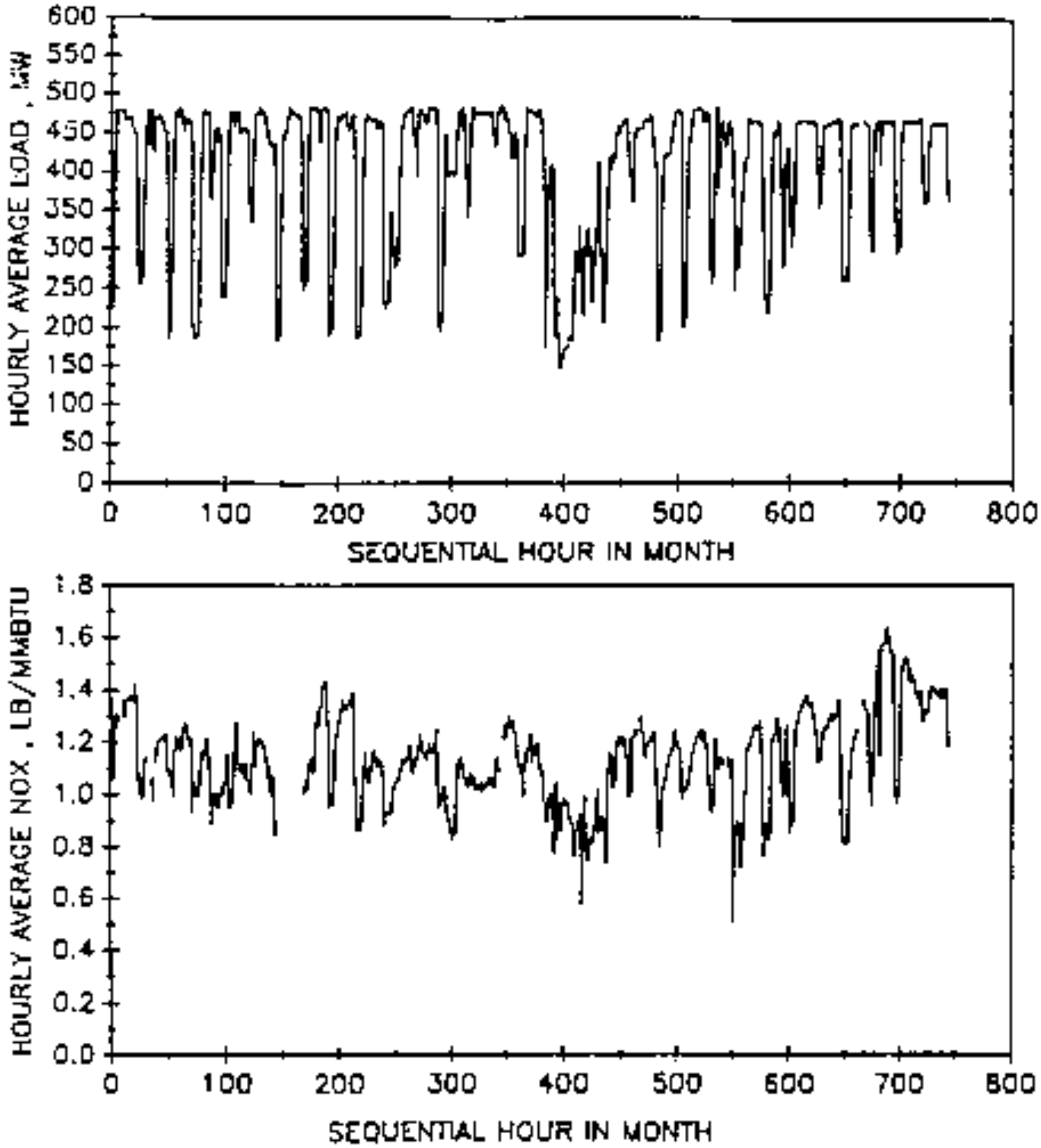
and 5) Comparison of Long-Term results to Short-Term results.

The following paragraphs describe the results of these analyses and additional information is provided in Appendix A.

6.1 Unit Operating Characteristics

As was mentioned in Section 4.2, difficulties were experienced with the KVB CEM system. The KVB system experienced difficulties that resulted in loss of data capture during the first several months of the Long-term test effort. Figure 6-1 illustrates the NOx emissions for the load scenario during the month of March 1990. This was the month during which the data capture was the greatest for the KVB system. Other months which experienced lesser degrees of data capture are shown in Appendix A (Figures A-1, 2 and 3). From Figure 6-1 it can be seen that the five-minute average NOx emissions varied from approximately 1.6 to 0.5 lbNOx/MMBtu during the month of March. Similar but less dramatic variations were experienced during the other three months of testing. It is difficult to determine a trend using this type of data. The data does however illustrate that the unit experienced load changes from the minimum operating load (180MWe) to the maximum continuous operating load (480 MWe) during the entire Long-term test period.

FIGURE 6-1 HOURLY AVERAGE CHARACTERISTICS



From the data for the long-term testing (December 1989 through April 1990), the daily averages of load and NOx were determined and are shown in Figure 6-2. These daily average data were determined using the EPA criteria for valid data explained in Section 4.2.1. Only days with at least 18 hours of data are presented in this figure. These data are used to determine the 30-day rolling averages and the achievable emission levels discussed in later sections. It is evident that during the Long-term testing that the average daily load was in excess of 400 MWe. Only two days were at a load below 300 MWe. This unit is a base loaded unit which is generally the first unit on and the last unit off of Dispatch. For this period, the daily average emissions ranged from approximately 1.3 to 0.8 lbNOx/MMBtu.

One method of characterizing the boiler operating characteristics during the long-term testing is to examine the within-day variation of load and NOx. This was accomplished by segregating the data by hour of the day, i.e., 0100, 0200,...2400. For these segregated data, the mean load and NOx were computed. In addition, the hourly values representing the lower 5 percent and upper 95 percent of all values were determined. The results of this analysis are presented in Appendix A (Tables A-1 through A-6 and Figures A-6 through A-11). Figure 6-3 illustrates the daily trend for load and NOx emissions over the entire long-term test period. The figure illustrates that the unit was operated as a base loaded unit for most of the day (on average 16 hours were near the maximum continuous load of 480 MWe). It is evident that the NOx versus load characteristics are that NOx generally increases with increasing load. The exact relationship will be illustrated in the following Paragraphs.

6.2 Parametric Test Results

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

The NOx versus load relationship was determined by first segregating the 5-minute average load data into 20 MW wide load ranges. Table 6-1 provides the results for this segregation of the data for the entire long-term data set. The population for each load range, as well as the mean lower five percentile and upper ninety-five percentile are shown for both load and NOx emission values. Figure 6-4 illustrates the NOx versus load trend for these data. Analyses were conducted for each individual month of the long-term effort and are presented in Appendix A (Table A-7 through A-10 and Figures A-12 through A-15).

FIGURE 6-2 DAILY AVERAGE CHARACTERISTICS

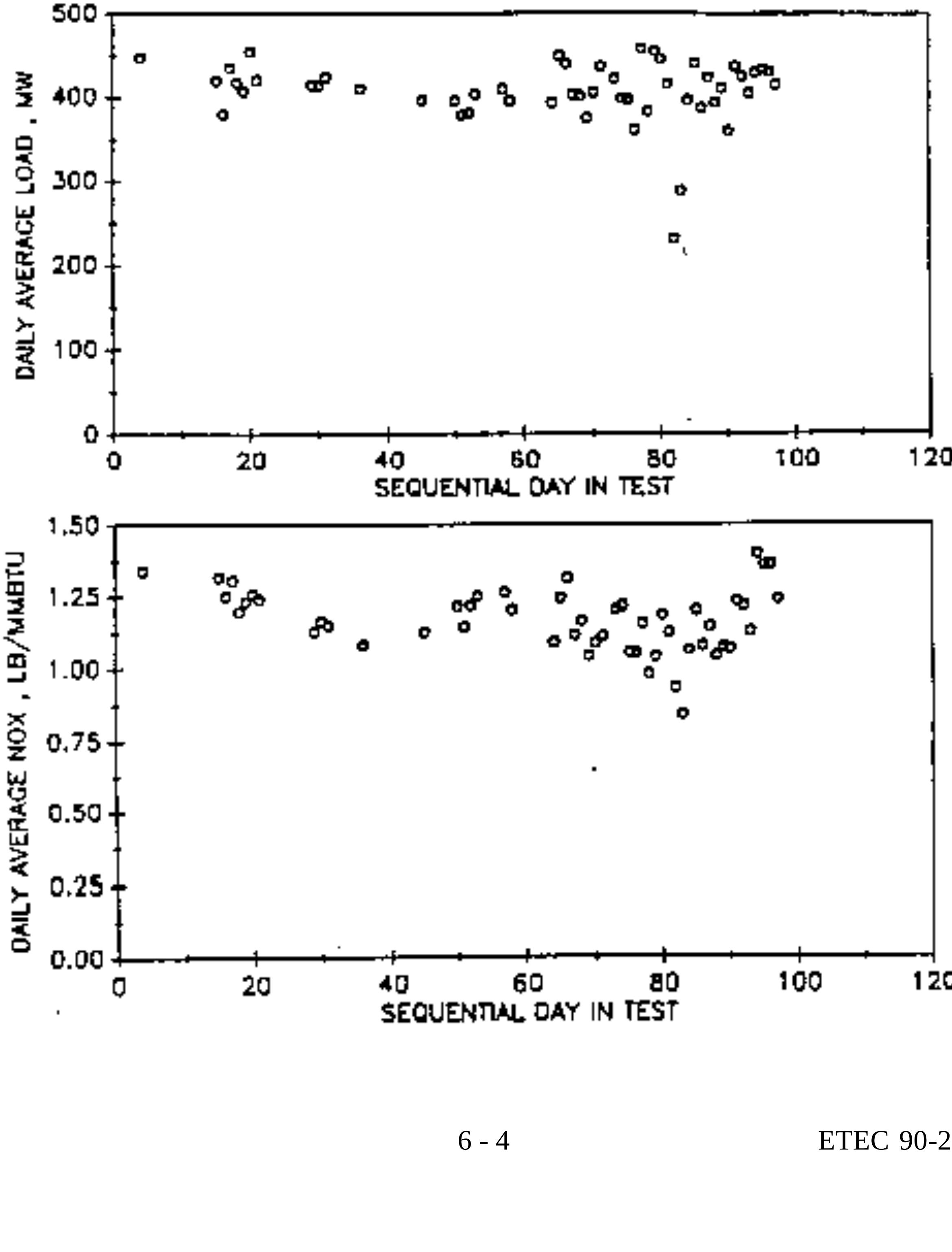


FIGURE 6-3 DIURNAL CHARACTERISTICS

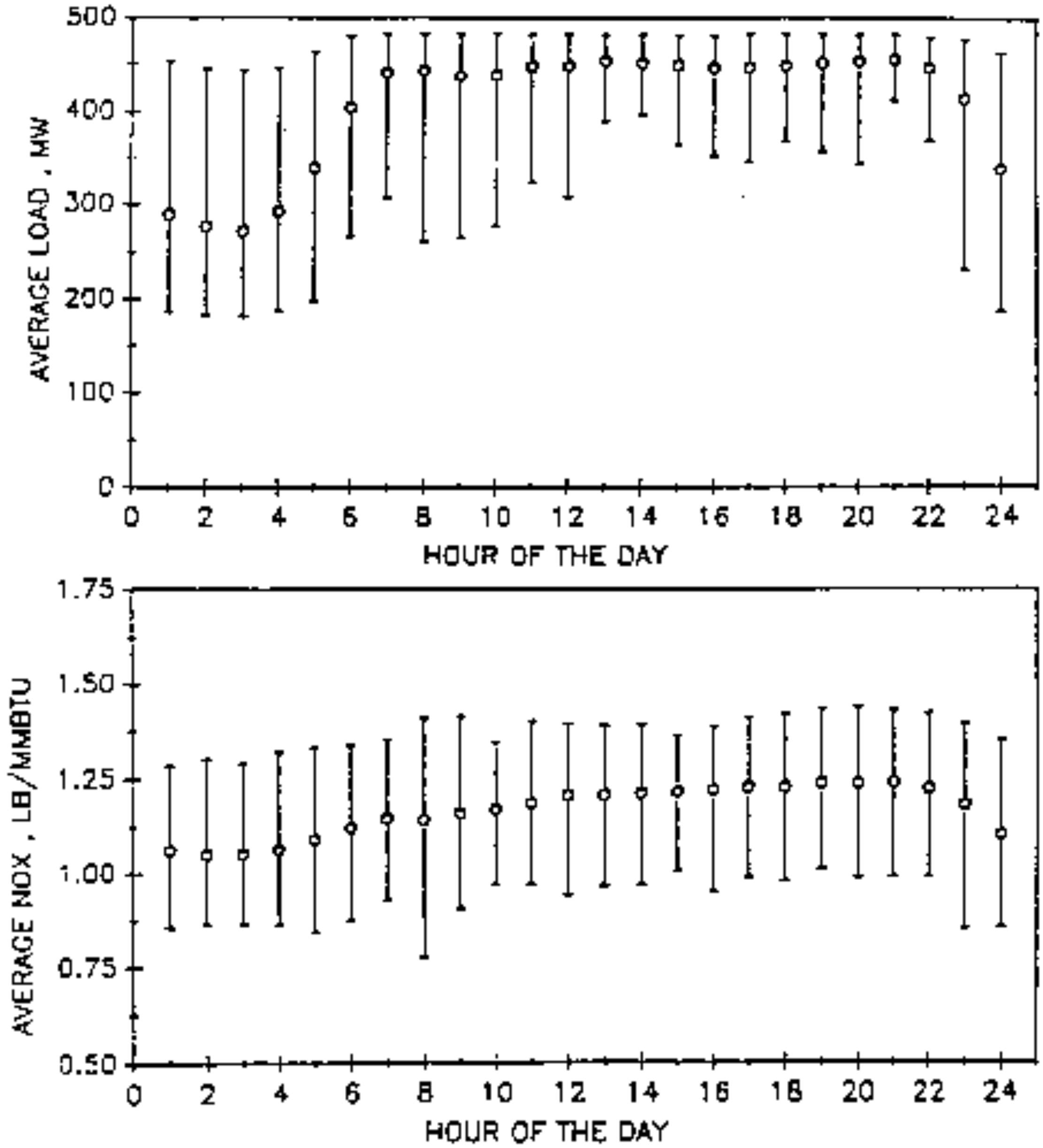
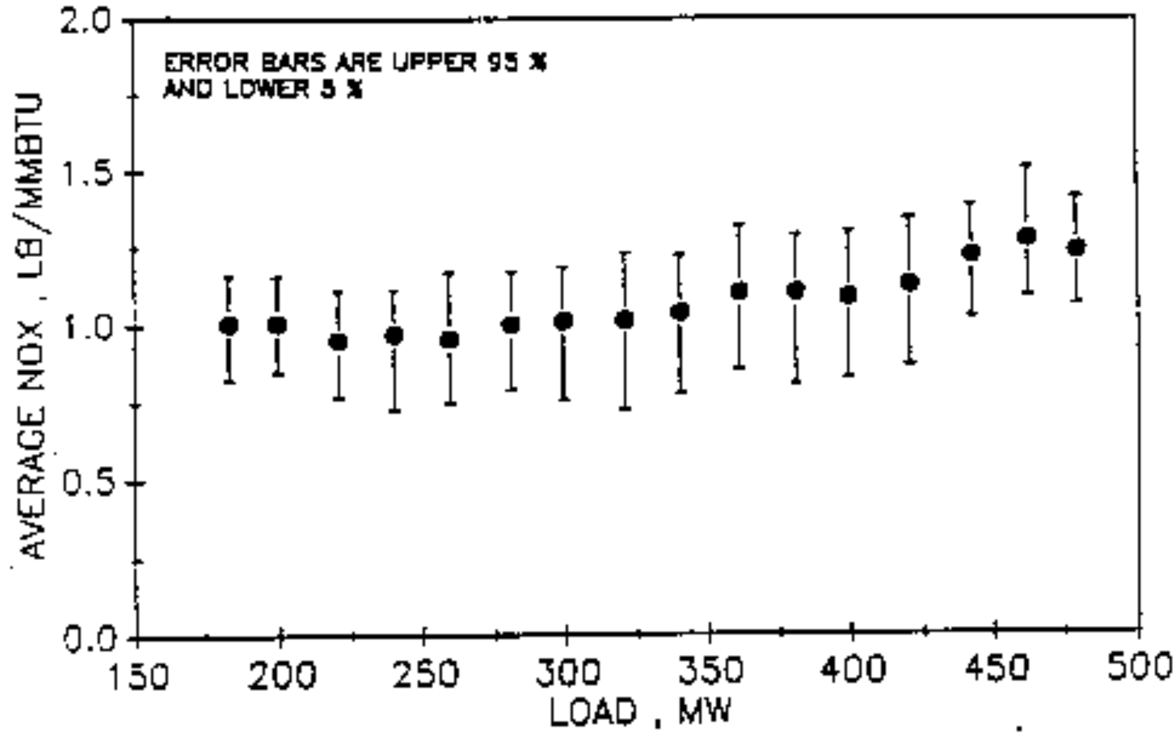


TABLE 6-1 PLANT HAMMOND BASELINE TESTING
AVERAGE BY LOAD RANGE
5-MINUTE DATA
December 1989 - April 1990

		Load			O2			No_x		
Load Range	N	Lower 5%	Average	Upper 95%	Lower 95%	Average	Upper 95%	Lower 5%	Average	Upper 95%
170-190	592	173.0	183.0	189.4	7.30	9.18	10.38	0.822	1.004	1.160
190-210	682	191.1	199.5	208.3	7.75	8.98	10.24	0.843	1.005	1.156
210-230	300	211.0	220.4	229.0	7.08	8.48	9.12	0.767	0.950	1.110
230-250	380	230.9	240.0	248.9	6.60	8.31	9.60	0.725	0.970	1.111
250-270	443	251.1	259.5	268.4	6.34	7.75	9.41	0.747	0.956	1.172
270-290	401	271.6	280.6	288.9	5.89	7.44	8.75	0.791	1.001	1.174
290-310	461	290.9	299.1	308.7	5.59	7.09	8.55	0.757	1.013	1.188
310-330	332	311.2	320.7	329.3	5.22	7.01	8.81	0.727	1.015	1.232
330-350	315	330.6	340.1	348.9	5.11	6.80	8.18	0.776	0.038	1.224
350-370	461	351.1	360.7	368.6	5.05	6.33	7.85	0.855	1.103	1.321
370-390	454	371.2	380.7	389.3	4.80	6.09	7.46	0.807	1.102	1.290
390-410	852	390.9	399.2	408.9	4.36	5.59	7.65	0.826	1.086	1.304
410-430	1031	410.9	420.2	429.2	4.49	5.54	7.15	0.867	1.125	1.347
430-450	1624	431.2	442.0	449.3	4.06	5.24	6.35	1.022	1.222	1.391
450-470	3991	451.8	462.1	469.1	4.15	4.95	5.70	1.088	1.274	1.510
470-490	5137	471.1	479.1	485.8	4.08	5.00	5.65	1.058	1.236	1.414
490-510	57	490.0	493.1	498.4	4.12	4.75	5.54	1.039	1.199	1.383

FIGURE 6-4 LOAD CHARACTERISTICS



For loads above 200 MWe, the trend is slightly increasing NOx with increasing load. In this load range the mean NOx varied by approximately 30 percent ranging from 0.95 to 1.27 lbNOx/MMBtu. The slight rise in NOx emissions at loads below 200 MWe were most likely due to the higher excess oxygen levels used at these reduced loads. Similar results were evident for the monthly data analyses (See Appendix A).

The effect of operating O2 on NOX emissions for certain mill patterns was examined for load ranges that corresponded to those tested during the Short-term test portion of the Phase 1 test effort. These ranges were the 180-190, 290-300, 390-400 and 470-480 MWe ranges. All of the valid five-minute data for these load ranges were used to assess the impact of excess oxygen level for the most commonly used mill patterns. In order to determine the most frequently used patterns the frequency distribution of the mills in service (MOOS) pattern was determined. Table 6-2 presents the frequency distribution for these data. It is apparent that there are certain preferred mill patterns for each load range. These patterns are dictated by the operational requirements of the unit, i.e., slag minimization, steam temperature control, etc..

TABLE 6-2 MILL PATTERN USE FREQUENCY

Load Cell (MW)	MOOS	Sample Size	Average Load (MW)	Average Nox (lb/MMBtu)	Average O_2 %
180-190	B,C,E	359	185.5	1.0	9.01
	D,F	39	185.4	0.90	9.05
	B,C,F	24	184.6	0.90	8.79
	D,E	4	184.2	1.04	9.50
290-300	E	145	294.7	1.08	7.08
	None	51	295.1	0.96	7.03
	F	39	295.0	0.84	6.83
	B,C,E	9	.294.9	1.03	7.25
390-400	None	257	394.4	1.13	5.72
	B,C	116	395.1	1.02	4.80
	E	56	396.0	1.16	5.45
	F	26	396.0	0.97	7.49
470-480	None	2580	475.4	1.22	4.91

Prior to commencing the Short-term testing effort, discussions with plant operations indicated that certain mill patterns were the preferred patterns. These patterns were then used during the Diagnostic and Performance testing with the intent of comparing the results with the same patterns during long-term testing. The mill patterns used during the Short-term test effort were the B-, E- and B&E-MOOS at loads below 400 MWe. Referring to Table 6-2 it is evident that these patterns were not the most prevalent during this long-term test effort. As a consequence of this, some comparisons will not be able to be made between the Short- and Long-term results discussed in Section 6.5.

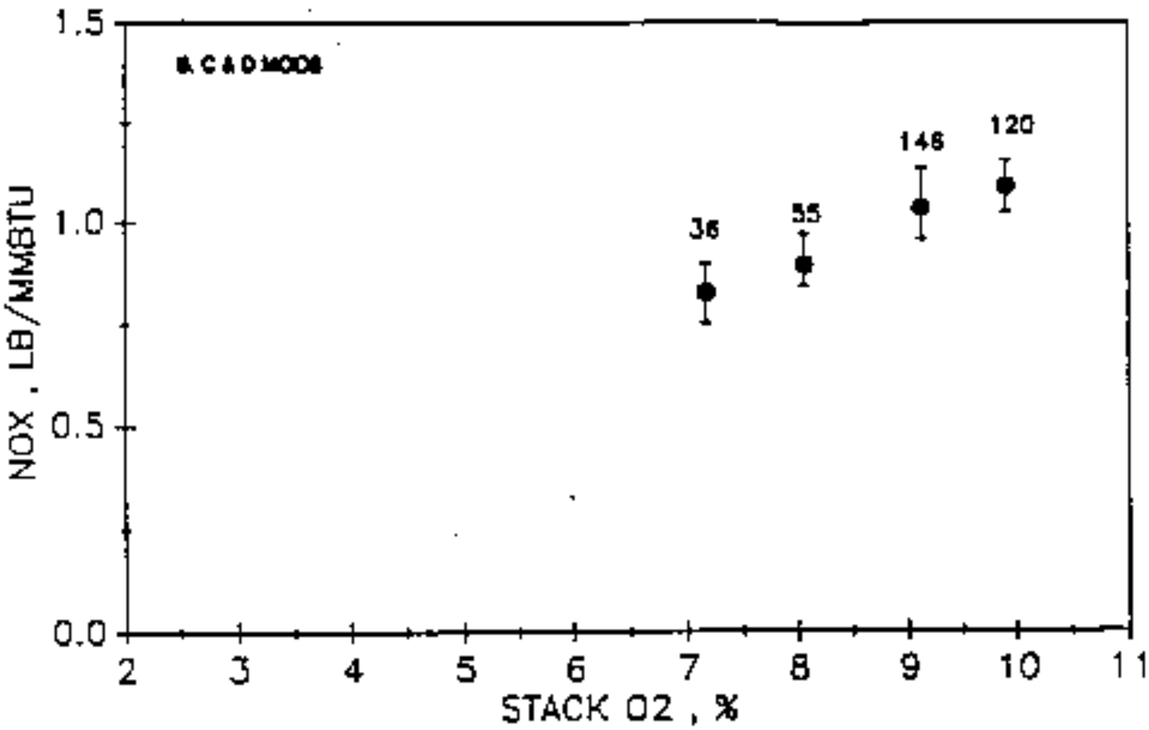
All of the valid five-minute load data was analyzed for the most prevalent Long-term MOOS patterns for each of the four load categories in order to establish the NOx versus O_2 characteristics. The NOx versus O_2 relationships for these patterns were evaluated using statistical regression techniques.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

The results of the above analyses are shown in Figures 6-5 through 6-8. In every instance, regardless of the MOOS pattern, the NOx emissions increased as the O_2 increased. In addition, there were significant variations in NOx emissions for different MOOS patterns at the same load. At the nominal 395 MWe load condition, the NOx varied by as much as sixteen percent. The variation was less for the lower load ranges (Nominal 295 and 185 MWe). These results will be compared to the Short-term results for the same mill patterns in Section 6.5.

6.3 Thirty-day Rolling Averages

The NSPS Subpart Da and Db standards are based upon compliance on a thirty-day rolling average. While this unit is not required to comply with these standards, it is of some value to evaluate the data for Phase 1 on a thirty-day rolling average basis and later compare it to the results from subsequent Phases. Thirty-day rolling average load, NOx, and O_2 were computed using the valid hourly data as defined by the EPA criteria explained in Section 4.2.2. These thirty-day rolling averages are shown in Figure 6-9 for the 92 (63 rolling averages) valid days (by EPA criteria) of data.

FIGURE 6-5 180 MWe EXCESS OXYGEN CHARACTERISTICS



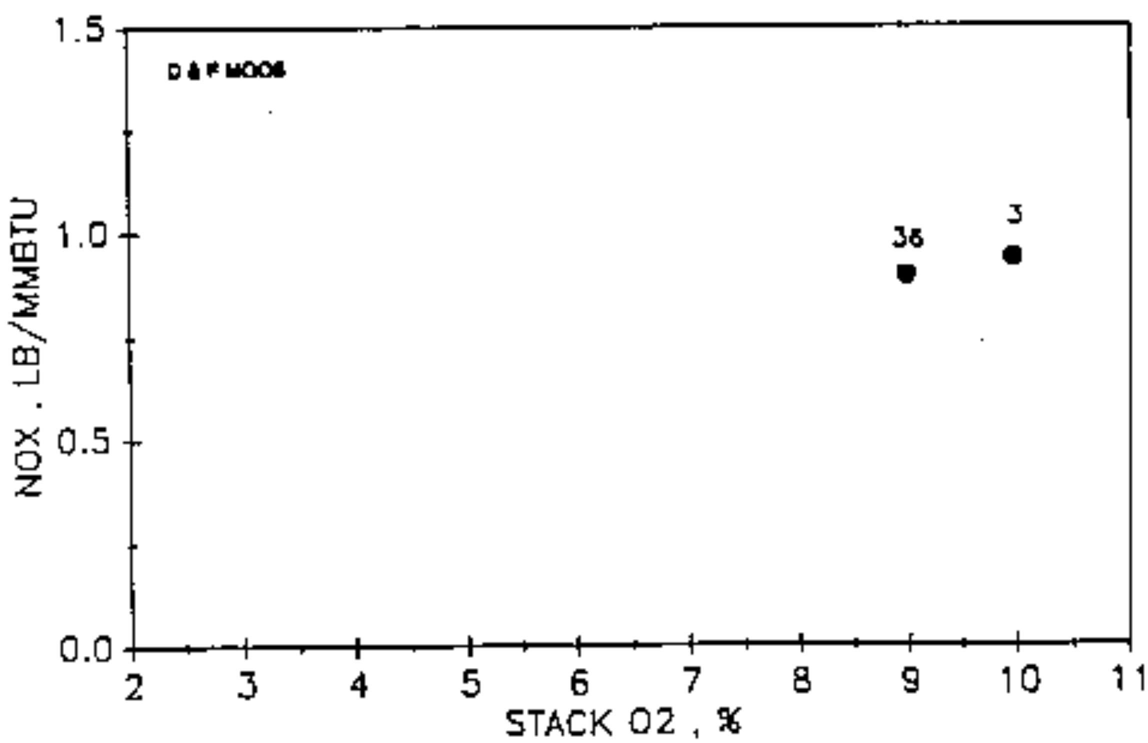


FIGURE 6-6 300 MWe EXCESS OXYGEN CHARACTERISITCS

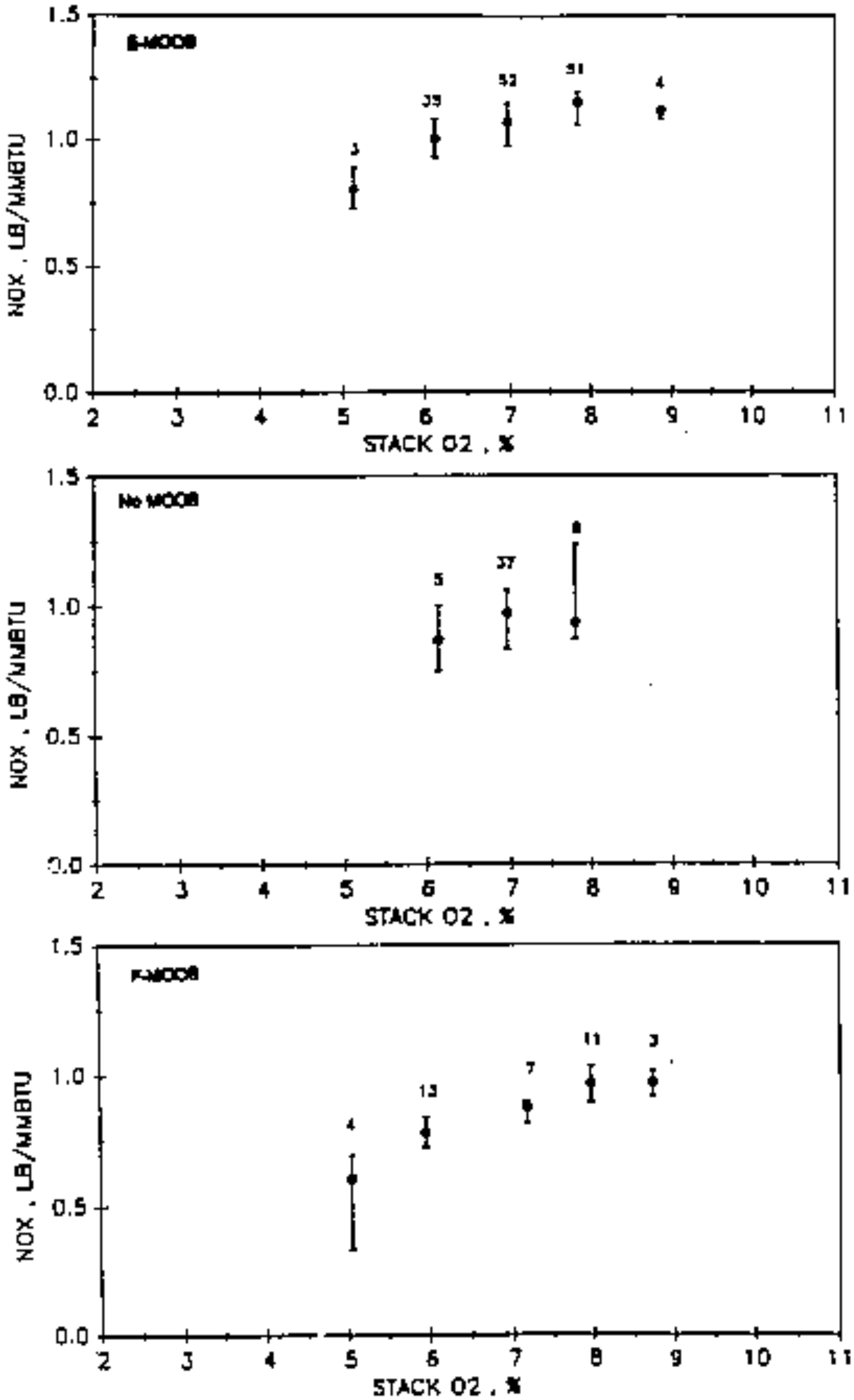


FIGURE 6-7 400 MWe EXCESS OXYGEN CHARACTERISTICS

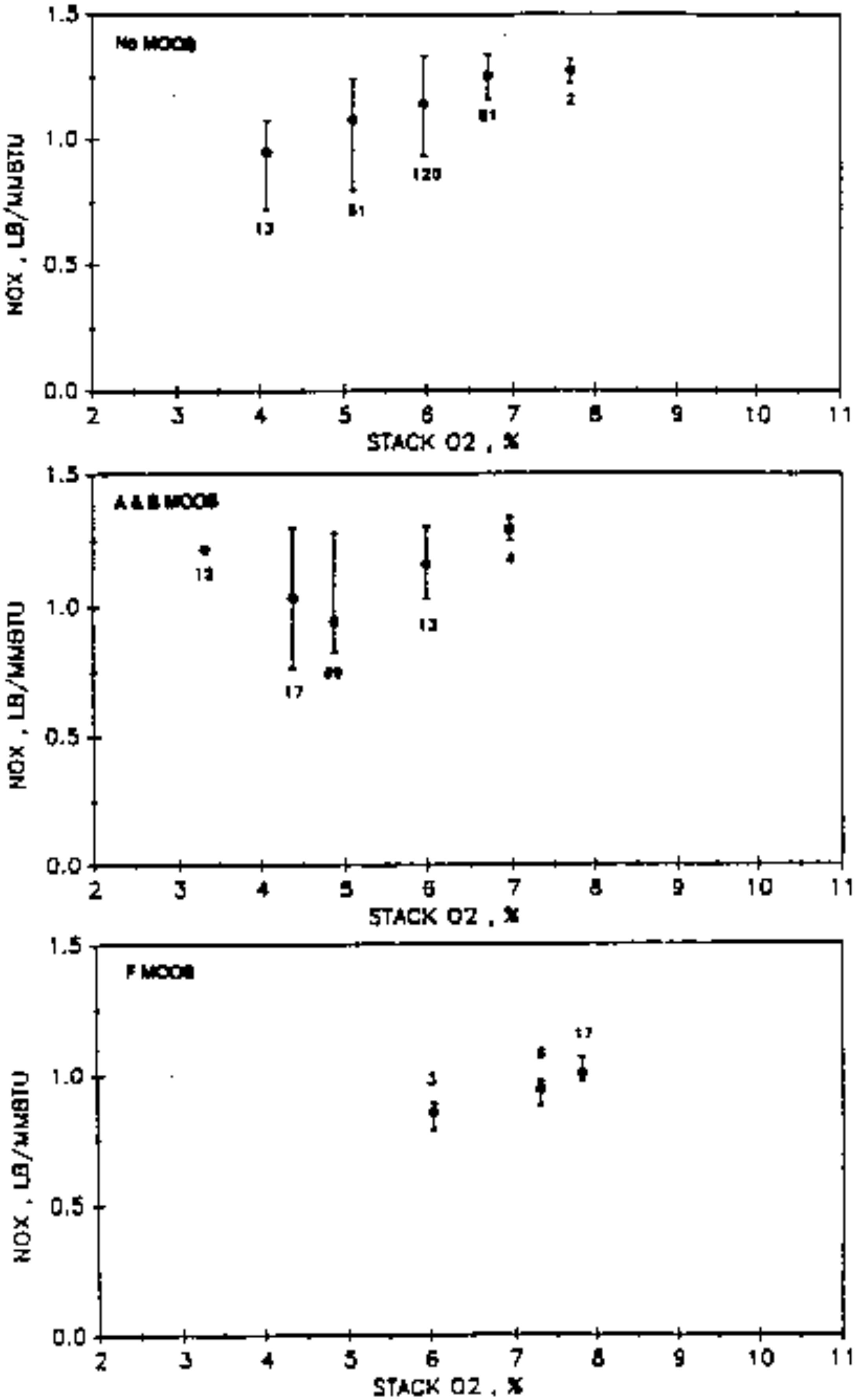


FIGURE 6-8 480 MWe EXCESS OXYGEN CHARACTERISTICS

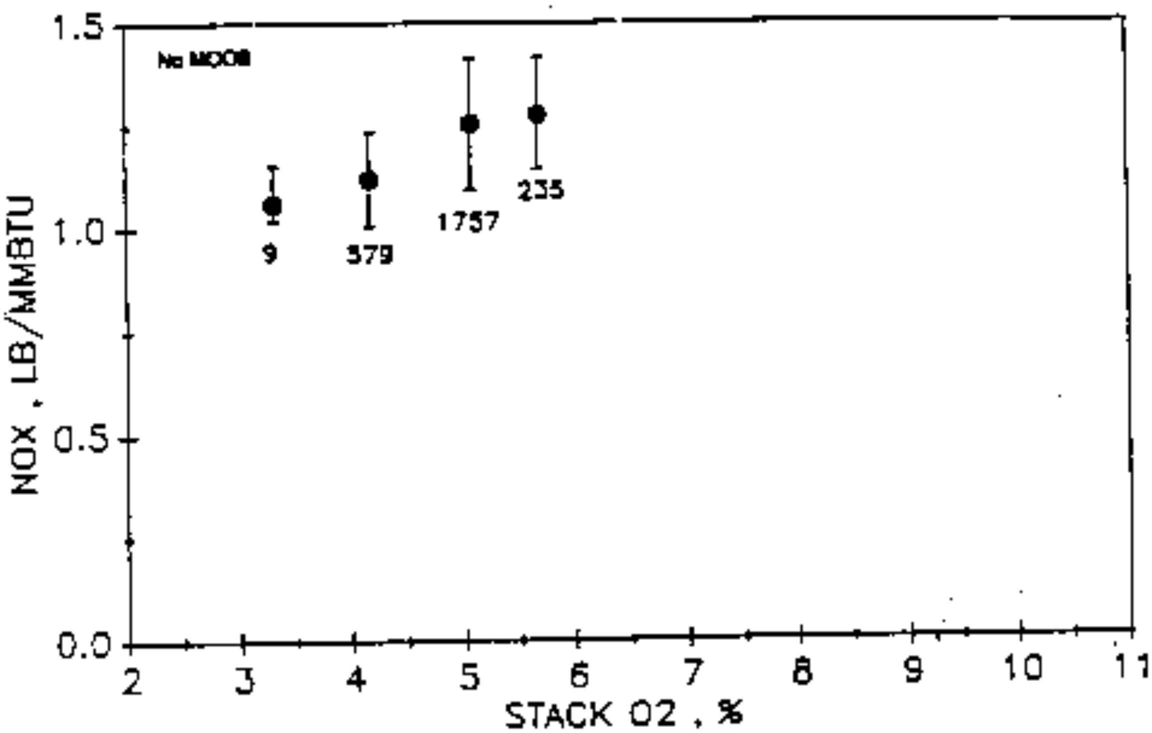
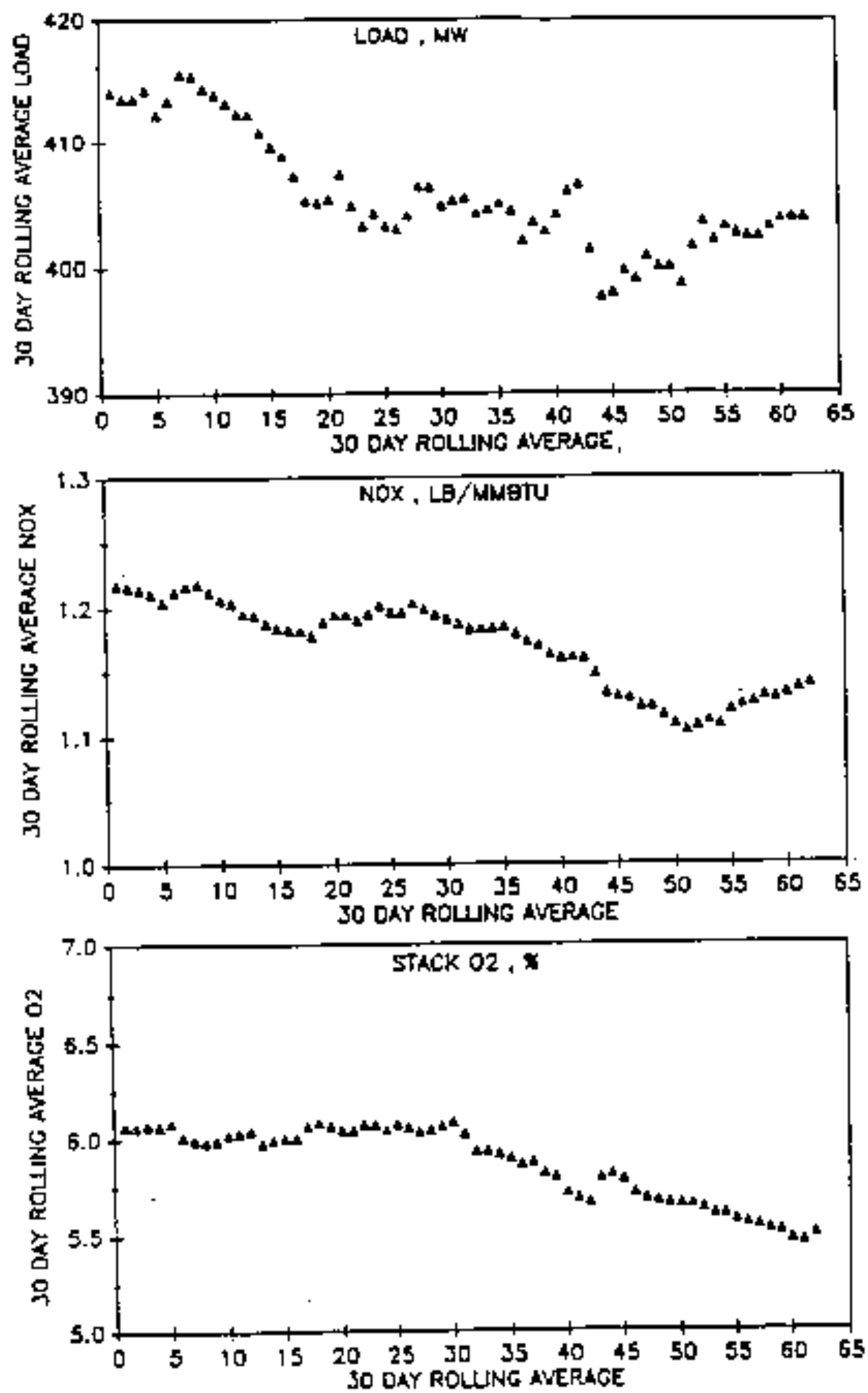


FIGURE 6-9 30-DAY ROLLING AVERAGE CHARACTERISTICS



It should be pointed out that the thirty-day rolling average results shown in Figure 6-9 are only representative of the load scenario that was experienced by the unit during this long-term test period. During other periods when the load might be significantly different, the rolling averages would be expected to be somewhat different. For this particular period, it can be seen that there was a slight decrease in the daily load as the testing progressed as evidenced by the declining thirty day rolling average load. Since it was shown in the previous paragraphs that the NOx increases with increasing load, it is obvious that the rolling average NOx emissions should decrease as the testing progressed. In the final report, thirty-day rolling average values will be computed for a consistent synthesized load scenario. These synthesized results will be used to illustrate the NOx emissions (and reductions) that would be reported on a unit if it were required to comply on a thirty-day rolling average basis standard.

6.4 Achievable Emission Characterization

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

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

TABLE 6-3 DESCRIPTIVE STATISTICS FOR DAILY AVERAGE NOx EMISSIONS

Number of Daily Values	52
Average Emissions (lbNOx/MMBtu)	1.166
Standard Deviation (lbNOx/MMBtu)	0.111
Distribution	Normal
First Order Autocorrelation (ρ)	0.539
Standard Error of Autocorrelation	0.119

Based upon the EPA criteria, the achievable NOx emission limit should only be exceeded, on average, once per 10 years on a 30 day rolling average basis. The achievable emission depends on the long-term mean, variability, and autocorrelation level shown in Table 6-3. The achievable emission limit is computed using these values as discussed in Section 4.2.2. Table 6-4 provides the achievable emission level, based on the daily values given in Table 6-3. The achievable NOx emission limits shown in this table, are computed for two conditions - no autocorrelation (ρ=0) and the estimated value of 0.539. The assumption in this table is that the Hammond Unit will be operated in the future under similar load dispatching as that during the baseline test phase. As explained above under other load scenarios, the thirty-day rolling averages would be different and therefore the achievable emission level would also be different.

TABLE 6-4 30-DAY ROLLING AVERAGE ACHIEVABLE NOx EMISSION LIMIT

Autocorrelation	Achievable Emission Limit (lb NOx/MMBtu)
$\rho = 0$	1.18 lb NOx/106Btu
$\rho = 0.539$	1.24 lb NOx/106Btu

It should be noted that the mean, variability, and autocorrelation levels given in Table 6-3 are only estimates of the true mean, variability, and autocorrelation. There is an uncertainty level implicit in the estimates of each of these statistical parameters. The uncertainty level for the first order autocorrelation is given in Table 6-3. The uncertainty level in the mean is dependent on the variability. The estimated variability is, to some extent, dependent on the level of autocorrelation. Thus, uncertainty levels in the descriptive statistics are linked.

As noted in Section 4.2.2, methods are available to incorporate uncertainty levels into the determination of the achievable NOx emission limit. Since the achievable emission limit is dependent upon the autacorrelation level, factoring in the uncertainties in the statistical parameters results in various levels of the achievable emission limit. Table 6-5 provides estimates of the achievable emission limit for the various levels of uncertainty. The achievable emission level can vary from 1.18 to 1.55 lbNOx/MMBtu depending upon the degree of autocorrelation and the level of uncertainty.

TABLE 6-5 EFFECT OF UNCERTAINTY LEVEL ON NOx EMISSION LEVEL

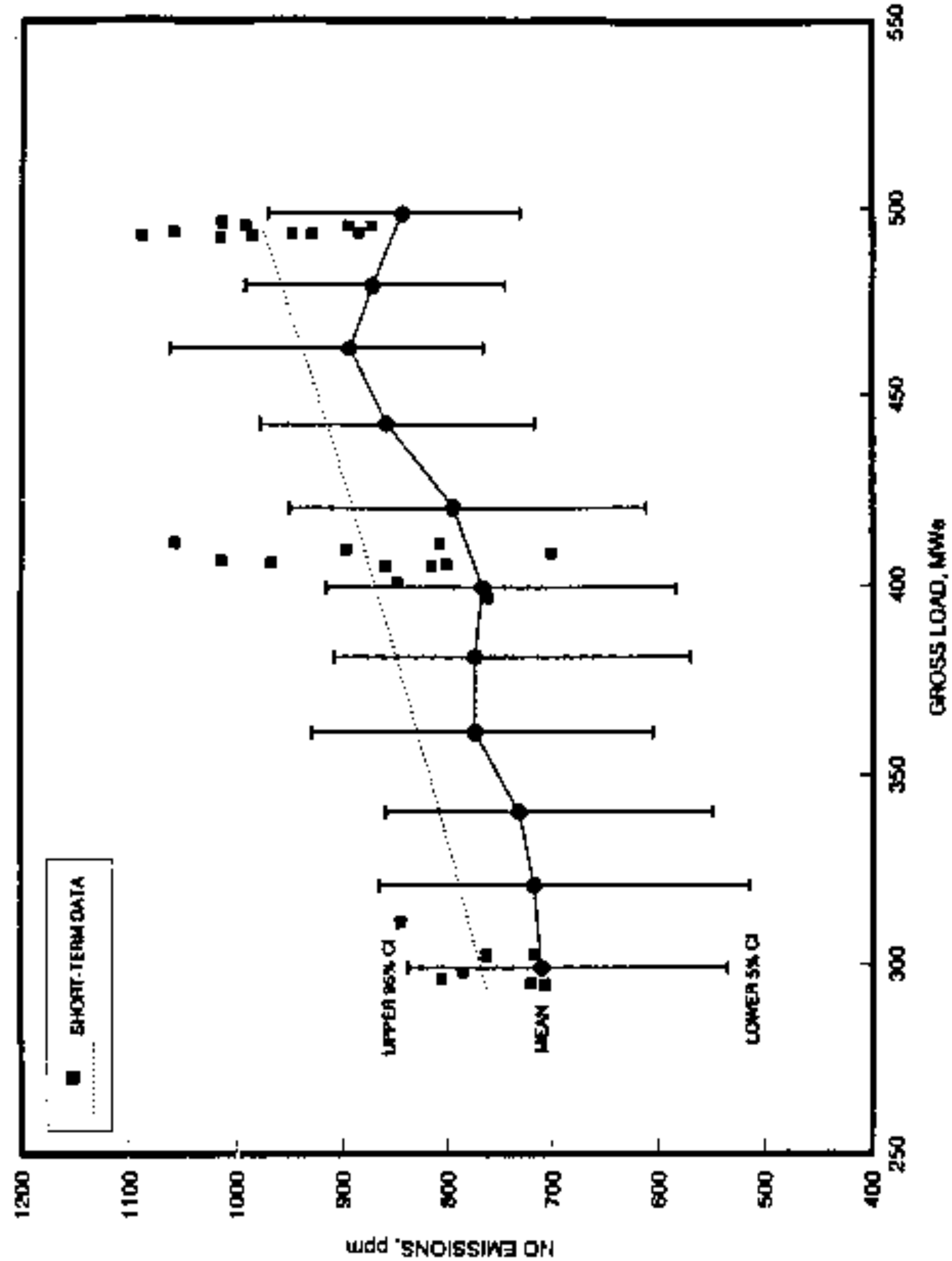
Assumed Uncertainty Level	Achievable Limit (lbNOx/MMBtu)
None, $\rho = 0$	1.18
None, $\rho = 0.539$	1.24
Uncertainty level in mean, variability, $\rho = 0.539$	1.39
Uncertainty level in mean, variability, $\rho = 0.739$ (upper 95% [one tail])	1.55

6.5 Comparison of Long- and Short-Term NO Data

As was mentioned in the previous paragraphs, the configurations tested in the Diagnostic portion of the Short-term effort were unfortunately not the most frequently used configurations during the Long-term test effort. As a result only a few comparisons can be made between Long- and Short-term data. These comparisons are for the load range characteristics and excess oxygen characteristics at the 480 and 300 MWe load points.

Section 5.1 presented data for the load characteristics (See Figure 5-3). This data included a number of mill configurations and a range of excess oxygen levels. Similar data was collected during the Long-term effort and is shown in Figure 6-4. The data in Figure 6-4 includes all of the configurations normally experienced during the period from late December 1989 through early April 1990. Figure 6-10 provides a comparison between these two sets of data showing the confidence interval (upper 95% and lower 5%) for the long-term data. From the comparison it is evident that the data obtained during the Short-term efforts was, in many cases, outside the confidence interval particularly at the high load points. The exact explanation for this is not certain, however, it was pointed out in Section 5.1 that the conditions selected for testing encompassed the outer limits of the range of variation of the excess oxygen that might be expected during long-term testing. If the outer limits of the short-term NO emissions were used to make estimates of the characteristic unit emissions, they would be severely overestimated. An interesting outcome of the comparison is that for this particular set of short-term data, the trends for the mean levels for both the Long- and Short-term data agree reasonably well. It is difficult to say if the same outcome would occur if the mix of configurations used in the short-term effort were the same as that experienced during the long-term effort.

FIGURE 6-10 COMPARISON OF LONG- AND SHORT-TERM NO DATA
MEDIUM TO HIGH LOADS, ALL EXCESS OXYGEN LEVELS

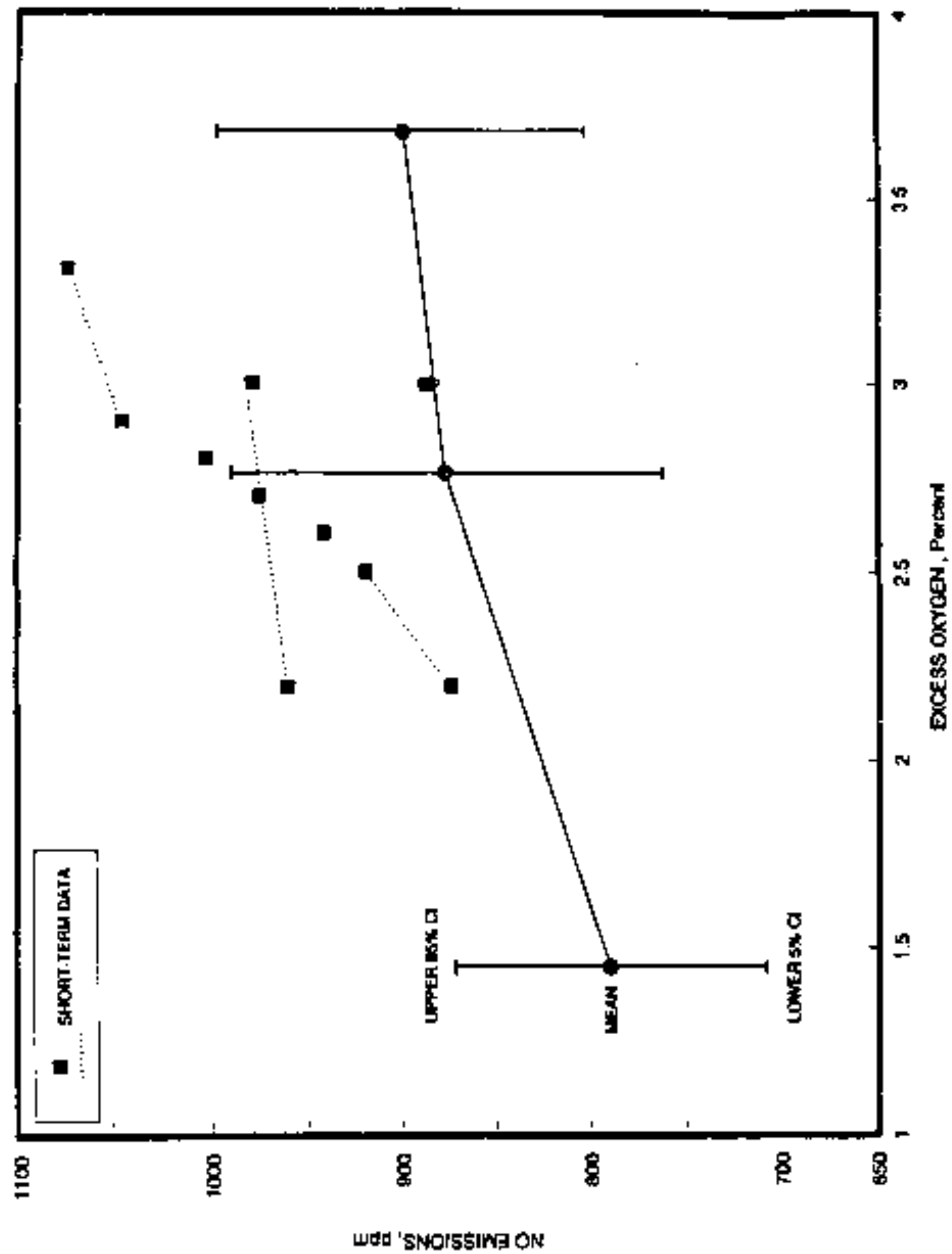


All of the testing at the 480 MWe test point was performed with all mills in service. This is the normal configuration and is the configuration that would be experienced during long-term testing. A comparison can be made between the long- and short-term data as a function of the operating excess oxygen. The long-term data was obtained from the ECEM after the air preheater. As a result of this, the air preheater leakage was included in the oxygen measurement at this point. The short-term Diagnostic results were obtained at the economizer exit and consequently did not include the APH leakage. Before the comparisons could be made, the long-term data had to be adjusted for the APH leakage based upon the best fit of the leakage data, i.e., not on an individual test point basis. Figure 6-11 shows the comparison for data obtained from Figure 5-4 for short-term data and Figure 6-8 for long-term data. This comparison again points out that most of the NOY data from the short-term effort falls within the confidence band, however some of the data is well above the band. It is difficult to ascertain if the trends are similar since the short-term data exhibits a wide range of trends (slopes). The true trend is, however, represented by the long-term data mean values.

During the short-term Diagnostic testing at 300 MWe, the E-MOOS was tested. At this load the E-MOOS was the predominate mill pattern used during long-term testing (See Table 6-2). Figure 6-12 provides a comparison of the short-term data from Figure 5-6 and the long-term data from Figure 6-6. Again, due to the preheater leakage, the long-term excess oxygen had to be adjusted. From Figure 6-12 it can be seen that the available short-term data at this load point falls within the confidence band. In addition, the trends appear to agree reasonably well for both long- and short-term data.

The comparisons of the long- and short-term data indicate that, for the most part, the measured data falls within the confidence band determined for the long-term emissions. With the exception of the high load point (480 MWe) the trends appear to agree between the two sets of data. It is evident from the comparison that the true characteristics are provided by the long-term data. The short-term data do, however, provide some insight into the general characteristics of the NO emissions.

FIGURE 6-11 COMPARISON OF LONG- AND SHORT-TERM NO DATA
480 MWe NOMINAL LOAD



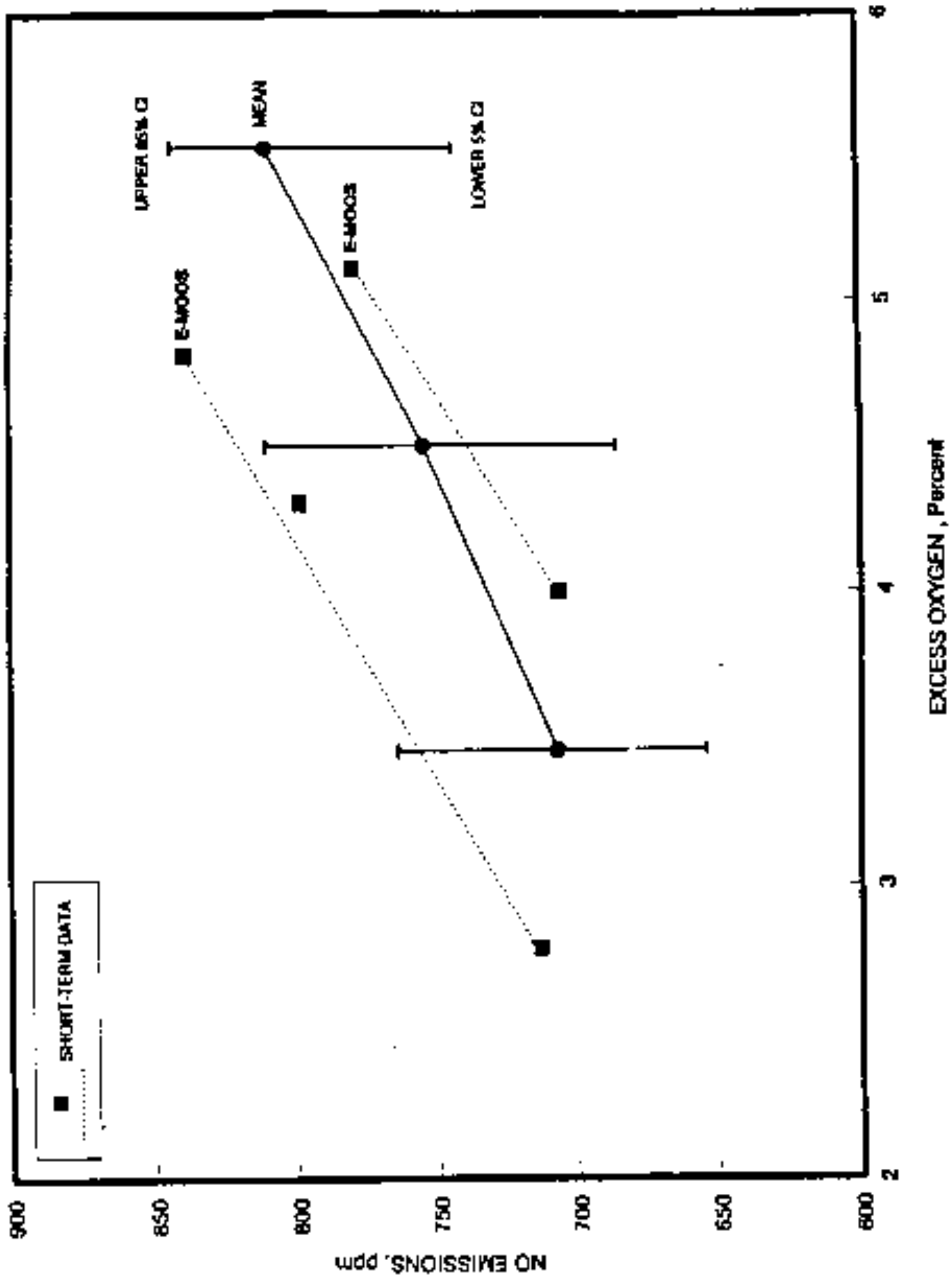


FIGURE 6-12 COMPARISON OF LONG- AND SHORT-TERM NO DATA
300 MWe NOMINAL LOAD

7.0 CONCLUSIONS

7.0 CONCLUSIONS

The primary objective of the Phase I test effort was to document the existing condition of Unit 4 and to establish the "as-found" NO emissions under short-term well controlled conditions and under long-term normal System Load Dispatch conditions. In addition, other important performance data related to the present operation of the boiler were documented for comparison to those measured during subsequent Phases after retrofit of low NO combustion control techniques. A secondary objective of this phase was to establish protocols for data collection and instrumentation operation for subsequent phases of the demonstration.

The following paragraphs provide brief discussions of the conclusions that can be drawn for the short-term and the long-term test results. Conclusions related to the comparison of the short- and long-term results are also presented. After the completion of Phase II (and subsequent Phases), comparative analyses will be perform to assess the effectiveness of the individual NO control techniques with respect to the Baseline emissions. Conclusions for these comparative analyses will be presented at that time.

7.1 Short-Term Characterization Tests

During both the Diagnostic and Performance portions of this test effort, the coal supply remained relatively constant and no significant difficulties with Unit 4 equipment were experienced. The initial test plan was established based upon the then known characteristics of the unit. Upon initiation of the test effort it was discovered that considerably more time was required to establish satisfactory test conditions than was anticipated. This resulted in fewer than anticipated tests being performed (41 initially planned vs. 36 performed) in the time allotted for the Diagnostic test portion of the testing. This finding will be incorporated into the plans for subsequent phases of the project.

During the Short-Term testing, protocols were established for test procedures and instrumentation operation. Adjustments to the procedures were made and noted and instrumentation data retrieval deficiencies were noted and corrected as required. With the exception of the difficulties with the KVB extractive continuous monitor (ECEM), all major instrumentation problems were rectified during the Short-Term effort. The following paragraphs provide the major conclusions that can be drawn from the short-term test results.

7.1.1 Diagnostic Test Conclusions

The conclusions for the Diagnostic portion of the testing are based primarily upon testing performed at 400 and 480 MWe although a limited number of tests at 185 and 300 MWe were also performed. The major conclusions for the Diagnostic testing are:

1) Due to the variability of the short-term NO data, it was determined that the "Experimental Design" approach to establishing a test matrix was inappropriate for the Diagnostic test portion of the chart-term tests. This was believed to be primarily due to the condition of the burner registers and other as yet undetermined influencing parameters related to establishing identical operating conditions.

2) NO emissions were extremely variable for the seemingly identical operating conditions. At similar conditions, the NO varied as much as 25 percent at high loads. The reasons for this large variation are not known at this time, however, as will be discussed later, the long-term data showed the same high variability.

3) For one operating condition (mill pattern and load) NO trends could be determined if O_2 excursions were performed on the same day and in a monotonic fashion. Trends at the same condition on different days exhibited like patterns which were biased by as much as 15 percent. All of the trends for all loads and mill patterns exhibited increasing NO with increasing O_2, however, the slopes were different.

4) NO emissions generally increased linearly with increasing load. Due to the limited tests at 185 MWe, the trend could not be quantitatively established below 300 MWe. The mean NO value ranged from 750 to 950 ppm over the load range from 300 to 480 MWe.

7.1.2 Performance Test Conclusions

The Performance tests documented the unit characteristics at nominal loads of 300, 400 and 480 MWe. Over the 10 to 12 hour period of the individual performance tests, the unit operated under extremely stable normal operating conditions. The conclusions for the Performance tests are:

1) The NO scatter evidenced during the Diagnostic tests was also present during the tests for nearly identical operating conditions (mill pattern and load).

2) NO and O_2 spatial distributions within the economizer exit ducts were dissimilar for identical operating conditions on successive days of testing. This indicated that the combustion characteristics were different for as yet undetermined reasons. The absolute (average) levels of O_2 were nearly identical for the

successive days testing, however the NO levels differed by as much as 150 ppm (15 %) at 480 MWe.

3) Combustion air flow imbalances from front to rear were indicated from the flow measurements, however, no indications of imbalances from side to side were evident. Due to the difficult location for obtaining the flow measurements in the entrance to the windbox, the measurements can only be used as qualitative indications.

4) Furnace exit gas temperatures exceeded 2600 F near the nose based not only on thermocouple readings but on the fact that stainless steel shields melted in this location. O2 measurement showed extremely low levels (well below 1 %) in some regions at the furnace exit.

5) Mill coal particle fineness was near the low end of the acceptable range. The coal fineness was determined to be 70 percent through a 200 mesh screen.

6) ESP entrance particle size was within the range predicted by the EPRI Database Predictions for Precipitator Performance. The mass-median diameter was 18 D with a standard deviation of 2.3 ν.

7) ESP entrance ash resistivity was within the expected range for this coal.

8) LOI was nominally two to five percent as expected. The LOI measurements indicated that LOI increased with decreasing excess oxygen.

7.1.3 Verification Test Conclusions

Based upon the results of eleven tests at high loads (400 and 480 MWe) performed subsequent to the long-term testing, it can be concluded that no significant changes in NO characteristics occurred between the short-term and verification testing.

7.2 Long-Term Characterization Tests

Long-term testing took place from late December 1989 through early April 1990. During this period the KVB Extractive Continuous Emission Monitor (ECEM) was operated 24 hours per day except during periods of repair and calibration. Early in the long-term testing the ECEM experienced operational difficulties related to SO3 contamination of the sample entering the monitors. This difficulty prevented obtaining data for all of the unit operating days during the long-term test period. Sufficient data was collected to perform meaningful statistical analyses for both engineering and regulatory purposes.

The following paragraphs provide the major conclusions that can be drawn from the long-term test results.

1) Data confirmed that the unit typically operates at high load for the majority of it's on-line time. Data show that over 70 percent of the time the unit operated at loads in excess of 400 MWe.

2) Daily average NO emission levels ranged from approximately 0.8 to 1.3 lb/MMBtu while the daily average load ranged from 360 to 460 MWe.

3) Data for the various mill patterns indicated that NO increased with increasing O2. The 95 percent confidence intervals for NO emissions at high load mill patterns was in the order of ±0.2 lb/MMBtu about the mean.

4) The mean load characteristics showed that NO generally increased as load increased from 180 to 480 MWe. Emissions ranged from 1.0 to 1.27 lb/MMBtu over the load range. The 95 percent confidence intervals for NO emissions over the load range was in the order of ± 0.2 lb/MMBtu about the mean.

5) Based upon 30-day rolling averages, the data showed that the average load slowly decreased from 415 to 400 MWe over the period of the testing. 30-day rolling average NO decreased from slightly above 1.2 lb/MMBtu to 1.1 lb/MMBtu.

6) Statistical analyses indicated that the data were autocorrelated with a correlation coefficient of $\rho = 0.54$. The data are therefore autocorrelated (time dependent).

7) Non-time dependent ($\rho = 0$) analyses resulted in an achievable emission level of 1.18 lb/MMBtu for the load scenario experienced during the long-term testing. Time dependent ($\rho = 0.54$) resulted in an achievable emission limit of 1.24 lb/MMbtu which was moderately higher than the non-time dependent analysis. Uncertainty analyses of the data indicated that the upper bound of the correlation coefficient would result in an achievable emission limit of 1.55 lb/MMBtu (30 % higher than for $\rho = o$) .

7.3 Short-Term/Long-Term Comparison Conclusions

After completion of the long-term testing it was discovered that the mill patterns (mills-out-of-service) chosen for evaluation during the short-term test period were not those most frequently used during normal operation as evidenced by the long-term test results. This did not compromise the analysis of the long-term data, however, as will be seen in the comparison of short- and long-term data, few direct comparisons can be made. Only data for the load range comparison and the comparison of two mill patterns - one at 400 MWe and one at 480 MWe - could be made.

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

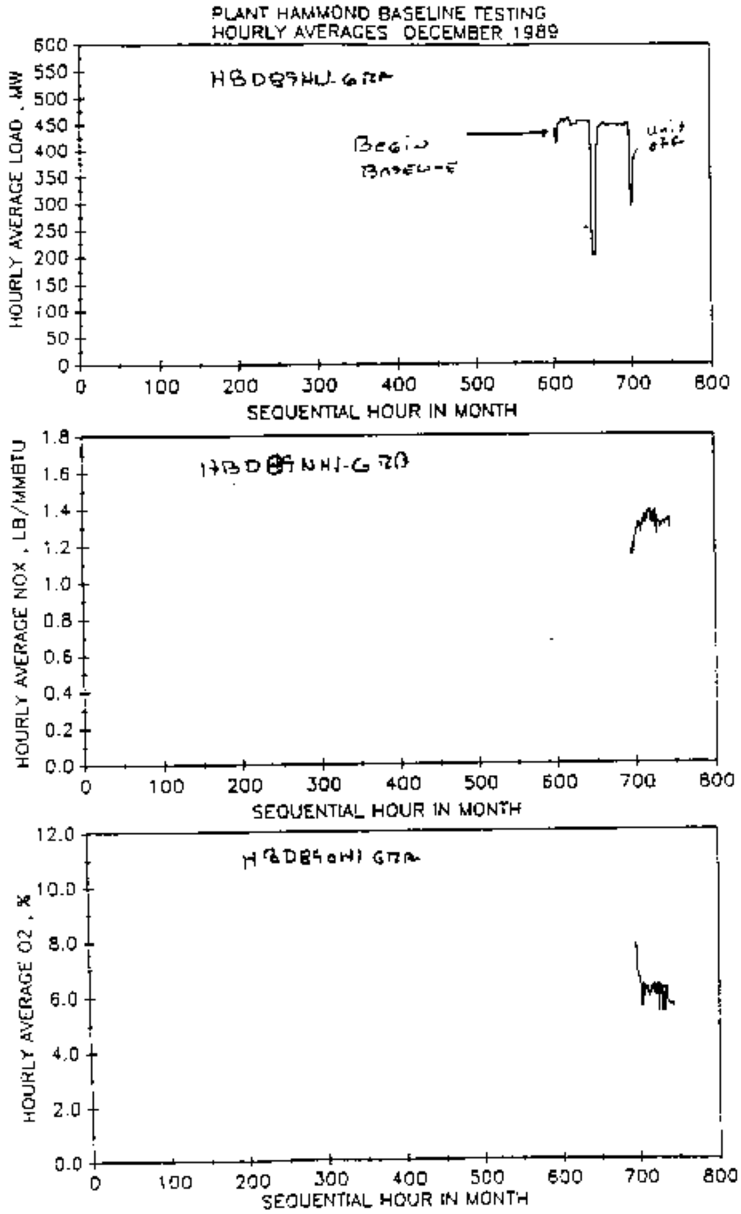
1) In general, the NO trends were similar for both shortand long-term data. Where slopes (NO vs O_2) could be defined from the data, they agreed to a reasonable extent for both test series. The high load (480 MWe) short-term NO trends were not defined by one slope and consequently, a valid quantitative comparison could not be made. The range of slopes for this condition were, however, similar to the long-term mean slope.

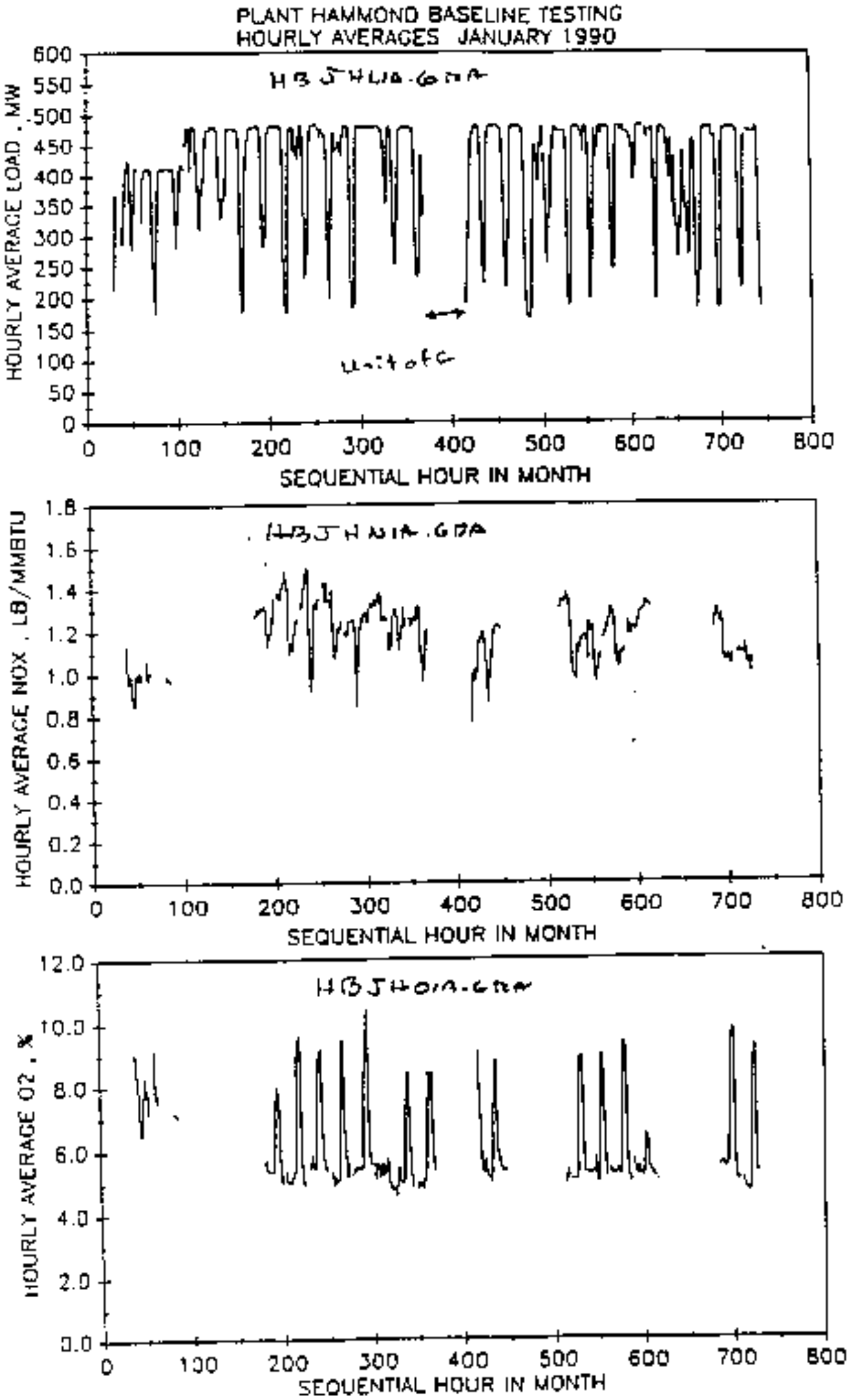
2) At high load conditions (400 and 480 MWe), the upper bound of the NO emissions for the short-term data was well above the upper bound of the 95 percent confidence band. Few short-term data point fell below the lower confidence band.

APPENDIX A

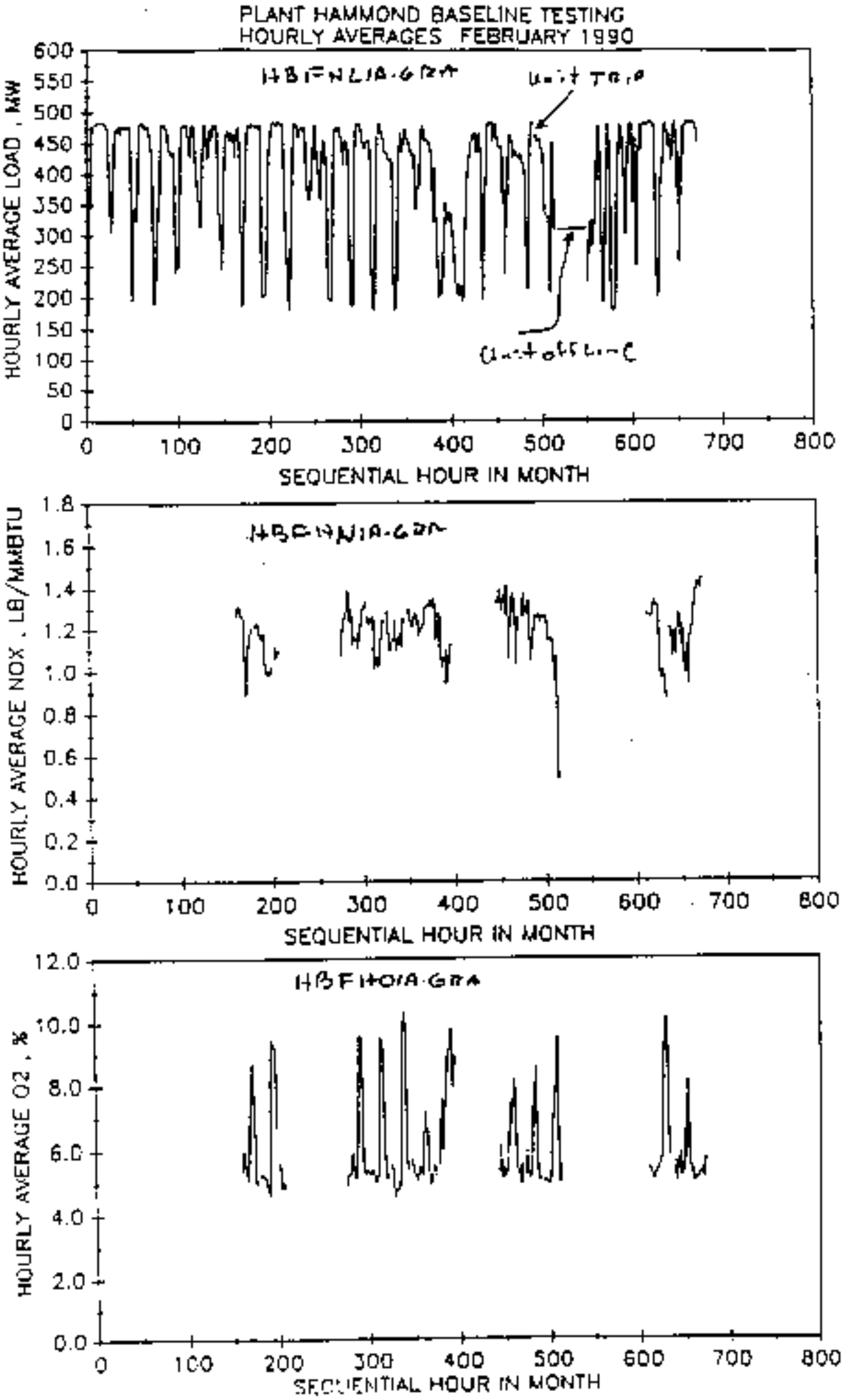
APPENDIX A

SUPPORTING GRAPHICAL AND TABULAR STATISTICAL ANALYSES

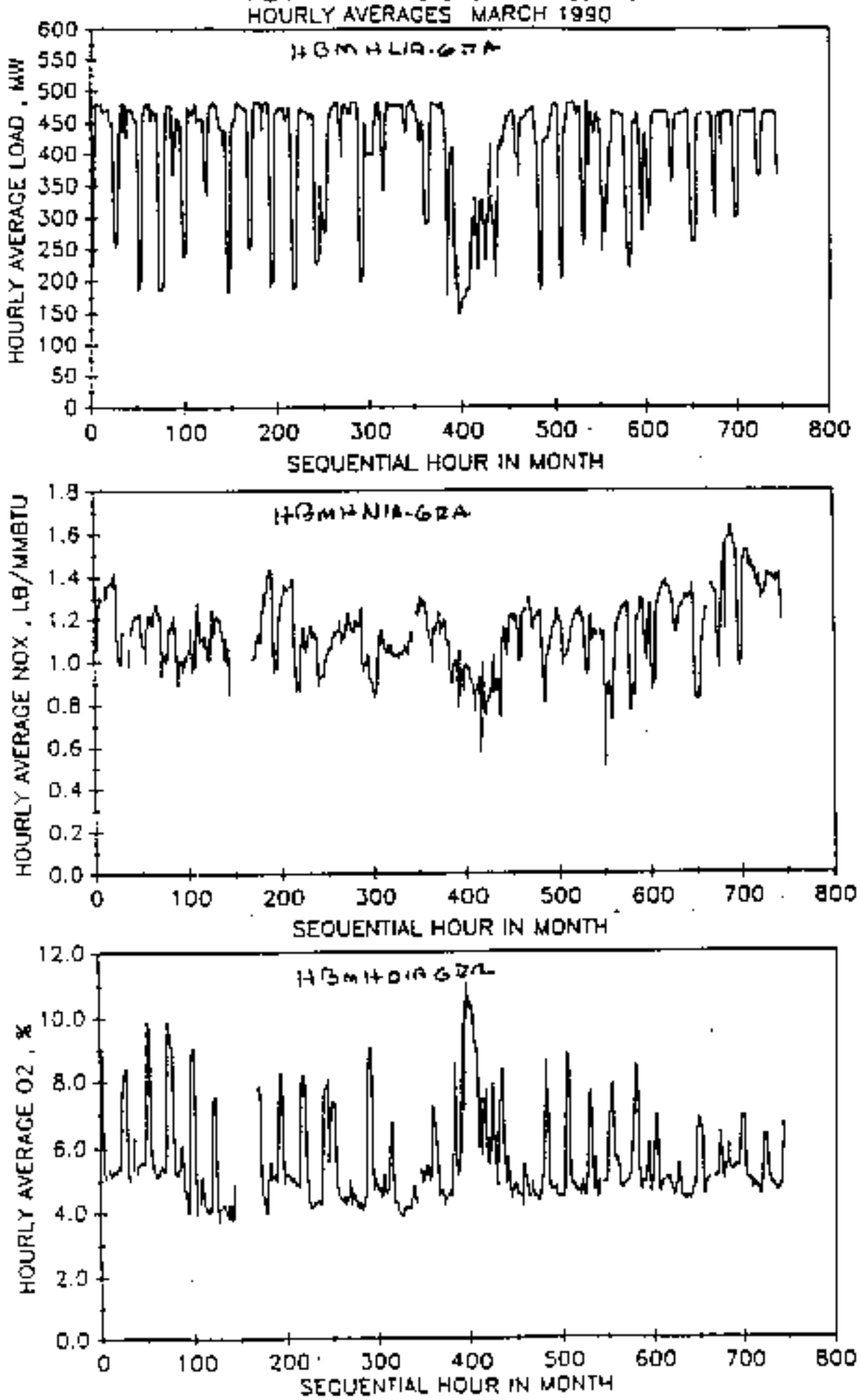

PLANT HAMMOND BASELINE TESTING
HOURLY AVERAGES DECEMBER 1989
HOURLY AVERAGE LOAD, MW
SEQUENTIAL HOUR IN MONTH
HOURLY AVERAGE NOX, LB/MMBTU
SEQUENTIAL HOUR IN MONTH
HOURLY AVERAGE O2, %
SEQUENTIAL HOUR IN MONTH

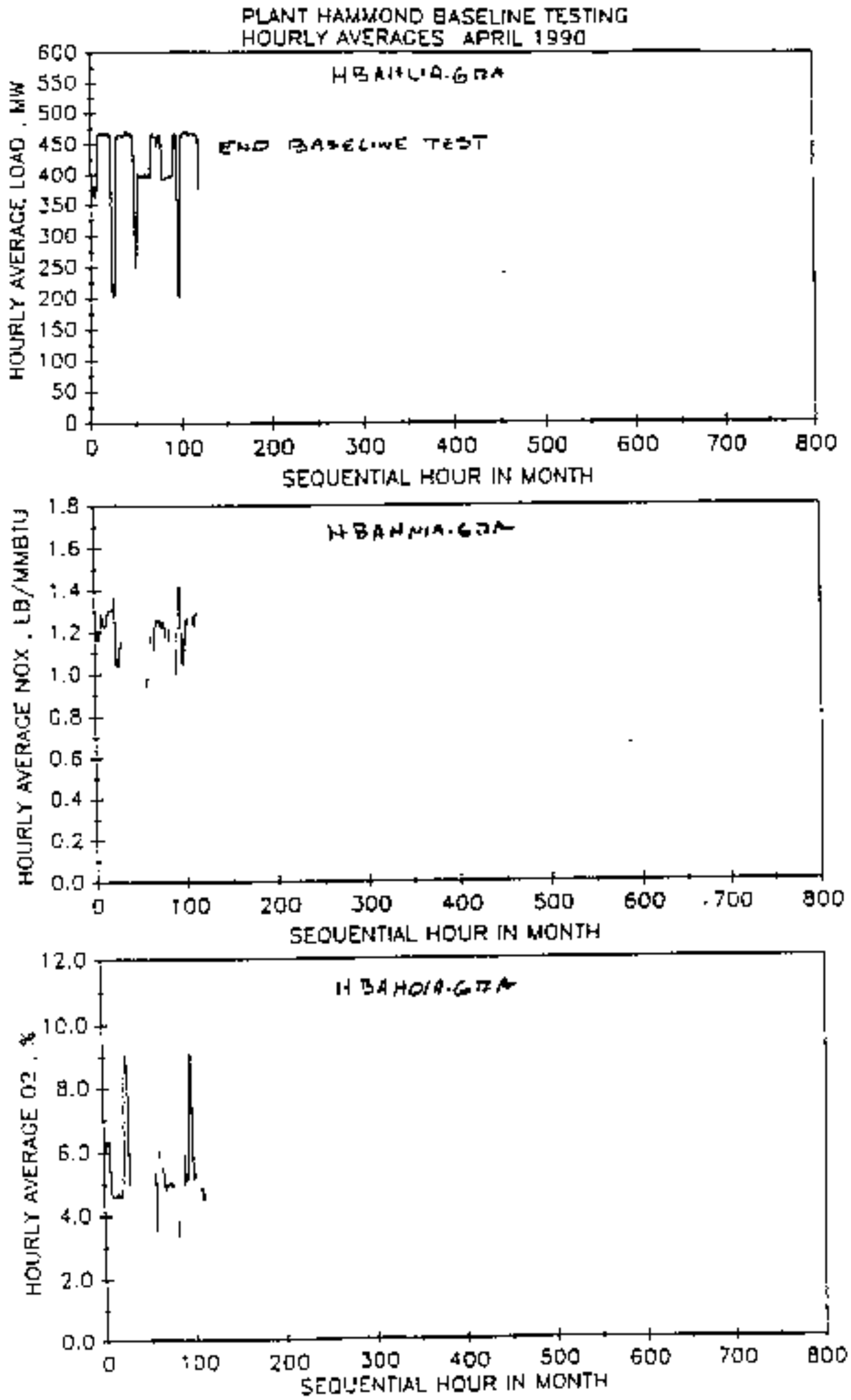


PLANT HAMMOND BASELINE TESTING
HOURLY AVERAGES JANUARY 1990
HOURLY AVERAGE LOAD, MW
SEQUENTIAL HOUR IN MONTH
HOURLY AVERAGE NOX, LB/MMBTU
SEQUENTIAL HOUR IN MONTH
HOURLY AVERAGE O2, %
SEQUENTIAL HOUR IN MONTH


PLANT HAMMOND BASELINE TESTING
HOURLY AVERAGES FEBRUARY 1990
HOURLY AVERAGE LOAD , MW
SEQUENTIAL HOUR IN MONTH
HOURLY AVERAGE NOX , LB/MMBTU
SEQUENTIAL HOUR IN MONTH
HOURLY AVERAGE O2 , %
SEQUENTIAL HOUR IN MONTH

PLANT HAMMOND BASELINE TESTING
HOURLY AVERAGES MARCH 1990





PLANT HAMMOND BASELINE TESTING
HOURLY AVERAGES APRIL 1990
HOURLY AVERAGE LOAD, MW
END BASELINE TEST
SEQUENTIAL HOUR IN MONTH
HOURLY AVERAGE NOX, LB/MMBTU
SEQUENTIAL HOUR IN MONTH
HOURLY AVERAGE O2, %
SEQUENTIAL HOUR IN MONTH

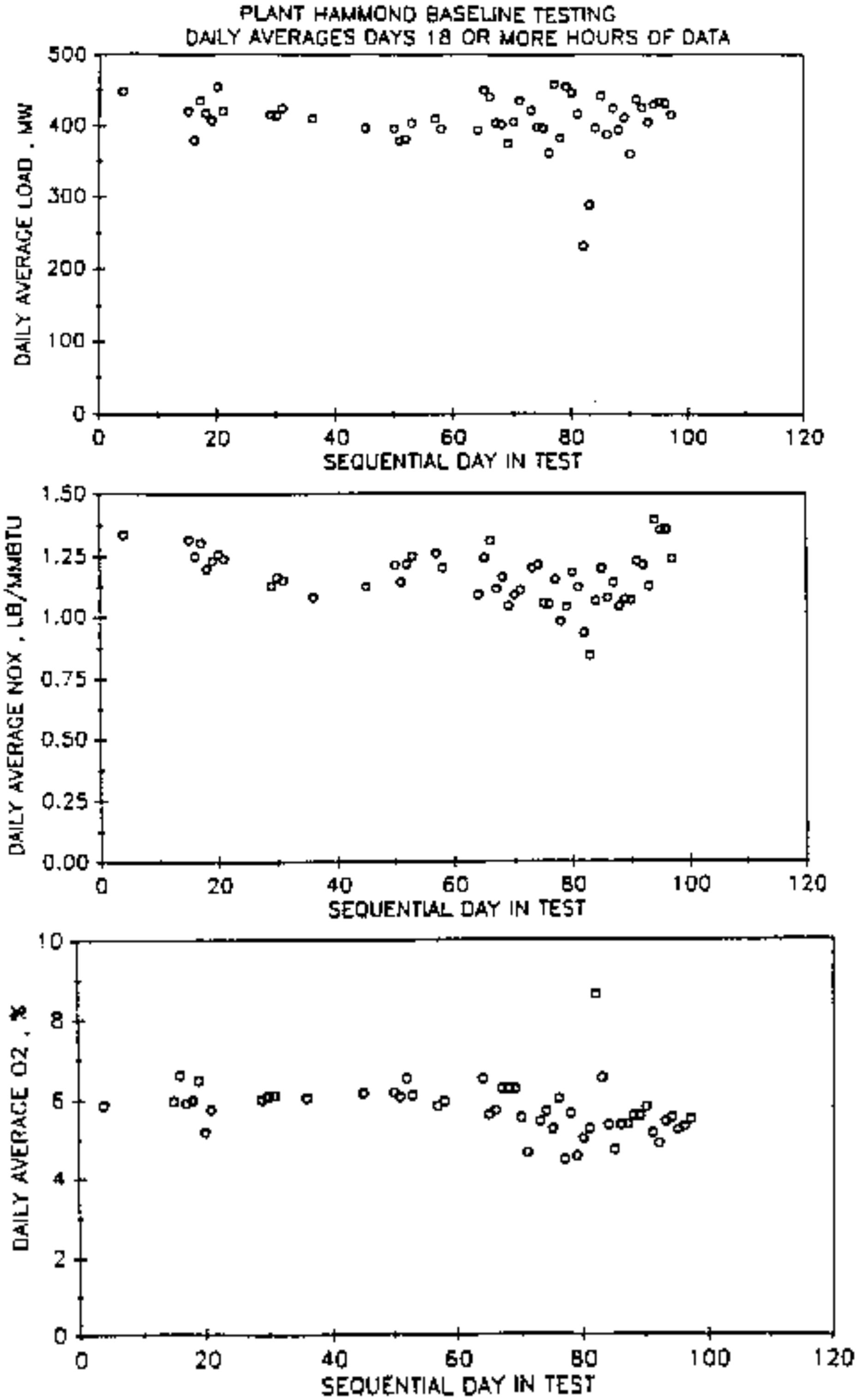

PLANT HAMMOND BASELINE TESTING
DAILY AVERAGES DAYS 18 OR MORE HOURS OF DATA
DAILY AVERAGE LOAD , MW
500
400
300
200
100
0
0 20 40 60 80 100 120
SEQUENTIAL DAY IN TEST
DAILY AVERAGE NOX , LB/MMBTU
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0 20 40 60 80 100 120
SEQUENTIAL DAY IN TEST
DAILY AVERAGE O2 , %
10
8
6
4
2
0
0 20 40 60 80 100 120
SEQUENTIAL DAY IN TEST

TABLE 6.1.1. PLANT HAMMOND BASELINE TESTING
WITHIN-DAY AVERAGES

HOUR	N	LOWER 95%	LOAD AVERAGE	UBPER 95%	LOWER 95%	O2 AVERAGE	UPPER 95%	LOWER 95%	Nox AVERAGE	UPPER 95%
1	64	185.810	289.661	453.19	4.9420	7.50183	9.517	0.853	1.06147	1.2860
2	64	183.420	277.850	446.17	5.3500	7.65886	9.551	0.861	1.05070	1.3030
3	64	181.920	272.741	444.70	5.0560	7.80395	9.760	0.863	1.05166	1.2920
4	63	187.120	293.553	446.98	5.0560	7 55562	9.789	0.862	1.06386	1.3210
5	64	197.570	340.295	463.92	4.9240	6.83248	9.670	0.842	1.09052	1.3320
6	63	267.330	405.246	481.29	4.4760	5.83792	8.866	0.874	1.12311	1.3390
7	6l	307.540	440.743	482.86	4.2720	5.40175	6.898	0.928	1.14700	1.3540
8	58	261.740	442.937	483.41	4.2630	5.32231	7.929	0.774	1.14416	1.4100
9	52	264.730	437.682	483.77	4.2640	5.43321	7.870	0.904	1.16133	1.4140
10	49	276.510	438.675	484.46	4.1380	5.37576	7.730	0.969	1.17196	1.3460
11	55	323.640	447.509	482.87	3.9360	5.13142	7.061	0.970	1.18733	1.4010
12	60	307.255	447.867	483.19	4.2865	5.34775	7.528	0.942	1.20783	1.3945
13	65	389.810	453.605	482.22	4.1560	5.24425	7.050	0.967	1.20869	1.3910
14	66	396.120	451.138	482.29	4.3840	5.30468	7.050	0.970	1.21273	1.3930
15	62	364.920	448.856	481.60	4.2950	5.23123	6.250	1.006	1.21674	1.3630
16	62	351.890	446.171	481.55	4.2470	5.24803	7.483	0.953	1.22234	1.3880
17	64	345.610	446.490	483.47	4.0870	5.26606	7.517	0.991	1.22797	1.4120
18	64	368.720	447.982	483.87	4.2280	5.25653	6.250	0.980	1.22925	1.4210
19	64	357.970	451.184	483.30	4.1320	5.21738	6.250	1.011	1.23895	1.4340
20	64	344.240	453.293	482.57	4.1140	5.13500	6.250	0.990	1.23833	1.4390
21	64	412.290	455.356	483.12	4.2310	5.10792	6.250	0.992	1.24220	1.4300
22	64	369.880	447.104	480.80	4.1160	5.15184	6.450	0.991	1.22466	1.4220
23	64	231.340	415.072	477.82	4.1490	5.58003	8.134	0.854	1.18375	1.3940
24	64	185.930	339.418	463.99	4.6590	6.62625	9.059	0.858	1.10466	1.3500

TABLE 6.1.1

TABLE 6.1.2. PLANT HAMMOND BASELINE TESTING
DECEMBER 1989 - APRIL 1990
WITHIN-DAY AVERAGES

MONTH	HOUR	N	LOWER 5%	LOAD AVERAGE	UPPER 95%	LOWER 5%	02 AVERAGE	UPPER 95%	LOWER 5%	NOX AVERAGE	UPPER 95%
12	1	2	436.14	442.08	448.02	5.700	6.025	6.350	1.283	1.327	1.371
12	2	2	342.66	395.39	448.12	6.350	6.564	6.817	1.139	1.260	1.380
12	3	2	297.41	372.94	448.47	6.350	7.079	7.808	1.169	1.280	1.391
12	4	2	291.22	369.10	446.98	6.350	7.025	7.700	1.142	1.267	1.391
12	5	2	298.82	373.22	447.61	6.350	7.079	7.808	1.14B	1.26B	1.387
12	6	2	325.99	386.63	447.26	6.350	6.934	7.517	1.178	1.284	1.389
12	7	2	377.76	411.B3	445.90	5.986	6.302	6.617	1.225	1.290	1.354
12	8	2	388.40	416.91	445.41	5.950	6.250	6.550	1.225	1.274	1.323
12	9	3	390.02	432.42	454.95	5.650	5.983	6.550	1.246	1.304	1.345
12	10	3	392.16	433.09	453.63	5.617	5.939	6.550	1.258	1.294	1.323
12	11	2	453.82	456.33	458.83	5.508	5.579	5.650	1.287	1.307	1.326
12	12	4	443.53	447.66	453.17	5.650	5.916	6.364	1.25B	1.299	1.331
12	13	1	455.44	455.44	455.44	5.650	5.550	5.650	1.342	1.342	1.342
12	14	3	447.69	450.23	454.20	5.550	5.883	6.250	1.252	1.304	1.33d
12	15	2	445.61	44B.19	450.77	5.850	6.050	6.250	1.300	1.305	1.309
12	16	2	449.00	449.13	449.25	5.850	6.050	6.250	1.314	1.335	1.355
12	17	2	442.87	446.84	450.81	5.717	5.984	6.250	1.324	1.325	1.325
12	18	2	439.37	443.54	447.70	5.517	5.884	6.250	1.304	1.305	1.306
12	19	2	444.33	444.97	445.61	5.850	6.050	6.250	1.299	1.335	1.371
12	20	2	444.89	447.48	450.07	5.433	5.842	6.250	1.302	1.311	1.319
12	21	2	445.65	447.45	449.24	5.350	5.800	6.250	1.313	1.315	1.317
12	22	2	443.75	446.03	448.30	5.350	5.800	6.250	1.28B	1.298	1.308
12	23	2	444.80	447.36	449.91	5.350	5.800	6.250	1.283	1.311	1.339
12	24	2	445.78	447.11	448.43	5.350	5.800	6.250	1.301	1.326	1.350

TABLE6.1.2

TABLE 6.1.3. PLANT HAMMOND BASELINE TESTING
DECEMBER 1989 - APRIL 1990
WITHIN-DAY AVERAGES

MONTH	HOUR	N	LOWER 5%	LOAD AVERAGE	UPPER 95%	LOWER 5%	02 AVERAGE	UPPER 95%	LOWER 5%	NOX AVERAGE	UPPER 95%
1	1	16	182.21	257.07	481.33	5.350	8.267	9.463	0.841	1.063	1.351
1	2	16	181.12	254.28	482.02	5.350	8.404	9.516	0.861	1.072	1.353
1	3	16	175.15	264.33	483.12	5.550	8.322	9.7S0	0.959	1.096	1.385
1	4	16	183.68	286.14	481.78	5.750	8.054	9,799	0.969	1.120	1.385
1	5	16	193.30	349.99	482.26	5.508	7.123	10.450	1.007	1.145	1.343
1	6	16	282.06	422.10	483.99	4.917	5.988	9.225	0.970	1.150	1.319
1	7	16	412.73	465.48	484.50	4.917	5.486	7.150	0.967	1.174	1.306
1	8	14	222.35	456.92	483.41	4.792	5.492	9.083	0.766	1.185	1.359
1	9	13	264.73	456.67	483.77	4.750	5.536	7.870	0.979	1.191	1.344
1	10	10	292.78	455.66	483.47	4.833	5.569	7.193	0.986	1.176	1.346
1	11	10	329.04	455.45	482.57	4.750	5.625	7.058	0.970	1.204	1.344
1	12	13	297.61	440.65	483.19	5.122	5.955	9.133	0.961	1.181	1.382
1	13	18	389.81	465.38	482.37	4.650	5.539	7.717	0.967	1.214	1.419
1	14	20	357.32	457.62	483.35	4.642	5.598	8.253	O.980	1.206	1.396
1	15	18	287.07	451.49	482.60	4.975	5.611	9.042	1.006	1.207	1.354
1	16	17	289.04	448.84	482.40	4.850	5.611	8.700	0.953	1.216	1.372
1	17	17	315.06	456.97	484.17	4.875	5.597	8.258	0.991	1.240	1.431
1	18	16	368.72	467.70	484.17	4.743	5.403	7.950	0.980	1.252	1.444
1	19	16	395.63	472.45	483.30	4.664	5.362	7.800	0.997	1.266	1.482
1	20	16	412.20	474.16	484.05	4.698	5.293	7.008	0.913	1.267	1.493
1	21	16	423.93	474.65	483.95	4.706	5.285	6.450	0.851	1.264	1.501
1	22	16	338.19	462.46	481.67	4.634	5.407	7.708	0.852	1.235	1.432
1	23	16	231.34	440.08	480.04	4.739	5.692	8.842	0.846	1.210	1.408
1	24	16	183.10	340.68	479.06	5.186	7.014	9.603	0.862	1.134	1.314

TABLE 6.1.3

TABLE 6.1.4. PLANT HAMMOND BASELINE TESTING
DECEMBER 1989 - APRIL 1990
WITHIN-DAY AVERAGES

MONTH	HOUR	N	LOWER 5%	LOAD AVERAGE	UPPER 95%	LOWER 5%	02 AVERAGE	UPPER 95%	LOWER 5%	NOX AVERAGE	UPPER 95%
2	1	12	184.48	271.18	435.75	5.627	8.125	9.743	0.953	1.113	1.315
2	2	12	180.12	243.66	426.45	5.722	8.359	9.922	0.886	1.075	1.192
2	3	12	179.47	232.70	378.42	6.624	8.886	10.28l	0.985	1.085	1.245
2	4	11	187.04	246.50	377.60	6.638	8.784	10.338	0.981	1.080	1.203
2	5	12	204.19	304.24	380.07	6.538	7.882	9.779	0.934	1.090	1.270
2	6	12	267.33	391.96	455.71	5.175	6.269	9.114	0.905	1.109	1.357
2	7	11	229.53	438.54	478.93	4.960	5-755	9.7B8	0.864	1.147	1.372
2	8	11	291.63	439.96	483.49	4.941	5.501	7.929	0.827	1.116	1.347
2	9	9	309.76	442.45	487.15	4.930	S.585	7.951	0.479	1.118	1.320
2	10	8	317.52	454.41	484.75	4.993	5.705	8.968	1.036	1.202	1.310
2	11	10	323.64	458.01	484.00	4.814	5.476	8.621	1.029	1.188	1.330
2	12	12	438.05	468.75	484.20	4.905	5.320	5.914	1.078	1.243	1.330
2	13	13	433.75	465.85	483.82	4.961	5.279	6.084	1.085	1.238	1.345
2	14	13	438.53	465.94	483.80	4.939	5.226	5.639	1.057	1.248	1.348
2	15	11	433.49	467.89	483.10	4.817	5.143	5.364	1.094	1.241	1.327
2	16	12	427.70	458.39	482.69	4.739	5.205	5.607	1.121	1.259	1.391
2	17	13	414.00	448.60	484.27	4.489	5.319	5.996	1.089	1.261	1.398
2	18	13	419.52	446.80	485.82	4.699	5.367	5.972	1.075	1.263	1.404
2	19	13	357.97	445.69	484.73	4.803	5.422	6.968	1.140	1.268	1.428
2	20	13	319.19	443.44	432.19	4.738	5.342	7.559	1.132	1.251	1.426
2	21	13	325.46	443.79	485.03	4.739	5.370	7.281	1.152	1.268	1.430
2	22	13	332.39	435.10	482.41	4.574	5.403	6.781	1.125	1.258	1.392
2	23	13	223.94	399.34	471.14	5.132	5.972	8.472	0.988	1.233	1.439
2	24	13	198.45	340.06	451.34	5.602	6.877	9.489	1.010	1.179	1.446

TABLE6.1.4

TABLE 6.1.5. PLANT HAMMOND BASELINE TESTING
DECEMBER 1989 - APRIL 1990
WITHIN-DAY AVERAGES

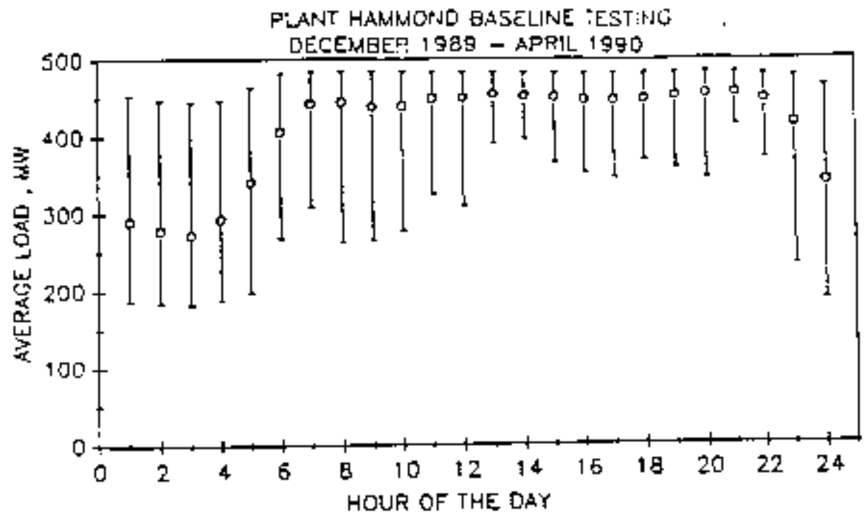
MONTH	HOUR	N	LOWER 5%	LOAD AVERAGE	UPPER 95%	LOWER 5%	02 AVERAGE	UPPER 95%	LOWER 5%	NOX AVERAGE	UPPER 95%
3	1	30	191.61	301.30	453.90	4.139	6.964	8.861	0.846	1.011	1.233
3	2	30	189.94	292.03	445.68	4.429	7.112	8.993	0.763	1.005	1.303
3	3	30	185.07	277.28	433.53	4.528	7.272	9.481	0.814	0.990	1.215
3	4	30	187.12	292.17	426.27	4.813	7.127	9.218	0.808	0.998	1.130
3	5	30	195.10	333.67	454.43	4.813	6.449	9.040	0.773	1.036	1.255
3	6	30	207.08	400.96	478.99	4.433	5.547	8.866	0.826	1.097	1.339
3	7	30	290.63	431.26	485.01	4.170	5.137	6.898	0.829	1.117	1.445
3	8	30	261.74	438.95	482.71	4.009	5.124	6.821	0.774	1.121	1.517
3	9	25	.216.12	427.29	479.52	4.100	5.294	7.579	0.904	1.150	1.523
3	10	25	218.48	429.88	481.61	4.138	5.220	7.730	0.912	1.153	1.392
3	11	29	280.90	442.79	480.69	4.042	4.955	7.061	0.864	1.176	1.513
3	12	29	279.97	441.12	480.62	4.085	5.052	7.339	0.845	1. 190	1.501
3	13	30	290.90	442.24	480.70	4. 133	5.056	7.106	0.828	1.188	1.427
3	14	27	326.42	440.09	479.73	4.093	5.092	6.299	0.852	1.189	1.480
3	15	27	297.71	439.41	476.14	4.021	5.009	6.162	0.860	1.193	1.456
3	16	28	231.00	439.33	480.62	3.898	5.042	7.834	0.847	1.195	1.441
3	17	29	231.44	439.55	479.06	3.868	5.05	7.906	0.894	1.199	1.421
3	18	30	233.19	441.32	480.64	4.008	5.082	7.758	0.961	1.207	1.437
3	19	30	279.57	443.43	481.80	4.051	5.005	5.978	0.972	1.208	1.439
3	20	30	316.62	445.45	482.20	3.920	4.941	5.505	0.966	1.205	1.439
3	21	30	366.21	449.66	482.66	4.108	4.87	5.604	0.969	1.206	1.424
3	22	30	379.89	444.70	480.66	3.917	4.85	5.571	0.948	1.190	1.422
3	23	30	246.22	410.41	477.82	3.920	5.283	6.885	0.849	1.136	1.380
3	24	30	184.65	335.44	477.30	4.366	6.272	8.537	0.823	1.039	1.278

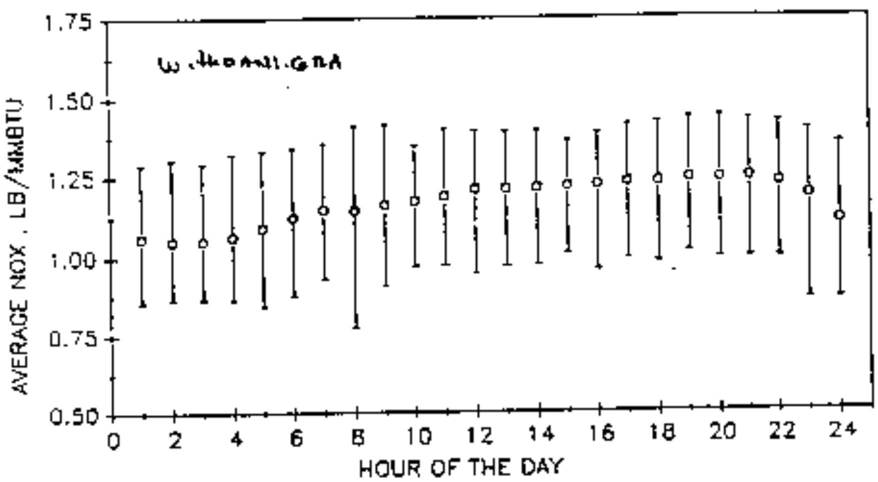
TABLE6.1.5

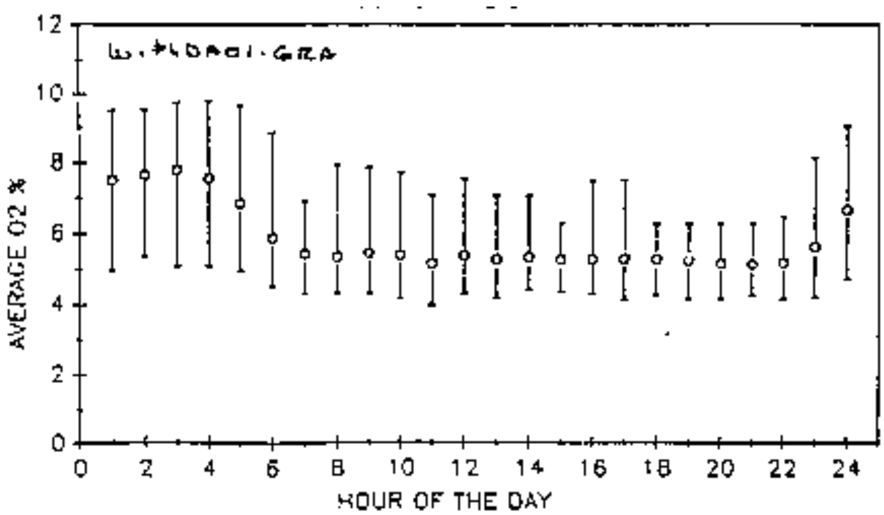
TABLE 6.1.6. PLANT HAMMOND BASELINE TESTING
DECEMBER 1989 - APRIL 1990
WITHIN-DAY AVERAGES

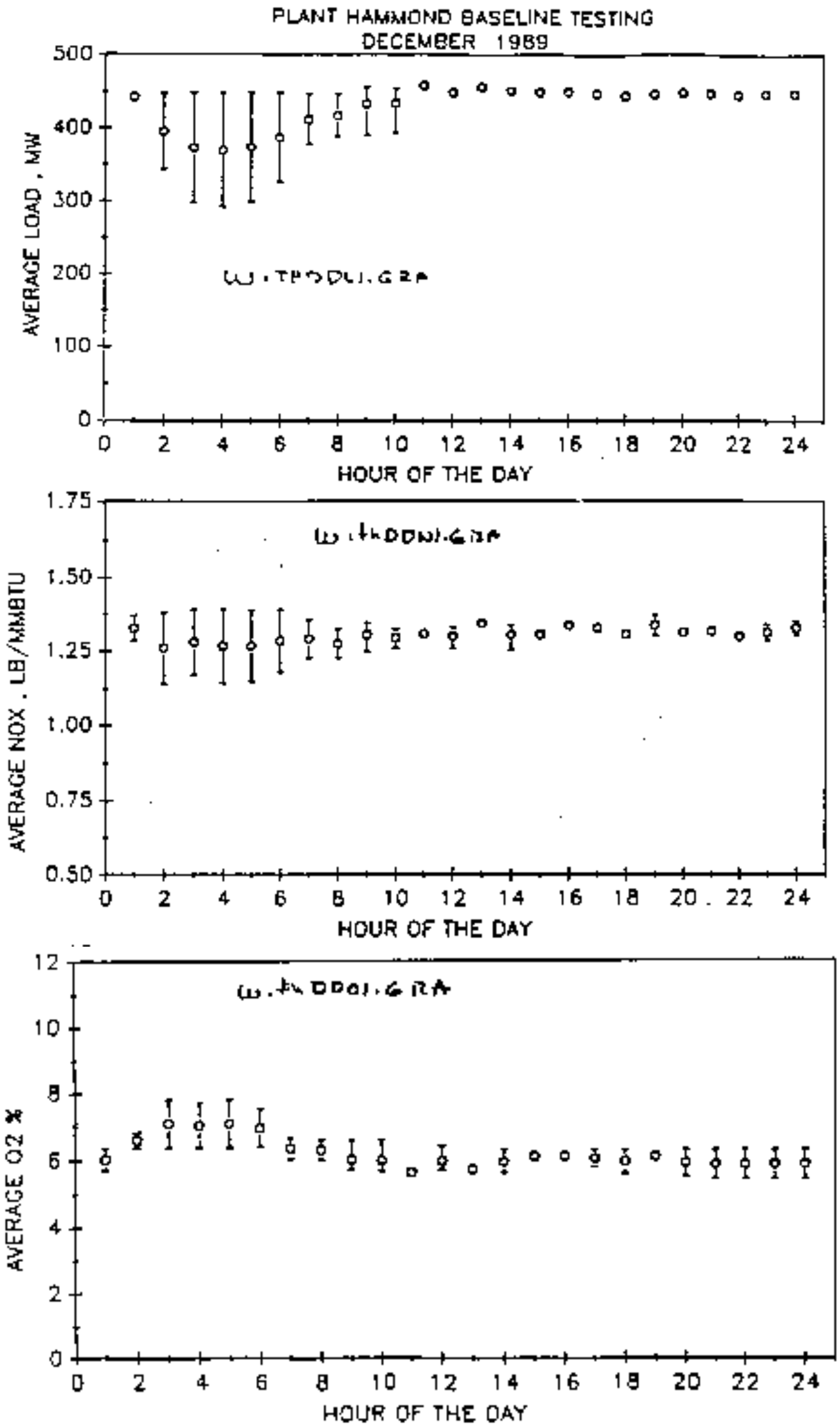
MONTH	HOUR	N	LOWER 5%	LOAD AVERAGE	UPPER 95%	LOWER 5%	02 AVERAGE	UPPER 95%	LOWER 5%	NOX AVERAGE	UPPER 95%
4	1	4	201.60	311.93	443.67	4.942	7.342	9.114	1.045	1.149	1.286
4	2	4	202.07	309.56	447.38	5.075	7.220	9.056	1.038	1.134	1.244
4	3	4	232.61	342.37	466.57	5.024	6.834	8.421	1.031	1.127	1.251
4	4	4	378.85	425.18	463.57	4.970	5.665	6.321	1.123	1.191	1.241
4	5	4	375.16	442.94	467.86	4.864	5.274	6.241	1.157	1.197	1.228
4	6	3	358.28	423.74	469.52	4.904	5.496	6.355	1.155	1.195	1.258
4	7	2	381.79	426.23	470.67	5.353	5.855	6.357	1.222	1.248	1.274
4	8	1	451.62	431.62	451.62	5.058	5.058	5.058	1.295	1.295	1.295
4	9	2	395.34	430.56	465.77	4.673	4.995	5.317	0.934	1.092	1.250
4	10	3	393.10	419.01	467.25	3.813	4.586	5.311	0.969	1.116	1.221
4	11	4	393.90	431.27	467.74	3.284	4.092	5.007	0.985	1.166	1.232
4	12	2	467.08	467.74	468.40	4.567	4.711	4.855	1.221	1.251	1.280
4	13	3	400.75	442.91	467.22	4.554	5.075	5.843	1.141	1.211	1.254
4	14	3	396.12	444.12	469.52	4.417	5.027	6.059	1.186	1.226	1.269
4	15	4	395.98	448.80	467.73	4.484	4.855	5.635	1.265	1.305	1.359
4	16	3	398.69	444.05	468.09	4.672	4.750	4.814	1.257	1.289	1.311
4	17	3	400.63	444.82	467.17	4.534	4.701	4.931	1.107	1.233	1.312
4	18	3	389.67	417.46	466.22	4.550	5.327	5.914	0.996	1.138	1.302
4	19	3	408.35	443.23	467.66	4.583	5.127	5.658	1.070	1.209	1.309
4	20	3	464.76	466.99	469.15	4.561	4.857	5.182	1.261	1.319	1.405
4	21	3	462.17	404.88	467.17	4.768	4.879	5.003	1.227	1.324	1.374
4	22	3	395.17	441.97	467.02	4.958	5.250	5.597	1.260	1.323	1.425
4	23	3	214.11	375.03	461.57	4.963	6.107	8.134	1.038	1.227	1.376
4	24	3	199.82	297.87	461.58	5.031	7.564	9.000	1.071	1.135	1.263

TABLE6.1.6

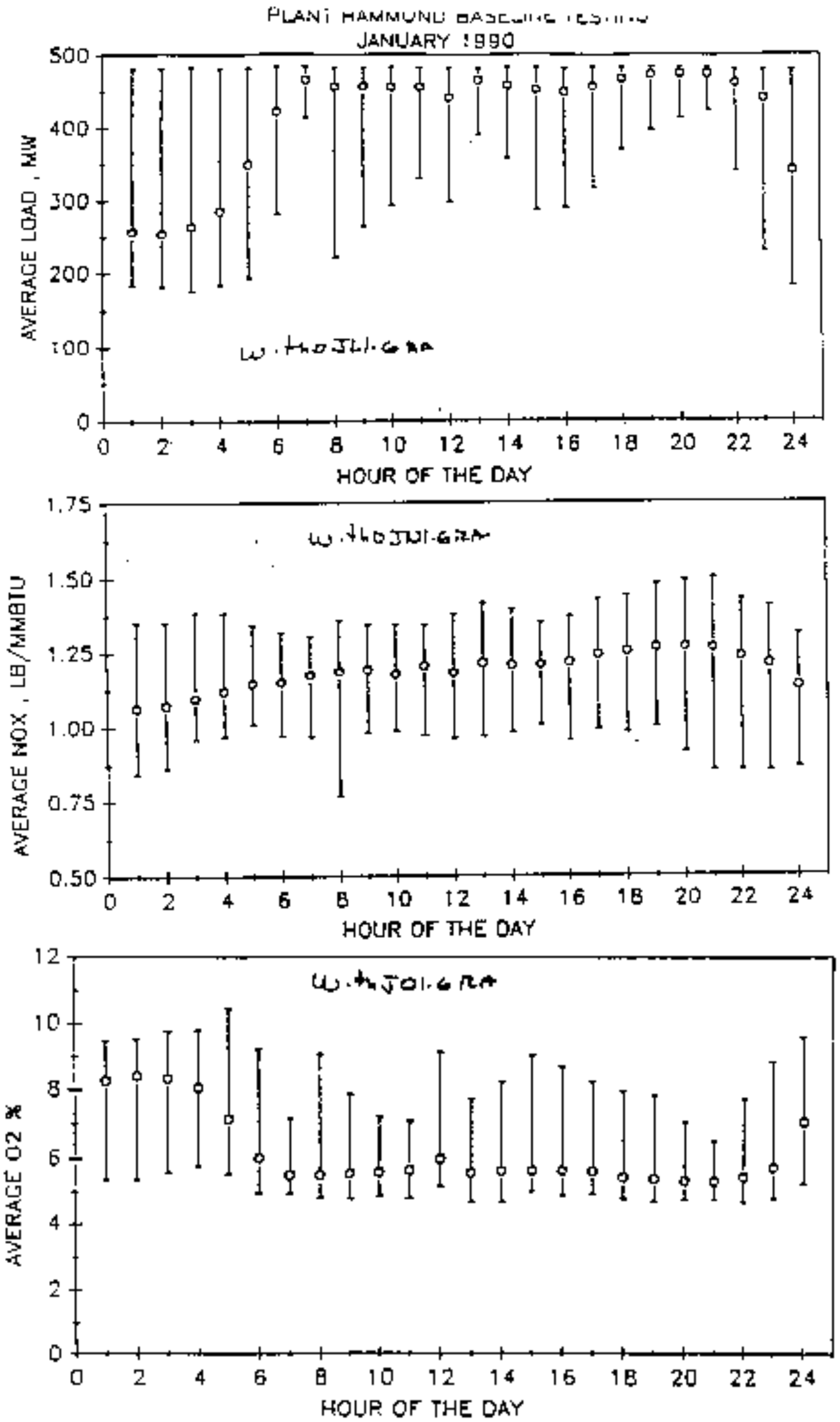

PLANT HAMMOND BASELINE TESTING
DECEMBER 1989 – APRIL 1990
AVERAGE LOAD, MW
HOUR OF THE DAY

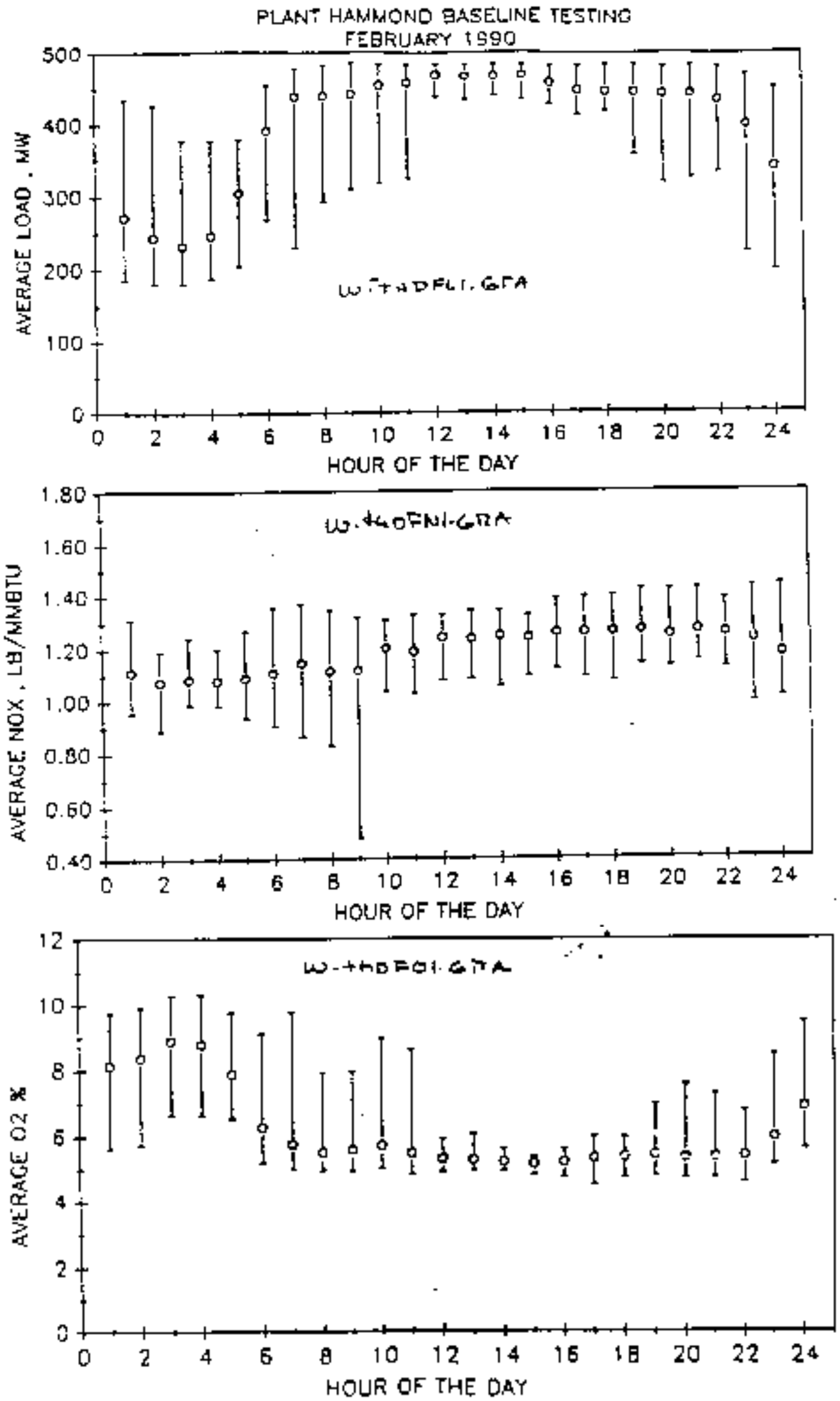

AVERAGE NOX, LB/MMBTU
HOUR OF THE DAY

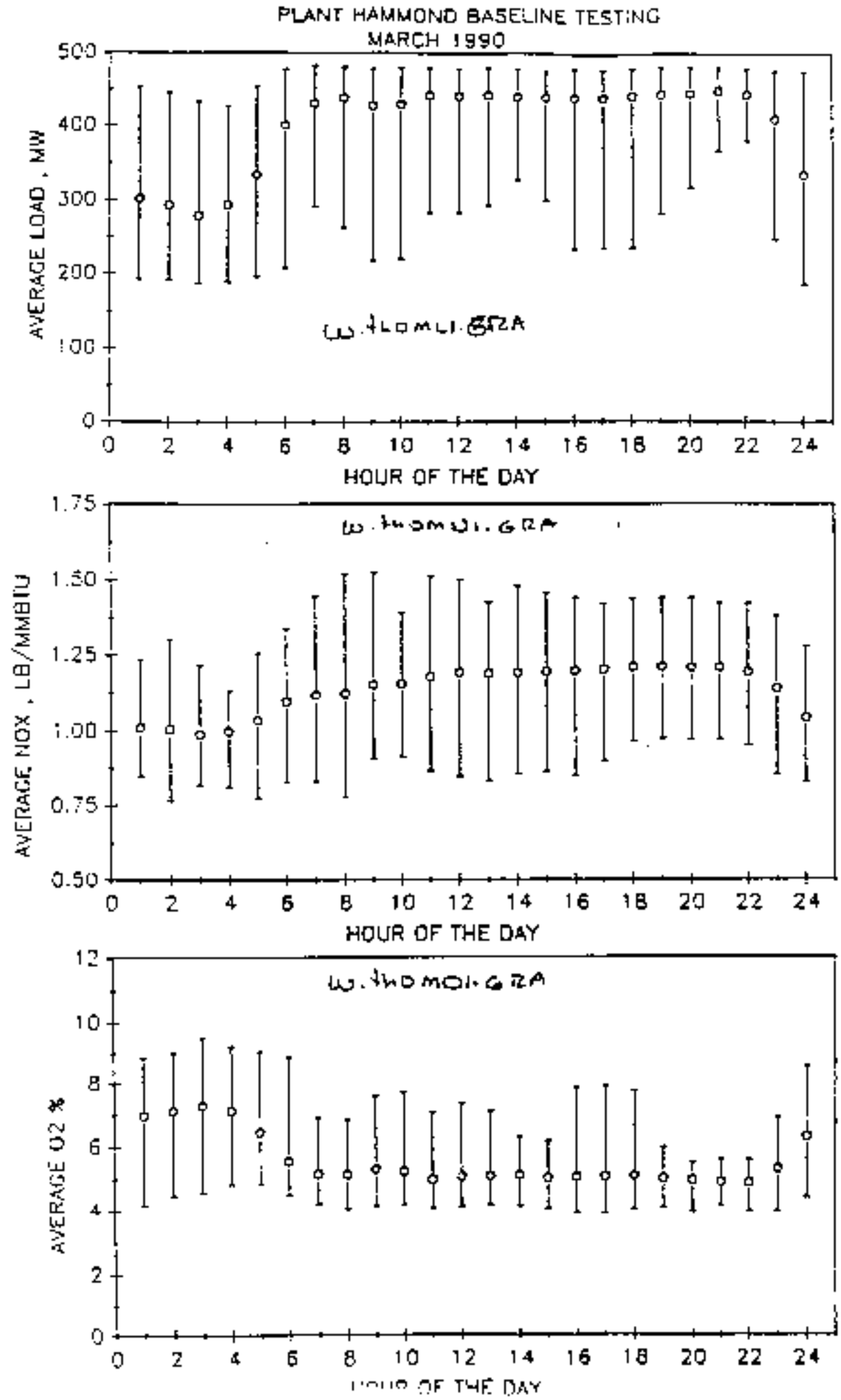

AVERAGE O2 %
HOUR OF THE DAY

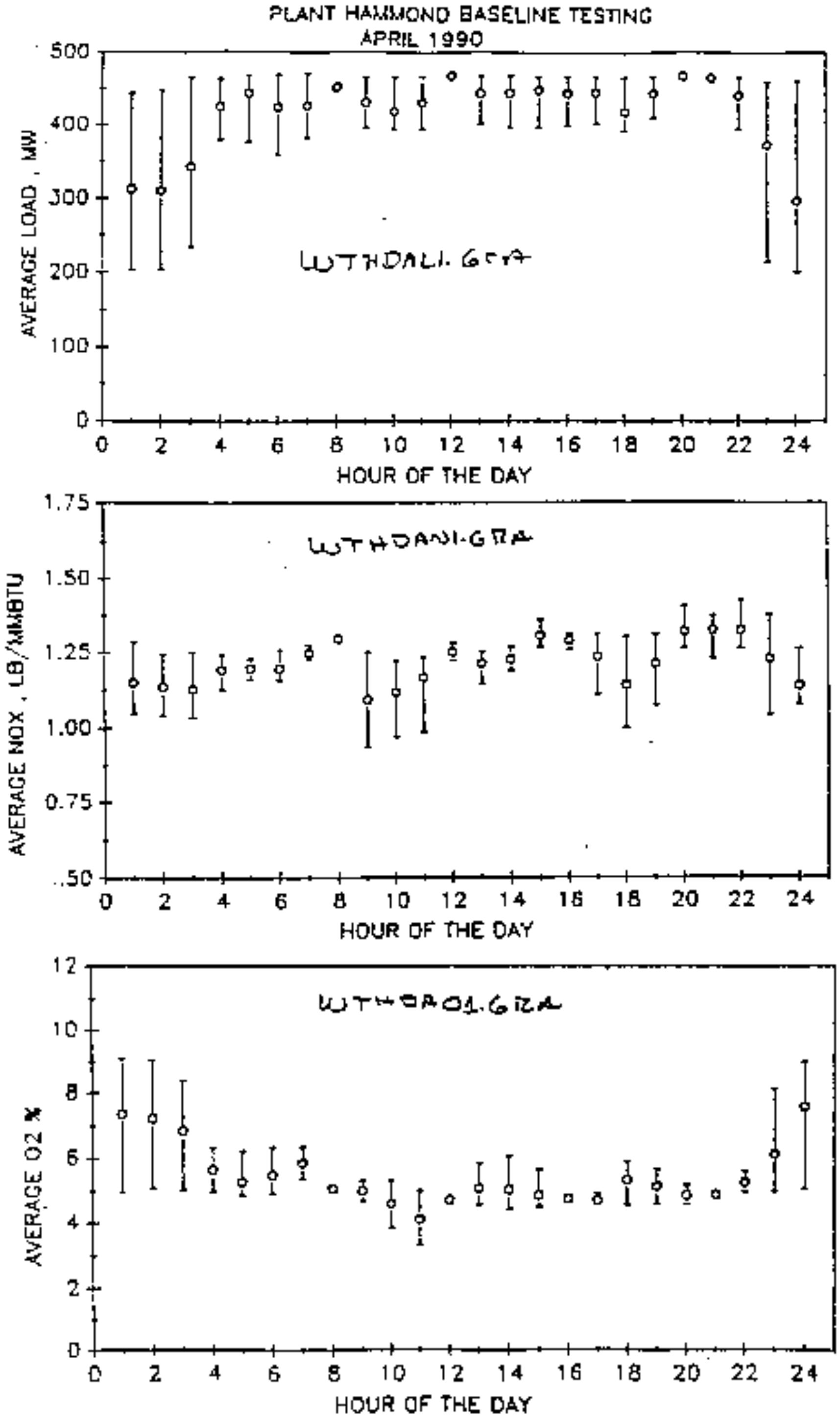


PLANT HAMMOND BASELINE TESTING
DECEMBER 1989
AVERAGE LOAD , MW
500
400
300
200
100
0
HOUR OF THE DAY
0 2 4 6 8 10 12 14 16 18 20 22 24
AVERAGE NOX , LB/MMBTU
1.75
1.50
1.25
1.00
0.75
0.50
HOUR OF THE DAY
AVERAGE O2 %
12
10
8
6
4
2
0
HOUR OF THE DAY

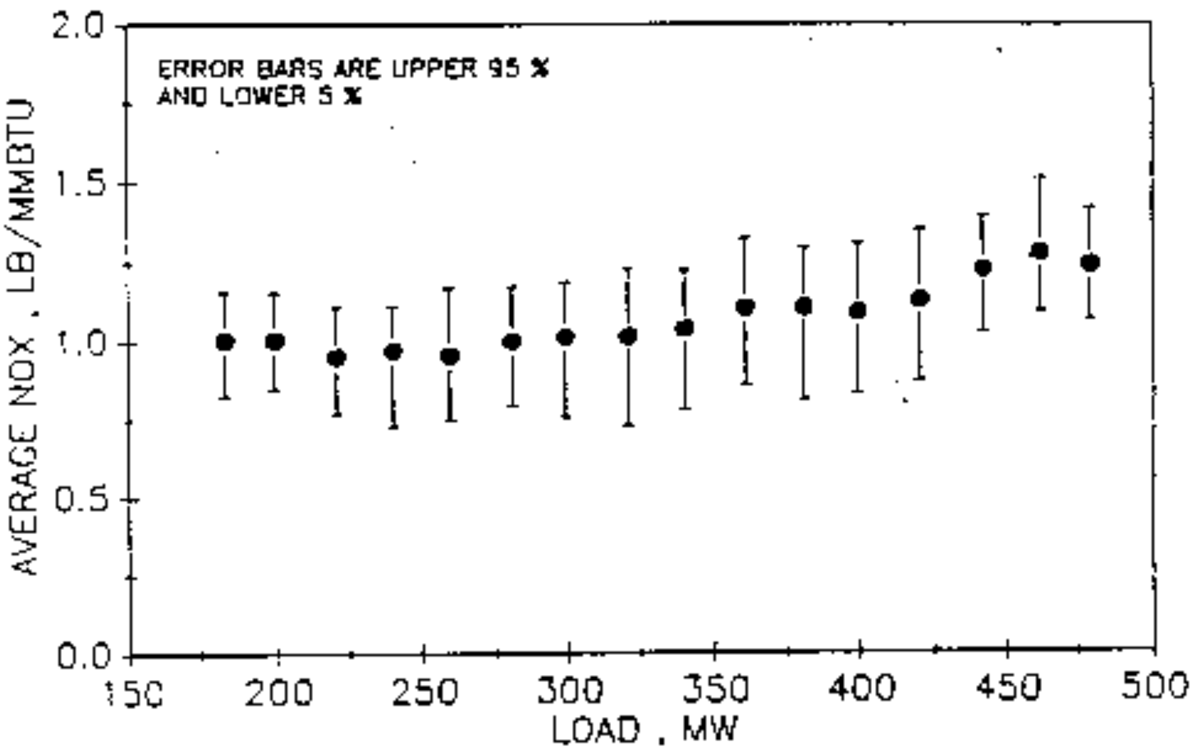

PLANT HAMMOND BASELINE TESTING
JANUARY 1990
AVERAGE LOAD , MW
HOUR OF THE DAY
AVERAGE NOX , LB/MMBTU
HOUR OF THE DAY
AVERAGE O2 %
HOUR OF THE DAY

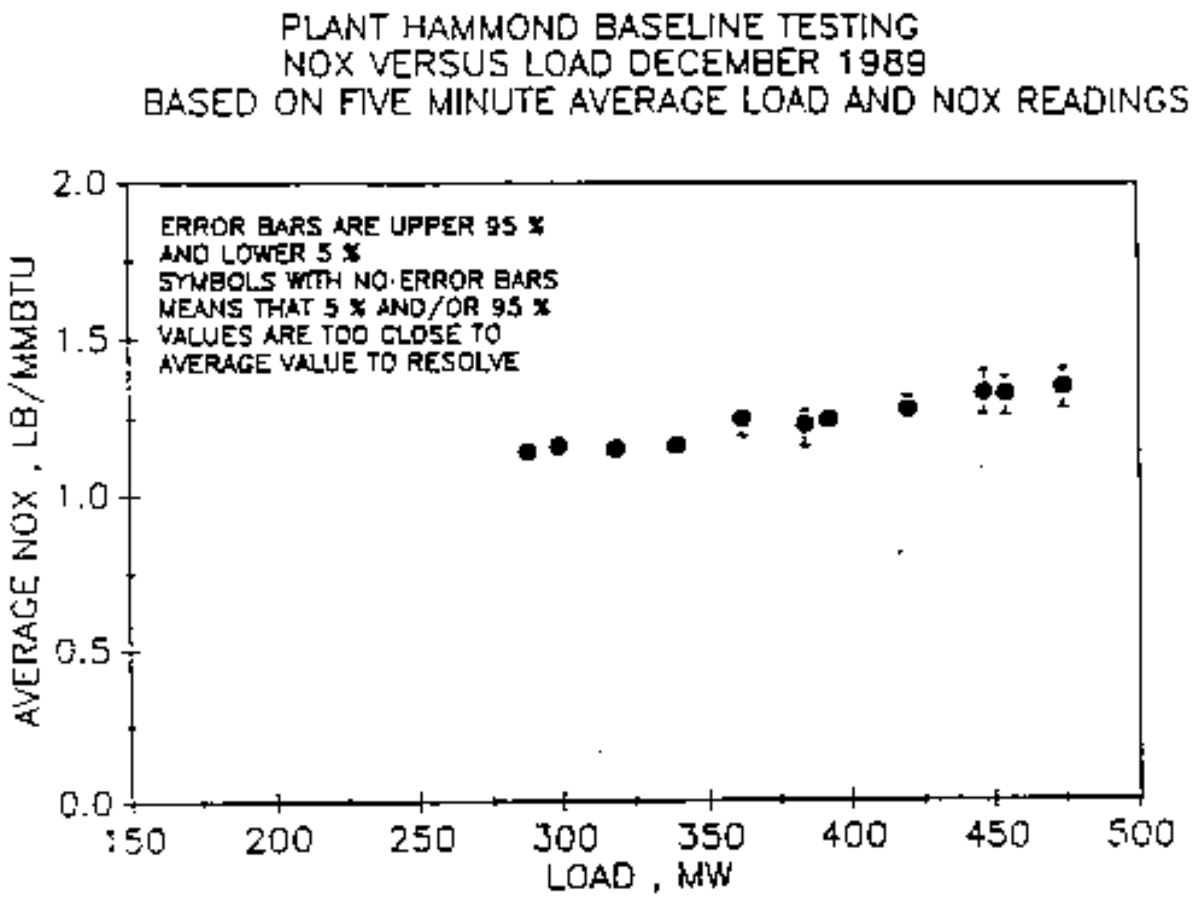

PLANT HAMMOND BASELINE TESTING
FEBRUARY 1990
AVERAGE LOAD, MW
HOUR OF THE DAY
AVERAGE NOX, LB/MMBTU
HOUR OF THE DAY
AVERAGE O2 %
HOUR OF THE DAY


PLANT HAMMOND BASELINE TESTING
MARCH 1990
AVERAGE LOAD , MW
HOUR OF THE DAY
AVERAGE NOX , LB/MMBTU
HOUR OF THE DAY
AVERAGE O2 %
HOUR OF THE DAY

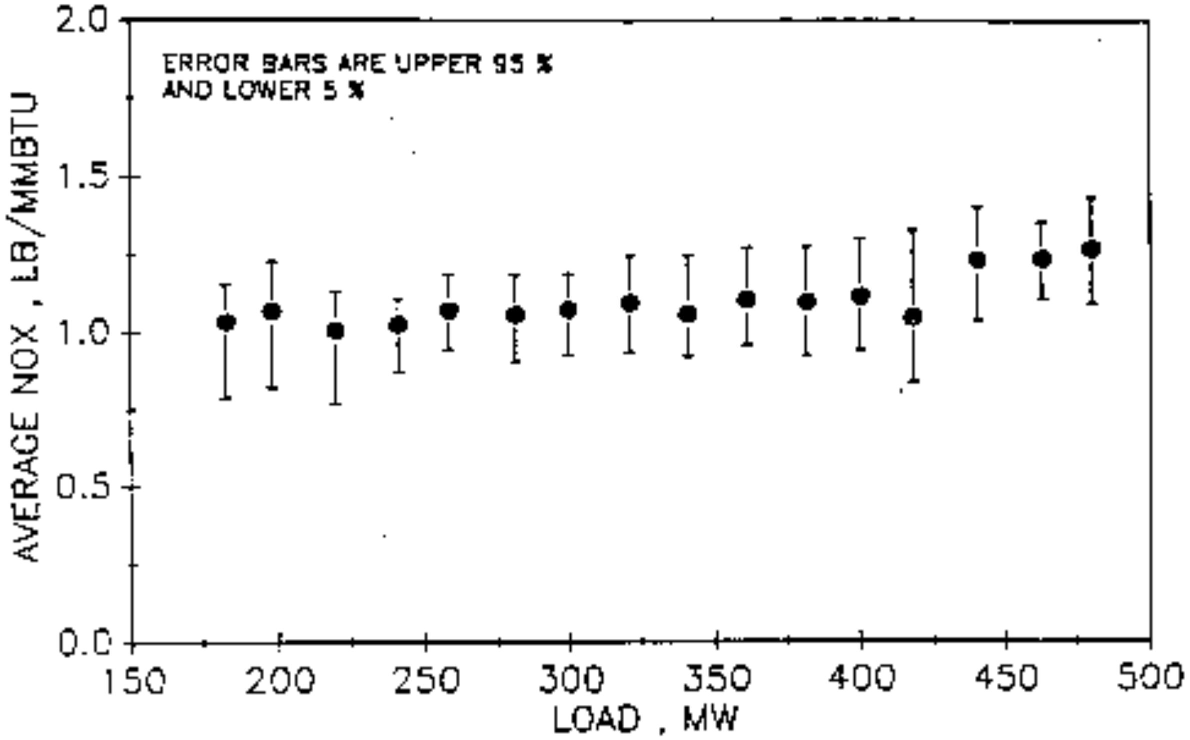

PLANT HAMMOND BASELINE TESTING
APRIL 1990
AVERAGE LOAD , MW
HOUR OF THE DAY
AVERAGE NOX , LB/MMBTU
HOUR OF THE DAY
AVERAGE O2 %
HOUR OF THE DAY

PLANT HAMMOND BASELINE TESTING
NOX VERSUS LOAD DEC 1989 – APRIL 1990
BASED ON FIVE MINUTE AVERAGE LOAD AND NOX READINGS




PLANT HAMMOND BASELINE TESTING
NOX VERSUS LOAD DECEMBER 1989
BASED ON FIVE MINUTE AVERAGE LOAD AND NOX READINGS
ERROR BARS ARE UPPER 95 %
AND LOWER 5 %
SYMBOLS WITH NO ERROR BARS
MEANS THAT 5 % AND/OR 95 %
VALUES ARE TOO CLOSE TO
AVERAGE VALUE TO RESOLVE
AVERAGE NOX , LB/MMBTU
2.0
1.5
1.0
0.5
0.0
150
200
250
300
350
400
450
500
LOAD , MW

PLANT HAMMOND BASELINE TESTING
NOX VERSUS LOAD JANUARY 1990
BASED ON FIVE MINUTE AVERAGE LOAD AND NOX READINGS



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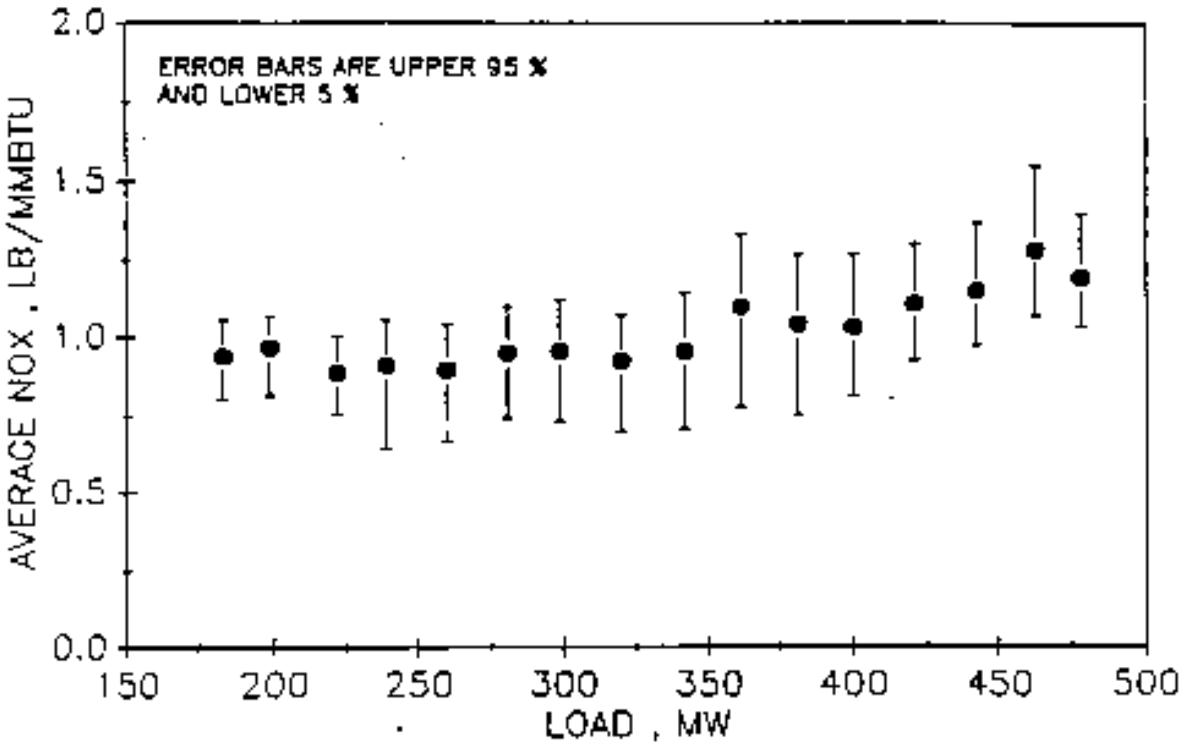
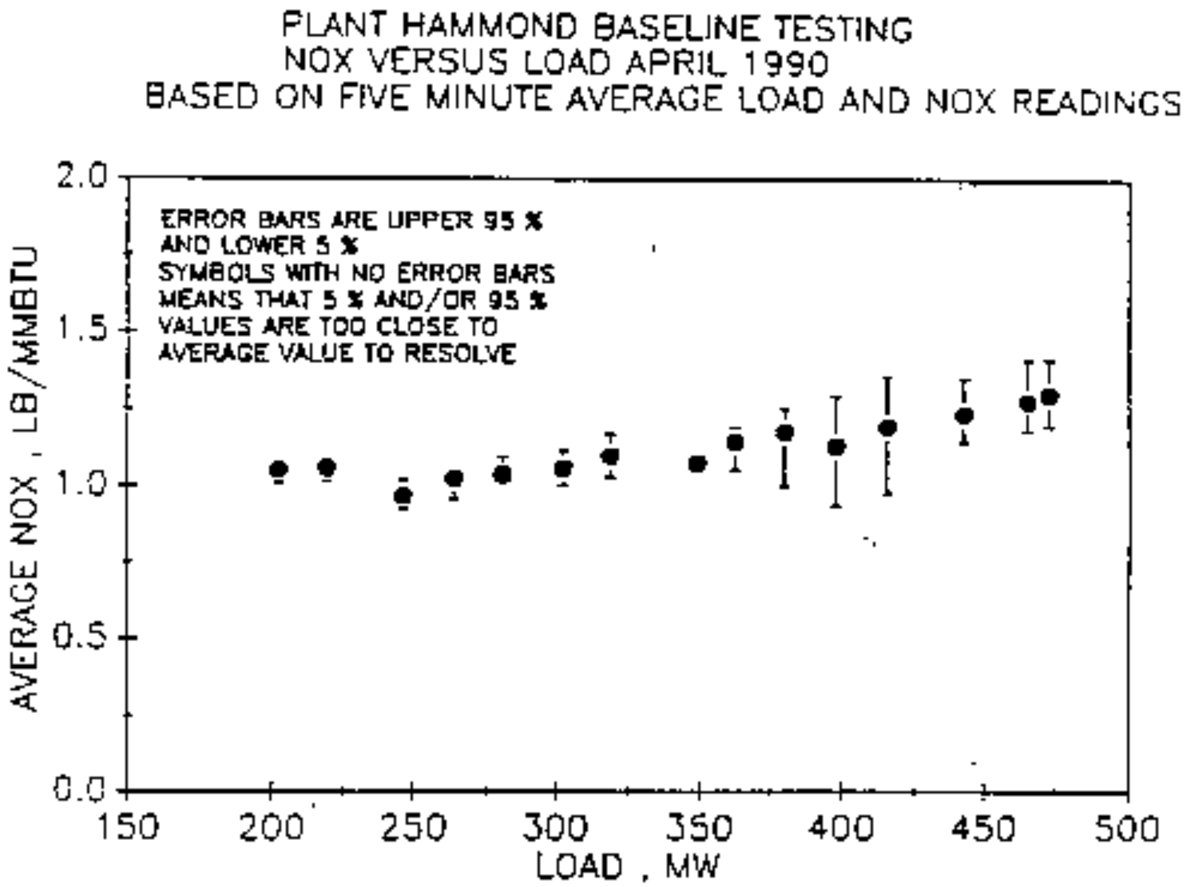
PLANT HAMMOND BASELINE TESTING
NOX VERSUS LOAD MARCH 1990
BASED ON FIVE MINUTE AVERAGE LOAD AND NOX READINGS





PLANT HAMMOND BASELINE TESTING
NOX VERSUS LOAD APRIL 1990
BASED ON FIVE MINUTE AVERAGE LOAD AND NOX READINGS
ERROR BARS ARE UPPER 95 %
AND LOWER 5 %
SYMBOLS WITH NO ERROR BARS
MEANS THAT 5 % AND/OR 95 %
VALUES ARE TOO CLOSE TO
AVERAGE VALUE TO RESOLVE
AVERAGE NOX , LB/MMBTU
2.0
1.5
1.0
0.5
0.0
150
200
250
300
350
400
450
500
LOAD , MW

TABLE 6.2.1.PLANT HAMMOND BASELINE TESTING
AVERAGE BY LOAD RANGE
5-MINUTE DATA
December 1989 - April 1990

		Load			O2			No_x		
Load Range	N	Lower 5%	Average	Upper 95%	Lower 95%	Average	Upper 95%	Lower 5%	Average	Upper 95%
170-190	592	173.0	183.0	189.4	7.30	9.18	10.38	0.822	1.004	1.160
190-210	682	191.1	199.5	208.3	7.75	8.98	10.24	O.843	1.005	1.156
210-230	300	211.0	220.4	229.0	7.08	8.48	9.72	0.767	0.950	1.110
230-250	380	230.9	240.0	248.9	6.60	8.31	9.60	0.725	0.970	1.111
250-270	443	251.1	259.5	268.4	6.34	7.75	9.41	0.747	0.956	1.172
270-290	401	271.6	280.6	288.9	5.89	7.44	8.75	0.791	1.001	1.174
290-310	461	290.9	299.1	308.7	5.59	7.09	8.55	0.757	1.013	1.188
310-330	332	311.2	320.7	329.3	5.22	7.01	8.81	0.727	1.015	1.232
330-350	315	330.6	340.1	348.9	5.11	6.80	8.18	0.776	1.038	1.224
350-370	461	351.1	360.7	368.6	5.05	6.33	7.85	0.855	1.103	1.321
370-390	454	371.2	380.7	389.3	4.80	6.09	7.46	0.807	1.102	1.290
390-410	852	390.9	399.2	408.9	4.36	5.59	7.65	0.826	1.086	1.304
410-430	1031	410.9	420.2	429.2	4.49	5.54	7.15	0.867	1.125	1.347
430-450	1624	431.2	442.0	449.3	4.06	5.24	6.35	1.022	1.222	1.391
450-470	3991	451.8	462.1	469.1	4.15	4.95	5.70	l.O88	1.274	1.510
470-490	5137	471.1	479.1	485.8	4.08	5.00	5.65	1.058	1.236	1.414
490-510	57	490.0	493.1	498.4	4.12	4.75	5.54	1.034	1.199	1.383

TABLE 6.2.1

TABLE 6.2.2. PLANT HAMMOND BASELINE TESTING AVERAGE BY LOAD RANGE
5-MINUTE DATA December 1989

			Load			O2			Nox		
Load Range	Honth	n	Lower 5%	Average	Upper 95%	Lower 95%	Average	Upper 95%	Lower 5%	Average	Upper 95%
170 190	12/89	0									
190 210	12/69	0									
210 230	12/89	0									
230 250	12/89	0									
250 270	12/89	0									
270 290	12/89	7	285.14	287.40	289.74	7.450	7.56	7.750	1.111	1.136	1.159
290 310	12/89	38	290.54	298.49	305.04	7.550	7.78	7.850	1.136	1.156	1.179
310 330	12/89	3	316.44	318.44	322.24	7.350	7.71	7.950	1.122	1.145	1.158
330 350	12/89	4	333.94	339.09	345.54	6.950	7.05	7.350	1.148	1.155	1.162
350 370	12/89	3	352.04	361.37	366.24	6.950	6.95	6.950	1.183	1.240	1.278
370 390	12189	32	3?1.24	383.59	389.64	6.150	6.53	6.950	1.149	1.222	1.267
390 410	12/89	21	390.64	392.02	394.54	6.150	6.49	6.550	1.223	1.238	1.259
410 430	12/89	3	416.44	419.41	421.54	5.550	5.95	6.150	1.238	1.272	1.314
430 450	12/89	334	439.34	445.85	449.54	5.350	6.01	6.350	1.257	1.326	1.396
450 470	12/89	158	450.44	453.71	459.64	5.250	5.73	6.250	1.253	1.322	1.379
470 490	12/89	3	470.84	474.44	481.24	5.350	5.78	6.250	1.275	1.344	1.401
490 510	12/89	0									

TABLE 6.2.2

TABLE 6.2.3. PLANT HAMMOND BASELINE TESTING
AVERAGE BY LOAD RANGE
5-MINUTE DATA
January 1989

			Load			O2			Nox		
Load Range	Honth	n	Lower 5%	Average	Upper 95%	Lower 95%	Average	Upper 95%	Lower 5%	Average	Upper 95%
170 190	l/90	184	173.44	182.72	189.34	8.150	9.237	10.050	0.786	1.034	1.155
190 210	1/90	92	190.24	197.86	208.04	7.750	9.277	10.450	0.620	1.067	1.229
210 230	1/90	102	211.44	214.48	228.14	7.450	8.851	9.666	0.765	1.007	1.131
230 250	1/90	150	231.04	241.08	248.74	7.550	8.649	9.650	0.869	1.025	1.109
250 270	1/90	107	250.64	258.39	267.94	7.750	8.629	9.550	0.940	1.070	1.187
270 290	1/90	127	271.74	280.74	288.74	7.050	9.076	9.150	0.902	1.056	1.187
290 310	1/90	95	291.24	299.25	308.64	6.750	7.905	8.950	O.924	1.073	1.188
310 330	1/90	51	311.34	320.86	329.54	5.950	7.860	9.250	0.932	1.094	1.249
330 350	1/90	52	331.54	340.52	348.~4	4.950	7.326	8.550	0.921	1.O58	1.248
350 370	1/90	94	350.44	360.27	369.14	5.250	6.724	8.250	0.956	1.103	1.272
370 390	1/90	90	371.44	381.08	369.24	4.950	6.471	7.950	0.924	1.096	1.276
390 410	1/90	161	391.14	399.74	408.94	5.257	6.594	7.850	0.939	1.114	1.303
410 430	1/90	271	410.54	417.70	428.24	5.150	6.435	7.350	0.837	1.046	1.327
430 450	1/90	200	431.09	440.12	448.89	4.850	5.501	6.250	1.034	1.230	1.401
450 470	1/90	381	452.54	463.12	469.74	4.650	5.276	5.95O	1.102	1.232	1.352
470 490	1/90	2279	471.74	480.01	435.54	4.750	5.226	5.850	1.086	1.264	1.429
490 510	1/90	3	490.54	49O.94	491.54	4.950	5.283	5.450	1.112	1.316	1.492

TABLE 6.2.3

TABLE 6.2.4. PLANT HAMMOND BASELINE TESTING
AVERAGE BY LOAD RANGE
5-MINUTE DATA
February 1989

			Load			O2			Nox		
Load Range	Honth	n	Lower 5%	Average	Upper 95%	Lower 95%	Average	Upper 95%	Lower 5%	Average	Upper 95%
170 19G	2/90	153	176.34	183.07	189.64	1.890	9.450	10.411	0.850	1.078	1.190
190 210	2/90	198	191.34	200.67	207.74	7.777	9.330	10.307	0.927	1.013	1.171
210 230	2/90	48	210.64	218.69	229.84	7.127	8.880	10.313	0.837	1.002	1.140
230 250	2/90	44	230.84	240.47	248.64	7.330	8.772	10.275	0.876	1.029	1.194
250 270	2/90	39	250.54	260.16	269.44	6.729	8.245	9.795	0.925	1.095	1.213
270 290	2/90	44	271.34	280.70	268.54	6.512	7.842	8.932	0.886	1.066	1.251
290 310	2/90	63	292.74	302.58	309.44	6.355	7.514	8.695	0.550	1.096	1.258
310 330	2/90	107	312.14	322.36	329.64	6.455	7.693	8.772	O.9S3	1.116	1.252
330 350	2/90	129	330.34	338.43	347.34	5.827	7.222	8.262	0.950	1.108	1.228
350 370	2/90	77	350.44	359.48	368.34	5.42B	6.672	7.974	0.843	1.087	1.269
370 390	2/90	100	371.44	379.54	386.69	S.302	6.468	7.306	0.894	1.151	1.329
390 410	2/90	135	390.44	399.85	408.64	4.869	5.866	7.108	0.615	1.131	1.385
410 430	2/90	302	412.44	422.56	429.54	4.642	5.383	6.437	1.021	1.220	1.390
430 450	2/90	409	430.44	440.15	449.14	4.615	5.292	6.146	1.073	1.246	1.387
450 470	2/90	549	451.34	459.54	469.04	4.836	5.274	5.789	1.119	1.271	1.394
470 490	2/90	g67	471.54	480.03	486.74	4.726	5.197	5.678	1.087	1.248	1.408
490 510	2/90	14	490.04	490.95	492.33	4.482	5.247	5.598	1.088	1.251	1.409

TABLE 6.2.4

TABLE 6.2.5. PLANT HAMMOND BASELINE TESTING
AVERAGE BY LOAD RANGE
5-MINUTE DATA
March 1989

Load Range	Honth	n	Load Lower 5%	Load Average	Load Upper 95%	O2 Lower 95%	O2 Average	O2 Upper 95%	Nox Lower 5%	Nox Average	Nox Upper 95%
170 190	3/90	255	171.44	183.09	189.44	7.085	8.983	10.442	0.801	0.939	1.059
190 210	3/90	313	191.24	198.57	208.84	7.669	8.675	9.888	0.814	0.967	1.071
210 230	3/90	142	211.44	221.71	228.94	7.027	8.047	8.942	0.753	0.886	1.006
230 250	3/90	183	230.84	238.92	249.04	6.319	7.943	9.158	0.642	0.910	1.058
250 270	3/90	293	251.24	259.70	268.44	6.231	7.370	8.675	0.665	0.896	1.045
270 290	3/90	218	271.64	280.30	289.14	5.530	6.973	8.015	0.741	0.950	1.101
290 310	3/90	273	290.64	298.35	308.44	5.515	6.628	7.649	0.728	0.955	1.122
310 330	3/90	169	310.94	319.72	328.64	4.991	6.304	7.526	0.696	0.924	1.073
330 350	3/90	128	331.24	341.46	349.34	4.763	6.161	7.571	0.708	0.954	1.146
350 370	3/90	248	351.44	361.08	368.84	4.952	6.078	7.578	0.777	1.099	1.333
370 390	3/90	190	371.14	381.03	389.24	4.484	5.641	7.046	0.748	1.042	1.266
390 410	3/90	379	391.04	399.85	409.24	4.372	5.203	6.431	0.808	1.032	1.269
410 430	3/90	442	411.14	420.22	428.74	4.289	5.100	6.168	0.922	1.106	1.299
430 450	3/90	637	431.24	441.80	449.34	3.708	4.738	5.688	0.969	1.148	1.367
450 470	3/90	2508	452.14	462.59	46e.94	4.098	4.798	5.508	1.067	1.277	1.547
470 490	3/90	1816	470.84	477.83	485.44	3.886	4.613	5.461	1.029	1.191	1.392
490 510	3/90	40	490.54	494.09	499.78	4.093	4.516	5.104	1.030	1.172	1.305

TABLE 6.2.5

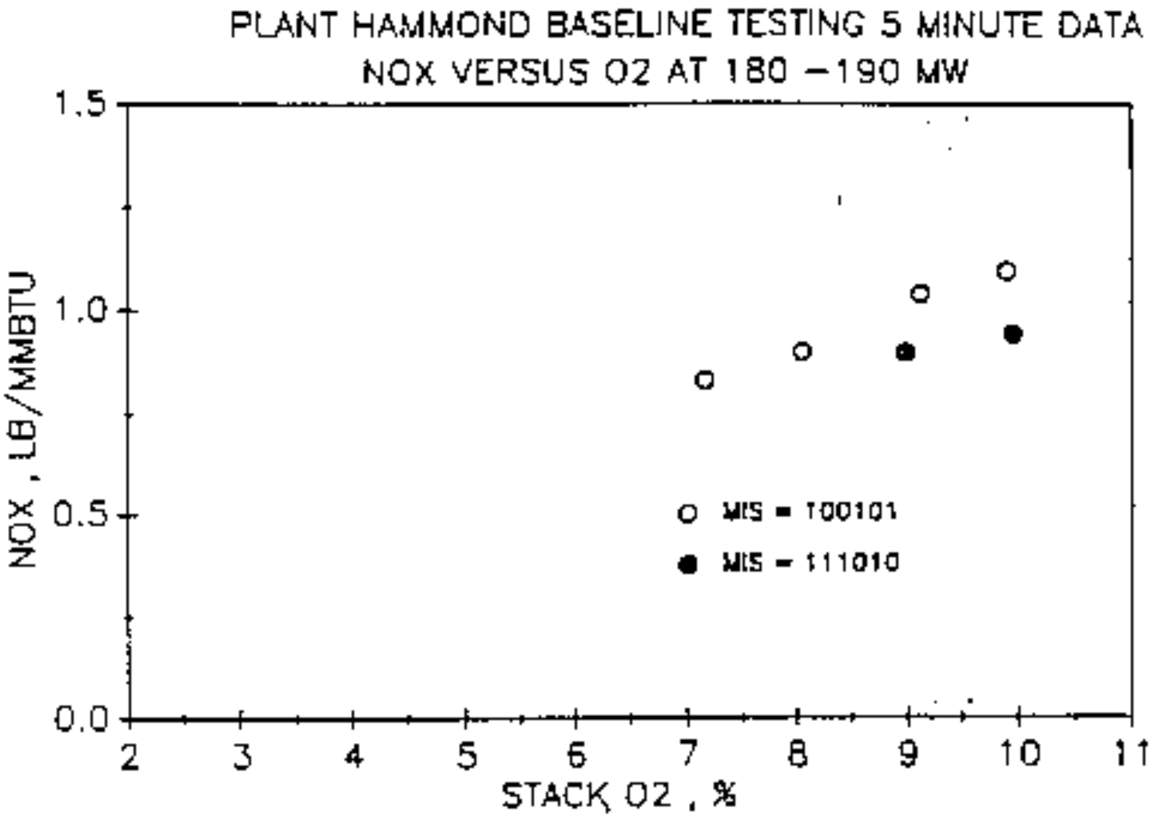
TABLE 6.2.6. PLANT HAMMOND BASELINE TESTING
AVERAGE BY LOAD RANGE
5-MINUTE DATA
April 1989

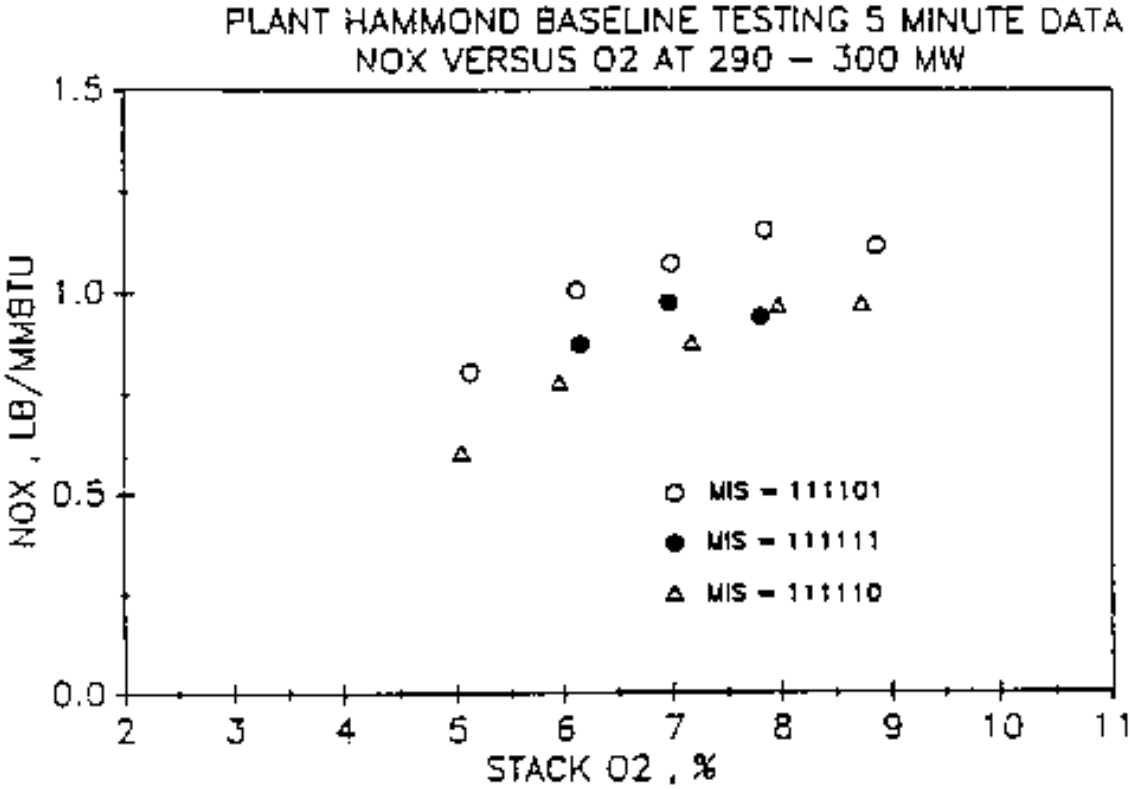
Load Range	Honth	n	Load Lower 5%	Load Average	Load Upper 95%	O2 Lower 95%	O2 Average	O2 Upper 95%	Nox Lower 5%	Nox Average	Nox Upper 95%
170 190	4/90	0									
190 210	4/90	79	193.64	201.88	207.64	8.247	8.951	9.496	1.009	1.052	1.089
210 230	4/90	8	210.34	219.25	228.34	8.260	8.889	9.702	1.013	1.057	1.080
230 250	4/90	3	243.04	246.11	248.64	6.493	7.443	8.077	0.924	0.966	1.022
250 270	4/90	4	251.54	263.49	269.g4	6.337	7.441	8.846	0.955	1.024	1.066
270 290	4/90	5	270.14	280.32	286.34	6.606	7.669	8.298	1.000	1.037	1.097
290 310	4/90	2	297.44	302.24	307.04	6.355	6.812	7.269	1.001	1.059	1.117
310 330	4/90	2	315.54	318.59	321.64	7.137	7.219	7.301	1.029	1.100	1.171
330 350	4/90	2	348.24	348.44	348.64	6.834	6.856	6.977	1.063	1.075	1.087
350 370	4/90	39	351.94	361.63	369.44	5.388	6.205	6.746	1.051	1.144	1.192
370 390	4/90	42	372.44	379.30	388.34	4.716	6.017	6.523	0.999	1.176	1.252
390 410	4/90	156	391.44	397.56	408.14	2.959	5.153	5.311	0.933	1.130	1.292
410 430	4/90	13	410.24	415.27	424.64	2.634	5.415	6.353	0.973	1.194	1.356
430 450	4/90	44	431.84	442.20	449.54	4.747	5.134	5.734	1.142	1.232	1.349
450 470	4/90	395	456.74	464.95	469.24	4.385	4.846	5.394	1.174	1.275	1.411
470 490	4/90	72	470.24	472.48	476.74	4.500	4.963	5.496	1.193	1.297	1.412
490 510	4/90	0									

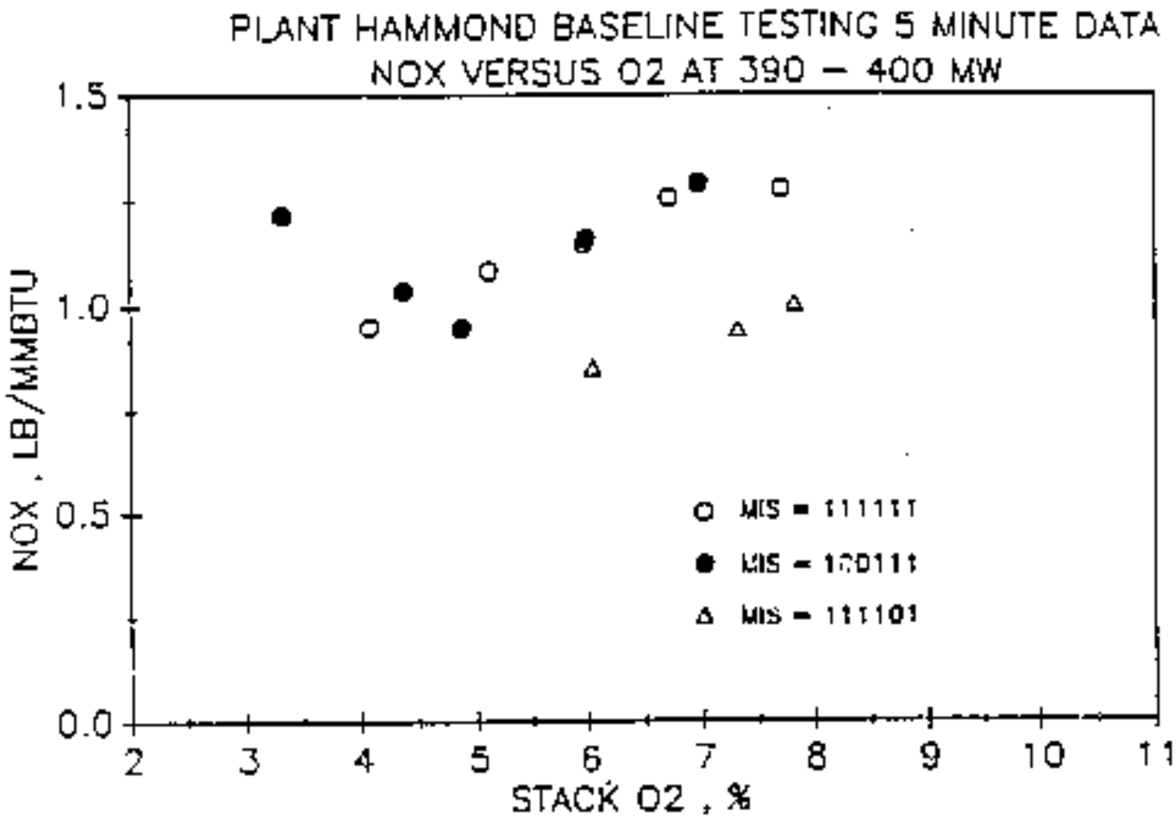
TABLE 6.2.6

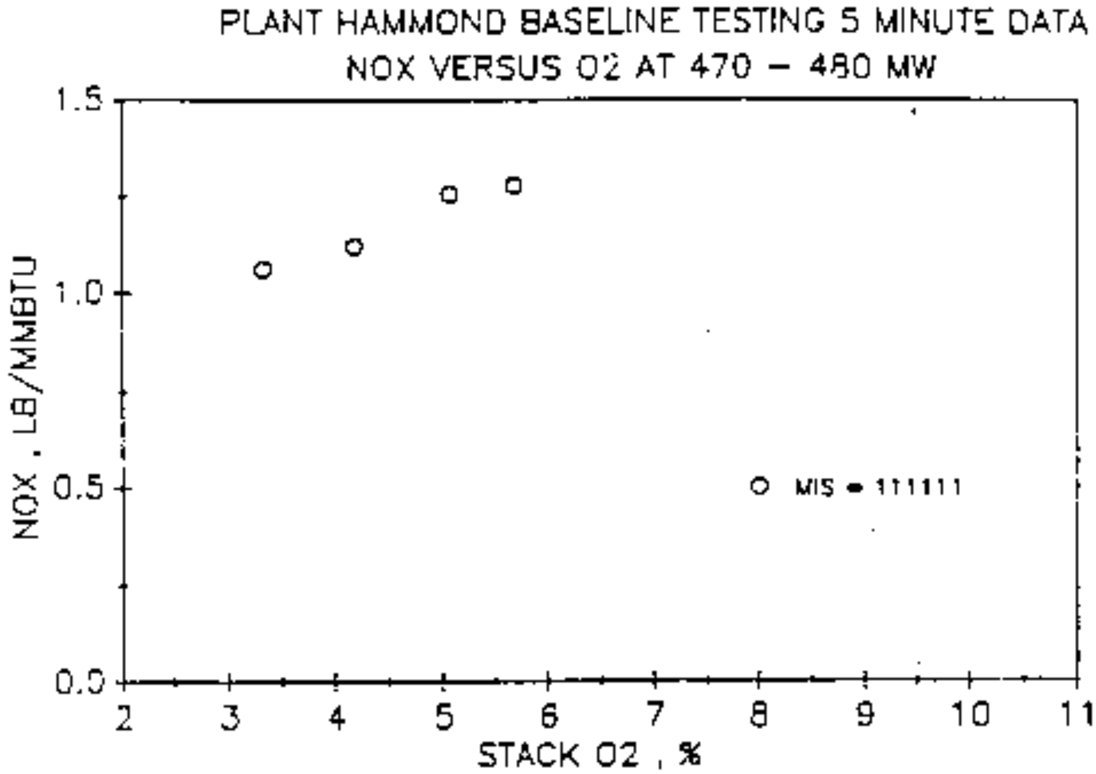
TABLE 6.2.9. REGRESSION ANALYSIS OF Nox VERSUS O2

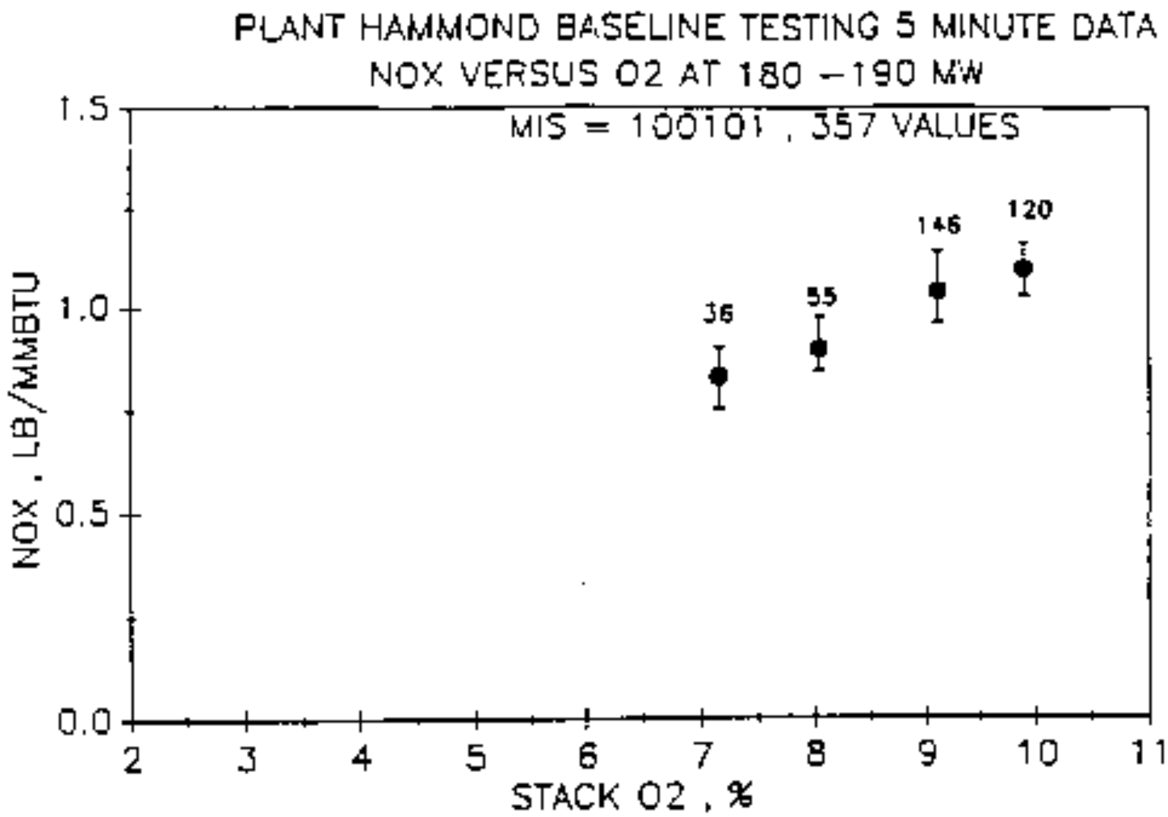
Load Range	MIS	Model	R2
180 - 190 MW	100101	NOX - 0.08 + 0.10 (O_2)	0.81
180 - 190 MW	111010	NOX - 0.54 + 0.04 (O_2)	0.72
290 - 300 MW	111101	NOX - -1.01 + 0.52 (O_2) -0.031(O_2)2	0.68
290 - 300 MW	111111	NOX - 0.33 + 0.09 (O_2)	0.27
290 - 300 MW	111110	NOX - -0.73 + 0.37(O_2) -0.019(O_2)	0.82
390 - 400 MW	111111	NOX - 0.56 - 0.10(O_2)	0.27
390 - 400 MW	100111	NOX - 2.87 - 0.80(O_2) + 0.083(O_2)2	0.32
390 - 400 MW	111110	NOX - 0.96 + 0.35 (O_2)	0.12
470 - 480 MW	111111	NOX - -0.44 + 0.58(O_2) -0.048(O_2)2	0.32

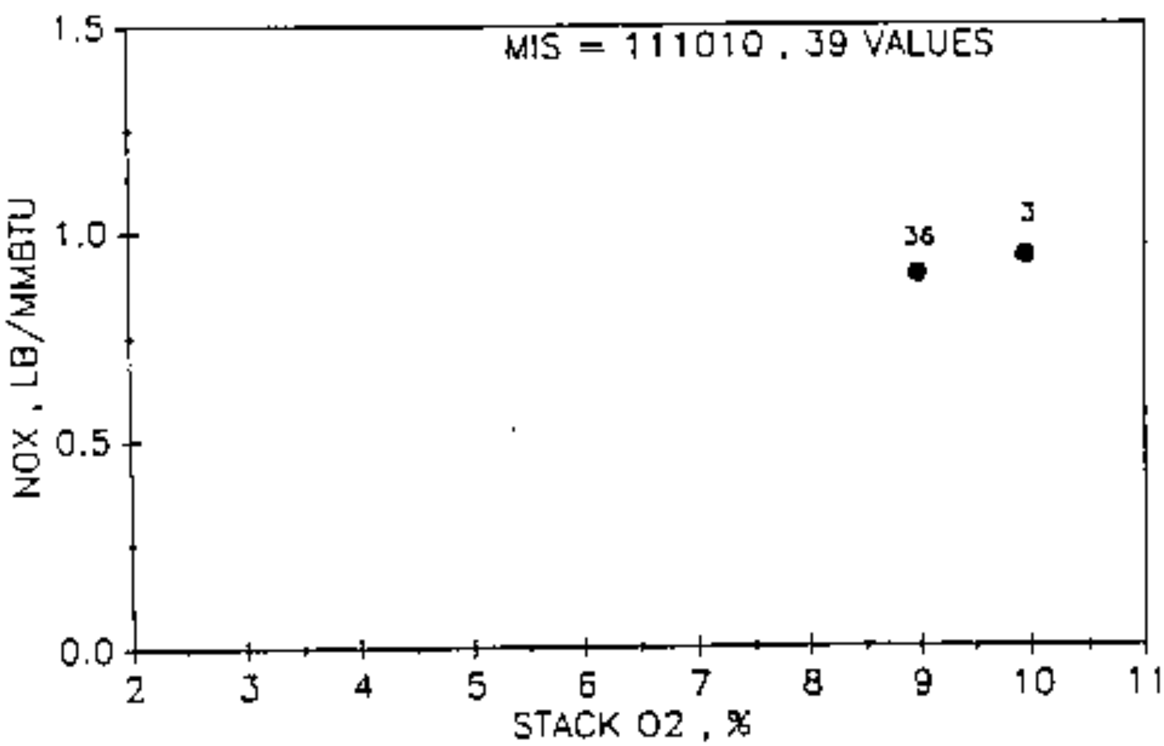

PLANT HAMMOND BASELINE TESTING 5 MINUTE DATA
NOX VERSUS O2 AT 180 –190 MW
NOX , LB/MMBTU
STACK O2 , %
MIS = 100101
MIS = 111010
1.5
1.0
0.5
0.0
2
3
4
5
6
7
8
9
10
11


PLANT HAMMOND BASELINE TESTING 5 MINUTE DATA
NOX VERSUS O2 AT 290 – 300 MW
NOX , LB/MMBTU
1.5
1.0
0.5
0.0
2
3
4
5
6
7
8
9
10
11
STACK O2 , %
MIS = 111101
MIS = 111111
MIS = 111110

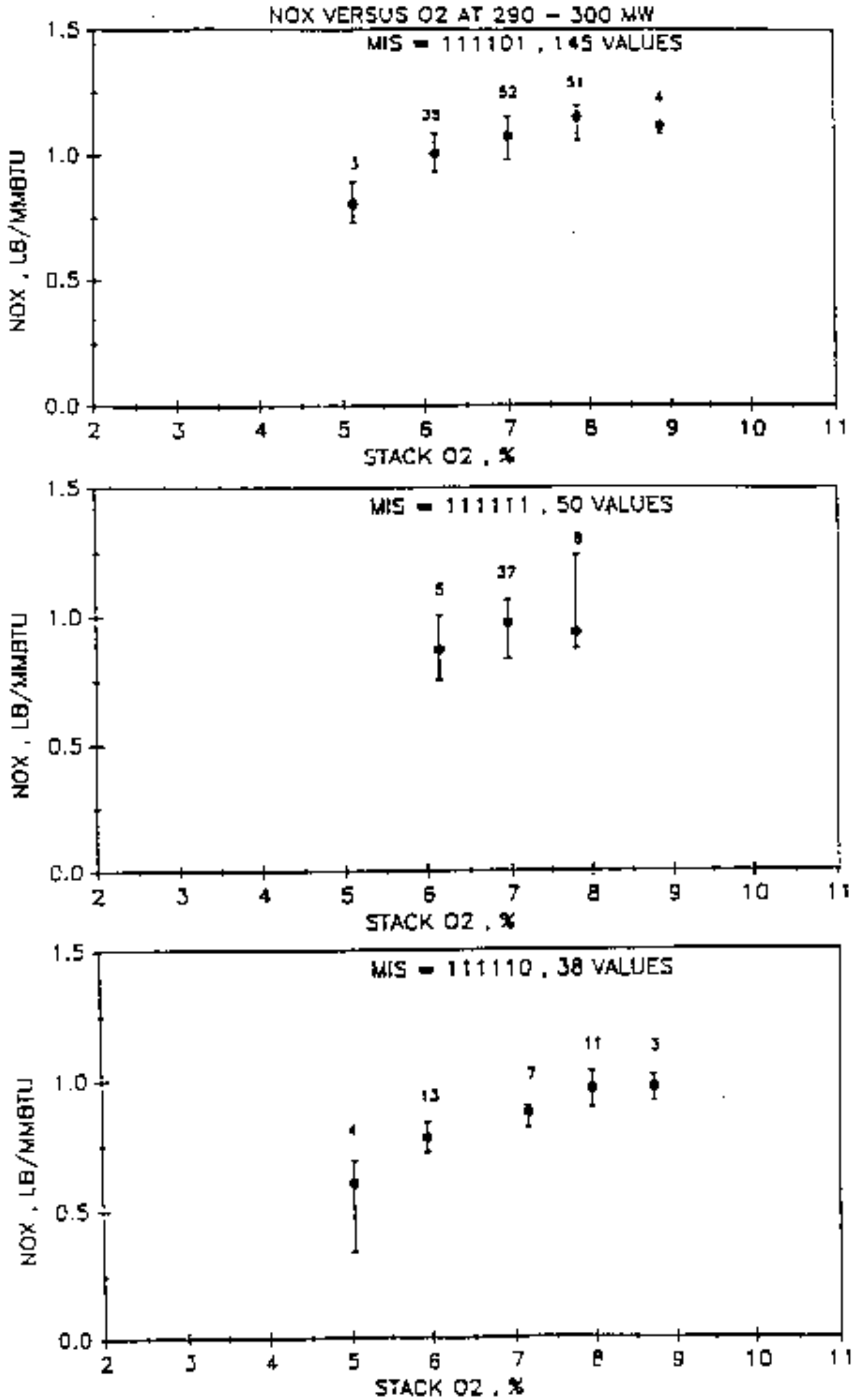

PLANT HAMMOND BASELINE TESTING 5 MINUTE DATA
NOX VERSUS O2 AT 390 – 400 MW
NOX , LB/MMBTU
1.5
1.0
0.5
0.0
2
3
4
5
6
7
8
9
10
11
STACK O2 , %
MIS = 111111
MIS = 100111
MIS = 111101

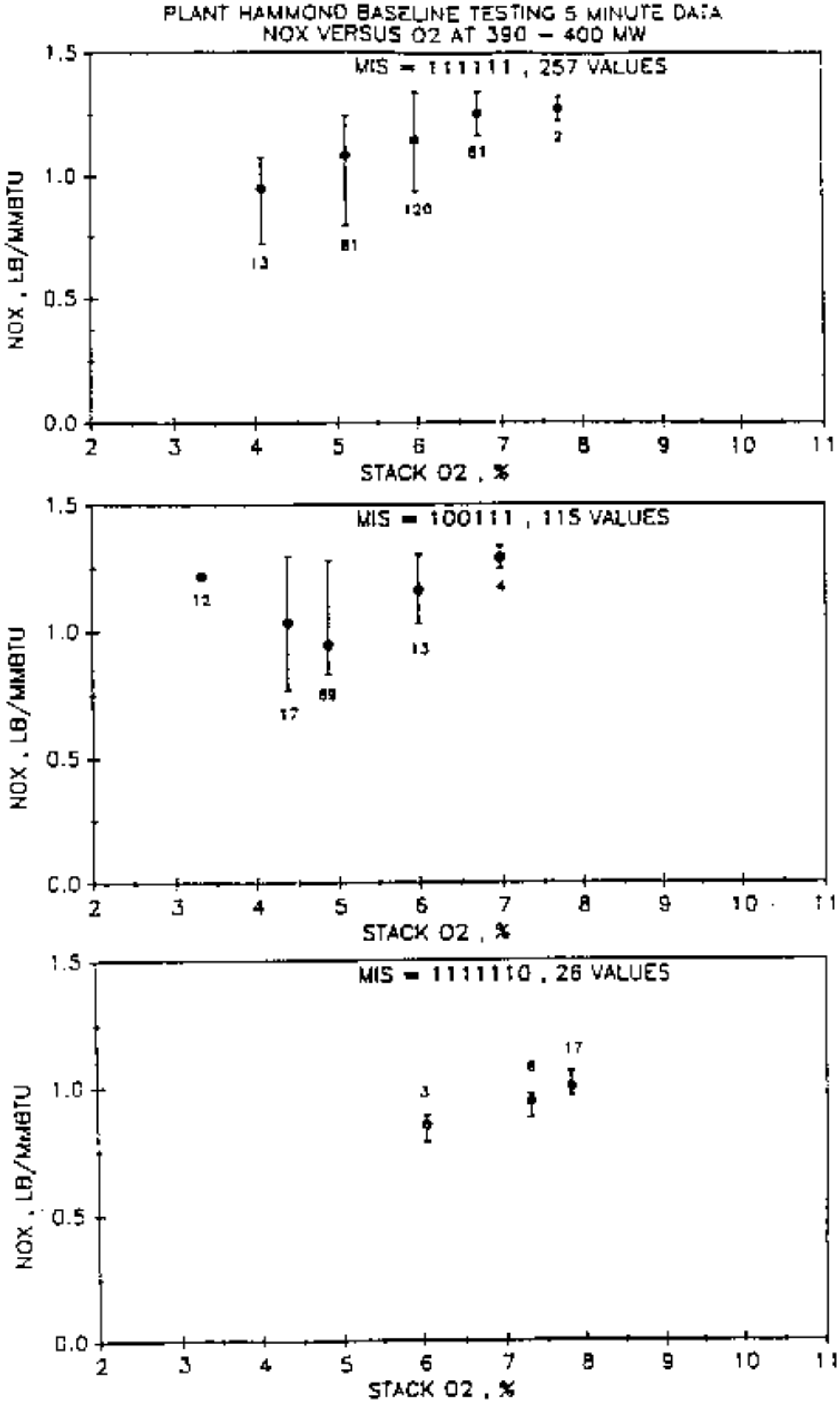

PLANT HAMMOND BASELINE TESTING 5 MINUTE DATA
NOX VERSUS O2 AT 470 – 480 MW
NOX , LB/MMBTU
1.5
1.0
0.5
0.0
2
3
4
5
6
7
8
9
10
11
STACK O2 , %
MIS = 111111

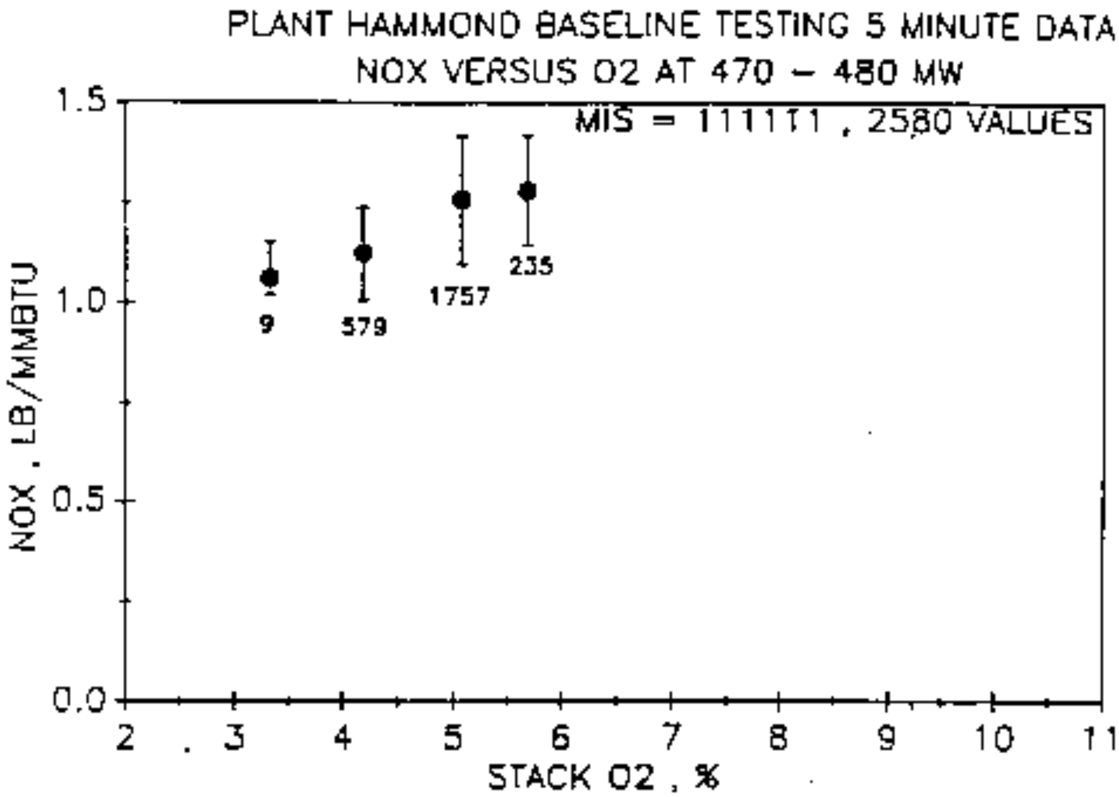

PLANT HAMMOND BASELINE TESTING 5 MINUTE DATA
NOX VERSUS O2 AT 180 –190 MW
MIS = 100101 , 357 VALUES
36
55
146
120
NOX , LB/MMBTU
0.0
0.5
1.0
1.5
2
3
4
5
6
7
8
9
10
11
STACK O2 , %

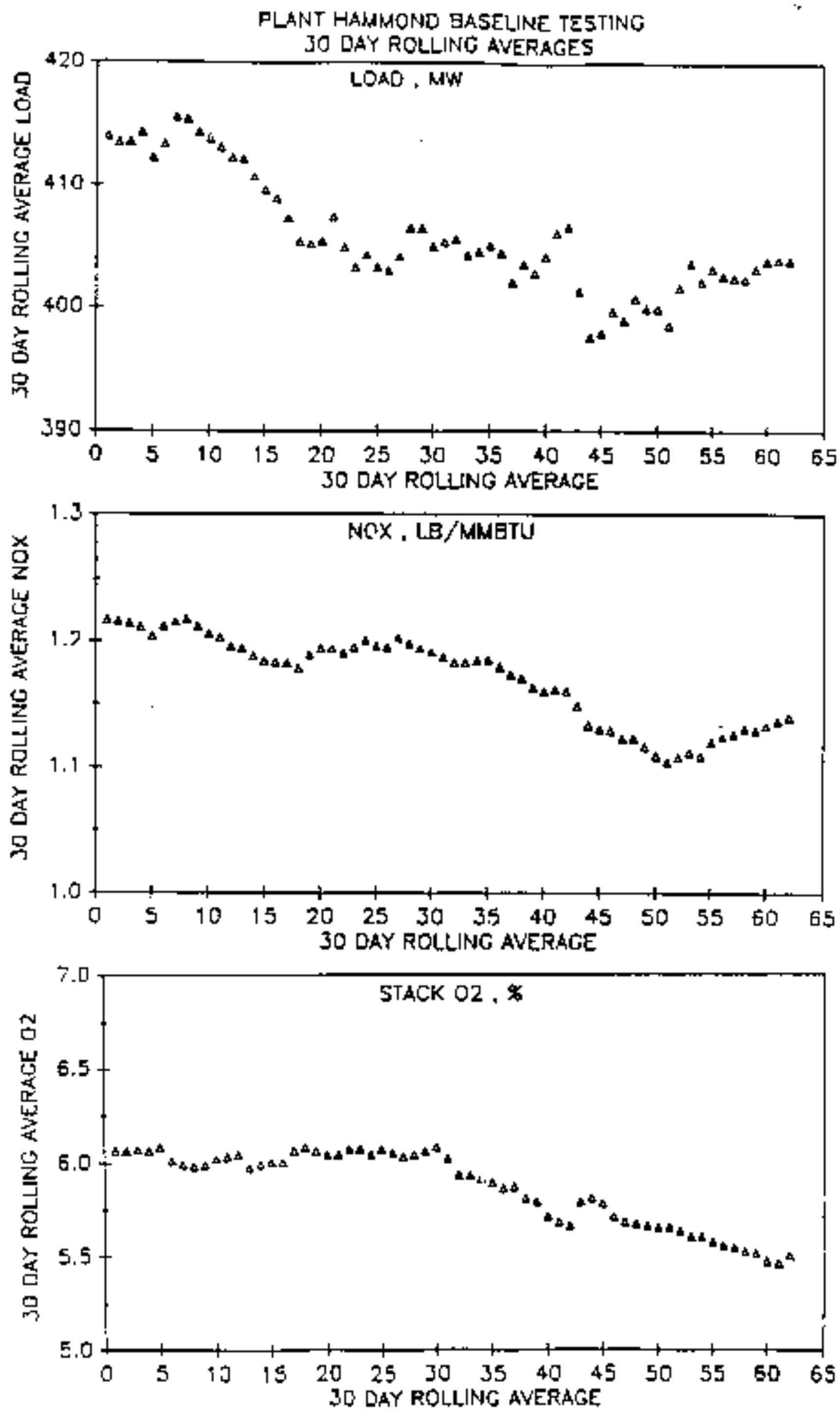

MIS = 111010 , 39 VALUES
36
3
NOX , LB/MMBTU
0.0
0.5
1.0
1.5
2
3
4
5
6
7
8
9
10
11
STACK O2 , %

PLANT HAMMOND BASELINE TESTING 5 MINUTE DATA




PLANT HAMMOND BASELINE TESTING 5 MINUTE DATA
NOX VERSUS O2 AT 390 - 400 MW
MIS = 111111 , 257 VALUES
MIS = 100111 , 115 VALUES
MIS = 1111110 , 26 VALUES
NOX , LB/MMBTU
STACK O2 , %


PLANT HAMMOND BASELINE TESTING 5 MINUTE DATA
NOX VERSUS O2 AT 470 – 480 MW
MIS = 111111 , 2580 VALUES
NOX , LB/MMBTU
1.5
1.0
0.5
0.0
9
579
1757
235
2
3
4
5
6
7
8
9
10
11
STACK O2 , %



PLANT HAMMOND BASELINE TESTING
30 DAY ROLLING AVERAGES
LOAD , MW
30 DAY ROLLING AVERAGE LOAD
30 DAY ROLLING AVERAGE
NOX , LB/MMBTU
30 DAY ROLLING AVERAGE NOX
30 DAY ROLLING AVERAGE
STACK O2 , %
30 DAY ROLLING AVERAGE O2
30 DAY ROLLING AVERAGE