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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 2 OVERFIRE AIR TESTS

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EXECUTIVE SUMMARY

This Phase 2 Test Report summarizes the testing activities and results for the second testing phase of an Innovative Clean Coal Technology (ICCT) demonstration of advanced wall-fired combustion techniques for the reduction of nitrogen oxide (NOx) emissions from coal-fired boilers. The second phase demonstrates the Advanced Overfire Air (AOFA) retrofit with existing Foster Wheeler (FWEC) burners. The project is being conducted at Georgia Power Company's Plant Hammond Unit 4 located near Rome, Georgia.

The primary goal of this project is the characterization of the low NOx combustion equipment through the collection and analysis of long-term emissions data supported by short-term characterization data. Ultimately a fifty percent NOx reduction target using combinations of combustion modifications has been established for this project.

The project provides a stepwise retrofit of an 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. Data collected from these activities are used to quantify NOx reductions achieved through the retrofits, and to evaluate the impact of these retrofits on other combustion and operational parameters such as particulate characteristics and boiler efficiency.

This demonstration project is divided into the following phases:

Phase 0	-	Pre-award activities
Phase 1	-	Baseline "as-found" testing,
Phase 2	-	AOFA installation and testing,
Phase 3a	-	LNB installation and testing,
Phase 3b	-	LNB plus AOFA testing,
and Phase 4	-	Final reporting.

The Phase 2 AOFA testing is the subject of this interim test report. An earlier test report discussed Phase 1 results, and interim test reports will subsequently be prepared for Phases 3a and 3b.

Described in this report are the test plans, data measurements, and data analysis performed during the Phase 2 effort. The present report also contains sufficient background material to provide an understanding of the overall program scope, the relationship of Phase 2 to the overall program, the testing methodologies, testing procedures, and unit configuration. However, the Phase 1 Baseline report should be referred for more detailed descriptions.

The first objective of the Phase 2 test effort was to establish the proper operating settings for the AOFA dampers and

to establish the NOx emissions under short-term well controlled conditions. Results from 104 Short-Term tests indicate fairly constant NOx emissions of approximately 0.85 lb/MBtu over the load range from 300 to 480 MWe at the minimum recommended excess oxygen level. Loss-on ignition (LOI) for these loads ranged from 5.0 to 10.0 percent, for loads of 300 and 480 MWe respectively. Boiler efficiency was measured to be 88.99 percent at the three loads tested (480, 400 and 300 MWe).

The second and more important objective of the Phase 2 effort was to document the long-term NOx emission trends while the unit was operating under normal day-to-day load dispatch conditions with the the AOFA equipment. Ninety-two days of Long-Term data were collected during the Phase 2 effort. These data were subjected to statistical analyses to determine the influence of operating variables (load, mill pattern, and excess oxygen) on NOx emissions, and to determine the achievable emission limits based upon annual average and 30-day rolling average criteria. Long-term test results indicated high-load (480 MWe) NOx emissions of approximately 0.90 lb/MBtu which is slightly higher than the Short-term test results. At the 300 MWe mid load point, the emissions remained at 0.90 lb/MBtu which again is slightly higher than the 0.80 lb/MBtu shown for the short-term data. The annual and 30-day average achievable NOx emissions were determined to be 0.923 and 0.956 lb/MBtu, respectively, for the load scenario experienced during the Phase 2 long-term test period. The statistical analysis showed that the data are highly autocorrelated (time dependent) with an autocorrelation coefficient of 0.69 which was used to establish the achievable emission limits.

Early in the Short-term test effort it was discovered that the full-load LOI was very high (approx. 15 percent) at the excess oxygen levels used during baseline testing. Carbon monoxide (CO) levels were also elevated at these excess oxygen levels. Excess oxygen levels were increased slightly during long-term operation to allow operation at lower LOI levels. This slight increase resulted in virtually no change in boiler efficiency from the baseline conditions. Operability of the boiler was only slightly impacted due to the necessity to manually modulate the AOFA ports as a function of load.

The results from the Phase 2 testing will be used in comparison to the Baseline and other test phases of the program to establish the NOx reductions for the various control technologies. Based on the long-term test results for this load scenario, at full-load the AOFA retrofit resulted in a NOx reduction of 24 percent. At the 300 MWe load point, the reduction dropped to approximately 12 percent. Upon completion of the final test phase, a comprehensive test report will be issued which will describe in more detail the results of analyses from the testing and draw conclusions relative to the effectiveness of the technologies based upon the same load scenarios.

ACKNOWLEDGMENTS

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 2 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. Richard Storm provided the highest quality testing related 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 Advanced Overfire Air report.

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

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

TABLE OF ABBREVIATIONS

AMIS	All-Mill-in-Service
AOFA	Advanced Overfire Air
APX	Air Preheater
ASME	American Society of Mechanical Engineers
CEM	Continuous Emission Monitor
CFSF	Controlled Flow-Split Flame
CO	Carbon Monoxide
COV	Coefficient of Variation
DAP	Data Acquisition Package
DAS	Data Acquisition System
DSCF	Dry Standard Cubic Feet
DSCFM	Dry Standard Cubic Feet per minute
ECEM	Extractive Continuous Emissions Monitor
EPRI	Electric Power Research Institute
ESP	Electrostatic Precipitator
ETEC	Energy Technology Consultants, Inc.
FPM	Feet per minute
FWEC	Foster Wheeler Energy Corp.
GPC	Georgia Power Corp.
HVT	High Velocity Thermocouple
ICCT	Innovative Clean Coal Technology
Klb	Thousand Pound
LNB	Low NOx Burner
LOI	Loss on Ignition
MBtu	10^6 Btu

MWe	Mega Watt - Electric
NOx	Nitrogen Oxide
NSPS	New Source Performance Standards
OFA	Overfire Air
O_2	Oxygen (dry)
ppm	Parts per Million
PTC	Power Test Code
SAS	Statistical Analysis System, SAS Institute, Inc.
SCS	Southern Company Services
SoRI	Southern Research Institute
SO_2	Sulfur Dioxide
THC	Total Hydrocarbons

1. 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) the Southern Company
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 project is being managed by Southern Company Services, Inc. (SCS) on behalf of the project co-funders: The Southern electric system, the U. S. Department of Energy (DOE), and the Electric Power Research Institute. In addition to SCS, the Southern electric system includes five electric operating companies: Alabama Power, Georgia Power, Gulf Power, Mississippi Power, and Savannah Electric and Power. SCS provides engineering, research, and financial services to the Southern electric system. The following briefly describes the overall organization and describes in detail the organization related to the test and evaluation activities.

This report is provided to document the testing performed and results achieved during Phase 2 - Advanced Overfire Air Retrofit. This effort began in May, 1990 following completion of Phase 1 -Baseline Testing and installation of the retrofit AOFA equipment. The Phase 1 effort and results were documented in Southern Company Services report titled as "500 MWe Demonstration of Advanced Wall-Fired Combustion Techniques for the Reduction of Nitrogen Oxides (NOx) Emissions from Coal-Fired Boilers - Phase Baseline Tests Report" (DOE Contract DE-F022-90PC89651).

Those reports contain detailed descriptions of the program, test plans and testing procedures. While the present report contains sufficient background material to provide an understanding of the program scope, testing procedures and the relationship of the Phase 2 testing to the overall program, the reader is referred to the previous documents for detailed descriptions of the program, test methods and unit configuration.

1.1 Project Description

On December 20, 1989, Southern Company Services was awarded a DOE Innovative Clean Coal Technology Round II (ICCT) 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 Plant Hammond located in Rome, Georgia. The project will characterize emissions and performance of a wall-fired boiler operating in the following configurations:

1) Baseline "as-found" configuration - Phase 1,
2) Retrofitted Advanced overfire air (A0FA) - Phase 2,
3) Retrofitted low NOx burners (LNB) - Phase 3a,
4) Combined AOFA and LNB configuration - Phase 3b.

The major objectives of the project are to:

1) Demonstrate (in a logical stepwise fashion) the performance of three combustion NOx control technologies, 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 (50 to 80 continuous days of 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 emissions characteristics that may have occurred during the long-term test period.

1.2 Project Organization

The Program Manager for the DOE ICCT Program at Southern Company Services is Mr. Steve M. Wilson of SCS who has overall responsibility for the SCS Clean Coal Program. The Project Manager is Mr. John Sorge, who directs in-house (SCS) and GPC personnel to perform various duties related to site coordination, design engineering, environmental matters and cost coordination, and has overall responsibility for the execution of this project. The Project Manager also directs subcontracted efforts of the burner manufacturer, installation contractors and test coordination contractor, supplying the NOx emissions control systems as described below.

Energy Technology Consultants Inc. ETEC has responsibility for the on-site testing and analysis of the data obtained for all Phases of the project, serving as the test coordinator and results engineer 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.

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 the instrument 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 on a daily basis.

Southern Research Institute (SoRI) 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. In addition to the testing activities, SoRI is responsible for ESP modeling efforts for each of the four phases.

Flame Refractories Inc. (Flame) 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.

W. S. Pitts Consulting, Inc. (WSPC) WSPC is responsible for data analysis of the emission a-.d performance data for the long-term characterization phases of the program.

Both raw and reduced data are archived by the subcontractors as well as by ETEC for future reference.

1.3 Hammond Unit 4 Description

Hammond Unit 4 is a Foster Wheeler Energy Corporation (FWEC) designed, opposed wall-fired boiler rated at 500 MWe with design steam conditions of 2500 psig and 1000/1000°F superheat/reheat temperatures, respectively. Six FWEC mills provide pulverized eastern bituminous coal to 24 Intervane burners arranged in a matrix of 12 (three rows of four burners) on the front and rear walls. Each mill provides coal to four burners.

Unit 4 is a balanced draft unit with two forced draft and three induced draft fans. The unit is equipped with a cold side ESP. The flue gases exit the economizer through two Ljungstrom air preheaters and into the cold side ESP, then through the induced draft fans and finally out to the stack.

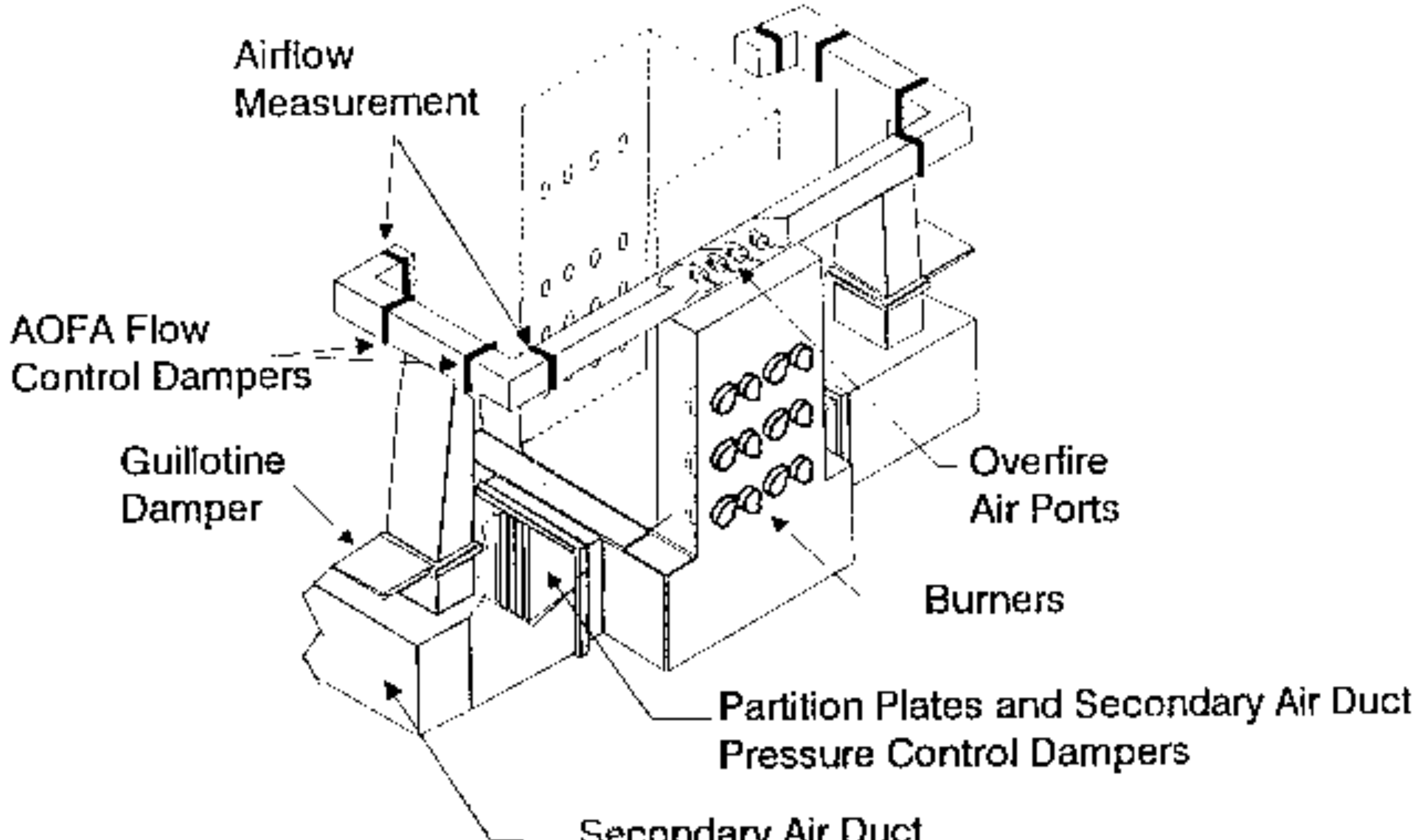
For Phase 2, an advanced overfire air system was retrofitted to the unit, consisting of ducts, dampers, various instrumentation and controls, and OFA ports above the top burner rows on both the front and rear furnace walls. The overfire air flow is extracted from the two main secondary air ducts between the air flow venturis and the entrances to the combustion air windbox (east and west sides of the boiler). Figure 1-1 depicts the major components of the AOFA retrofit.

1.4 Report Organization

The remainder of this 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 2 effort are presented in Section 5.0. Section 6.0 provides a description of the statistical approach used to analyze the continuous emission monitor (CEM) data. Section 7.0 provides a summary of conclusions for the analyses of both the short-term and long-term data.

Results of the Phase 3a low NOx burner retrofit and the Phase 3b combined AOFA and LNB will be presented in future reports.

FIGURE 1-1 AOFA RETROFIT CONFIGURATION



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. These demonstrations have provided only minimal amounts of information that could be used to extrapolate to the general 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- and 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 subsection describes the technologies that are to be investigated during the four phases of this program, the general methodology used to obtain data, and the general outline of Phase 2.

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 to be investigated are:

1) Advanced Overfire Air (AOFA),
2) Low NOx Burner (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 low NOx burner and AOFA hardware which will be retrofit to Hammond Unit 4.

The baseline configuration 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. 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 have been incorporated into Unit 4.

2.1.1 Advance Overfire Air System

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 which facilitates reduction of NOx. 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.

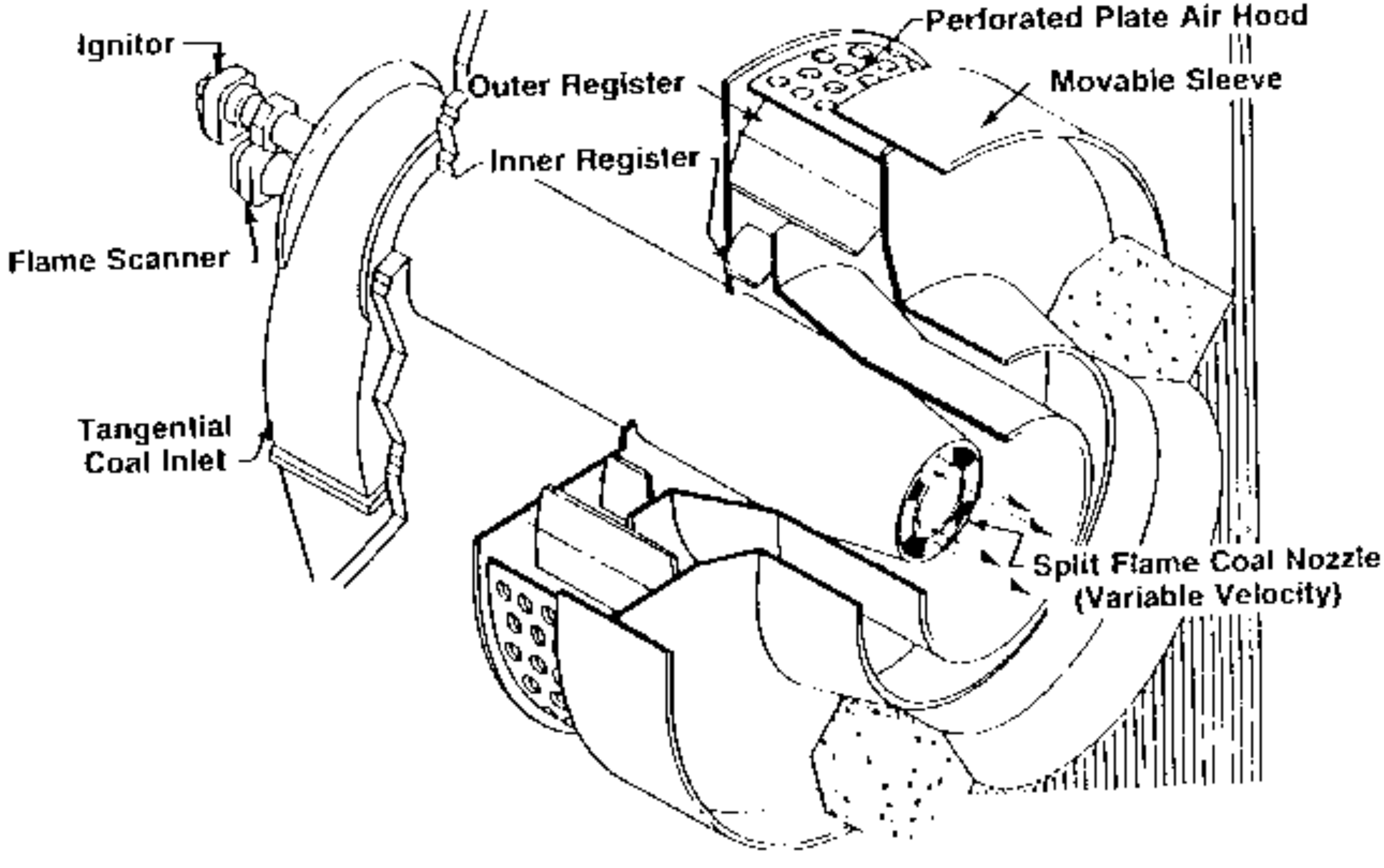
Studies by EPRI and boiler manufacturers have shown that the standard overfire air (OFA) offerings do not result in optimum NOx reduction due to inadequate mixing of the secondary air with the partially combusted products from the fuel rich burner zone. This inadequate mixing limits the effectiveness of the OFA technique. The advanced overfire air system (AOFA) provided by Foster Wheeler Energy Corp. incorporates 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. AOFA systems provide increased penetration velocities by supplying secondary air from completely separate aerodynamically designed ducts located above the existing burner windbox. The ports themselves are also designed to provide increased penetration velocities.

2.1.2 Low NOx Burners

In Phase 3a and 3b, Foster Wheeler will supply their Controlled Flow-Split Flame (CFSF) burner for retrofit into the existing wall penetrations of the 24 Intervane burners. The CFSF burner was originally developed for use on the San Juan Unit 1 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 more recently into older boilers to comply with the Clean Air Act Amendments of 1990. Figure 2-1 shows an illustration 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 manufacturers' concepts. These "internally" staged burners accomplish NOx reduction in a similar manner to that accomplished with overfire air, but in a much more efficient manner. Internally staged burners result in significantly better-mixed final products of combustion than do overfire air ports. This low N0x burner concept will be evaluated during Phase 3a of the project. Due to the unique design features of the burner, it can be operated with or without the AOFA system

FIGURE 2-1 CONTROLLED FLOW-SPLIT FLAME BURNER SCHEMATIC



described above. The combination of the CFSF burner operation used in conjunction with the AOFA system will be evaluated during Phase 3b 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 the 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. While NOx is comprised of NO and NO2, only a small fraction of NOx is NO_2 (<5%). During this program NO was measured since the NO_2 represents a small actual incremental contribution. To account for this small contribution significant instrumentation costs would have to be incurred. Aside from NOx measurements, short-term testing was also used to assess the performance of the boiler in the normal modes of operation. The characterization testing is divided into two elements -diagnostic tests 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 and mill performance. Both diagnostic and performance tests are conducted under operating conditions controlled by the project test personnel.

Diagnostic testing involves characterizing the gaseous emissions under three to four load conditions over the range of operating parameters that might normally be encountered on Unit 4 as well as excursions about these normal conditions. The primary parameters that were used for characterization were excess oxygen, mill pattern, mill bias and OFA flow. 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 ensure steady boiler operation.

Performance testing is accomplished at specified loads in configurations recommended by plant engineering and the vendor and which have beer, tested during the diagnostic testing. Each of these configurations represents one of the normal modes of operation for each load condition. The "nominal" OFA flow was defined as a setting of 50 percent open for all of the OFA dampers based upon initial testing by ETEC and FWEC. Performance data were 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 in Phase 2 (AOFA) are used for comparison with results from similar testing of the various NOx control technologies undertaken in Phases 1, 3a and 3b, i.e. Baseline, LNB, and LNB plus AOFA.

2.2.2 Long-Term Characterization

Long-term testing for each phase is conducted under normal system load dispatch control conditions with the OFA dampers set to 50 percent open at all load levels above 280 MWe. OFA dampers were maintained at 20 percent at loads from 280 to 180 MWe and shut off below 180 MWe. Generally, no intervention with respect to specifying the other operating configurations or conditions is 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, and 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.

2.2.3 Verification

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

2.3 Phase 2 Test Plan

The Hammond Unit 4 Phase 2 testing effort was begun on May 23, 1990, and completed on February 28, 1991, including five months of long-term testing. The following briefly describes the test sequence during this period.

2.3.1 Short-Term Characterization Testing

The test plan for Phase 2 short-term characterization incorporated four load points ranging from 185 to 490 MWe which duplicated the testing range of Phase 1.

The Phase 2 diagnostic test matrix for Unit 4 was performed over the period from May 23 to August 16, 1990. This diagnostic test matrix included the following basic test conditions:

LOAD, MWe	MILL PATTERN	NO. TESTS
480	All Mills in Service	39
450	All Mills in Service	8
400	2 MOOS Patterns	16
300	3 MOOS Patterns	20

Each of these tests was performed over a duration of from one to three hours.

The performance portion of the short-term-m characterization tests included tests at 50 percent OFA damper setting for 300, 400 and 480 MWe load levels, as well as 75 percent OFA damper at 480 MWe. An abbreviated performance test was conducted at 489 MWe with the OFA dampers closed.

2.3.2 Long-Term Characterization Testing

Long-term characterization testing began in October 1990 and was completed in March 1991. During this period a substantial amount of continuous emission data was collected. During this period the unit was on-line all but five days due to unscheduled outages.

2.3.3 Verification Testing

Verification testing took place between February 22 and February 28, 1991. Fifteen tests were performed during this period; six at 400 MWe and nine at 480 MWe.

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 data categories relating to the equipment and procedures used. These are: manual boiler data collection, automated boiler data collection, combustion systems tests, and solid/sulfur emissions tests. A brief description of each data category follows. A more complete description of each category is contained in Reference 1.

1) Manual Boiler Data Collection

Data were recorded manually onto data forms based on readings from plant instruments and controls. The data were subsequently entered manually into a computer data management program. Coal, bottom ash, and ESP hopper ash (which was taken separately from inlet and outlet hoppers on both east and west sides of the ESP) samples were collected regularly for subsequent laboratory analysis. In addition to the data readings taken during Phase 1, readings of OFA damper settings and flow rates were recorded during Phase 2.

2) Automated Boiler Data Collection

Two scanning data loggers were installed to record the signals both from pre-existing plant instrumentation and from instruments installed specifically for this test program. The data loggers were monitored by a central computer that maintained permanent records of the data and also allowed instantaneous, real-time interface with the data acquisition equipment. In addition to the measurements provided in Phase 1, signals were recorded from four OFA flow meters, one in each OFA windbox quadrant during Phase 2.

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 to measure furnace temperature contours across a plane in the upper furnace, fluxdomes to measure heat flux at selected points on the boiler wall, 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 from Flame Refractories, Inc. using specialized apparatus and procedures to measure parameters related to the combustion and thermal performance of the boiler. The measurements included the following:

Primary Air/Fuel Supply
- Primary air velocity to each burner
- Coal flow rate to each burner
- Coal particle size distribution to each burner

Secondary Air Supply
- Secondary air flow and temperatures, east/west
- Secondary air flow and temperatures, front/rear windbox

Overfire Air Supply
- OFA Flow to each quadrant of OFA (Front and rear/east and west)

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

4) Solid/Sulfur Emissions Tests

During the performance tests, a team of scientists and technicians from SoRI made measurements of particulate and gaseous emissions exiting the boiler, using specialized equipment and procedures. These measurements included:

- Total particulate emissions and particle sizes
- Fly Ash resistivity at the ESP inlet
- SO_2 and SO_3 concentrations

The results of the solid/sulfur emissions tests are to be used in calculations to estimate the effect of NOx controls on the performance of a generic ESP representative of large utility installations.

4.0 DATA ANALYSIS METHODOLOGY

Two distinctly different types of data analyses are utilized to characterize the data: 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 establish statistically 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 emissions 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 is for a single operating condition. Unlike the data collected in the long-term effort, the data collected during the short-term effort is generally not of sufficient quantity to apply sophisticated mathematical analysis. Most of the analysis of the short-term data is graphical.

4.1.1 Diagnostic Data

The emphasis of the diagnostic testing is to determine the NOx characteristics, although much more information is obtained for use during other phases of the project. The flux, O_2, CO, THC and SO_2 are automatically recorded every five seconds and stored in the historic files on a computer. The NOx measurements of interest during this element of the short-term testing are those obtained from the sample flow distribution manifold. The manifold allows sampling from individual probes or combinations of probes located in the economizer exit upstream of the primary and secondary air preheaters. The composite emission measurement 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. Sampling of 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 calculate the statistics for that period (e.g. average and standard deviation). 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.

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 jeopardized the ability to trend the emissions data adequately. 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.

During the Phase 2 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 that 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 during Phase 1 and found to be true.

4.1.2 Performance Data

Performance data are used (1) to establish baseline evaluation criteria for retrofits, (2) to quantify the boiler characteristics for comparison with other phases of the program and (3) for comparison with the results of the diagnostic trends. The emphasis for the performance tests was on the analysis of the flows, solids capture and boiler efficiency rather than on the NOx trends. As with the diagnostic test data, insufficient data samples were available to perform meaningful advanced statistics.

For each performance configuration (10- to 12-hour 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 ASME 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), and

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 and 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 CEM. A single emission measurement point in the ductwork just upstream of the stack breeching 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 SO2 in the lines. Prior to the start of the Phase 2 Long-term test effort, the CEM was certified by Spectrum Systems, Inc.

The primary focus of the long-term test effort was to monitor 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 operating in its normal day-to-day configuration under control of the Load Dispatcher. The only added constraint was that the new OFA system would be operated as determined during the short-term testing (i.e. 50 percent damper setting over the load range).

The thrust of the analysis of the long-term data is its interpretation primarily by statistical methods. The specific types of analysis used are related to regulatory issues and the engineering interpretation of 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 and annual 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 two subsections provide information on (1) the processing of the raw long-term data to produce a valid emission data set and (2) the fundamentals of the data-specific analytic techniques.

4.2.1 Data Set Construction

Five-minute Average Emission Data

The data collected during the long-term test program consisted of 5-minute averages of parameters related to boiler operating conditions and emissions. Since the intent of all analyses of the long-term test periods is to depict normal operating conditions, data collected during startup, shutdown and unit trips were excluded from the analyses.

The 5-minute average data are also used to compute hourly averages that are in turn used to compute daily average NOx emissions. The daily average emissions are used to estimate the achievable NOx emission limit.

The loss of 5-minute data due to CEM failure was treated based on an adaption of EPA NSPS guidelines for determining how much data is sufficient to compute an hourly average for emissions monitoring purposes. Also, in the case of daily average emissions EPA NSPS guidelines (at least 18 hours of valid hourly data per day) were used to define a valid daily average.

4.2.2 Data Analysis Procedures

Five-minute Average Emission Data

The edited 5-minute average data from the long-term tests were used to determine (1) the NOx versus load relationship and (2) the NOx versus O_2 response for various load levels.

Hourly Average Emission Data

The purpose of the hourly average emission analyses was to assess the hour-to-hour variation in NOx, O_2, and load for these periods. The within-day data analyses are performed by sorting the hourly averages by hour of the day and computing the average NOx, O_2, and load for these periods. The statistical properties for these hourly periods and the 95 percentile uncertainty band was computed for each hourly data subset. These data will be used to compare the effectiveness of each technology against the baseline load scenario.

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, O_2 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 packages UNIVARIATE and AUTOREG 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:

$$Z = (L - X) / (S30)$$

where:
- Z is the standard normal deviate
- L is the emission limit
- X is the long-term mean, and
- S30 is the standard deviation of the 30-day averages. S30 is computed using the estimated standard deviation S24 and autocorrelation (p) 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 excellence per ten years is equivalent to a compliance level of (3649/3650), or 0.999726. 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).

5.0 SHORT-TERM TEST RESULTS

The short-term testing consisted of first performing diagnostic testing to establish the general NOx and operating trends followed by performance testing to establish the characteristics of the fuel/air feed systems and the solid and gaseous emissions for the most representative configuration. 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 2 short-term program was from the normal supply source and was handled according to common plant practice. Subsequent to the completion of the long-term testing (Section 6.0) a short verification test effort was undertaken to determine whether significant changes had occurred during the long-term test effort.

The Phase 2 short-term characterization testing was begun on May 23, 1990 and was completed on August 16, 1990. A total of 82 diagnostic tests were performed during this period. An additional 15 tests were performed during the verification test effort at the end of the Phase 2 effort. The following paragraphs describe the diagnostic, performance and verification testing performed during the Phase 2 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. Eighty-two tests were performed at nominal loads of 300, 400 and 480 MWe. The diagnostic test efforts were interrupted to accomplish the performance testing due to scheduling conflicts. Diagnostic testing was then completed after the performance testing was completed. The diagnostic testing began shortly after Foster Wheeler AOFA start-up testing was completed. Generally, changes between test conditions during the diagnostic testing took from one to two 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, and economizer exit and preheater exit species and temperatures were recorded utilizing the sample distribution manifold and were recorded on the DAS. When sufficient time permitted, furnace backpass ash grab samples were collected from the CEGRIT ash samplers and coal samples were collected from the individual mills.

5.1.1 Unit Operating Condition

During the diagnostic test efforts no unusual operating conditions were encountered that placed restrictions on the test effort.

Table 5-l presents the "as tested" conditions during the diagnostic portion of the testing. Sixteen days of testing were executed comprising the 82 various excess oxygen, mill pattern, and OFA and load conditions. The recommended minimum O2 level shown in this figure is based upon results obtained during Performance Testing that indicated the necessity for increased O_2 levels to minimize LOI. Because historic load profiles indicated much greater operating times at 400 MWe and above, compared to lower loads, diagnostic testing was done more extensively at the higher load levels.

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 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 NOx characterization and economizer exit plane species distribution characterization. The overall NOx characterization tests were performed over a period of approximately one hour and were 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.

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 NOx emissions for the four nominal load levels tested during the diagnostic portion of the Phase II effort are shown in Figures S-1 and 5-2. The conditions represented in these figures include excess oxygen variation, mill-out-of-service variation, mill biasing, etc. As shown in Table 5-1, tests were run at various OFA damper openings in order to establish an "optimum" setting over the load range taking into account both NOx reduction and effects on boiler operation (excess O_2 level vs. CO and carbon loss).

TABLE 5-1
SUMMARY OF HAMMOND UNIT 4 PHASE 2 DIAGNOSTIC OFA TESTING

TEST NO.	DATE	TEST CONDITIONS	LOAD (MW)	MOOS PATTERN	GUILLOTINE POSITION	OFA DAMPER (%)	DAS 02 DRY (%)	AT
23-1	05/23/90	START-UP TEST	478	NONE	CLOSED	52	2.7	
24-1	06/11/90	HI LOAD O2 VARIATION	482	NONE	CLOSED	52	2.1	
24-2	06/11/90	•	480	NONE	CLOSED	52	3.0	
25-1	06/12/90	HI LOAD NORMAL O2	475	NONE	CLOSED	52	2.8	
25-2	06/12/90	•	478	NONE	CLOSED	52	2.5	
25-3	06/12/90	HI LOAD O2 VARIATION	478	NONE	CLOSED	1	2.5	
25-4	06/12/90	•	479	NONE	CLOSED	10	2.5	
25-5	06/12/90	•	476	NONE	OPEN	25	2.4	
25-6	06/12/90	•	475	NONE	OPEN	100	2.4	
26-1	06/13/90	HI LOAD OFA VARIATION	478	NONE	OPEN	0	2.1	
26-2	06/13/90	•	478	NONE	OPEN	50	2.8	
27-1	06/15/90	HI LOAD REGISTER MALDISTR	480	NONE	OPEN	6	2.8	
27-2	06/15/90	HI LOAD REGISTER ADJ	478	NONE	OPEN	6	5.3	
27-3	06/15/90	•	478	NONE	OPEN	7		
27-4	06/16/90	•	475	NONE	OPEN	7		
27-5	06/16/90	•	476	NONE	OPEN	7	2.6	
28-1	06/16/90	HI LOAD OFA VARIATION	482	NONE	OPEN	7	2.6	
28-2	06/16/90	•	483	NONE	OPEN	20	2.7	
28-3	06/16/90	•	483	NONE	OPEN	35	2.9	
28-4	06/16/90	•	480	NONE	OPEN	51	2.8	
28-5	06/16/90	HI LOAD OFA/O2 VARIATION	482	NONE	OPEN	51	2.3	
29-1	06/17/90	MID LOAD OFA VARIATION	405	NONE	OPEN	5	4.4	
29-2	06/17/90	•	405	NONE	OPEN	14	4.3	
29-3	06/18/90	•	408	NONE	OPEN	30	4.2	
29-4	06/18/90	•	408	NONE	OPEN	39	4.4	
30-1	06/19/90	HI LOAD O2 VARIATION	487	NONE	OPEN	5	2.5	
30-2	06/19/90	•	487	NONE	OPEN	4	2.7	
30-3	06/19/90	HI LOAD O2/OFA VARIATION	487	NONE	OPEN	30	2.5	
31-1	06/20/90	HI LOAD REGIST ADJ	482	NONE	OPEN	5	2.4	
31-2	06/20/90	•	487	NONE	OPEN	5	2.0	
31-3	06/20/90	•	490	NONE	OPEN	5	2.1	
31-4	06/20/90	HI LOAD OFA VARIATION	490	NONE	OPEN	30	2.2	
32-1	06/21/90	HI LOAD OFA VARIATION	485	NONE	OPEN	4	2.5	
32-2	06/21/90	•	485	NONE	OPEN	20	2.6	
32-3	06/21/90	•	482	E	OPEN	50	2.9	
33-1	06/25/90	LOW LOAD OFA VARIATION	308	E	OPEN	5	4.6	
33-2	06/26/90	•	300	E	OPEN	25	4.1	
33-3	06/26/90	•	302	E	OPEN	50	5.1	
33-4	06/26/90	•	310	E	OPEN	75	4.0	
33-5	06/26/90	LOW LOAD OFA/O2 VARIATION	302	E	OPEN	75	3.3	
34-1	06/26/90	LOW LOAD NORMAL	290	E	OPEN	5	3.2	
34-2	06/26/90	LOW LOAD O2 VARIATION	305	E	OPEN	50	4.2	
34-3	06/27/90	•	295	E	OPEN	50	3.2	
34-4	06/27/90	•	295	E	OPEN	50	3.5	
34-5	06/27/90	MID LOAD OFA VARIATION	390	E	OPEN	50	3.4	
34-6	06/27/90	•	390	E	OPEN	35	3.4	
34-7	06/27/90	•	390	E	OPEN	20	3.3	
34-8	06/27/90	•	390	E	OPEN	5	3.0	
35-1	06/26/90	MID LOAD OFA VARIATION	405	E	OPEN	5	3.4	
35-2	06/27/90	•	405	E	OPEN	25	3.4	
35-3	06/28/90	•	402	E	OPEN	50	3.5	
35-4	06/28/90	MID LOAD OFA/O2 VARIATION	407	E	OPEN	50	3.2	
35-5	06/28/90	•	410	E	OPEN	50	4.0	
35-6	06/28/90	MID LOAD OAF/O2 VARIATION	407	E	OPEN	75		

35-7	06/28/90	•	410	E	OPEN	5	
36-1	06/29/90	MID LOAD OFA VARIATION	475	NONE	OPEN	5	2.9
36-2	06/29/90	•	475	NONE	OPEN	25	2.9
36-3	06/29/90	•	480	NONE	OPEN	50	3.1
36-4	06/29/90	•	480	NONE	OPEN	75	2.9

TABLE 5-1 (continued)
SUMMARY OF HAMMOND UNIT 4 PHASE 2 DIAGNOSTIC OFA TESTING

TEST NO.	DATE	TEST CONDITIONS	LOAD (MW)	MOOS PATTERN	GUILLOTINE POSITION	OFA DAMPER (%)	DAS 02 DRY (%)	NOx AT 3% O2 PPM
			300					
46-1	08/14/90	LOW LOAD O2 VARIATION	300	E	OPEN	50	3.5	472
46-2	08/14/90	•	300	E	OPEN	50	4.4	55+
46-3	08/14/90	•	300	E	OPEN	50	5.1	624
46-4	08/14/90	•	400	E	OPEN	50	5.6	675
47-1	08/14/90	MID LOAD	400	NONE	OPEN	50	3.4	569
47-2	08/14/90	MID LOAD REPEAT	400	NONE	OPEN	50	3.4	570
47-3	08/15/90	MID LOAD O2 VARIATION	400	NONE	OPEN	50	3.5	581
47-4	08/15/90	•	400	NONE	OPEN	50	4.0	607
47-5	08/15/90	•	400	NONE	OPEN	50	4.6	637
48-1	08/15/90	HI LOAD O2 VARIATION	455	NONE	OPEN	50	2.5	502
48-2	08/15/90	•	455	NONE	OPEN	50	3.2	559
48-3	08/15/90	•	455	NONE	OPEN	50	3.9	604
48-4	08/15/90	HI LOAD O2/OFA VARIATION	455	NONE	OPEN	50	4.3	628
48-5	08/15/90	•	450	NONE	OPEN	35	4.2	662
48-6	08/15/90	•	450	NONE	OPEN	20	4.4	731
48-7	08/15/90	•	450	NONE	OPEN	5	4.6	774
48-8	08/15/90	•	450	NONE	OPEN	0	4.2	774
49-1	08/16/90	HI LOAD OFA VARIATION	475	NONE	OPEN	5	3.8	675
49-2	08/16/90	•	480	NONE	OPEN	20	2.9	620
49-3	08/16/90	•	482	NONE	OPEN	35	3.1	580
49-4	08/16/90		482	NONE	OPEN	50	3.2	553
49-5	08/16/90		480	NONE	OPEN	50	3.6	568
49-6	08/16/90		485	NONE	OPEN	50	4.3	619

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

TEST NO.	DATE	GROSS LOAD (MWE)	PLANT O2 E ECON OUTLET (DRY %)	PLANT O2 W ECON OUTLET (DRY%)	CEM O2 AVERAGE OUTLET (DRY%)	CEM AVG NOx COMPSOITE AT 3% O2 (PPM)	STACK OPACITY (PCT)	SAPHA OUT TEMP (°F)	SAPAH B OUT TEMP (°F)	STEAM FLOW (MLB/HR)	SH TEMP (°F)	SH SPRAY FLOWS LOWER SPRAY (kLB/HR)	SH SPRAY FLOWS UPPER SPRAY (kLB/HR)	HOT RH TEMP (°F)	PULV… MILL A	MILL B	MILL ((kLB/F
23-1	05/23/90	478	3.0	2.9	2.7	1027		230	250	3.2	990	15.3	13.2	10	58	88	58
24-1	06/11/90	482	2.5	2.6	2.1	889		200	240	3.2	995	15.4	11.7	992	57	48	57
24-2	06/11/90	480	3.1	3.0	3.0	945		190	240	3.2	995	17.0	11.3	995	57	49	57
25-1	06/12/90	475	3.1	3.4	2.8	801	8.9	190	230		998	11.5	7.0	940	58	50	58
25-2	06/12/90	478	3.2	3.5	2.5	809	10.6	200	240	3.2	997	13.0	15.0	994	58	50	58
25-3	06/12/90	478	3.2	3.2	2.5	883	10.0	200	230	3.2	1002	13.7	6.7	950	58	49	58
25-4	06/12/90	479	2.9	3.2	2.5	825	11.8	200	240	3.2	1000	14.3	6.7	950	58	50	58
25-5	06/12/90	476	2.8	3.2	2.4	783	12.6	190	230	3.2	1005	14.2	6.5	950	58	50	58
25-6	06/12/90	475	2.7	3.0	2.4	665	8.8	190	230	3.2	999	14.5	6.6		58	50	58
26-1	06/13/90	478	2.8	3.1	2.1	794	18.1	190	230	3.2	1008	12.8	12.5	930	88	44	58
26-2	08/13/90	478	3.0	3.2	2.8	835	9.5	200	230	3.2	1011	15.5	11.0	900	85	43	57
27-1	08/15/90	480	3.1	3.0	2.8	798	9.6	220	230	3.2	977	14.4	11.2	980	58	58	54
27-2	06/15/90	478	2.9	3.0	5.3	858	13.1	220	230	3.2	994	15.2	9.2	950	64	57	58
27-3	06/15/90	478	2.9	2.8			7.8	210	230	3.2	995	15.5	9.2	940	64	58	57
27-4	06/15/90	475	2.8	2.8			14.8	210	220	3.2	995	15.3	9.2	960	64	58	58
27-5	06/15/90	478	3.2	3.4	2.6	742	15.9	220	230	3.2	992	15.7	9.2	960	64	58	58
28-1	06/16/90	482	3.4	3.5	2.8	742	9.9	220	230	3.3	992	15.4	10.6	960	83	58	58
28-2	06/16/90	483	3.5	3.8	2.7	700	10.8	220	230		990	15.6	10.6	960	83	58	58
28-3	06/16/90	483	3.8	3.9	2.9	850	14.7	210	230	3.2		18.5	10.0	980	83	58	58
28-4	06/16/90	480	3.4	3.9	2.8	583	10.8	210	220	3.2	987	18.5	10.5	980	83	58	58
28-5	06/16/90	482	3.1	3.4	2.3	551	9.8	210	210	3.2	993	18.3	10.4	860	84	57	58
29-1	06/17/90	405	4.8	5.1	4.4	785	4.7	200	240	2.8	985	16.5	11.5	1004	54	48	48
29-2	06/17/90	405	4.8	5.0	4.3	772	5.6	200	240	2.7	998	16.0	10.0	1002	54	48	48
29-3	06/18/90	408	4.8	5.0	4.2	898	8.9	190	240	2.8	993	16.2	9.2	100	53	47	48
29-4	06/18/90	408	4.4	5.4	4.4	848	5.9	190	240	2.8	993	16.0	9.6	100	54	47	48
30-1	06/19/90	487	2.7	2.9	2.5	812	9.1	205	250	3.3	985	16.5	14.3	1000	79	85	52
30-2	06/19/90	487	3.2	3.0	2.7	877	14.0	210	280	3.3	978	17.5	14.2	950	59	83	58
30-3	06/19/90	478	3.3	3.0	2.5	717	17.3	200	280	3.3	975	17.3	14.2	920	59	83	58
31-1	06/20/90	482	2.9	2.7	2.4	802	11.4	200	240	3.3	1008	15.7	14.4	960	83	80	80
31-2	06/20/90	487	2.5	2.5	2.0	783	10.2	200	230	3.3	898	16.3	14.6	930	83	59	80
31-3	06/20/90	490	2.6	2.8	2.1	795	13.3	210	240	3.3	986	16.6	14.8	920	83	58	80
31-4	06/20/90	490	2.8	3.0	2.2	705	12.8	210	250	3.7	979	17.0	14.8	980	83	58	80
31-5	06/20/90	491	2.9	3.4			10.7	205	250	3.3	976	17.2	15.8	910	82	58	80
32-1	06/21/90	485	3.0	3.2	2.5	714	10.0	210	240	3.3	973	12.3	15.5	920	59	81	58
32-2	06/21/90	485	3.0	3.2	2.6	685	12.2	210	240	3.3	973	13.7	15.2	950	59	80	58
32-3	06/21/90	482	3.2	3.6	2.9	587	10.6	210	240	3.3	965	14.5	15.0	940	59	81	58
33-1	06/25/90	308	3.2	4.9	4.6	723	1.9	185	185	2.0	988	8.0	10.0	935	43	43	43
33-2	06/26/90	300	3.2	5.0	4.1	695	1.9	190	170	2.0	1007	7.8	10.0	980	43	43	43
33-3	06/26/90	302	3.2	4.9	5.1	626	1.0	190	170	2.0	1008	6.5	9.5	965	49	44	42
33-4	06/26/90	310	3.1	4.8	4.0	643	1.2	185	180	2.0	982	8.3	13.3	950	49	44	42
33-5	06/26/90	302	2.6	4.4	3.3	578	0.6	180	175	2.0	996	8.5	12.5	950	49	44	42

TABLE 5-2 (contd) SUMMARY OF PHASE 2 DIAGNOSTIC TESTS OPERATING AND EMISSION DATA

TEST NO.	DATE	GROSS LOAD (MWE)	PLANT O2 E ECON OUTLET (DRY %)	PLANT O2 W ECON OUTLET (DRY%)	CEM O2 AVERAGE OUTLET (DRY%)	CEM AVG NOx COMPSOITE AT 3% O2 (PPM)	STACK OPACITY (PCT)	SAPHA OUT TEMP (°F)	SAPAH B OUT TEMP (°F)	STEAM FLOW (MLB/HR)	SH TEMP (°F)	SH SPRAY FLOWS LOWER SPRAY (kLB/HR)	SH SPRAY FLOWS UPPER SPRAY (kLB/HR)	SH SPRAY FLOWS HOT RH TEMP (°F)	PULVERI MILL A	PULVERI MILL B	PULVERI MILL C (kLB/HR)
34-1	06/26/90	290	3.0	4.7	3.2	609	3.5	185	185	2.0	1013	7.5	7.5	930	46	44	42
34-2	06/26/90	305	3.6	4.6	4.2	557	1.5	190	180	2.0	987	7.8	7.0	930	46	45	42
34-3	06/27/90	295	2.5	3.9	3.2	480	0.2	180	170	2.0	993	5.5	5.7	920	46	45	42
34-4	06/27/90	295	2.8	4.2	3.5	507	0.1	180	170	2.0	1001	7.5	8.5	925	48	45	42
34-5	06/27/90	390	2.8	4.6	3.4	527	3.9	190	200	2.6	1004	11.0	10.7	955	59	57	54
34-6	06/27/90	390	2.7	4.6	3.4	531	5.7	185	205	2.6	1002	12.0	11.0	955	59	57	54
34-7	06/27/90	390	2.8	4.5	3.3	553	7.9	175	195	2.6	989	12.0	13.0	950	59	57	54
34-8	06/27/90	390	2.7	4.3	3.0	584	4.0	180	205	2.6	992	12.0	12.0	950	59	57	54
35-1	06/27/90	405	3.0	4.2	3.4	830	6.2	205	225	2.7	982	12.2	15.0	950	60	57	57
35-2	06/27/90	405	3.0	4.2	3.4	587	5.7	200	230	2.7	995	13.5	13.5	950	74	61	69
35-3	06/27/90	402	2.8	4.4	3.5	546	4.7	200	230	2.7	997	13.5	13.5	950	60	57	57
35-4	06/27/90	407	2.8	4.1	3.2	530	3.8	200	225	2.7	1003	13.5	13.5	950	60	60	55
35-5	06/28/90	410	3.4	4.8	50.0	4	9.0	202	230	2.6	993	14.2	13.5	952	60	60	55
35-6	06/28/90	407	2.9	4.6			9.7	195	235	2.6	995	14.0	13.5	950	60	61	55
35-7	06/28/90	410	2.8	4.1			5.2	195	225	2.7	999	13.8	13.5	950	60	61	55
36-1	06/29/90	475	3.0	3.2	2.9	859	10.2	190	220	3.3	982	15.2	10.0	980	63	80	50
36-2	06/29/90	475	2.9	3.2	2.9	598	10.3	190	230	3.2	986	12.2	10.0	990	63	80	50
36-3	06/29/90	480	2.8	3.6	3.1	538	12.2	190	240	3.2	982	13.8	10.0	990	64	80	50
36-4	06/29/90	480	2.8	3.5	2.9	516	13.4	195	245	3.2	981	13.0	10.0	985	63	80	50
46-1	08/14/90	300	3.3	4.1	3.5	472		200	200	2.0	991	5.0	5.8	950	44	45	42
46-2	08/14/90	300	4.1	4.4	4.4	556	2.3	200	210	2.0	998	5.8	5.8	970	44	45	42
46-3	08/14/90	300	4.6	5.2	5.1	824	3.0	200	210		997	8.3	5.8	982	44	45	42
46-4	08/14/90	305	5.0	5.6	5.6	875	4.0	190	210		987	8.2	5.7	992	44	45	43
47-1	08/14/90	402			3.4	589	22.8				986				46	51	45
47-2	08/14/90	402	3.2	3.6	3.4	570	29.4	200	210	2.7	993	11.6	6.7	990	46	51	45
47-3	08/14/90	405	3.0	3.6	3.5	581	19.2	220	210	2.7	997	10.3	6.7	993	48	51	48
47-4	08/14/90	410	4.0	4.6	4.0	607	18.3	210	220	2.7	994	11.0	6.7	995	48	51	48
47-5	08/14/90	410	4.2	5..0	4.8	637	19.4	210	230	2.7	990	11.6	6.7	995	48	52	48
48-1	08/15/90	455	2.9	2.6	2.5	502	20.2	200	280	31.2	992	8.6	8.2	995	54	58	58
48-2	08/15/90	455	3.1	3.3	3.2	559	24.9	200	280	3.1	993	8.6	8.2	997	51	55	55
48-3	08/15/90	455	3.6	4.0	3.9	604	27.4	200	270	3.1	992	8.6	8.1	999	51	58	58
48-4	08/15/90	455	3.9	4.4	4.3	828	19.4	200	280		993	8.5	8.0	1000	51	58	55
48-5	08/15//90	450	4.2	4.5	4.2	882	17.7			3.0	989	8.5	8.0	1000	54	57	48
48-6	08/15/90	450	4.2	4.4	4.4	731	18.3				1006	8.3	8.0	1004			
48-7	08/15/90	450	4.1	4.3	4.8	774	21.5				1016	8.3	7.8	1004			
48-8	08/15/90	450	4.0	4.2	4.2	774	20.5				1015	8.4	8.0	1003			
49-1	08/16/90	475	3.0	2.5	3.8	875	18.2	200	230	3.5	1006	5.0	9.0	995	83	64	62
49-2	08/16/90	480	3.2	2.7	2.9	820	15.2			3.4	998	5.0	9.0	995			
49-3	08/16/90	482	3.2	2.8	3.1	580	15.1			3.4	989	5.0	8.8	995			
49-4	08/16/90	482	3.6	3.0	3.2	553	21.7	200	240	3.4	983	5.0	8.0	995	83	64	53
49-5	08/16/90	470	3.6	3.4	3.6	588	20.1	220	230	3.4	1009	4.0	8.8	1000	83	64	52
49-6	08/16/90	485	4.5	4.0	4.3	819	19.9	200	240	3.4	979	2.5	8.0	997	83	64	52
50-1	10/24/90	487	4.2	3.2			50.1	230	280	3.3	991	185.0	10.0	1000	64	64	64

51-1	10/28/90	489	3.2	3.6			20.5	230	2540	3.3	1001	130.0	5.0	1000	64	65	62

Figure 5-1 illustrates that the testing was performed over a range of excess oxygen levels that were both below and above the levels recommended for this unit. The solid curve represents the mean level of the data sample at each given load. 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.

Figure 5-2 is a summary of all of the NOx data obtained for all test configurations. These configurations represented the range of normal configurations that were believed to be the predominant modes of operation that might be experienced during the system load dispatch mode of operation during long-term testing. The data scatter is partially due to the fact the different configurations are represented. The solid line in Figure 5-2 for loads from 280-to 490 MWe represents the recommended excess O_2 operating level. It should be pointed out that with more NOx data, the slope of the trend may change slightly. It is also emphasized that 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 NOx trend.

Short-term characterization of the NOx emissions generally were made for trends determined on the same day of testing for a particular configuration. This is believed to eliminate, to some extent, the influence of the uncontrollable parameters. Figures 5-3 through 5-6 show the diagnostic test results for the four nominal loads tested - 480, 450, 400 and 300 MWe, respectively. The legend for each data point indicates the test day for the particular data point. As shown in Table 5-1, tests were run at various OFA damper openings in order to establish an "optimum" setting over the load range taking into account both NOx reduction and effects on boiler operation (excess O_2 level vs CO and carbon loss).

Figure 5-3 shows the NOx data for the 480 MWe test point at the nominal OFA damper setting of 50 percent open. At this load, the only mill pattern tested was all-mill-in-service (AMIS). Over the wide range of usable excess oxygen (2.0 to 4.5 percent) the NOx increases with increasing excess oxygen and the rate of change is nearly constant at 65 ppm/% O_2. The data are labeled according to the test day in the program. .

NOx data for the 450 MWe test point is shown in Figure 5-4 for all mills in service and 50 percent OFA damper. The NOx increased at a rate of approximately 75 ppm/percent O_2 at this load over an excess oxygen excursion from 2.5 to 4.5 percent.

At 400 MWe, the oxygen range could be tested over the O_2 excursion range from 3.0 to 4.5 percent. For the two mill patterns tested at this load point (E MOOS and AMIS), the NOx

FIGURE 5-1 HAMMOND UNIT 4 OXYGEN LEVELS TESTED

PHASE 2 - AOFA

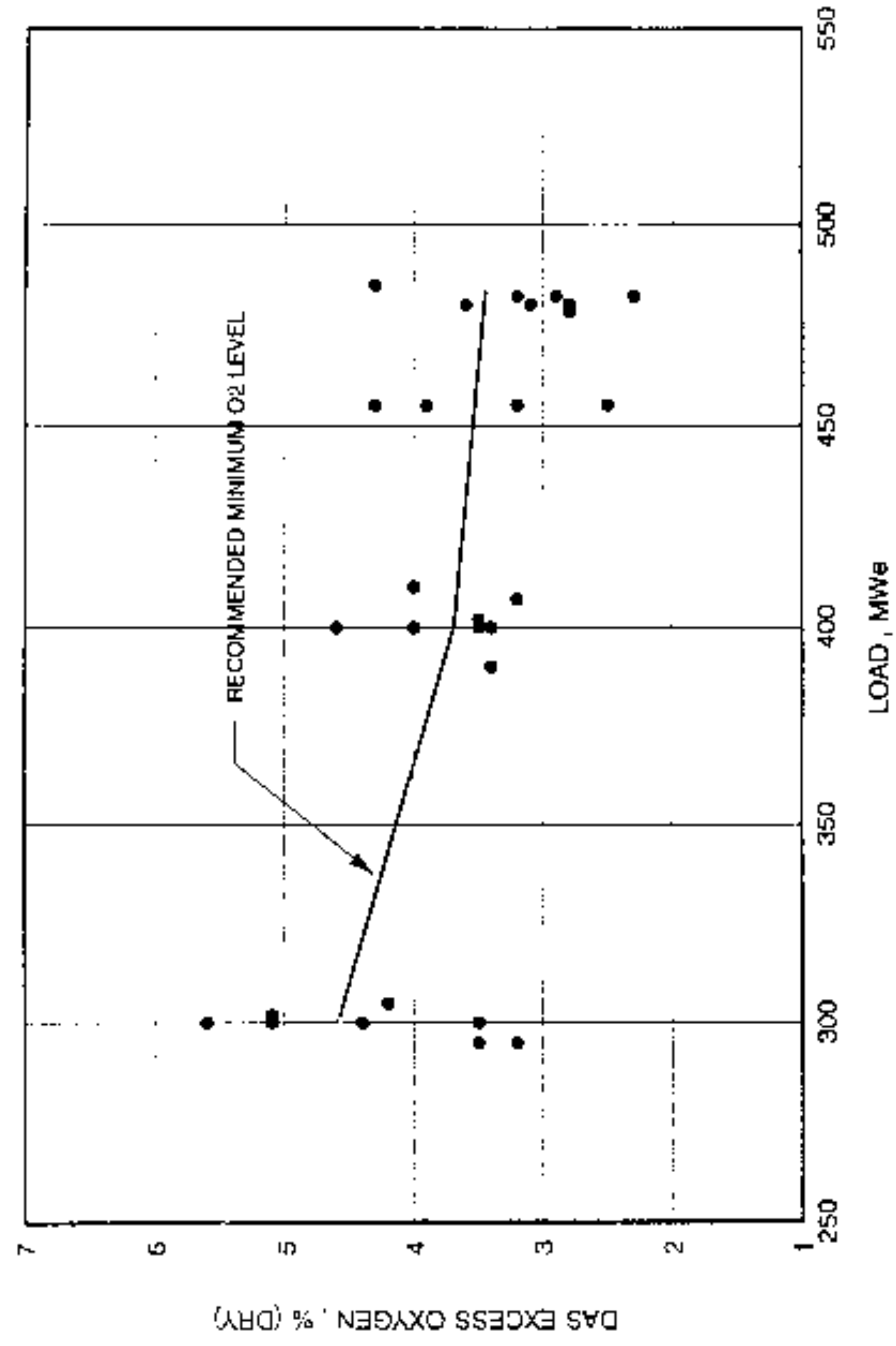


FIGURE 5-2 HAMMOND UNIT 4 NITRIC OXIDE MEASUREMENTS

PHASE 2 - AOFA

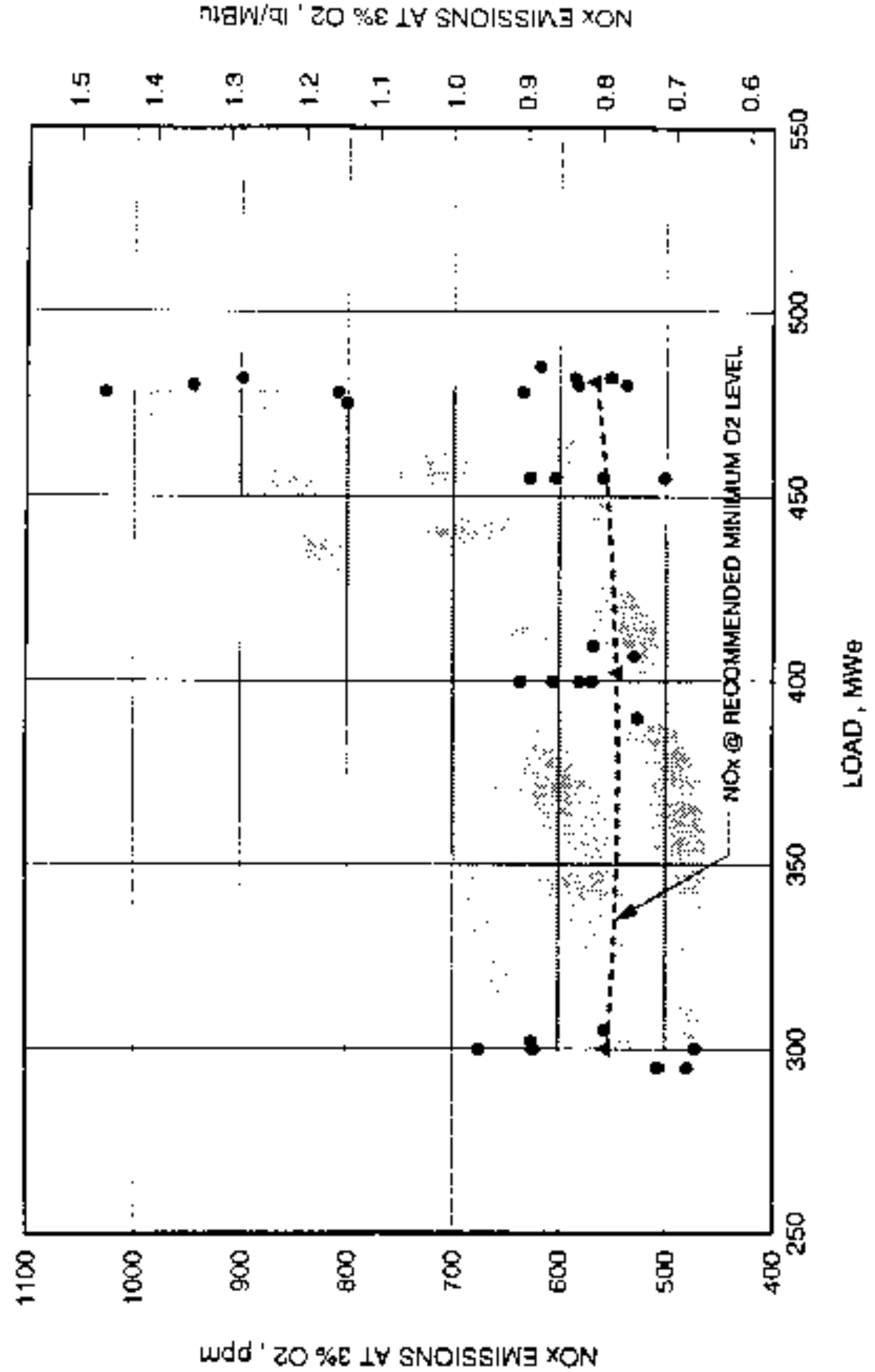


FIGURE 5-3 NOx CHARACTERIZATION @ 480 MWe NOMINAL LOAD
PHASE 2 - AOFA

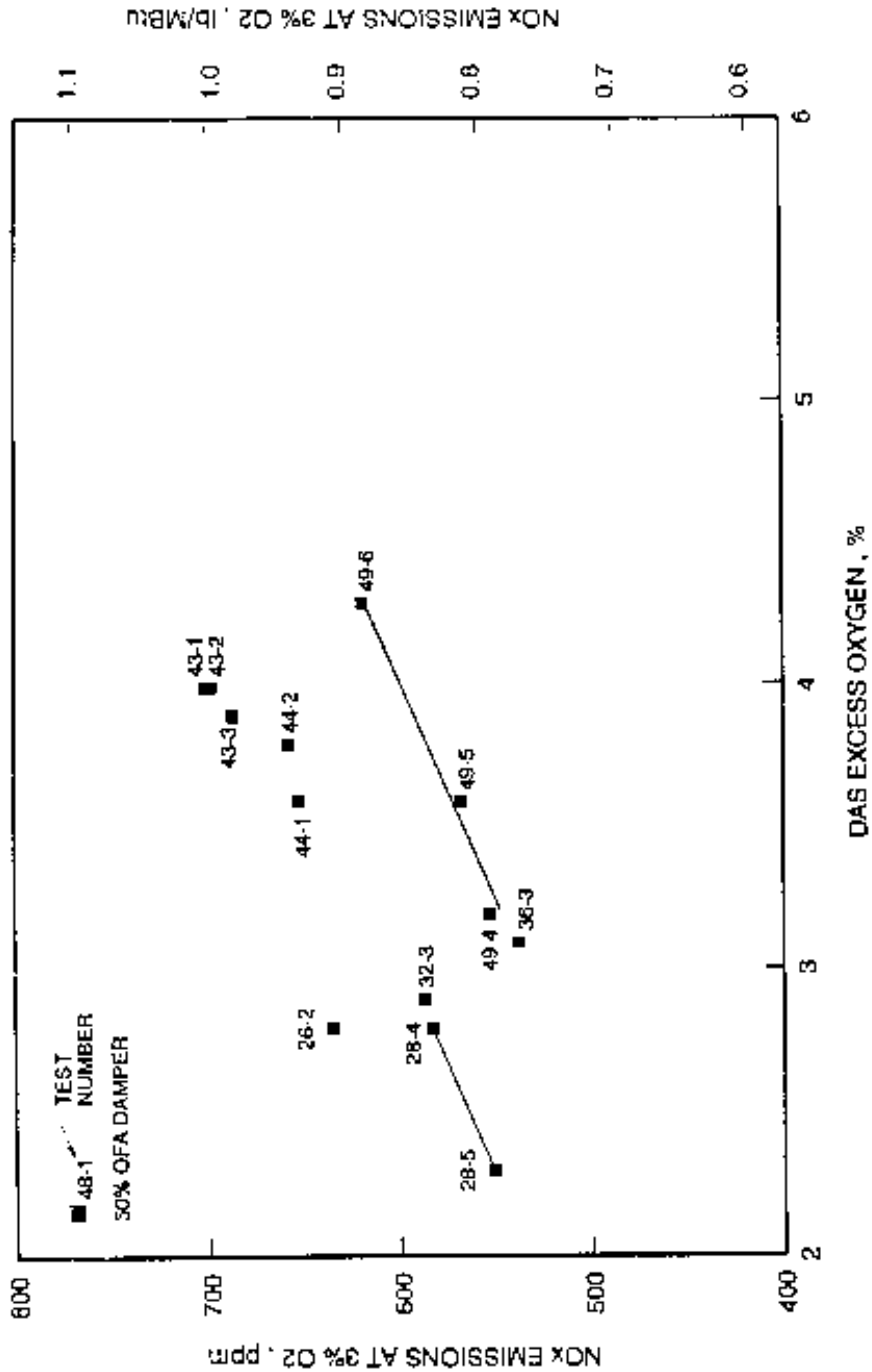


FIGURE 5-4 NOx CHARACTERIZATION @ 450 MWe NOMINAL LOAD
PHASE 2 - AOFA

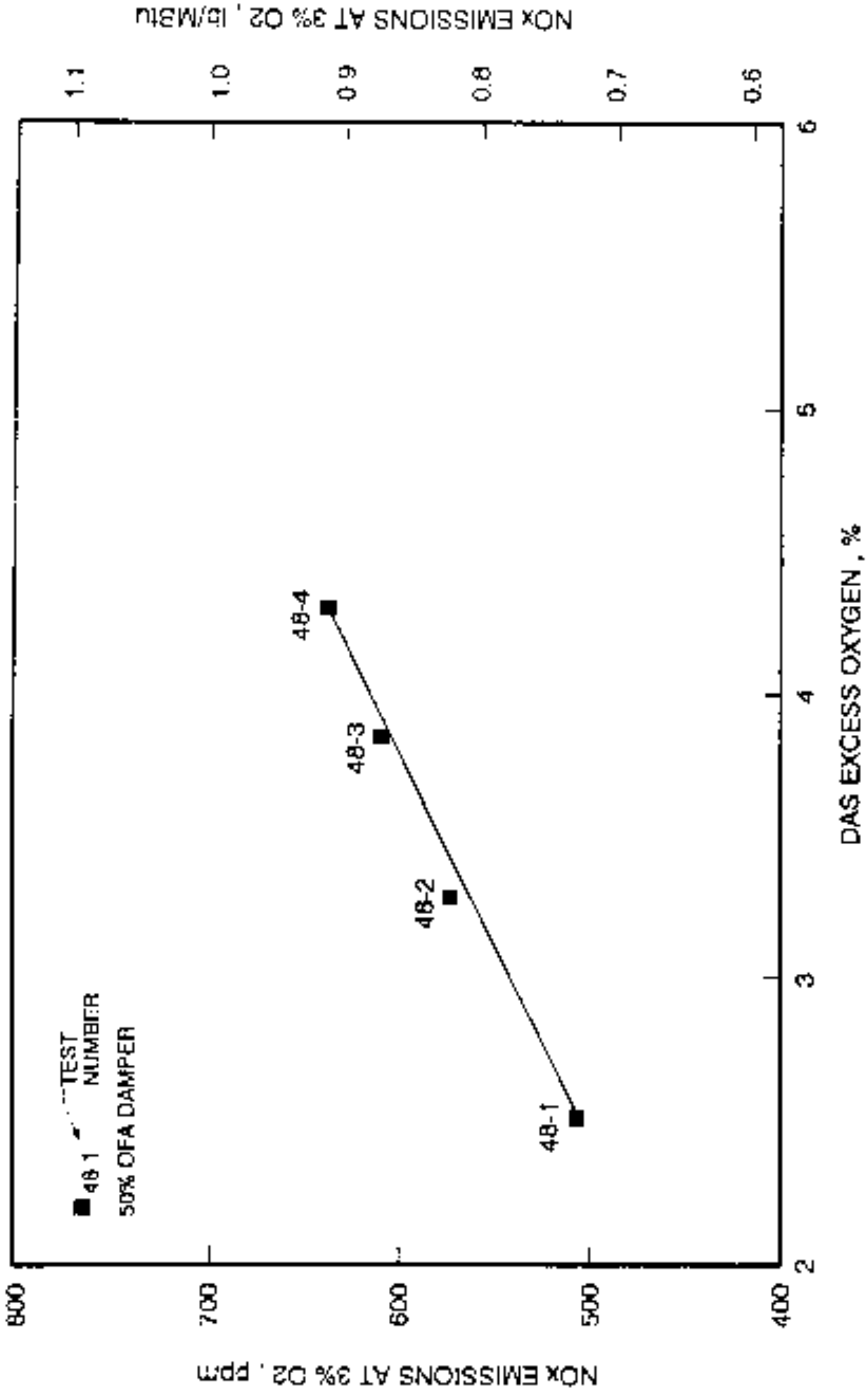


FIGURE 5-5 NOx CHARACTERIZATION @ 400 MWe NOMINAL LOAD
PHASE 2 - AOFA

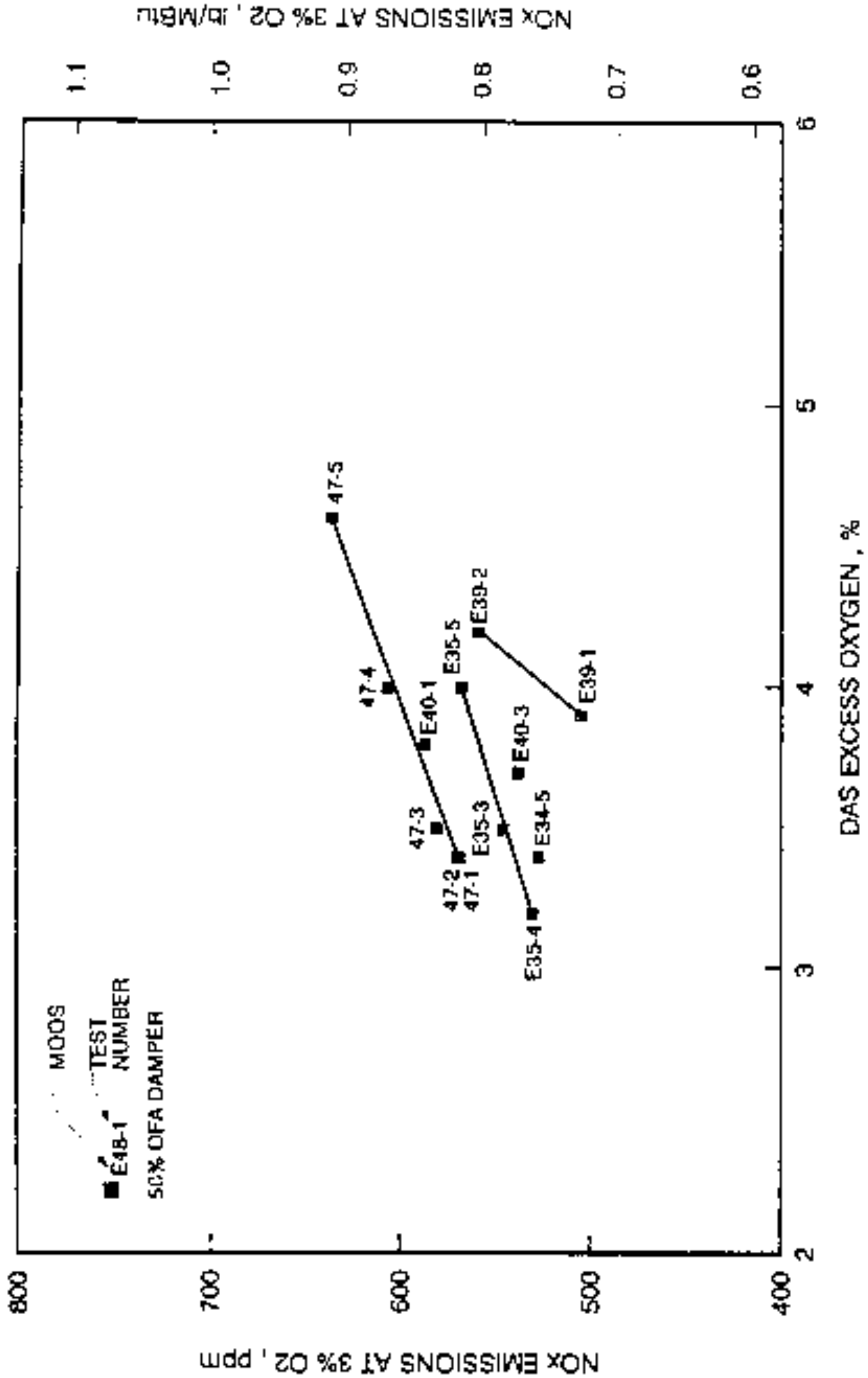
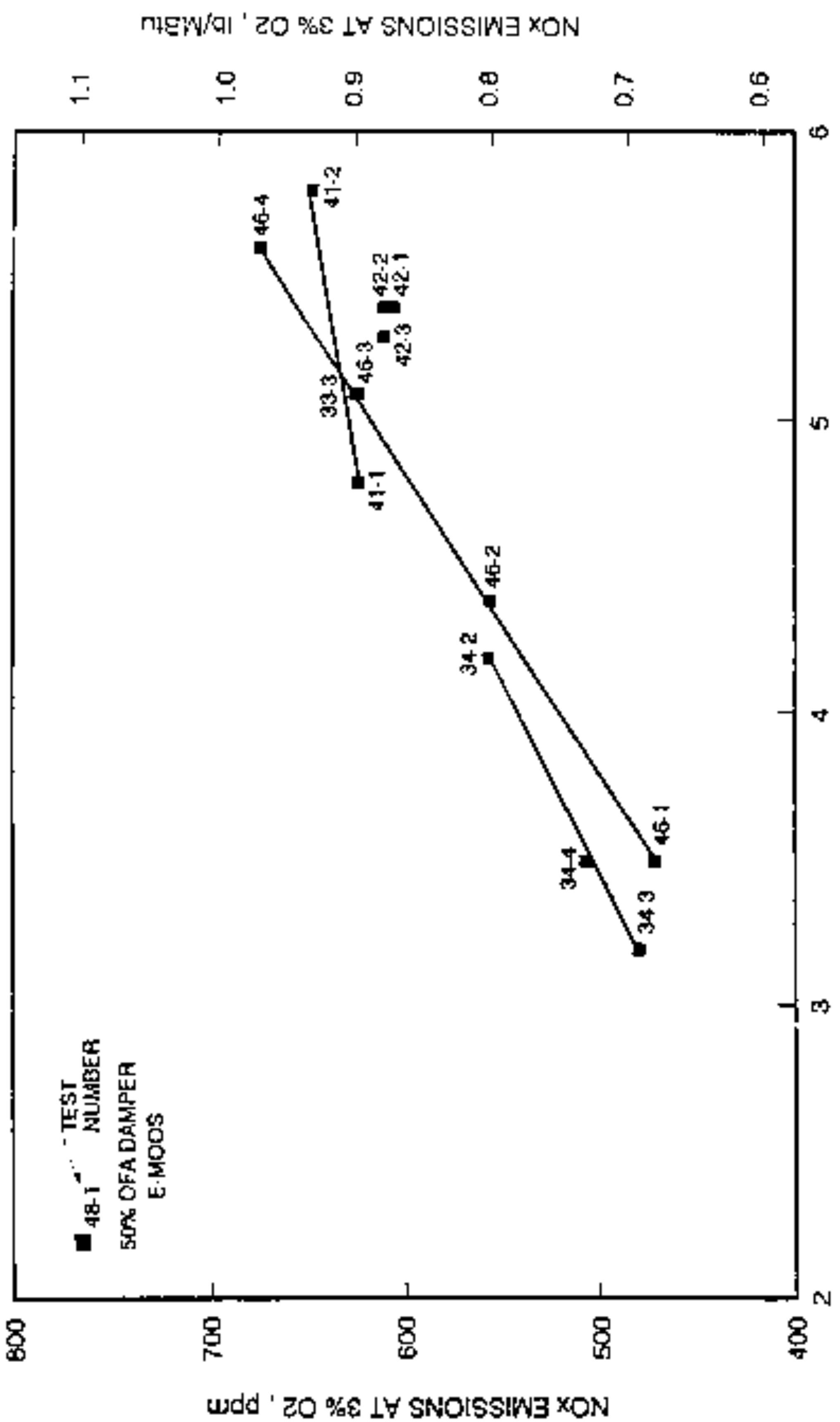


FIGURE 5-6 NOx CHARACTERIZATION @ 300 MWe NOMINAL LOAD
PHASE 2 - AOFA



trends appeared to be similar to the variability at 480 MWe load as shown in Figure 5-5. On average the NOx increased at a rate of approximately 80 ppm/percent O_2 over the excess oxygen excursion range.

Figure 5-6 shows the data for the single MOOS pattern (E MOOS) at the 300 MWe test point. For this mill pattern, the NOx trend characteristic exhibited a nominal 100 ppm/percent O_2 slope.

5.2 Performance Tests

Six performance tests were conducted at nominal gross loads of 480, 400 and 300 MWe with 50 percent OFA damper setting. Testing at each load point required two consecutive days to complete sampling of all of the parameters included in the performance matrix. At each nominal load the coal firing rate was kept as constant as possible and the electric load allowed to swing slightly as affected by coal variations, boiler ash deposits, ambient temperature, etc. Additional tests were performed at the 480 MWe load point to determine the impact of an increase in OFA damper setting on the NOx emissions. Each performance test covered a period from ten to twelve hours during which time manual and automated boiler operational data were recorded, fuel and ash samples acquired, gaseous and solid emissions measurements made, and the engineering performance tests conducted.

One additional test with abbreviated solid emissions measurements was made at 490 MWe with the OFA ports nominally closed.

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 some controls were placed in manual mode to minimize fluctuations in the fuel or air firing rate. This technique resulted in extremely stable operation over the test duration with only minor adjustment to the air flow over the day to maintain a near-constant stoichiometry.

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 air preheater 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.

Table 5-3 summarizes the conditions of each of the seven performance tests for ease of reference. Table 5-4 presents a summary of important operating parameters recorded on the DAS during this test series. The values shown in this table represent averages over the duration of the test segment during the day.

5.2.2 Gaseous Emissions

During the performance tests, gaseous emissions were measured with the CEM operating in the manual mode. At various times during the Performance Tests, flue gas was sampled from selected probes or probe groups in the primary and secondary air preheater inlet and outlet ducts. These groupings consisted of composites of the individual east and west economizer exit ducts and individual measurements from each probe in these ducts. Composite grouping was intended to be used to establish the overall emission characteristics while the individual probe measurements were intended to be used to establish spatial distributions of emission species. Composite average values of O_2 and NOx measured during each test segment are shown in Table 5-3.

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. The following paragraphs describe the results from these measurements.

<u>Total Mass Emissions</u> Total mass emissions reflect both a fraction of the total coal ash injected into the furnace (100 percent 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 5-5 presents the results of the Method 17 tests performed (see Section 3.4) at each test condition. For all tests the sampling rate was within six percent of isokinetic. The results shown for each load level represent the average of three replicate tests.

TABLE 5-3
SUMMARY OF HAMMOND UNIT 4 PHASE 2 PERFORMANCE OFA TESTING

TEST	DATE	TEST CONDITIONS	LOAD MW	MOOS PATTERN	OFA DAMPER	DAS O2 DRY (%)	NOx AT 3% O2 (ppm)
37-1	07/10/90	Hl LOAD PERFORMANCE	480	NONE	75	3	523
37-2	07/10/90	“	480	NONE	75	2.9	537
37-3	07/10/90	“	480	NONE	75	3	538
38-1	07/11/90	Hl LOAD PERFORMANCE	485	NONE	75	4.1	616
38-2	07/11/90	“	488	NONE	75	3.8	605
38-3	07/11/90	“	488	NONE	75	4.1	598
39-1	07/12/90	MID LOAD PERFORMANCE	400	E	50	3.9	505
39-2	07/13/90	“	400	E	50	4.2	559
40-1	07/13/90	MID LOAD PERFORMANCE	405	E	50	3.8	587
40-2	07/14/90	“	408	E		3.7	534
40-3	07/14/90	“	405	E	50	3.7	538
40-1	07/14/90	LOW LOAD PERFORMANCE	298	E	50	4.8	624
41-2	07/15/90	“	297	E	50	5.8	648
42-1	07/15/90	LOW LOAD PERFORMANCE	300	E	50	5.4	606
42-2	07/16/90	“	300	E	50	5.4	611
42-3	07/16/90	“	300	E	50	5.3	611
43-1	07/17/90	Hl LOAD PERFORMANCE	487	NONE	50	4	701
43-2	07/17/90	“	487	NONE	50	4	698
43-3	O7/17/90	“	487	NONE	50	3.9	687
44-1	07/18/90	Hl LOAD PERFORMNCE	487	NONE	50	3.6	653
44-2	07/18/90	“	487	NONE	50	3.8	658
45-1	07/18/90	Hl LOAD PERFORMANCE	489	NONE	1	3.8	902

TABLE 5-4 SUMMARY OF PHASE 2 PERFORMANCE TESTS OPERATING AND EMISSION DATA

			PLANT O2		CEM O2	CEM AVG NOx						SH SPRAY F	
TEST NO.	DATE	GROSS LOAD (MWE)	E ECON OUTLET (DRY %)	W ECON OUTLET (DRY%)	AVERAGE OUTLET (DRY%)	COMPSOITE AT 3% O2 (PPM)	STACK OPACITY (PCT)	SAPHA OUT TEMP (°F)	SAPAH B OUT TEMP (°F)	STEAM FLOW (MLB/HR)	SH TEMP (°F)	UPPER SPRAY (kLB/HR)	UPPER SPRAY (kLB/HI
37-1	07/10/90	480	2.6	3.4	3.0	523	15.1	207	200	3.1	997	16.0	12.7
37-2	07/10/90	480	2.6	3.4	2.9	537	16.2	205	212	3.1	995	17.0	12.0
37-3	07/10/90	480	2.8	3.6	3.0	538	13.7	205	210	3.2	984	19.0	10.2
38-1	07/10/90	485	4.0	4.6	4.1	616	19.4	205	235	3.1	989	17.5	7.3
38-2	07/11/90	488	3.6	4.4	3.8	605	17.0	205	242	3.1	1000	16.8	5.6
38-3	07/11/90	488	3.6	4.3	4.1	598	10.4	200	235	3.1	1002	18.0	5.6
39-1	07/12/90	400	3.5	4.8	3.9	505	6.1	202	180	2.5	997	13.5	15.0
39-2	07/13/90	400	3.7	4.8	4.2	559	8.4	200	180	2.5	995	14.0	14.0
40-1	07/13/90	405	3.4	4.4	3.8	587	11.8	210	195	2.5	995	13.0	14.9
40-2	07/14/90	408	3.4	4.5	3.7	534	10.8	210	165	2.5	996	13.8	14.5
40-3	07/14/90	405	3.3	4.5	3.7	538	7.7	210	192	2.5	897	14.3	14.7
41-1	07/14/90	298	4.8	6.5	4.8	624	3.5	185	180	1.8	1003	9.3	10.5
41-2	07/15/90	297	4.8	6.4	5.8	648	4.4	185	175	1.8	1011	19.5	10.2
42-1	07/15/90	300	4.5	5.6	5.4	606	4.3	177	168	1.8	1001	8.5	6.8
42-2	07/16/90	300	4.5	5.8	5.4	611	2.7	175	170	1.8	983	7.9	10.5
42-3	07/16/90	300	4.2	5.6	5.3	611	2.4	170	175	NA	987	8.5	10.5
43-1	07/17/93	487	3.9	4.2	4.0	701	10.3	220	270	3.1	993	17.5	10.5
41-2	07/17/90	487	3.8	4.3	4.0	698	7.2	210	275	3.1	984	18.6	10.5
43-3	07/17/90	487	3.8	4.2	3.9	687	9.7	210	2t0	NA	983	19.8	10.0
44-1	07/18/90	487	3.9	4.1	3.6	653	9.4	215	260	3.1	987	15.0	13.3
44-2	07/18/90	487	3.8	4.1	3.8	658	15.8	212	265	NA	996	15.6	10.5
45-1	07/18/90	489	3.7	4.1	3.8	902	24.8	210	265	3.1	982	17.0	10.5

TABLE 5-5

SUMMARY OF SOLID MASS EMISSIONS TESTS

TEST No	LOAD MWe	OFA Damper %	O_2 %,dry	LOADING gr/dscf	GAS FLOW dscfm	CARBON %	LOI %
37	480	75	3.0	2.74	1,318,000	10.0	10.8
43-44	480	50	3.9	2.66	1,403,000	9.6	9.6
45	480	0	3.8	2.82	1,420,000	6.3	5.4
39	400	50	3.8	2.86	1,040,000	8.7	10.2
41	300	50	S.4	1.81	1,008,000	5.0	7.1

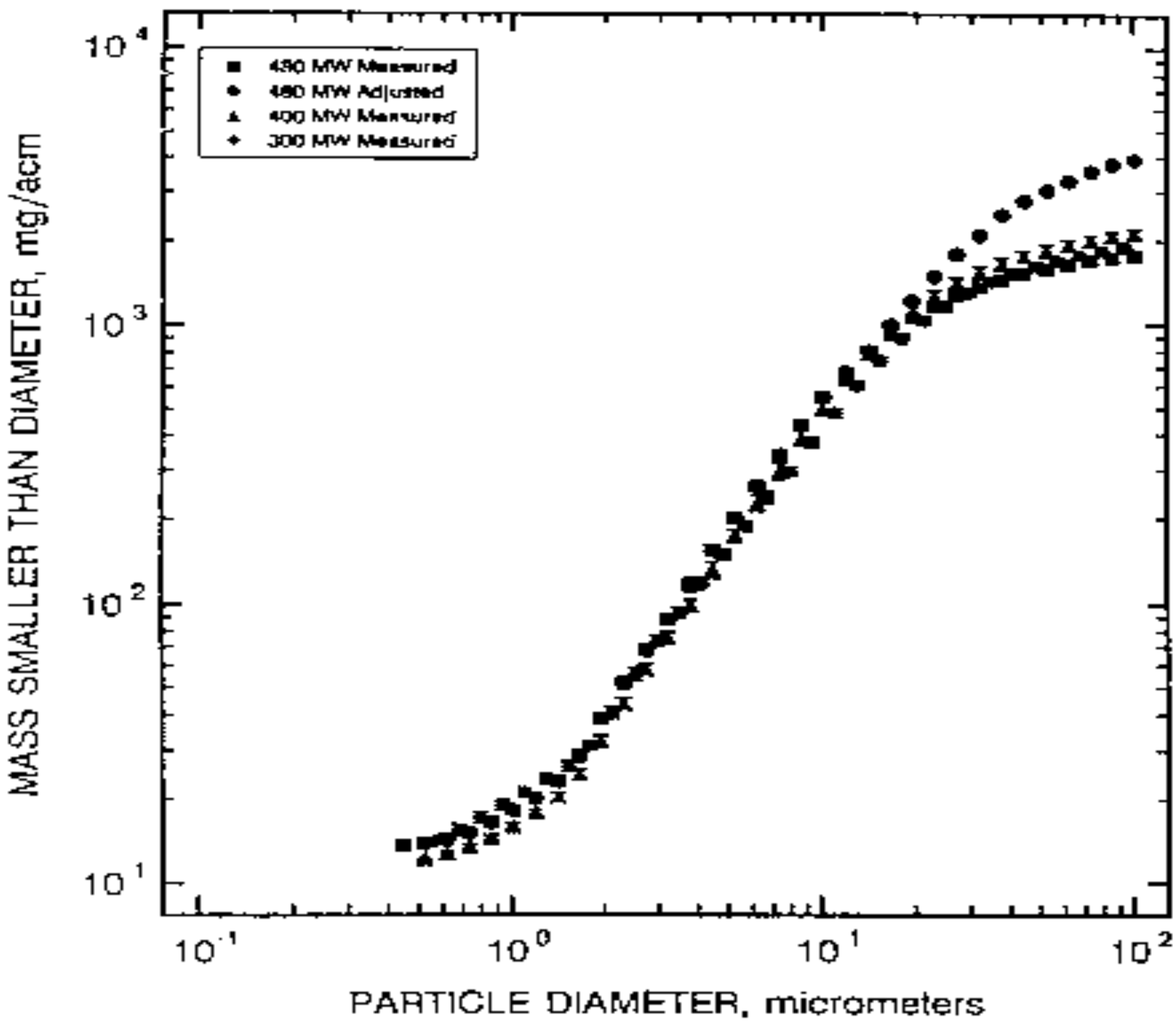
As a measure of the degree of completeness of combustion, the ash collected in the cyclone portion of the Method 17 train for each test was analyzed by two separate methods for carbon content and loss-on-ignition (LOI). The LOI is considered to represent carbon content along with volatile solids (sulfates, chlorides, etc.) driven off in the analysis procedure. The principal use of the performance tests LOI analyses is as a reference for comparison with ash samples acquired during other phases of the program.

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 conditions. Figure 5-7 shows the particle size distributions for all test conditions as the total percentage of cumulative mass. The vertical bars visible to the upper right show the 90 percent confidence level for the mass values determined at the indicated particle diameter while the symbols show the average of the replicate samples for each load. For most of the data, the 90 percent confidence interval is smaller than the plotting 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 agreement of all of the data indicates both excellent replication of test under common conditions and also the relatively minor effect of load on the ash particle size distribution. The total particulate mass collected per unit gas volume sampled in the particle size tests was comparatively less than in the Method 17 tests. This is attributed to the inability to sample as close to the bottom of the flue gas duct with the impactor probe as can be done with the Method 17 probe, resulting in the potential failure to capture some larger particle sizes which may stratify near the duct bottom. In order to account for the exclusion of some larger particle sizes (over 8 microns) when

FIGURE 5-7 ESP INLET MASS DISTRIBUTION

HAMMOND UNIT 4 PHASE 2 - ACFA



modeling ESP behavior, the 480 MWe particle size data are "adjusted" by extrapolating the data above 8 microns to the total mass loading measure with Method 17. Figure S-7 shows the additional mass of large particles associated with the "adjusted" 480 MWe data.

The derivative of cumulative mass with respect to diameter is presented in Figure 5-8. This type of presentation emphasizes the predominant concentration of mass vs. particle size. This format facilitates comparison of test data from Phase 2 and subsequent phases of the program with the Phase 1 data and will highlight any significant changes in particle size distribution and potential effect on ESP performance due to the low NOx retrofits.

Chemical Composition 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 5-5). The ESP hopper samples (East and West composites separately) were analyzed for mineral composition. Table 5-6 presents these data and allows a comparison of LOI between the air heater outlet (Method 17) and the ESP hopper chemical analysis.

As mentioned above, the carbon and LOI data are useful primarily to establish a comparison between baseline and post retrofit results 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.

Fly Ash Resistivity

Measurements of in situ resistivity were made during each AOFA test condition. For each run, two values of resistivity are reported, one measured by the spark method and one measured by the V-1 method. Considering the limitations of the two measurement techniques, relatively good agreement was observed. Because of the difficulty in measuring the voltage drop across the dust layer incrementally with the gas space voltage drop for low resistivities (>1 x 10 ohm-cm), the spark data are considered more reliable for these data and will be used for analysis.

Table 5-7 provides the results of the in situ ash resistivity measurements made during the tests with AOFA. The AOFA data measured in-situ generally indicate that the resistivity was sufficiently low not to detrimentally affect ESP operation. The exceptions occurred on 7/17/90 during 480 MWe operation with 50 percent OFA damper settings and on 7/18/90 with 0 percent OFA settings where the average values were in excess of 5x10 ohm-cm. This level of resistivity will begin to affect

FIGURE 5-8 INLET DIFFERENTIAL MASS DISTRIBUTION
HAMMOND UNIT 4 PHASE 2

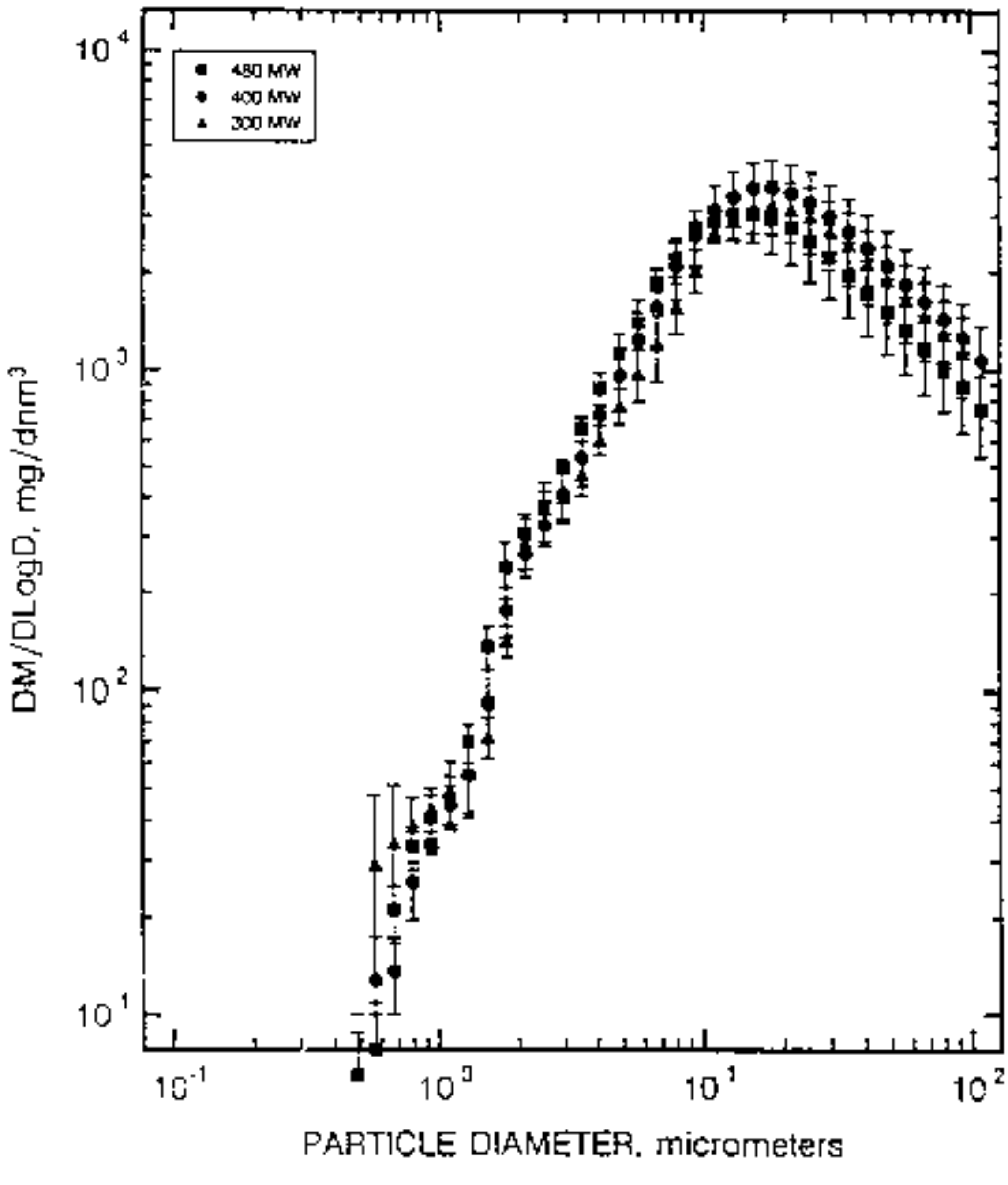


TABLE 5-6
CHEMICAL ANALYSIS OF AOFA HOPPER SAMPLES

	TEST 27, 480 MW 75% OFA SETTING		TEST 43, 480 MW 50% OFA SETTING		TEST 44, 480 MW 50% OFA SETTING		TEST 45, 480 MW 0% OFA SETTING		TEST 39, 400 MW 50% OFA SETTING		TEST 41, 30 50% OFA SETTING	
OXIDE	EAST	WEST	EAST	WEST	EAST	WEST	EAST	WEST	EAST	WEST	EAST	\
Li2O	0.04	0.04	0.03	0.04	0.05	0.05	0.05	0.05	0.04	0.01	0.03	(
Na2O	0.32	0.34	0.42	0.43	0.37	0.35	0.35	0.44	0.32	0.33	0.36	(
K2O	2.66	2.69	2.54	2.56	2.49	2.49	2.55	2.54	2.58	2.68	2.66	2
MgO	0.98	1.00	0.81	0.85	0.94	0.94	0.89	0.86	0.92	0 99	0.87	(
CaO	1.52	1.63	1.06	0.99	1.82	1.85	1.85	1.85	1.13	1.34	1.15	(
Fe2O3	16.50	15.10	18.30	17.50	13.80	12.70	13.40	12.70	14.20	14.80	16.90	1
Al2O3	26.40	26.70	26.20	26.60	26.80	27.4	27.10	27.40	26.20	26 70	26.60	2
S'O2	49.20	50.30	48.30	48.80	49.70	51.50	51.10	51.40	52.60	51.00	48.70	5
TiO2	1.27	1.25	1.28	1.25	1.41	1.36	1.34	1.33	1.12	1.19	1.29	1
P2Os	0.48	0.40	0.47	0.41	0.69	0.68	0.72	0.66	0.30	0.33	0.36	(
SO3	0.31	0.24	0.21	0.23	0.25	0.30	0.29	0 23	0.36	0.27	0.30	(
LOI	26.50	7.70	14.20	4.70	11.30	5.90	12.00	5.20	48.70	11.50	11.80	9
AVG LOI	17.1		←—— 9.0 →				8.6		30.1		10.4	
TOTAL LOI (Method 17)	10.8		9.6		5.4		5.4		10.2		7.1	

TABLE 5-7
AOFA IN-SITU ASH RESISTIVITY RESULTS

DATE	DUCT	GAS TEMP (F)	DUST LAYER (mm)	SPARK METHOD FIELD (kV/cm)	SPARK METHOD RESISTIVITY (ohm-cm)	V-I METHOD FIELD (kV/cm)	V-I METHOD RESISTIVITY (ohn-cm)
480 MW 75% OFA Damper Setting							
7/10/90	East	303	1.28	9.40	9.1E+09	2.90	1.4 E+10
Test 37		306	1.01	14.90	4.9 E+09	9.10	4.6 E+10
		307	0.67	17.90	8.4 E+09	11.20	5.6 E+10
		305	1.14	13.20	7.6 E+09	7.70	3.9 E+10
7/11/90	West	271	0.51	17.60	5.7 E+09	6.90	3.4 E+10
Test 38		274	0.66	15.90	4.9 E+09	6.50	3.3 E+10
		277	0.60	15.00	1.0 E+10	6.20	3.1 E+10
		273	0.62	29.00	6.9 E+09	3.10	1.5 E+10
Averaage 76% OFA Data		290			7.2 E+09		3.3 E+10
480 MW, 50% OFA Damper Setting							
7/17/90	West	274	0.82	14.60	5.5 E+10	20.70	1.0 E+11
Test 43		277	0.75	18.00	2.3 E+10	11.10	5.5 E+10
		280	0.80	13.10	7.9 E+10	15.40	7.7 E+10
		280	0.75	16.00	6.2 E+10	16.80	8.4 E+10
7/18/90	East	299	1.18	12.70	21.2 E+10	6.80	3.4 E+10
Test 44		301	1.11	14.90	2.4 E+10	3.50	1.8 E+10
Average 50% OFA Data		285			4.4 E+10		6.1 E+10
480 MW 50% OFA Damper Setting							
7/18/90	East	302	0.84	19.60	2.0 E+10	1.50	7.7 E+09
Test 45		302	0.98	15.30	8.6 E+10	4.30	2.1 E+10
Average o% OFA Data		302			5.3 E+10		1.4 E+10
400 MW t0% OFA Damper Setting							
7/12/90	West	251	1.00	16.50	1.9 E+09	1.80	9.0 E+09
Test 39		251	0.47	19.10	2.4 E+09	4.50	2.2 E+10
		252	0.67	22.40	1.2 E+09	8.10	4.0 E+10
7/13/90	East	284	0.95	6.30	4.4 E+10	3.20	1.6 E+10
		285	1.78	13.50	3.8 E+09	1.50	7.5 E+09
		285	0.66	9.10	9.1 E+09	5.90	3.0 E+10
		286	0.55	8.20	3.8 E+09	7.03	3.6 E+10
400 MW Average		274			9.5 E+09		2.3 E+10
300 MW, 50% OFA Damper Setting							
7/14/90	East	285	0.81	16.70	3.3 E+09	4.20	2.1 E+10

Test 41		286	0.94	16.00	3.7 E+09	1.00	4.8 E+09
		284	1.43	11.50	2.9 E+09	1.00	5.2 E+09
7/15/90	West	247	0.88	17.00	1.0 E+09	3.60	1.8 E+10
Test 42		246	1.05	14.30	3.9 E+09	6.60	3.3 E+10
		245	0.96	15.60	2.6 E+09	5.70	2.9 E+10
		247	0.98	12.20	4.9 E+09	5.10	2.6 E+10
300 MW Average		263			3.2 E+09		2.0 E+10

ESP performance. Figures 5-g and 5-10 depict the ash resistivity trends with temperature at various SO_3 levels for the East and West ducts, respectively.

Laboratory resistivity measurements were also run on the ESP hopper samples obtained during the AOFA test program. Figure s-11 shows the results for the 480 MWe, 50 percent OFA tests, including the effect of the addition of SO_3. These data do not follow the exact same trends observed in the in-situ resistivities. However, the data do indicate that all samples should respond to SO_3 in the flue gas environment and produce resistivity values which would not limit ESP performance. This result agrees with the baseline test data.

The AOFA resistivity data are contrasted with the baseline data in Table 5-8. The average spark resistivity for the full-load baseline test was 4.0×10^{10} ohm-cm, almost identical to the average for the full-load, 50 percent OFA test (4.4×10^{10} ohm-cm). At full load, there is essentially no difference between the baseline and AOFA resistivities. There is also no significant difference at either of the reduced loads, even though both the baseline and the AOFA resistivities decrease as load is reduced. The drop in resistivity with load appears to be primarily related to temperature. Because of the similarity of the baseline and AOFA full-load resistivity values, and because the 0 percent OFA test (#45) resistivity values were the highest measured during the AOFA test program, the conclusion is the resistivity was unchanged by AOFA.

5.2.4 Flue Gas SO_3 Concentration

Ash resistivity is strongly attenuated by surface films of sulfuric acid produced by the adsorption of SO_3 and water vapor from the flue acts. Thus, ash resistivity can be significantly affected by changes in SO_3 and water vapor concentration in the flue gas. The concentrations of SO_3 measured at the ESP inlet during the AOFA tests are given in Table 5-9. Since resistivity is affected by the actual concentration of SO_3 present, the values are not normalized to a constant oxygen level. However, since SO_3 is formed by the oxidation of SO_2, it is reasonable to expect the SO_3 concentration to vary with fluctuations in SO_2 and O_2 levels. As shown in Table 5-9, variations in SO_3 concentration do not necessarily track the variations in SO_2 level, i.e., the SO_3-to-SO_2 ratio is not constant. In fact, it varied from a low of 0.116 percent to a high of 0.385 percent. Coincidentally, both of these extremes occurred during the same test (480 MWe, 75 percent OFA). This could be explained by wider fluctuations in O_2 during these tests, or by other factors such as variations in temperature profiles or factors affecting catalytic conversion of SO_2 to SO_3. It is beyond the scope of this test program to correlate the observed SO_3-to-SO_2 ratios with all of these variables. However, an understanding of these factors promotes a better appreciation for the limitations on the data.

FIGURE 5-9 EAST DUCT IN-SITU ASH RESISTIVITY

HAMMOND UNIT 4 PHASE 2 - AOFA

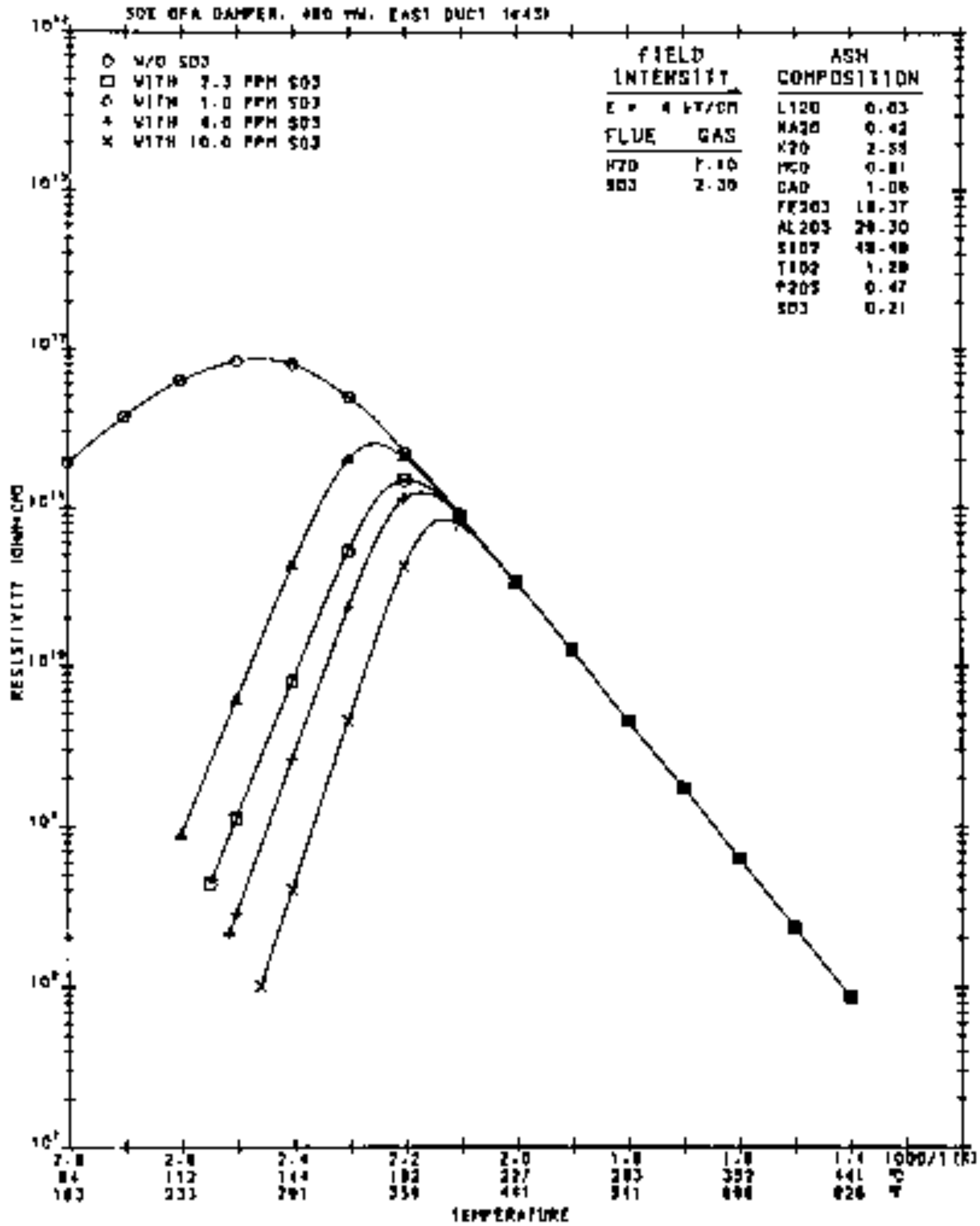


FIGURE 5-10 WEST DUCT IN-SITU ASH RESISTIVITY

HAMMOND UNIT 4 PHASE 2 - AOFA

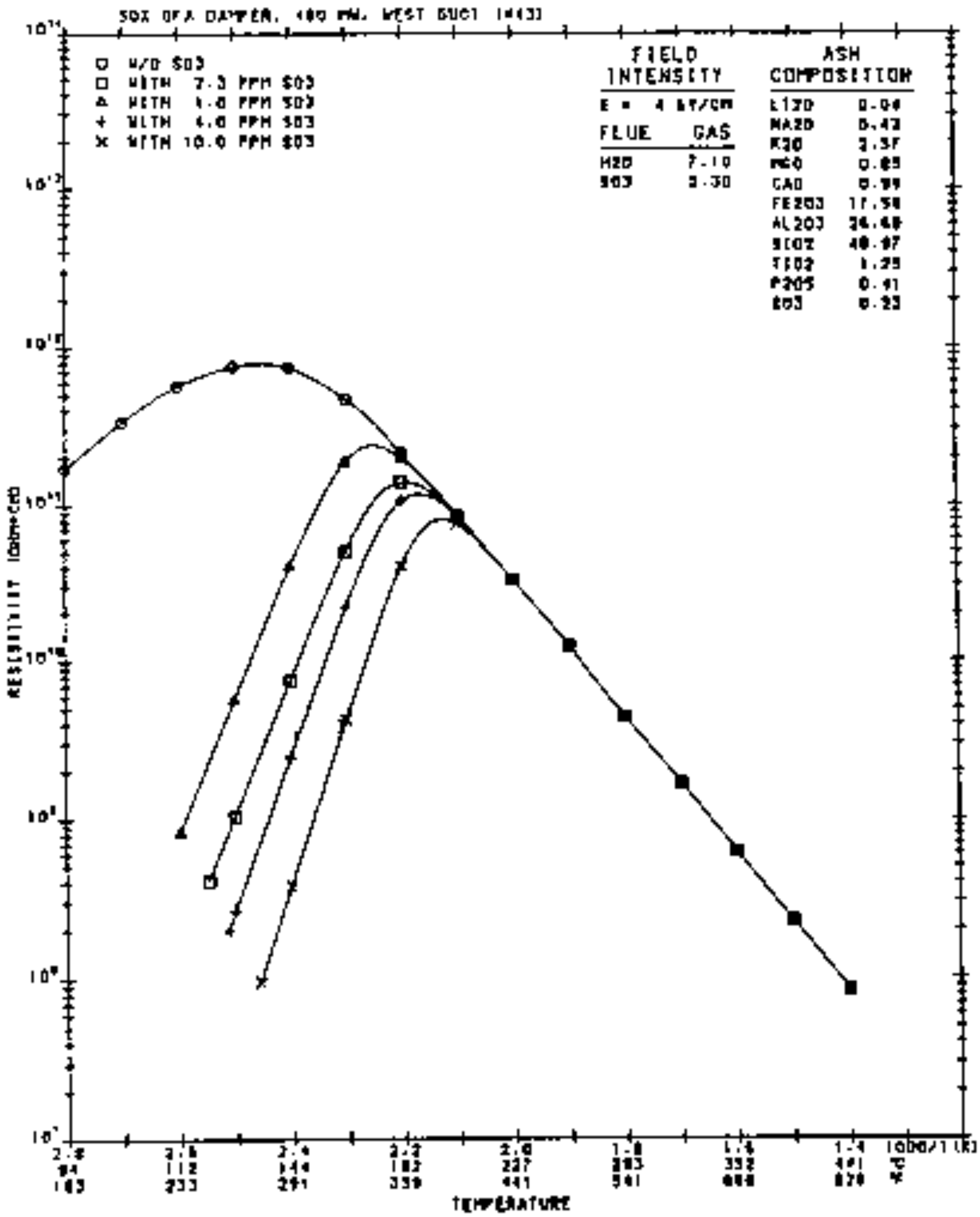


FIGURE 5-11 ESP HOPPER ASH RESISTIVITY
HAMMOND UNIT 4 PHASE 2 - AOFA

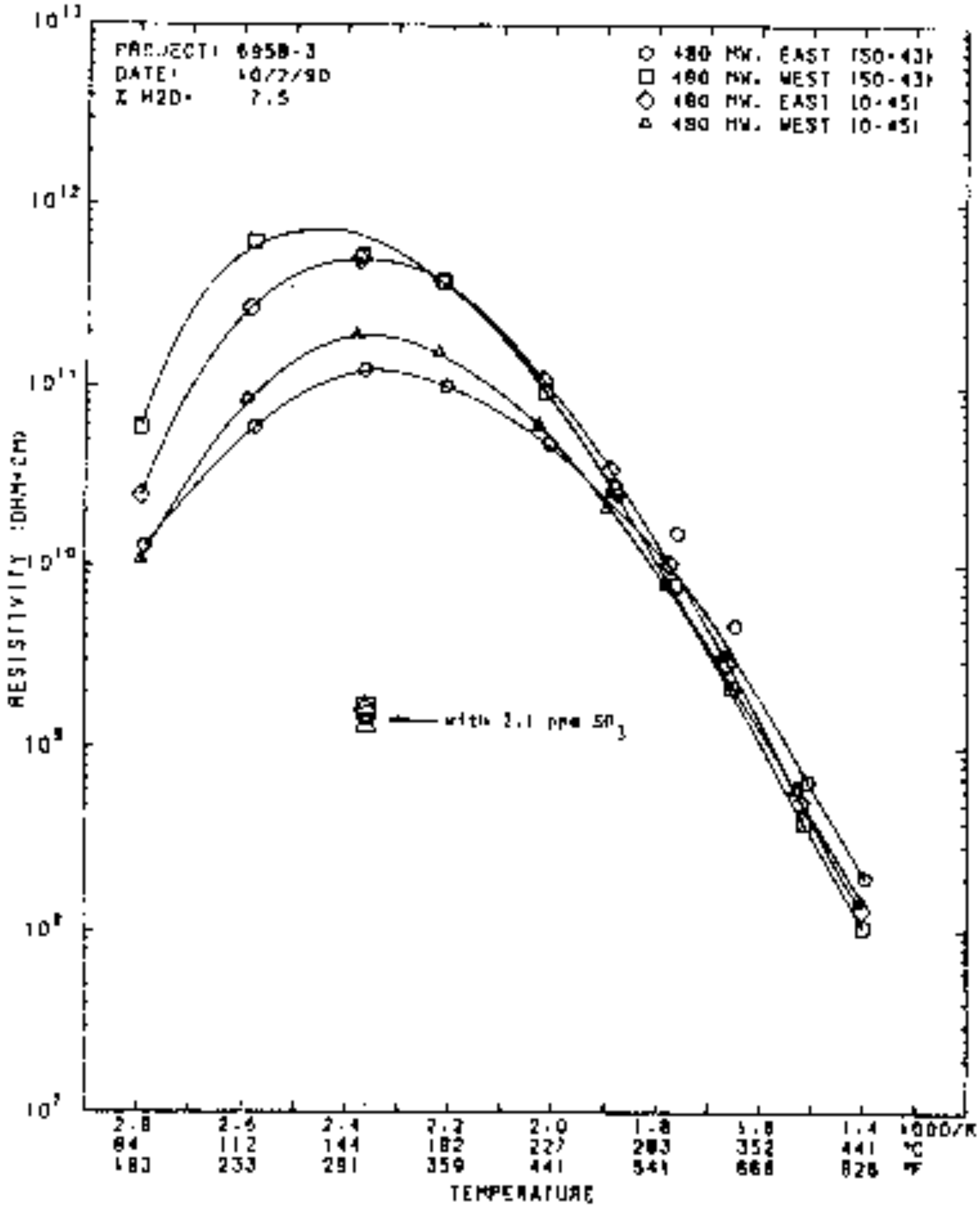


TABLE 5-8
EFFECT OF AOFA ON IN-SITU RESISTIVITY

LOAD (MW)	TEST CONDITION	GAS TEMP (F)	SO_3 (ppm)	H_2O (%)	IN—SITU RESISTIVITY[a] (ohm-cm)	
					SPARK METHOD	V-l METHOD
480	Baseline	284	2.3	6.6	4.0E+10	5.0E+10
	75% OFA	290	2.2	8.3	7.2E+09	3.3E+10
	50% OFA	285	2.3	7.1	4.4E+10	6.1E+10
	0% OFA	302	NM[b]	6.6	5.3E+ 10	1.4E+ 10
400	Baseline	273	2.21	6.4	1.1E+10	3.5E+10
	50% OFA	274	1.6	7.7	9.5E+09	2.3E+10
300	Baseline	268	3.3	6.6	4.4E+09	3.0E+10
	50% OFA	263	2.2	6.9	3.2E+09!	2.0E+10

[a]Measurements that showed poor agreement between spark and V- I methods were discarded prior to determining this average
[b]Not measured during this test

TABLE 5-9
AOFA SOx RESULTS

DATE	DUCT	GAS TEMP (F)	CONCENTRATION (ppm) SO3	SO2	SO3 - TO - SO2 RATIO (%)
480 MW 75% OFA Damper Setting					
7/10/90	East	271	1.2	1035	0.116
Test 37		284	1.4	1050	0.133
		282	1.5	1050	0.146
		286	1.8	1056	0.17
7/11/90	West	266	2.1	855	0.246
Test 38		266	2.9	868	0.334
		267	3.2	871	0.367
		268	3.4	883	0.385
Averaage 75% OFA Data		274	2.2	959	0.237
480 MW, 50% OFA Damper Setting					
7/17/90	East	265	1.8	764	0.236
Test 43		267	2.2	768	0.286
		269	2.4	763	0.315
		272	2.5	762	0.328
7/18/90	West	266	1.9	792	0.24
Test 44		266	2.5	797	0.314
		268	2.6	786	0.331
		268	2.7	791	0.341
Average 50% OFA Data		285	2.3	778	0.299
400 MW 50% OFA Damper Setting					
7/12/90	West	242	1.7	800	0.213
Test 39		242	2	810	0.247
		243	2.1	818	0.257
		242	2.4	817	0.294
7/13/90	East	225	1.1	943	0.117
Test 40		229	1.2	931	0.129
		230	1.3	924	0.141
		231	1.2	934	0.128
Average of 400 MW Data		236	1.6	872	0.191
300 MW, 50% OFA Damper Setting					
7/14/90	West	246	1.6	756	0.212
Test 41		247	2.2	747	0.295
		247	2.4	739	0.325
		246	2.6	739	0.352
7/15/90	East	230	1.8	718	0.251
Test 42		229	2.2	719	0.306
		228	2.2	715	0.308
		228	2.3	703	0.327
Average of 300 MW Data		238	2.2	730	0.297

To aid interpretation of the data, the average values and COVs for the SO_3 concentration and SO_3-to-SO^2 ratio for each test series have been extracted from Table 5-9 and summarized below.

Test Series	SO3, ppm	COV	SO_3-to-SO_2 ratio	COV
480 MWe, 75 percent OFA	2.2	0.39	0.237	0.471
480 MWe, 50percent OFA	2.3	0.14	0.299	0.137
480 MWe, 0percent OFA	Not Measured			
400 MWe, 50percent OFA	1.6	0.31	0.191	0.367
300 MWe, 50percent OFA	2.2	0.15	0.297	0.152

The average SO_3 concentrations are very similar for three of the four tests for which these data were obtained. Only the 400 MWe, 50 percent OFA test shows a significant difference in SO_3, with a lower average of 1.6 ppm compared to 2.2-2.3 ppm for the other tests. This may be a result of the low gas temperatures experienced during this test resulting in sub-dewpoint operation. Fortunately, this appears to be a problem in only one of the test cases. Based on the data taken in the absence of dewpoint excursions, it appears that neither OFA damper setting nor load had a significant effect on SO_3 concentration.

The SO_3 concentrations measured with AOFA are comparable to the baseline SO_3 values measured in Phase 1. Comparison of the data for the full-load tests shows no difference between the baseline, the 75 percent OFA, and the 50 percent OFA tests. The apparently low value obtained for the 400 MWe, 50 percent OFA test has already been explained above. The only other outliner is the high SO_3 value (3.3 ppm) obtained during the baseline test at ~00 MWe. During Phase 1 testing at 300 MWe the excess oxygen was 4.0-4.4 percent and one mill was out of service. For the other baseline particulate tests excess oxygen levels from 2.4 to 3.5 percent were observed. Thus the oxygen level was significantly higher during the baseline test that produced the highest SO_3 level.

5.2.5 Combustion System Tests

As in the Phase 1 baseline testing, combustion performance tests were performed at each of three load levels to document the specific performance parameters related to the fuel and air combustion systems. The results of the Phase 2 testing are presented below.

Mill Performance 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 all three load levels (480, 400 and 300 MWe. Table 5-10 summarizes the results of these tests. From Table 5-10 it can be seen that despite the mills being set to approximately equal coal flows with the boiler controls, the measured coal flows varied considerably from mill to mill.

The measured ratio of primary air to coal flow varied from approximately 2.2 to 3.7 over the load range.

During these mill tests the coal fineness was found to be below 70 percent through 200 mesh on all mills except for E Mill at 480 MWe and C and D Mills at 300 MWe. This could potentially cause the NOx emissions to be lower than for a condition with fineness better than 70 percent through a 200 mesh screen.

Secondary Air Supply The secondary combustion air flow was measured at two [orations as described in Section 3.3. Table 5-11 presents the results of the flow 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 at eight locations within the boiler furnace at the 7th (furnace nose) and 8th floor (convective section above nose) levels. At each port approximately 9 measurements were made at different probe insertion depths. Measurements were made of temperature, excess oxygen and carbon monoxide at loads of 480, 400 and 300 MWe.

Figure 5-12 shows the distribution of temperature and excess oxygen at the 487 MWe nominal load point with the OFA dampers set to 50 percent open. Species concentrations of O_2 and CO made simultaneously with the temperature measurements indicate a significant stoichiometry non-uniformity within the furnace. Generally speaking the excess O_2 level ranged from 0.2 to 3.5 percent. One reason for this maldistribution is the non-uniformity of the coal flows to the burners (see Table 5-10).

Figures 5-13 and 5-14 illustrate typical temperature and excess oxygen distributions for the 400 and 300 MWe load test conditions, respectively. These figures exhibit the same general excess oxygen maldistribution as that for the 487 MWe condition.

TABLE 5-10
HAMMOND UNIT 4 SUMMARY OF MILL PERFORMANCE TEST
PHASE 2 - AOFA

TEST No.	UNIT LOAD MWe	PARAMETER	MILL A	MILL B	MILL C	MILL D	MILL E	MILL F
37-1	480	Measured Coal Flow, KLb/hr	53.4	64.9	64.3	68.7	50.2	56.7
		Measured PA Flow, Klb/hr	149.1	167.8	128.1	150.1	136.3	154.9
		A/F Ratio	2.57	2.75	2.17	2.50	2.72	2.50
		Avg. Burner Pipe Velocity, FPM	7174	7689	7022	7889	8726	7321
		High Pipe Coal Flow,, Klb/hr	16.9	17.9	19.5	23.9	20.4	20.9
		Low Pipe Coal Flow, Klb/hr	10.1	14.6	13.1	8.0	Plugged	9.8
		Avg. Passing 200 mesh, PCT	61.5	68.4	69.7	65.9	73.5	59.1
		Avg. Passing 50 mesh, PCT	96.3	97.3	98.0	97.1	98.8	95.8
39-1	400	Measured Coal Flow, KLb/hr	47.5	64.2	55.2	49.0	0	58.4
		Measured PA Flow, Klb/hr	148.6	137.5	139.1	152.1	0	155.7
		A/F Ratio	2.65	2.31	2.48	2.72	0	2.78
		Avg. Burner Pipe Velocity, FPM	6906	7233	7575	8478	0	8186
		High Pipe Coal Flow,, Klb/hr	14.1	17.7	16.5	14.9	0	19.4
		Low Pipe Coal Flow, Klb/hr	8.5	14.0	11.2	9.0	0	11.2
		Avg. Passing 200 mesh, PCT	62.3	64.9	69.4	67.0	NA	63.1
		Avg. Passing 50 mesh, PCT	96.6	97.7	97.7	98.0	NA	97.3
41-1	300	Measured Coal Flow, KLb/hr	42.4	50.6	42.8	45.6	0	49.3
		Measured PA Flow, Klb/hr	136.7	136.6	143.3	143.7	0	153.0
		A/F Ratio	3.42	2.79	3.26	3.27	0	3.73
		Avg. Burner Pipe Velocity, FPM	6746	7101	7951	7482	0	8019
		High Pipe Coal Flow,, Klb/hr	13.4	15.0	12.6	15.7	0	17.5
		Low Pipe Coal Flow, Klb/hr	7.1	10.3	8.7	8.6	0	9.1
		Avg. Passing 200 mesh, PCT	68.1	68.6	73.7	71.3	NA	64.8
		Avg. Passing 50 mesh, PCT	98.1	98.9	97.2	98.2	NA	98.5

TABLE 5-11
COMBUSTION AIR FLOW DISTRIBUTION
HAMMOND UNIT 4, PHASE 2 - AOFA

TEST #	LOAD MWe	OFA DAMPER Percent	EXCESS O_2 dry percent	AIR FLOW RATES				
				SECONDARY	PRIMARY		OFA	
				Mlb/hr	Mlb/hr	percent of total air	Mlb/hr	percent of total air
37-1	480	75	3.0	2.561	0.886	25.7	NA	NA
38-1	480	75	4.0	3.377	0.914	24.8	0.795	21.6
39-1	400	50	4.O	2.116	0.733	25.7	0.795	26.7
40-1	405	50	3.7	2.107	0.701	25.1	0.670	24.2
41-1	298	50	4.8	1.9Zl	0.715	27.1	0.628	23.8
42-1	300	50	5.4	1.681	0.730	30.3	0.498	20.6
43-1	487	50	4.0	3.002	0.848	22.0	0.881	22.9
44-1	487	50	3.6	3.128	0.860	21.6	0.800	20.0
45-1	489	1	3.8	2.995	0.855	22.2	0.240	6.2

FIGURE 5-12 FURNACE EXIT HVT AND OXYGEN DISTRIBUTIONS

HAMMOND UNIT 4 PHASE 2 - AOFA

TEST 43-1 487 MWe, 50% OFA DAMPER

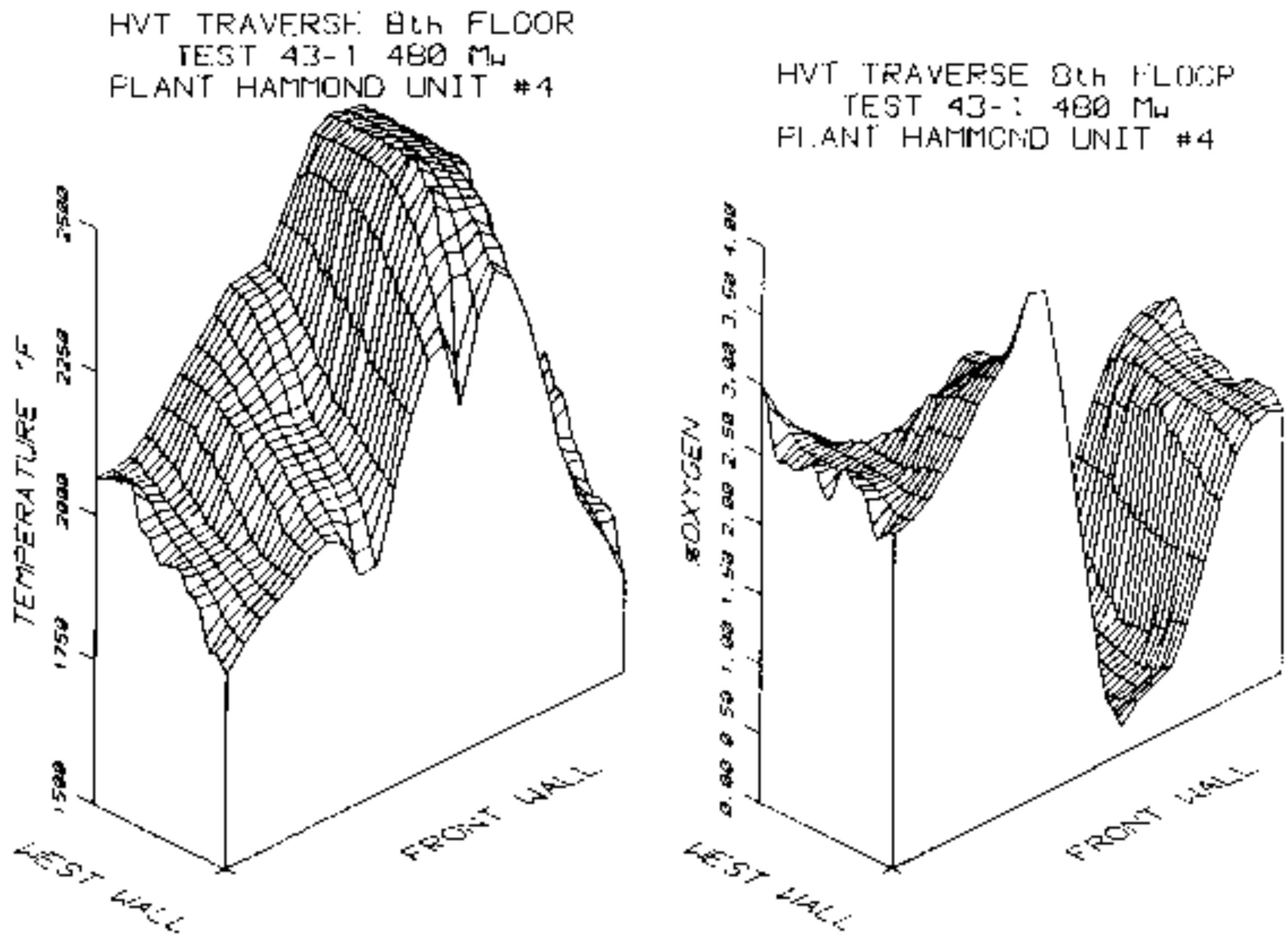


FIGURE 5-13 FURNACE EXIT HVT AND OXYGEN DISTRIBUTIONS

HAMMOND UNIT 4 PHASE 2 - AOFA

TEST 39-1 400 MWe, 50% OFA DAMPER

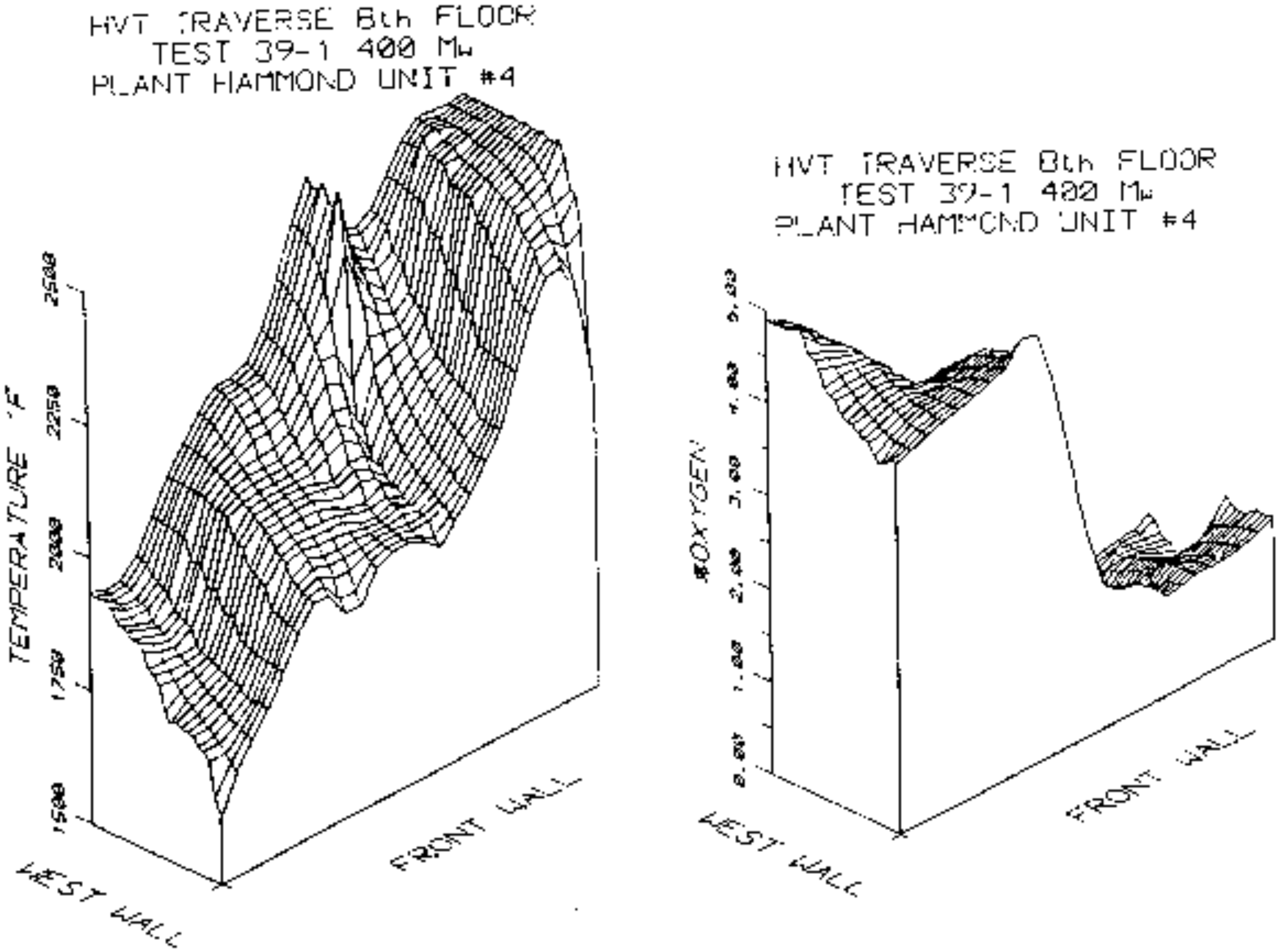
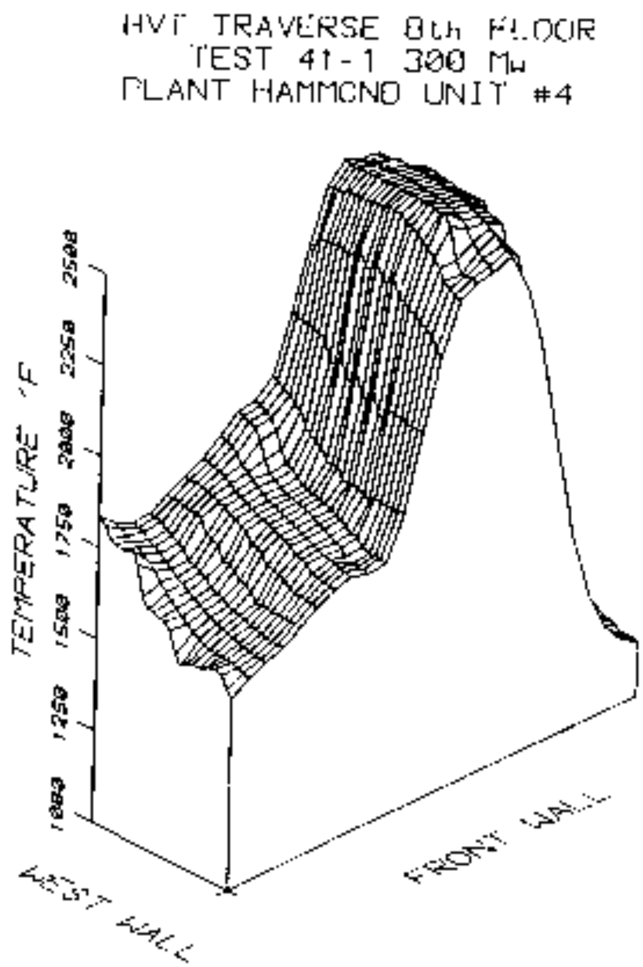
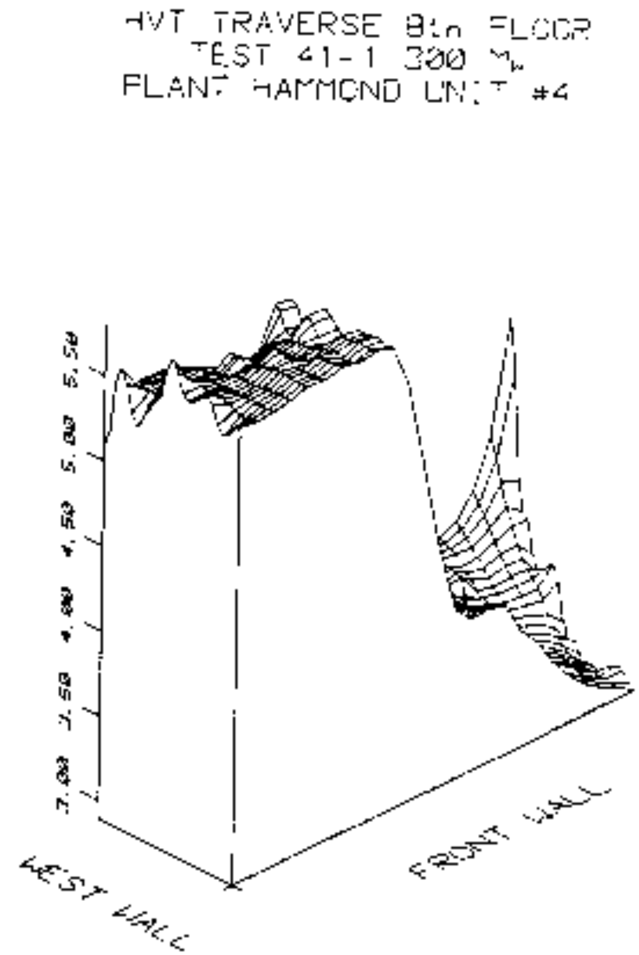


FIGURE 5-14 FURNACE EXIT HVT AND OXYGEN DISTRIBUTIONS

HAMMOND UNIT 4 PHASE 2 - AOFA

TEST 41-1 298 MWe, 50% OFA DAMPER





5.2.6 Coal and Ash Analyses

During each of the seven days of Phase 2 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, calorific value, grindability and ash fusion properties. Table 5-12 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 Phase 1 effort.

The results of the CEGRIT furnace ash and the furnace bottom ash analyses are shown in Table 5-13. As in the baseline testing (Phase 1), the CEGRIT LOI values were much higher than the bottom ash samples except for the 480 KWe test at low O_2. In the Phase 2 tests the bottom ash carbon content was also ,relatively high for the 489 MWe test with the OFA dampers closed, even though the excess O_2 was 3.8 percent.

5.2 7 Boiler Efficiency

During selected performance tests at each load point, measurements were recorded for the flue gas temperatures and gaseous species, both upstream and downstream of the air preheaters, using the DAP and the ECEM for the purpose of calculating the heat loss efficiency. Over several hours of each test the in-situ O_2 probes upstream and downstream of the air preheater were sampled continuously. In addition, the gas temperatures in each duct were measured continuously (every 5 seconds - compiled into 5-minute averages) over the entire test duration. CO measurements were obtained from composite sampling of the ECEM at discrete intervals over the 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 5-14. The efficiencies are determined for "as measured" conditions and for "design" air preheater temperature conditions.

The purpose of the boiler efficiency calculations is to document the Phase 2 boiler efficiencies at specific operating conditions for comparison to the efficiencies determined subsequent to the Low NOx 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

TABLE 5-12 HAMMOND UNIT 4 PERFORMANCE TEST COAL ANALYSIS PHASE 2 -AOFA

	Ultimate Analyses, (%)								
Date	H2O	C	H	N	Cl	S	Ash	O	TOTAL
07/10/90	4.44	73.77	4.79	1.33	0.088	1.72	9.58	4.38	100.10
07/10/90	4.46	73.25	47.3	1.43	0.058	1.73	10.02	4.38	100.06
07/10/90	5.07	72.74	4.74	1.38	0.058	1.77	9.75	4.57	100.09
07/10/90	4.95	72.16	4.54	1.49	0.040	1.71	9.76	5.39	100.04
07/11/90	5.00	74.20	4.70	1.42	0.058	1.75	8.82	4.11	100.06
07/11090	5.40	73.75	4.65	1.35	0.087	1.72	8.94	4.18	100.08
07/11/90	5.15	74.76	4.69	1.21	0.087	1.71	8.46	4.02	100.09
07/12/90	5.31	73.44	4.69	1.34	0.077	1.71	8.97	4.54	100.08
07/13/90	5.08	74.19	4.79	1.43	0.087	1.57	8.65	4.29	100.09
07/13/90	5.12	72.46	4.79	1.47	0.078	1.82	9.46	4.88	100.08
07/13/90	6.29	72.75	4.75	1.42	0.086	1.64	8.62	4.54	100.10
07/14/90	5.82	73.19	4.77	1.38	0.058	1.65	8.80	4.40	100.07
07/14/90	5.81	73.18	4.85	1.43	0.048	1.67	8.38	4.68	100.05
07/14/90	6.63	73.30	4.80	1.39	0.047	1.59	8.24	4.06	100.06
07/14/90	6.16	72.85	4.53	1.44	0.030	1.60	8.30	5.12	100.03
07/15/90	7.34	72.83	4.78	1.39	0.047	1.61	7.85	4.20	100.05
07/15/90	7.45	72.36	4.73	1.39	0.028	1.58	7.97	4.53	100.04
07/15/90	6.23	73.03	4.78	1.43	0.038	1.62	8.27	4.64	100.04
07/16/90	6.04	72.59	4.79	1.49	0.048	1.63	8.70	4.74	100.03
07/16/90	6.62	72.37	4.75	1.48	0.066	1.65	8.38	4.74	100.06
07/17/90	5.99	72.89	4.78	1.51	0.057	1.59	8.53	4.72	100.07
07/17/90	6.84	72.53	4.63	1.51	0.057	1.44	8.05	5.00	100.06
07/17/90	4.93	75.38	4.83	1.42	0.048	1.55	7.53	4.36	100.05
07/18/90	5.30	72.24	4.63	1.44	0.038	1.55	10.20	4.30	99.70
07/18/90	4.11	73.37	4.72	1.49	0.029	1.55	10.01	4.76	100.04
07/18/90	4.17	73.46	4.58	1.52	0.020	1.56	9.86	4.85	100.02
07/18/90	5.40	72.48	4.65	1.46	0.038	1.50	10.15	4.35	100.03
AVERAGE	5.60	73.17	4.72	1.42	0.056	164	8.90	4.55	100.04
STD	0.88	0.77	0.08	0.07	0.020	0.09	0.76	0.33	0.07
VAR	0.78	0.59	0.01	0.00	0.000	0.01	0.58	0.11	0.01

TABLE 5-13
HAMMOND UNIT 4 PERFORMANCE TEST CEGRIT ASH ANALYSIS

TEST NUMBER	DATE	NOMINAL LOAD (MWe)	EXCESS OXYGEN (%)	A-SIDE LOI (%)	B-SIDE LOI (%)	AVERAGE LOI (%)	BOTTOM ASH TOTAL CARBON (%)
37-1	07/10/90	480	3.0	9.34	4.76	7.05	8.35
37-2	07/10/90	480	2.9	-	-	-	
37-3	07/10.90	480	3.0	10.82	3.88	7.35	
38-1	07/11/90	485	4.1	8.36	4.66	6.51	1.07
38-2	07/11/90	488	3.8	8.80	5.03	6.92	
38-3	07/11/90	488	4.1	8.87	4.68	6.78	
39-1	07/12/90	400	3.9	10.82	3.23	7.03	0.82
39-2	07/13/90	400	4.2	11.37	2.64	7.01	
40-1	07/13/90	405	3.8	13.45	4.99	9.22	0.33
40-2	07/14/90	408	3.7	13.50	5.15	9.33	
40-3	07/14/90	405	3.7	15.16	5.85	10.51	
41-1	07/14/90	298	4.8	3.27	4.36	3.82	0.82
41-2	07/15/90	297	4.8	3.43	2.17	2.80	
42-1	07/15/90	300	5.4	3.78	2.77	3.28	0.56
42-2	07/16/90	300	5.4	-	-	-	
42-3	07/16/90	300	5.3	3.33	2.44	2.89	
43-1	07/17/90	487	4.0	8.64	3.67	6.16	0.82
43-2	07/17/90	487	4.0	7.15	3.59	5.37	
43-3	07/17-90	487	3.9	6.57	3.69	5.13	
44-1	07/18-90	487	3.6	8.18	3..98	6.08	0.58
44-2	07/18-90	487	3.8	9.43	3.58	6.51	
45-1	07/18/90	489	3.8	7.19	3.23	5.21	6.88

upon the measured calorific value, moisture and chemical composition of the as-fired fuel samples taken during each test.

TABLE 5-14

HAMMOND UNIT 2 ASME PTC 4.1 BOILER EFFICIENCY

TEST NO.	DATE	AVERAGE LOAD, MWe	TEST DURATION HOURS:MIN.	MEASURED EFFICIENCY percent	NORMALIZED EFFICIENCY, percent
39-1,2	7/12/91	394.5	2:20	88.99	89.25
41-1	7/14/91	289.9	1:35	88.99	89.28
43-1,3	7/17/91	477.6	2:35	88.99	89.14

5.3 Verification Tests

Subsequent to the long-term testing, testing was performed to ascertain if significant changes in the NOx characteristics had occurred during the long-term test period. These tests were performed from February 22 to February 28, 1991. During this period, fifteen 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 at 300 MWe.

Table 5-15 presents a summary of the data taken during the verification testing. Six tests were performed at the 400 MWe load point and nine were performed at the 480 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 out of service.

Figure 5-15 presents a comparison of the verification test results with those for the diagnostic testing (see Figure 5-3) for the 480 MWe load point with 50 percent OFA Damper. From FIGURE 5-15 it can be seen that for all practical purposes, the data for the two periods are the same and exhibit the same trend. The NOx data fit within the data scatter for the diagnostic tests. Based upon this it can be concluded that the full load NOx characteristics did not significantly change during the long-term test period.

Figure 5-16 presents a comparison of the verification test results with those for the diagnostic testing (see Figure 5-S) for the 400 MWe load point with 50 percent OFA damper. Testing at the 400 MWe load point was with only one of the two mill patterns used during the diagnostic testing (i.e. E Moos). From Figure 5-16 it is evident that the verification trends and the absolute levels of NOx were remarkably similar to those for the diagnostic test results, although the oxygen levels were different for LOI considerations determined during performance tests.

TABLE 5-15

SUMMARY OF HAMMOND PHASE 2 VERIFICATION TENTING

TEST #	DATA	LOAD Mwe	MOOS PATTERN	OFA DAMPER	DAS O_2 DRY %	Nox AT 3% O_2 PPM
52-1	02/22/91	395	E	50	5.5	586
52-2	02/22/91	398	E	50	5.0	543
52-3	02/22/91	398	E	50	6.2	652
53-1	02/23/91	402	E	50	5.2	575
53-2	02/23/91	402	E	50	4.8	542
53-3	02/23/91	402	E	50	5.7	620
54-1	02/25/91	480	NONE	50	3.7	615
54-2	02/25/91	480	NONE	50	2.8	540
54-3	02/25/91	480	NONE	50	3.2	566
54-4	02/25/91	480	NONE	50	4.3	689
54-5	02/25/91	480	NONE	50	3.8	630
55-1	02/26/91	481	NONE	50	3.9	621
55-2	02/26/91	480	NONE	25	3.9	758
56-1	02/27/91	480	NONE	50	4.0	579
57-1	02/28/91	480	NONE	50	3.3	638

FIGURE 5-15 COMPARISON OF DIAGNOSTIC AND VERIFICATION TEST DATA
PHASE 2 480 MW 50% OFA DAMPER, AMIS

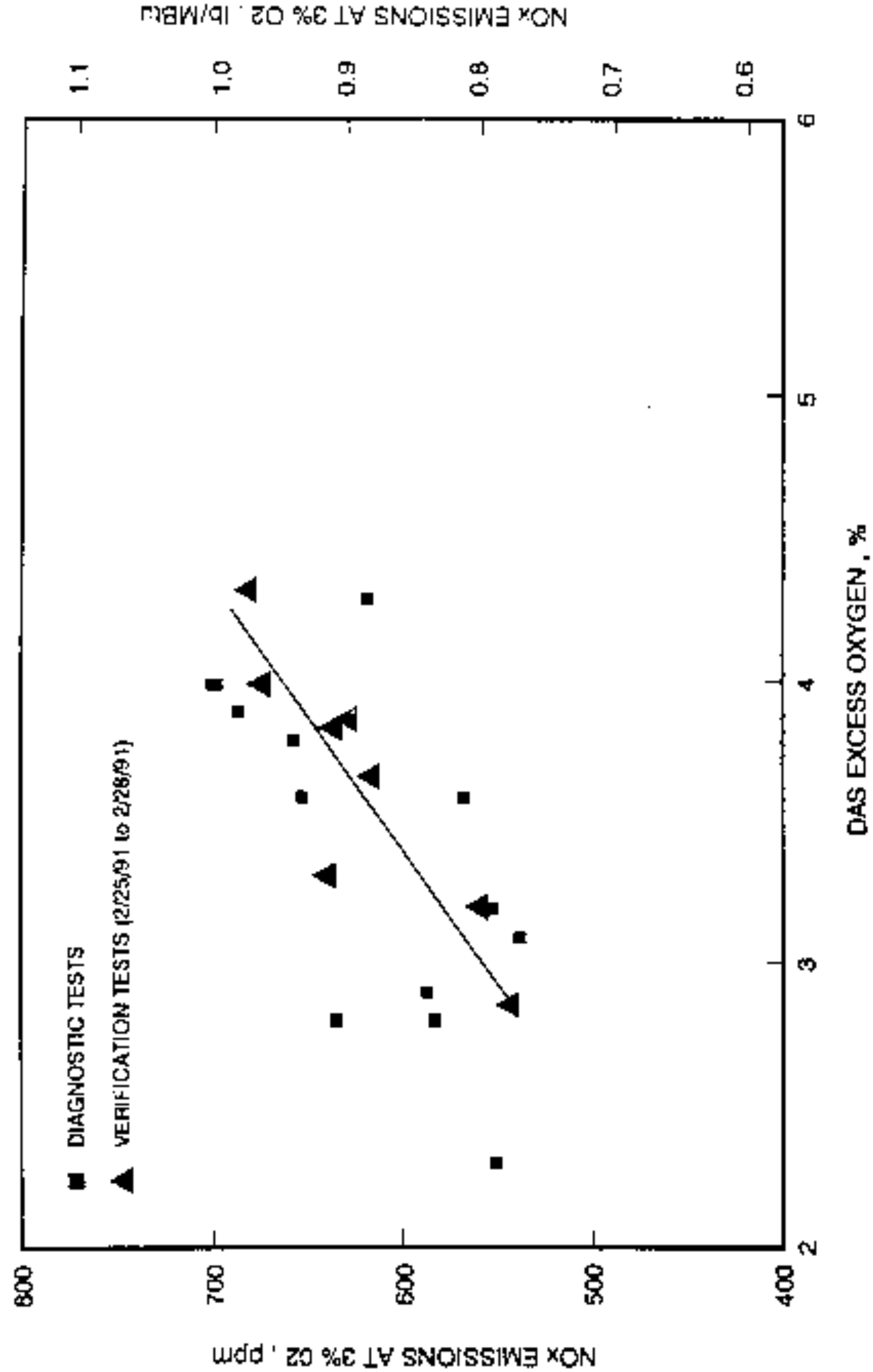
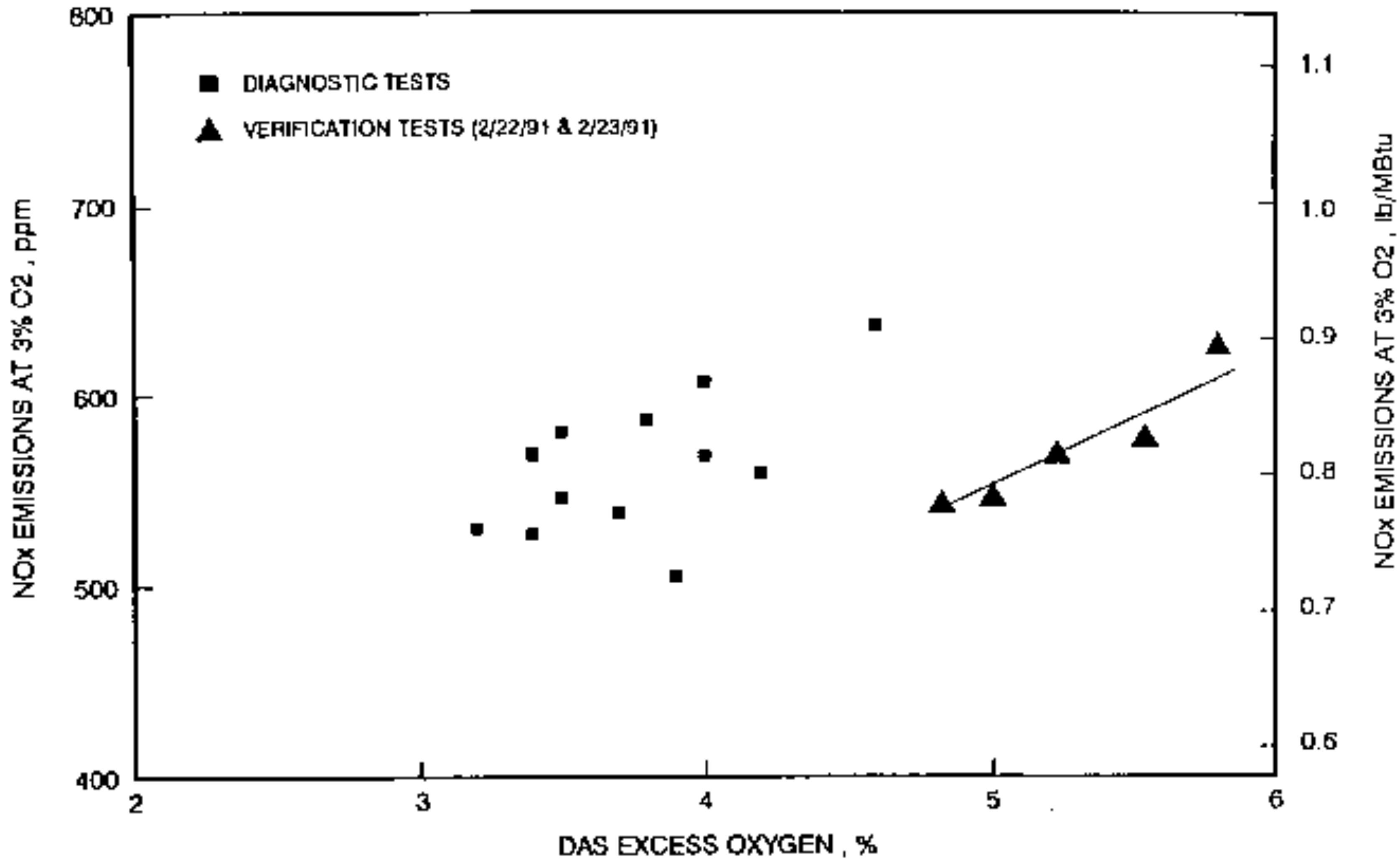


FIGURE 5-16 COMPARISON OF DIAGNOSTIC AND VERIFICATION TEST DATA PHASE 2 400 MWe 50% OFA DAMPER, EMOOS



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 October 1990 through March 1991. During this period a number of unit outages were experienced that resulted in lost days of data capture. The data capture was, however, sufficient to fully characterize 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 major results of these analyses.

6 1 Unit Operating Characteristics

Figure 6-1 illustrates the NOx emissions for the load scenario during the month of November 1991. This was the month during which the data capture was the greatest. Other months which experienced lesser degrees of data capture exhibited similar characteristics. From Figure 6-1, it can be seen that the five-minute average NOx emissions varied from approximately 0.7 to 1.0 lb/MBtu during the month of November. Similar 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 (180 MWe) to the maximum continuous operating load (480 MWe) during the entire long-term test period.

From the data for the long-term testing (October 1990 through March 1991), 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. During the first half of the long-term testing, the average daily load was generally in excess of 400

FIGURE 6-1 HOURLY AVERAGE CHARACTERISTICS

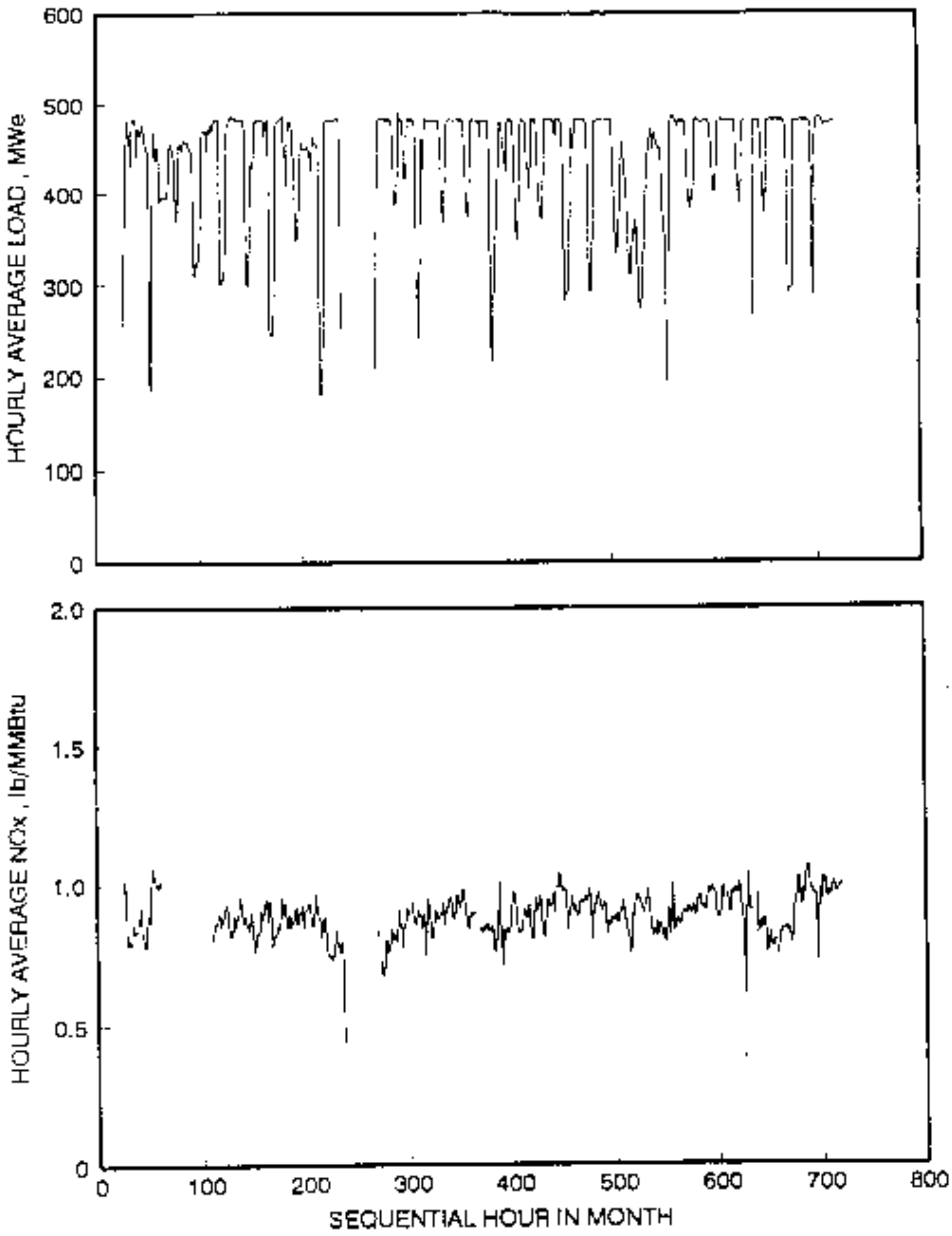


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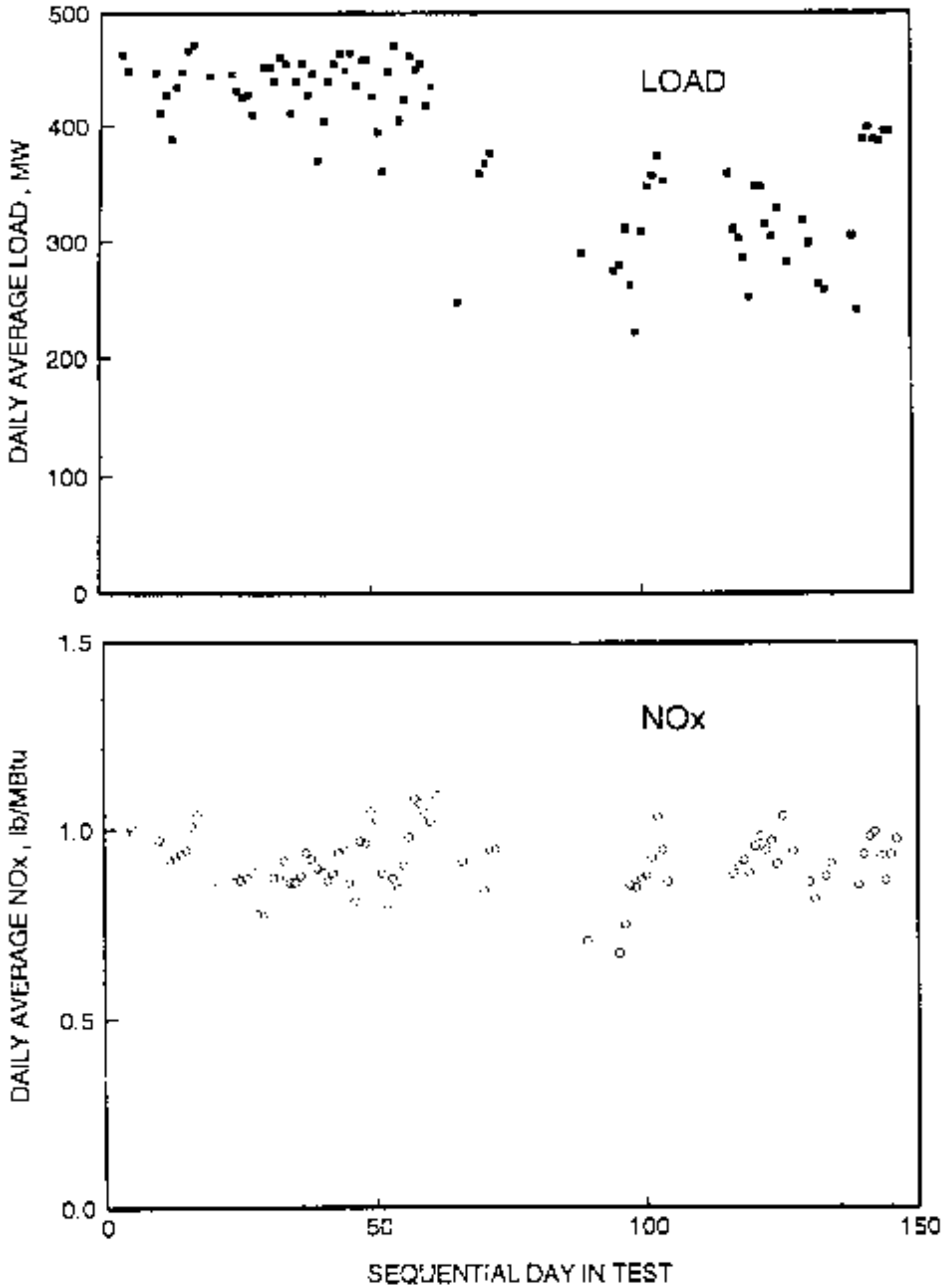
FIGURE 6-2 DAILY AVERAGE CHARACTERISTICS



Mwe. Midway in the long-term test effort, the load decreased to below 300 MWe. This unit has been a base loaded unit in the past was generally the first unit on and the last unit off of dispatch. During the Phase 2 test effort, the unit was reclassified within the system and, while still a base loadedunit, was operated at lower load than in the past. For the Phase 2 long-term test period, the daily average emissions ranged from approximately 1.1 to 0.7 lb/MBtu.

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 S percent and upper 95 percent of all values were determined. Typical results of this type of analysis are shown in Figure S-3 which 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 13 hours were above 400 MWe). It is evident that the NOx versus load characteristics are very flat with respect to load change. 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 MWe 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 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.

The effect of operating O_2 on NOx emissions for certain mill patterns was examined for load ranges that corresponded to some of the loads tested during the short-term test portion of the Phase 2 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 pattern was determined. Table 6-2 presents the frequency distribution for the two most used mill patterns. It is apparent that there are

FIGURE 6-3 DIURNAL CHARACTERISTICS

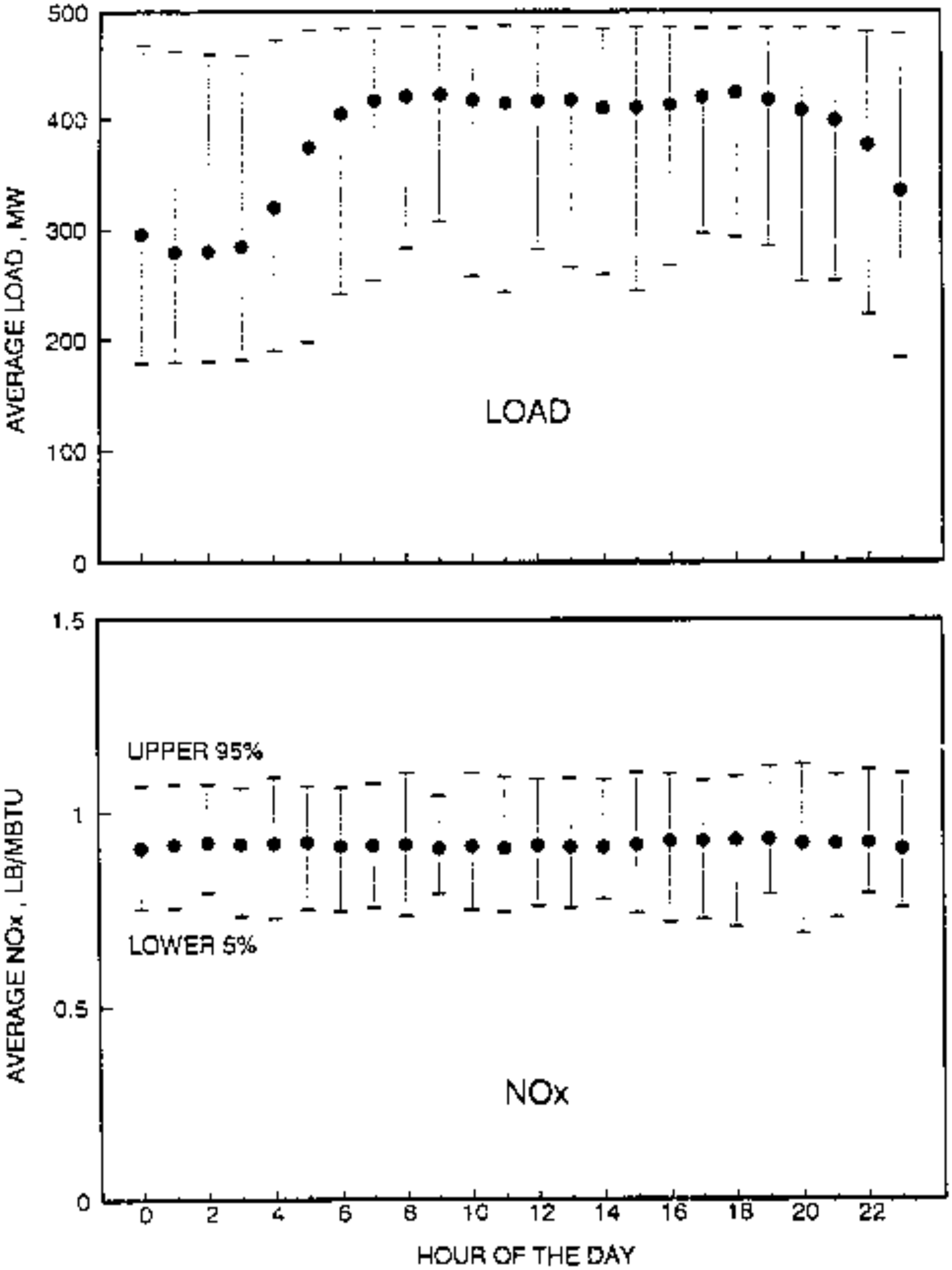


TABLE 6-1 PHASE 2 AOFA LONG-TERM TEST STATISTICS

October 1990 Through March 1991

LOAD CATEGORY (MW)	SAMPLE SIZE	(MW) LOWER 5%	(MW) AVERAGE	(MW) UPPER 95%	(%DRY) LOWER 5%	(%DRY) AVERAGE	(%DRY) UPPER 95%	(LB/MBTU) LOWER 5%	(LB/MBTU) AVERAGE	(LB/MBTU) UPPER 95%
170-190	1397	175	182	189	8.0	9.6	11.3	0.73	0.904	1.055
190-210	827	191	200	209	7.1	9.1	11.0	0.68	0.881	1.046
210-230	714	211	219	229	7.5	9.3	11.4	0.71	0.898	1.107
230-250	849	231	240	249	7.1	9.0	10.5	0.71	0.900	1.012
250-270	696	251	260	269	7.1	8.8	10.5	0.66	0.B95	1.071
270-290	1056	271	281	289	6.6	8.3	10.0	0.59	0.877	1.057
290-310	1269	291	300	309	6.5	8.2	9.7	0.65	0.878	1.046
310-330	133B	311	320	329	6.3	7.8	9.5	0.69	0.888	1.050
330-350	1301	331	340	349	6.3	7.8	9.3	0.74	0.897	1.051
350-370	992	351	360	369	6.1	7.7	9.2	0.75	0.910	1.076
370-390	1297	371	380	389	6.0	7.4	8.7	0.70	0.908	1.098
390-410	1090	391	400	409	5.9	7.2	8.7	0.70	0.893	1.094
410-430	1316	411	420	429	5.8	6.9	8.2	0.75	0.910	1.110
430-450	1950	432	441	449	5.8	6.8	7.8	0.80	0.959	1.139
450-470	1989	451	459	469	5.4	6.4	7.5	0.79	0.939	1.104
470-490	7918	473	480	486	5.3	6.5	7.8	0.80	0.944	1.089
490-510	19	490	493	500	5.5	6.2	7.4	0.68	0.925	1.171

FIGURE 6-4 LOAD CHARACTERISTICS

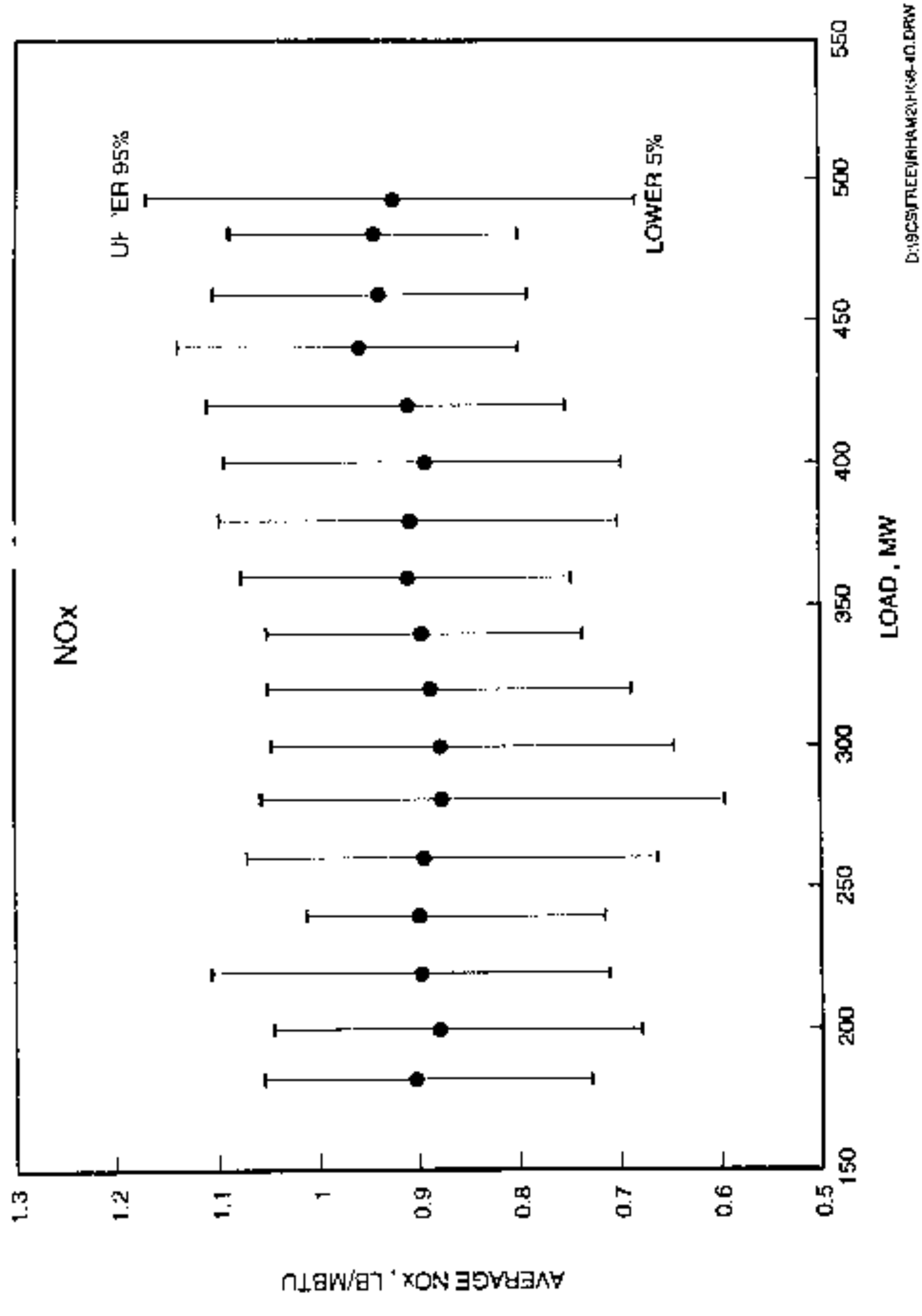


TABLE 6-2 MILL PATTERN USE FREQUENCY

AVERAGE LOAD MWe	MOOS	SAMPLE SIZE	AVERAGE O2 %	AVERAGE NOx ppm
184	A E	179	8.6	0.84
184	B,E	655	9.0	0.87
295	B	81	6.0	0.85
295	E	367	8.5	0.93
395	B	97	6.5	0.82
395	NONE	319	7.1	0.94
477	NONE	3207	6.4	0.97

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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.).

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 base- upon compliance on a thirty-day roiling 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 6-5 180 MWe EXCESS OXYGEN CHARACTERISTICS

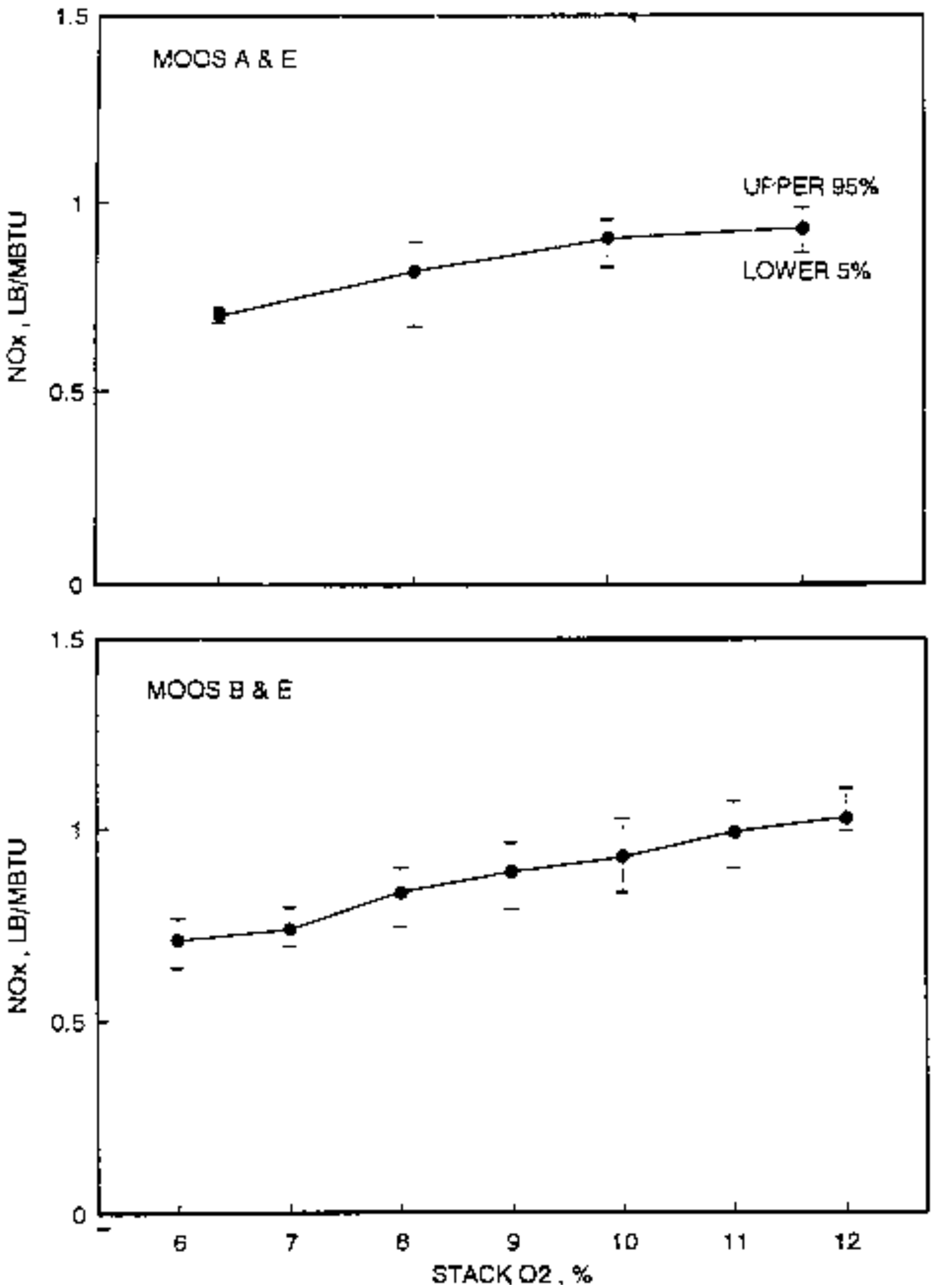


FIGURE 6-6 300 MWe EXCESS OXYGEN CHARACTERISTICS

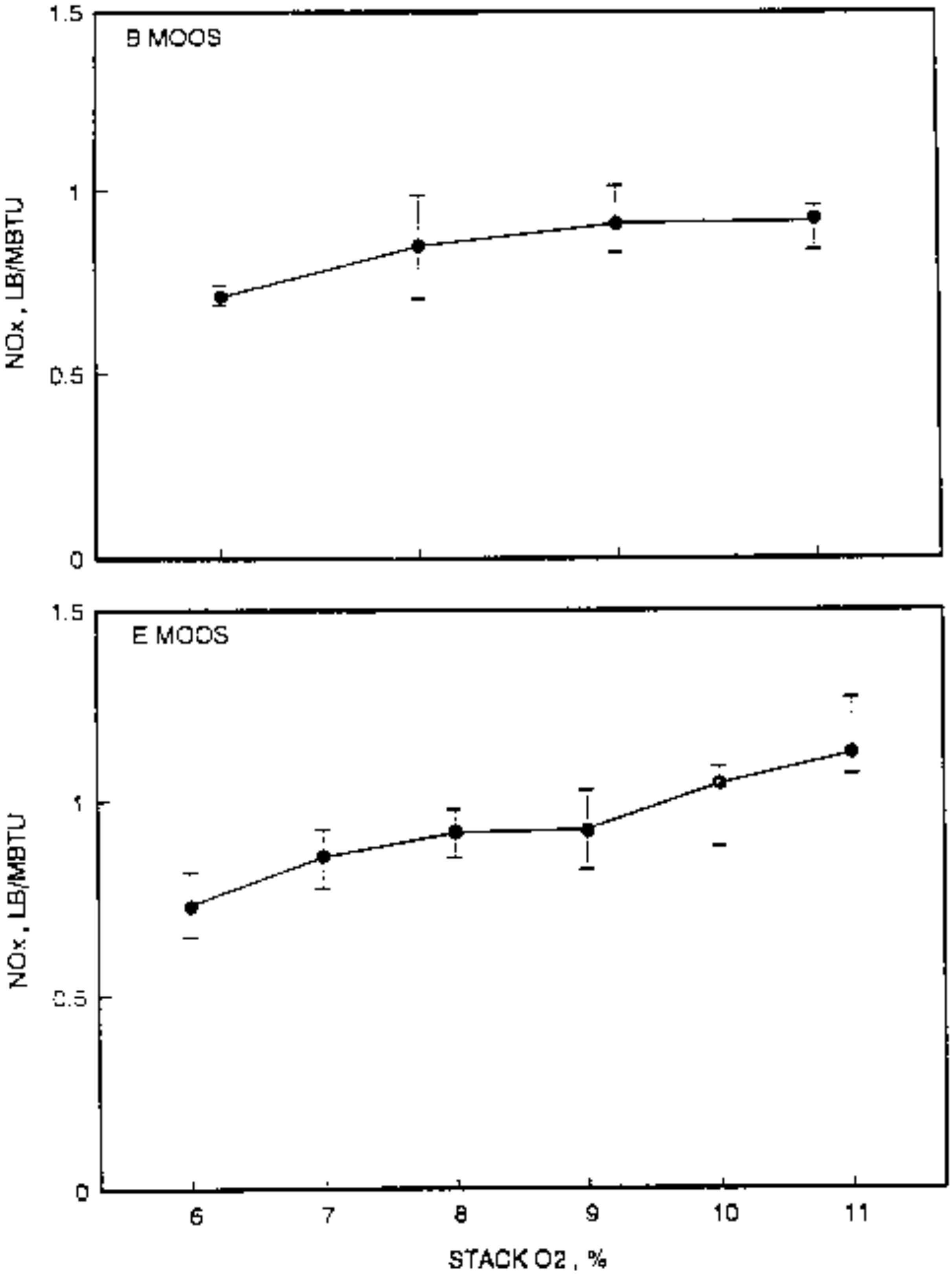


FIGURE 6-7 400 MWe EXCESS OXYGEN CHARACTERISTICS

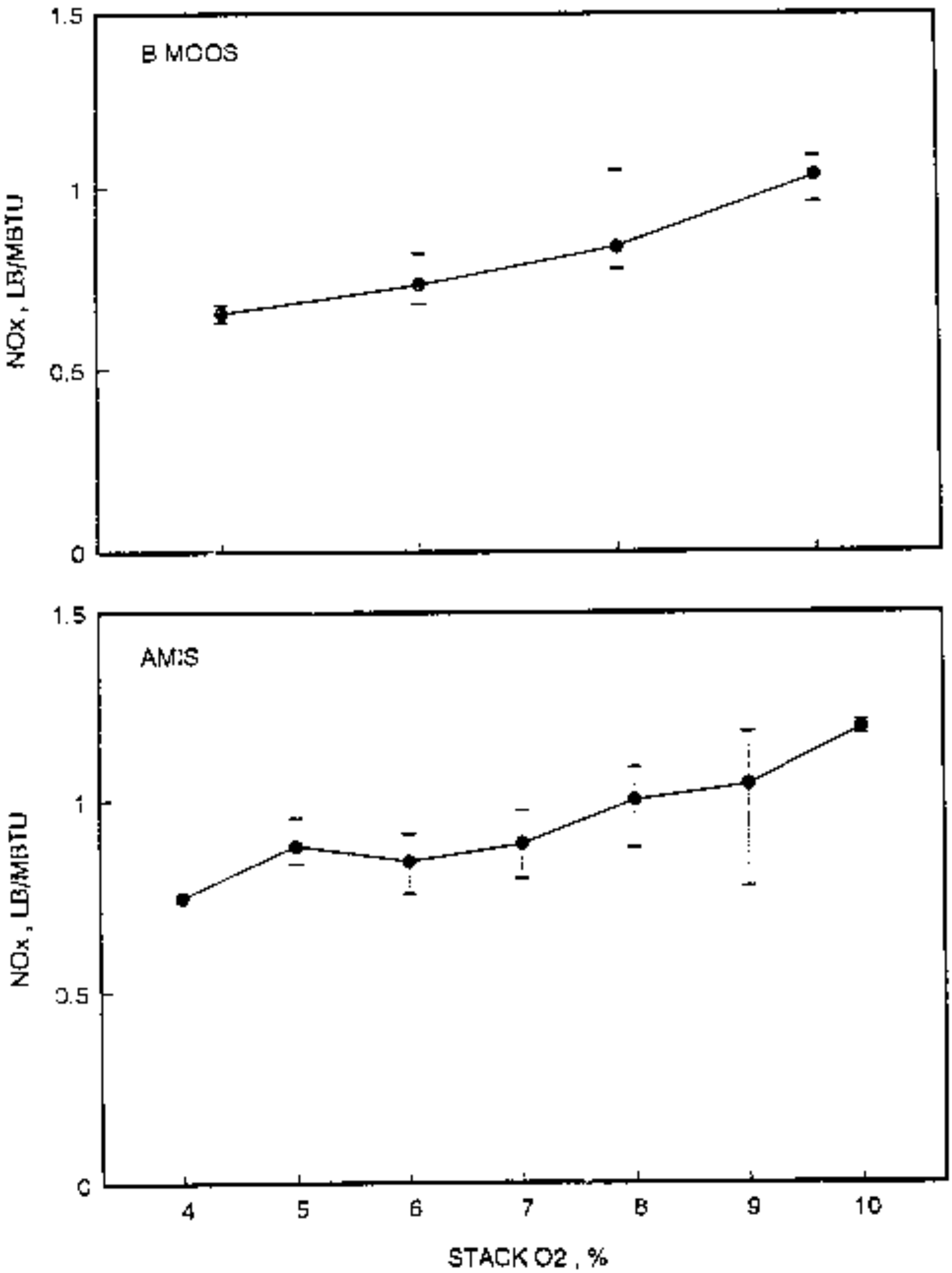


FIGURE 6-8 480 MWe EXCESS OXYGEN CHARACTERISTICS

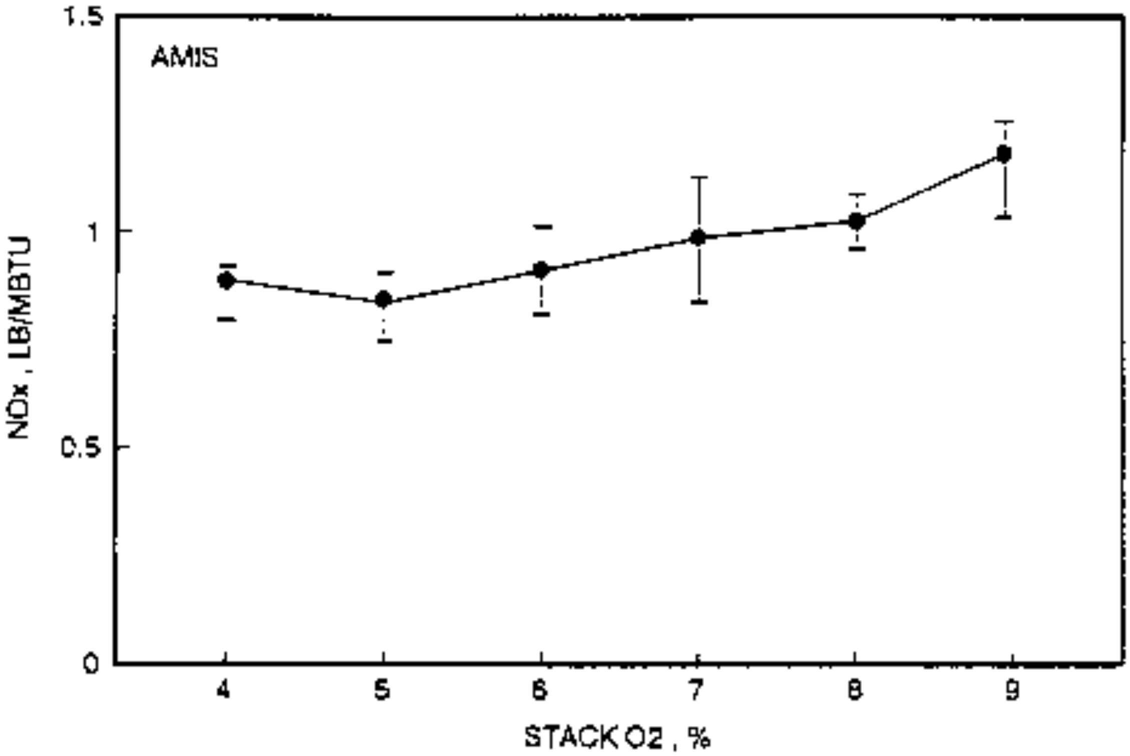


Figure 6-9 for the 92 (63 rolling averages) valid days (by EPA criteria) of data.

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

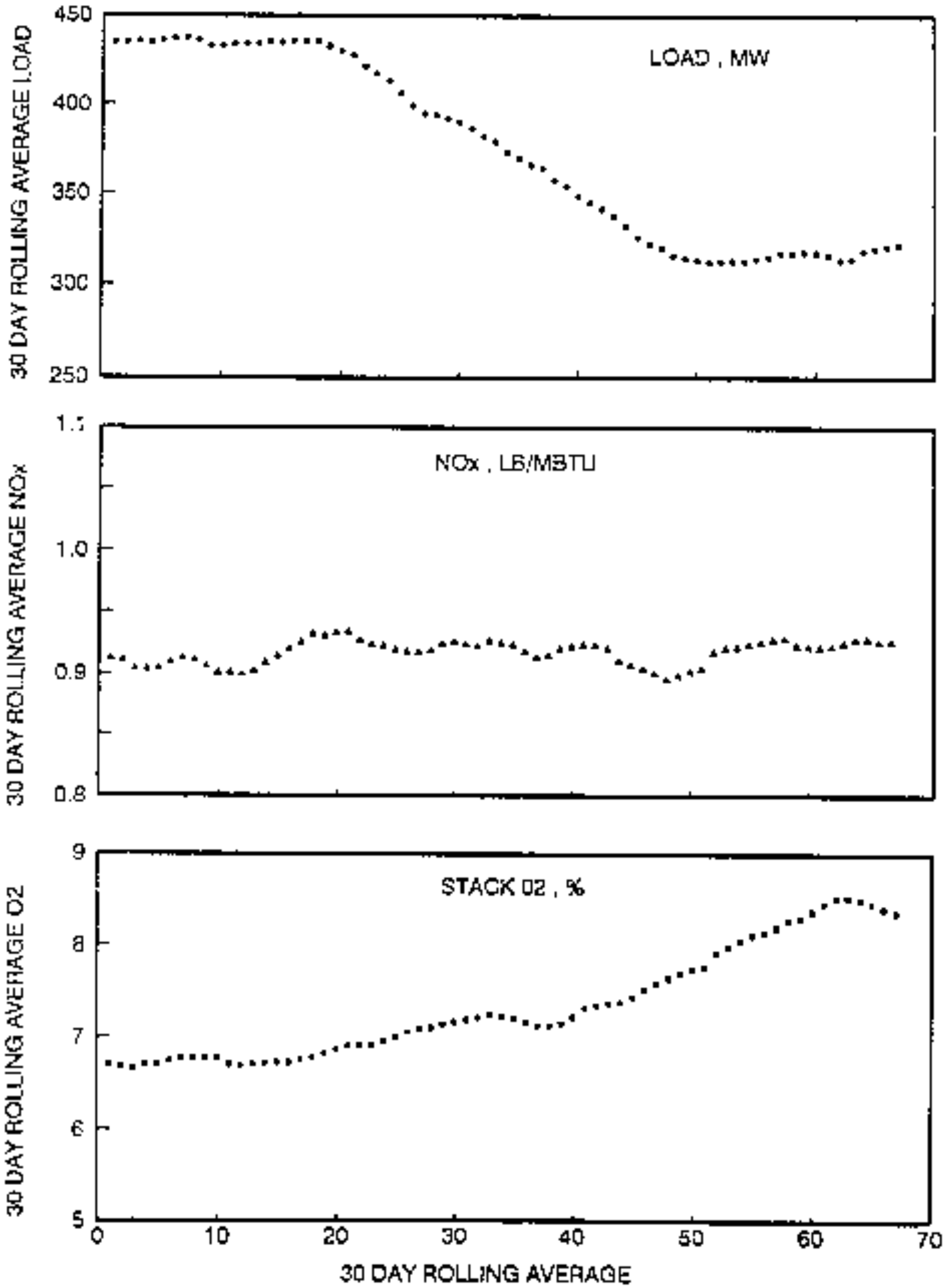
EPA in their rulemaking process establishes an achievable emission level based upon daily average data samples obtained from CEMs. Most of this data is from NSPS Subpart Da units or units that used CEMs to obtain data during demonstration programs. The achievable NOx emission limit on a 30-day rolling 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	86
Average Emissions (lb/MBtu)	0.92
Standard Deviation (lb/MBtu)	0.079
Distribution	Normal
First Order Autocorrelation (ρ)	0. 69

FIGURE 6-9 30 DAY ROLLING AVERAGE CHARACTERISTICS



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 ($\rho=0$) and the estimated value of 0.69 (which indicates highly time dependent data). 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.

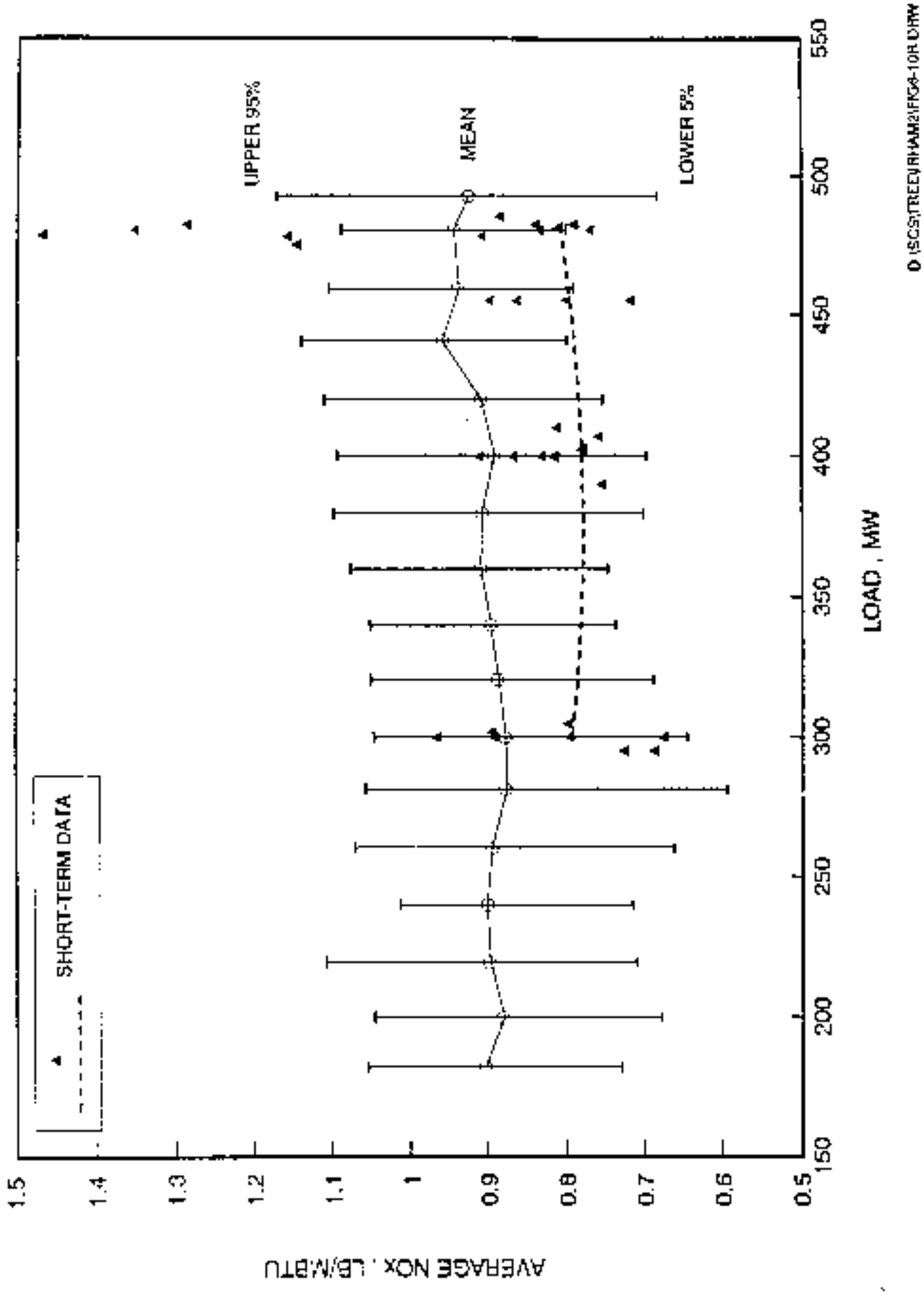
TABLE 6-4 3 O-DAY ROLLING AVERAGE ACHIEVABLE NOx EMISSION LIMIT

Autocorrelation	Achievable Emission Limit (lb/MBtu)	
	30-Day	Annual
$\rho = 0$	0.966	0.923
$\rho = 0.69$	1.03	0.93

It should be noted that the mean, variability, and autocorrelation levels given in Table 6-3 are only estimates. There is an uncertainty level implicit in the estimates of each of these statistical parameters. The uncertainty level in the mean is dependent on the variability. The estimated variability is, to some extent, dependent on the level of autocorrelation. Thus, uncertainty levels in the descriptive statistics are linked. 6.5 Comparison of Phase 2 Long- and Short-Term NOx Data

Section 5.1 presented data for the load characteristics (See Figure 5-2). 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 October 1990 through Mid-March 1991. Figure 6-10 provides a comparison between these two sets of data showing the confidence interval (upper 95 percent and lower 5 percent) for the long-term data. From the comparison it is evident that the data obtained during the short-term efforts was, in many cases, within the upper 95 and lower 5

FIGURE 6-10 COMPARISON OF LONG AND SHORT-TERM NOx DATA
MEDIUM TO HIGH LOADS , ALL EXCESS OXYGEN LEVELS



percent range. Only a small about of data was above this range at the high load point.

Early in the diagnostic testing, the O_2 levels tested were those normally experienced during baseline tests. It was discovered during the performance tests that a backpass leak had developed. As a consequence, the excess oxygen levels measured at the economizer exit represented the air at the burners plus the air in-leakage. This resulted in the Phase 2 tests being performed at true burner O_2 that were lower than required for complete combustion. The LOI levels for these tests were high and it was recommended that the excess oxygen level be raised by one percentage point to compensate for the leak. The net result is that the short-term test results from the diagnostic testing is lower than the long-term data due to differences in the operating excess oxygen level.

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.

6.6 Comparison of Phase 1 and Phase 2 Long-Term NOx Results

The true measure of the effectiveness of the particular NOx control technique is represented by the long-term load characteristics. A useful engineering comparison can be made by comparing the mean value of the baseline and the retrofit load characteristics. Figure 6-11 illustrates the load characteristics for both configurations. At the top load the AOFA retrofit resulted in approximately 24 percent reduction in NOx. Figure 6-12 shows that the effectiveness drops off as the load is decreased. This is primarily due to the fact that the OFA ports are gradually closed as the load is decreased.

While the backpass leak causes the operating excess oxygen to appear to be significantly higher than the baseline case, actually at the burners, the excess oxygen level was only slightly elevated. Even with this slight elevation, the LOI was increased as illustrated in Figure 6-13.

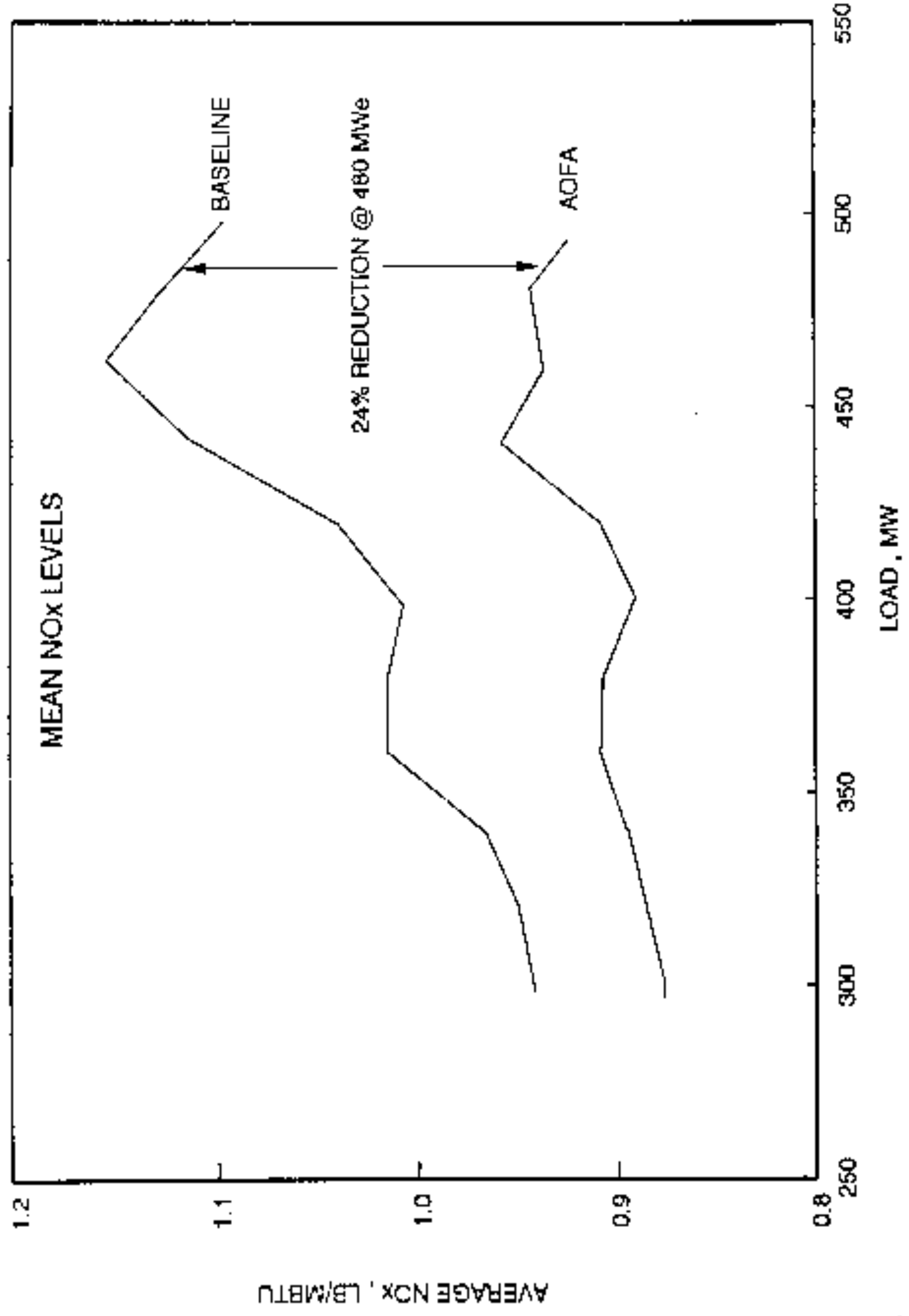


FIGURE 6-11 COMPARISON OF PHASE 1 AND PHASE 2 LONG-TERM NOx DATA

FIGURE 6-12 AOFA RETROFIT TECHNOLOGY EFFECTIVENESS

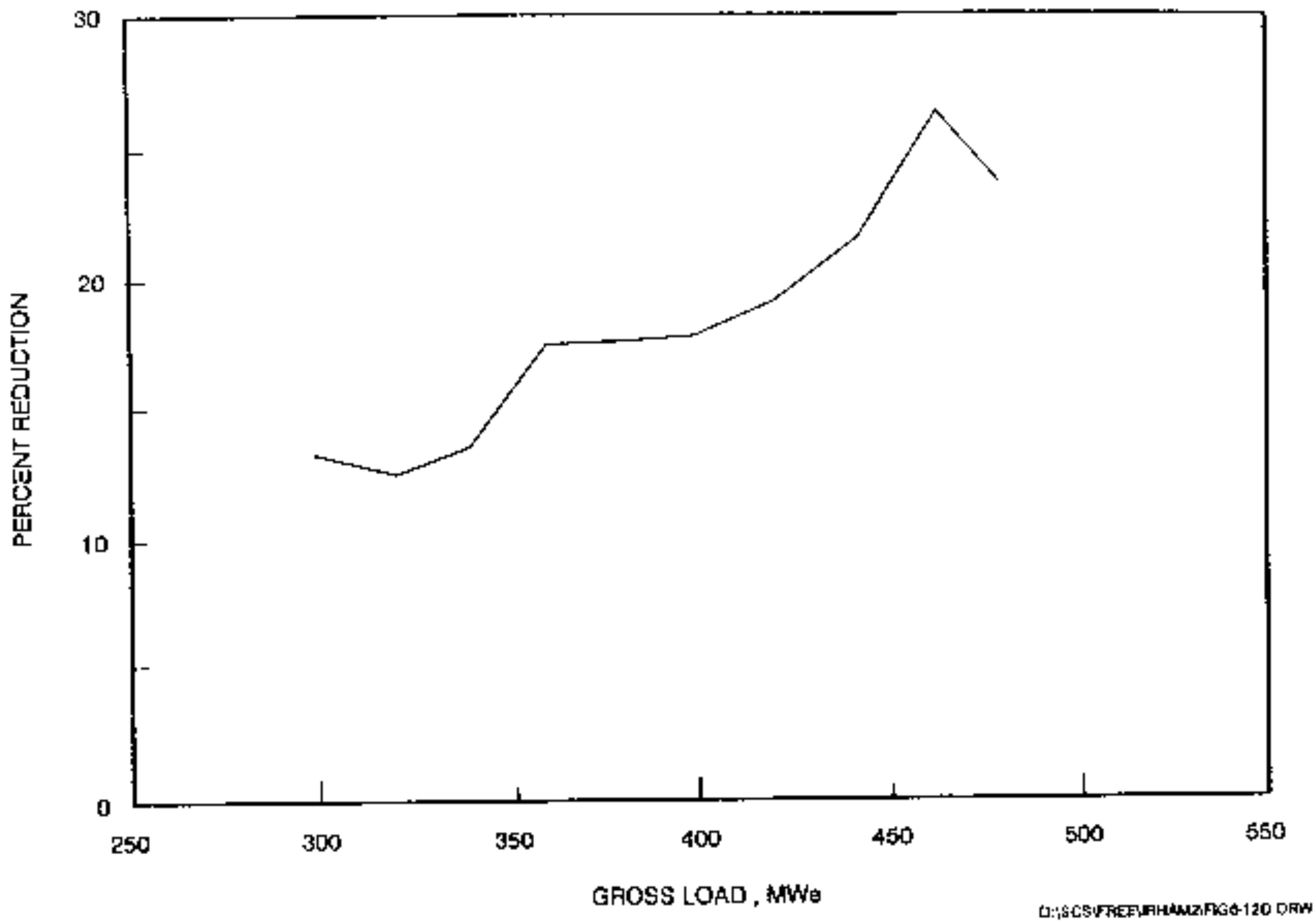
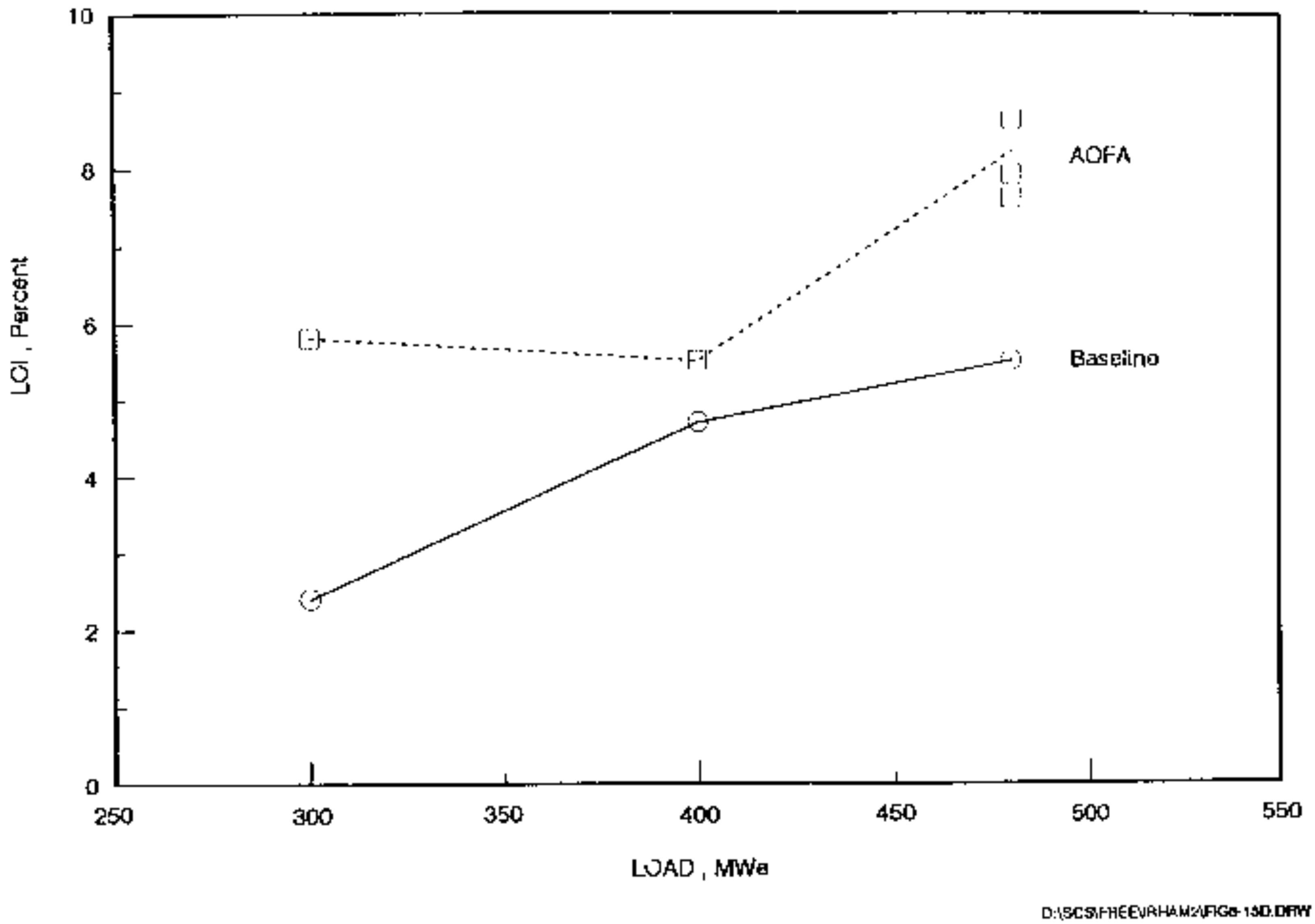


FIGURE 6-13 BASELINE AND AOFA LOI CHARACTERISTICS



7.0 CONCLUSIONS

The primary objective of the Phase 2 test effort was to establish AOFA retrofit NOx emission characteristics under short-term well controlled conditions and under long-term normal system load dispatch conditions. In addition, other important performance data related to the operation of the boiler in this retrofit configuration were documented for comparison to those measured during the Phase 1 baseline test effort. Protocols for data collection and instrumentation operation were established during Phase 1 (see Phase 1 Baseline Tests Report).

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. A brief discussion related to the comparison between Phase 1 and Phase 2 data are included. More thorough comparisons will be presented in the final report after detailed analyses have been performed.

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 that would have affected the NOx emissions. The following paragraphs provide a brief description of the major conclusions for the Phase 2 short-term testing.

7.1.1 Diagnostic Test Conclusions

The conclusions for the diagnostic portion of the testing are based primarily upon testing performed at 300, 400 and 480 MWe. The major conclusions for the Diagnostic testing are:

1) NOx emissions were variable for the seemingly identical operating conditions. At similar conditions, the NOx varied as much as 15 percent at high loads. This is a slight decrease in the variability over the data collected during Phase 1. The exact reasons for these large variations are not known at this time, however, it is believed to be a consequence of the condition of the Intervane burner registers.

2) For one operating condition (mill pattern and load) NOx 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 10 percent. All of the trends for all loads and mill patterns exhibited increasing NOx with increasing O_2 and the slopes were essentially the same.

3) NOx emissions remained relatively constant over the load range from 300 to 480 MWe. The measured average short-term NOx emissions were approximately 0.8 lb/MBtu. Since the 185 MWe load point was not tested, the trend could not be quantitatively established below 300 MWe. It should be pointed out that the NOx emissions during the diagnostic testing were determined at an excess oxygen level approximately one percent lower than that used during the performance and long-term testing.

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 major conclusions for the performance tests are:

1) The NOx scatter evidenced during the diagnostic tests was also present during the tests for nearly identical operating conditions (mill pattern and load).

2) NOx and O_2 spatial distributions within the economizer exit ducts indicated that significant maldistributions in flue gas temperature and O_2 levels. These maldistributions tended to exhibit themselves as low O_2 and corresponding high temperatures on the east side of the boiler. Similar conditions were experienced during Phase 1 testing.

3) Primary air flow ranged from 25 to 30 percent at loads of 480 and 300 MWe, respectively. Overfire air flow at the 50 percent open AOFA damper averaged approximately 23 percent of the total air flow over the load range from 300 to 480 MWe.

4) Furnace exit gas temperatures exceeded 2600^{o} F in the regions of low excess oxygen near the furnace nose. O2 measurements at the furnace nose showed extremely low levels swell below one percent) in some regions at the furnace nose.

5) Mill coal particle fineness was near the low end of the acceptable range. The coal fineness was determined to be 67 percent' average through a 200 mesh screen at 480 MWe. Pipe-to-pipe coal flow were +9 to -16 percent from the mean at the full-load point. Primary air to coal ratio in the mills was +8 to -15 percent from the mean at the same load.

6) ESP entrance ash resistivity was within the expected range for this coal. The resistivity remained unchanged from the baseline configuration.

7) LOI ranged from 7 to 10 percent over the load range. The LOI measurements indicated that LOI increased with the use of AOFA by approximately 80 percent to approximately 10 percent at full load.

7.1.3 Verification Test Conclusions

At the 4S0 MWe load point, it can be concluded that no significant changes in NOx characteristics occurred between the short-term and verification testing. At the 400 MWe load point, however, the slopes remained unchanged but the O_2 data were biased approximately one and one-half percent higher than the diagnostic test results. The reason for this shift is unexplained at this time but will be investigated and reported on in the final report.

7.2 Long-Term Characterization Tests

Long-term testing took place from late December 1989 through early April 1990. During this period the ECEM was operated 24 hours per day except during periods of repair and calibration. From time-to-time, the instrumentation experienced operational difficulties which resulted in lost data capture. These periods were minimal and did not affect the quality of the remainder of the data. 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) In the past, the unit typically operated at high load for the majority of its on-line time. The data taken during Phase 2 illustrated that the unit did not now operate at high loads for the majority of the time. Data show that the unit experienced significant periods of time where the average daily load was in the 300 MWe range (60 percent load).

2) Daily average NOx emission levels for the long-term test period were nearly constant at a level slightly above 0.9 lb/MBtu.

3) The mean load characteristics showed that NOx generally remained constant at near 0.9 lb/MBtu over the load range from 180 to near 500 MWe. The 95 percent confidence intervals for NOx emissions over the load range was on the order of + 0.2 lb/MBtu about the mean.

4) Based upon 30-day rolling averages, the data showed that the average load slowly decreased from 440 to 320 MWe over the period of long-term testing. Because of the flat NOx versus load characteristics, the 30-day rolling average Nox remained relatively constant at near 0.9 lb/MBtu.

5) Statistical analyses indicated that the data were autocorrelated with a correlation coefficient of $\rho = 0.69$. The Phase 2 data are therefore autocorrelated (time dependent). The data are more highly autocorrelated than the data collected in Phase 1.

6) Non-time dependent ($\rho = 0$) 30-day rolling average analyses resulted in an achievable emission level of 0.966 lb/MBtu for the load scenario experienced during the long-term testing. This compares to the 30-day rolling average level of 1.18 for the baseline configuration results. Time dependent (ρ= 0.69) resulted in a 30-day rolling average achievable emission limit of 1.03 lb/MBtu (1.24 for baseline) which was moderately higher than the non-time dependent analysis.

7) Subsequent to the Phase 1 testing the Clean Air Act Amendments of 1990 passed requiring annual average emission rate limits. Non-time dependent (ρ = Q) annual average emission analyses resulted in an achievable emission level of 0.923 lb/MBtu for the load scenario experienced during the long-term testing or four percent less than the 30-day rolling average level. Time dependent ($\rho = 0.69$) resulted in an annual average achievable emission limit of 0.93 lb/MBtu or almost identical to the non-time dependent emission levels and 10 percent less than the 30-day rolling average emission level.

7.3 Comparison of Phase 1 and Phase 2 Emission Data

While the Phase 1 and Phase 2 efforts were not performed with the same load scenario, some general conclusions can be made with regard to the effectiveness of the AOFA retrofit. The following briefly summarizes these conclusions.

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

2) LOI emissions increased over the baseline configuration. At the 430 MWe load point, the LOI increased approximately 80 percent to a level of near 10 percent.

3) NOx emissions decreased by 24 percent from the baseline configuration at 480 MWe. The emission reduction decreased as the. load decreased to the 300 MWe load point where the reduction was approximately seven percent.

REFERENCES

1) Innovative Clean Coal Technology II, "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", Southern Company Services, Inc. DOE Contract Number DE-FC22-9OPC89651, July 1991.