INNOVATIVE CLEAN COAL TECHNOLOGY (ICCT)

180 MW DEMONSTRATION OF ADVANCED TANGENTIALLY-FIRED COMBUSTION TECHNIQUES FOR THE REDUCTION OF NITROGEN OXIDE (NOx) EMISSIONS FROM COAL-FIRED BOILERS

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CONSULTANTS, INC.

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

ADVANCED TANGENTIALLY-FIRED LOW NOx COMBUSTION DEMONSTRATION

PHASE I BASELINE TESTS

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PHASE I BASELINE TESTS

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EXECUTIVE SUMMARY

This Phase I Baseline Test Report summarizes the testing activities and results for the first testing phase of an Innovative Clean Coal Technology (ICCT) demonstration of advanced tangentially-fired combustion techniques for the reduction of nitrogen oxide (NOx) emissions from coal-fired boilers. The project is being conducted at Gulf Power Company's Plant Lansing Smith Unit 2 located near Panama City, Florida. 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. A fifty percent NOx reduction target using three levels of combustion modifications has been established for this project.

The project provides a stepwise retrofit of three versions (Levels 1, 2 and 3) of Asea Brown Boveri-Combustion Engineering Services (ABB-CES) Low NOx Concentric Firing System (LNCFS). During each of the three test phases of the project, diagnostic, performance, long-term, and verification testing will be performed. Data collected from these activities are used to quantify the resultant NOx reductions achieved through retrofit of LNCFS Levels 1, 2 and 3 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 I - Baseline "as-found" testing,
Phase II - LNCFS Level 2 with Separated Overfire Air Ports,
Phase IIIa - LNCFS Level 3 with Separated Overfire Air Ports and Close Coupled Overfire Air Ports,
Phase IIIb - LNCFS Level 1 with Close Coupled Overfire Air Ports,
and Phase IV - Final reporting.

The Phase I baseline configuration is the subject of this interim test report. Subsequent interim test reports will be prepared for Phases 2, 3a and 3b. The Phase I "as-found" configuration is defined as the configuration under which the unit has operated in the recent past. Described in this report are the test program plans, data collection procedures and measurements, and data analysis methodologies used to perform this Phase I effort. Results from 85 short-term tests and 104 days of long-term baseline tests are presented.

An objective of the Phase I tests effort was to document the existing condition of Unit 2 and to establish the NOx emissions under short-term well controlled conditions. Short-term testing results indicated baseline full-load (180 MWe) NOx emissions of approximately 0.65 (~±0.1) lb/MMBtu diminishing to 0.55 (~±0.1) lb/MMBtu at low load (115 MWe). Loss-on ignition (LOI) for these loads were 5.0 and 4.0 percent, respectively.

The primary objective of the Phase I effort was to document the long-term NOx emission trends while the unit was operating under normal day-to-day load dispatch conditions. These data were subjected to statistical analyses to determine various characteristics (NOx versus load, mill pattern and excess oxygen) and to determine the achievable emission limits based upon annual average and 30-day rolling average criteria. Long-term testing results indicated baseline full-load (180 MWe) NOx emissions of approximately 0.63 lb/MMBtu which is approximately equal to that for the short-term data. At the 110 MWe low load point, the emissions diminished to 0.61 (+0.091 upper 95 percent CI and 0.137 lower 5 percent CI) lb/MMBtu or slightly higher than that shown for the short-term data. The annual and 30-day average achievable NOx emissions were determined to be 0.63 and 0.68 lb/MMBtu, respectively, for the load scenario experienced during day long-term test period. The statistical analysis showed that the data are highly autocorrelated (time dependent) with an autocorrelation coefficient of 0.75 which was used to establish the achievable emission limits.

The results from this baseline test phase will be used in subsequent test phases to establish the NOx reductions for the various control technologies. 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.

ACKNOWLEDGMENT

Energy Technology Consultants (ETEC) 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 and Mr. James Gibson of Spectrum Systems provided invaluable assistance in collecting all of the short-term and long-term data. In addition Mr. Perez and Mr. Gibson maintained the instrumentation in excellent working condition during the entire Phase I effort.

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

Both Southern Research Institute under the direction of Mr. Carl Landham and Flame Refractories, Inc. under the direction of Mr. 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 Baseline report.

ETEC would like to acknowledge Mr. J. D. McDonald of Plant Smith for his efforts in insuring that the testing progressed with the maximum level of efficiency through his coordination efforts.

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TABLE OF ABBREVIATIONS

ABB CES	Asea Brown Boveri Combustion Engineering Services
APH	Air Preheater
CEM	Continuous Emission Monitor
CI	Confidence Intervals
DAP	Data Acquisition Package
DAS	Data Acquisition System
DOE	Department of Energy
ECEM	Extractive Continuous Emissions Monitor
EPRI	Electric Power Research Institute
ESP	Electrostatic Precipitator
ETEC	Energy Technology Consultants
GAS	Gas Analysis System
GPC	Gulf Power Company
HDD	Historical Data Display
HTFREAD	Historical Trend File Read Program
HVT	High Velocity Thermocouple
ICCT	Innovative Clean Coal Technology
I&PI	Instrumentation and Process Inputs
LNBFS	Low NOx Bulk Furnace Staging
LNCFS	Low NOx Concentric Firing Systems
LOI	Loss on Ignition
LPU	Local Processing Units
NOx	Nitrogen Oxide
NSPS	New Source Performance Standards
OFA	Overfire Air

PC's	Personal Computers
SCS	Southern Company Services
SoRI	Southern Research Institute
T/C	Thermocouple
THC	Total Hydrocarbons
TP	Test Points
WSPC	W.S. Pitts Consulting, Inc.

1.0 INTRODUCTION

This Innovative Clean Coal Technology II project to evaluate NOx control techniques on a 180 MWe utility boiler is funded by three organizations:

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

Through its costs sharing in the installed low NOx retrofit technology, Asea Brown Boveri Combustion Engineering Services (ABB CES) is also participating as a project co-funder. Gulf Power Company (GPC) provided Plant Lansing Smith as the host site and provides on-site assistance and coordination for the project. The following briefly describes the overall organization and describes in detail the organization related to the test and evaluation activities.

1.1 Project Description

On September 19, 1990, Southern Company Services was awarded a DOE Innovative Clean Coal Technology Round II (ICCT) contract for the project, "180 MWe Demonstration of Advanced Tangentially-Fired Combustion Techniques for the Reduction of Nitrogen Oxide (NOx) Emissions from Coal-Fired Boilers". The primary objective of the project is to investigate the long-term effects of commercially available tangentially-fired low NOx combustion technologies on NOx emissions and boiler performance on Unit 2 at Gulf Power Company's Plant Lansing Smith located near Lynn Haven, Florida. The project will characterize emissions and performance of a tangentially-fired boiler operating in the following configurations:

1) Baseline "as-found" configuration - PHASE I,
2) Retrofitted Low NOx Concentric Firing System (LNCFS) Level II and simulated Low NOx Bulk Furnace Staging (LNBFS) - PHASE II,
3) Retrofitted Low NOx Concentric Firing System (LNCFS) Level III - PHASE IIIa and simulated LNCFS Level I - Phase IIIb,

The major objectives of the project are to:

1) Demonstrate (in a logical stepwise fashion) the short-term NOx reduction capabilities of the following advanced low NOx combustion technologies:
    a) Low NOx Bulk Furnace Staging (LNBFS)
    b) Low NOx Concentric Firing System (LNCFS) Levels I, II, and III,

2) Determine the dynamic long-term NOx emission characteristics of the three levels of LNCFS using sophisticated statistical techniques,

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

1.2 Project Organization

The Program Manager for the DOE ICCT Demonstration Project being conducted at the Plant Lansing Smith, is Mr. Steven M. Wilson of Southern Company Services, Inc. (SCS) who has overall responsibility for execution of this project and other ICCT projects. Mr. Robert R. Hardman is the Project Manager. The Project Manager directs in-house (SCS) and GPC personnel to perform various duties related to site coordination, design engineering, environmental matters and cost coordination. The Manager also directs subcontracted efforts of the burner manufacturer, installation contractors and test coordination contractor. ABB/Combustion Engineering (ABB/CES) is the subcontractor supplying and installing the NOx Emissions Control Systems. Energy Technology Consultants, Inc., (ETEC) provides Test Coordination and Results Engineering Services. The United States Department of Energy (DOE) and the Electric Power Research Institute (EPRI) provide direction and technical input to the project.

ABB CE Services, Inc. ABB CES is responsible for designing, furnishing, and installing the low NOx combustion equipment. ABB CES provides technical assistance during the startup and tuning activities associated with each of the project phases. In addition, ABB CES is responsible for designing, constructing and testing the 1/12 scale flow model of the Plant Lansing Smith Unit 2 boiler.

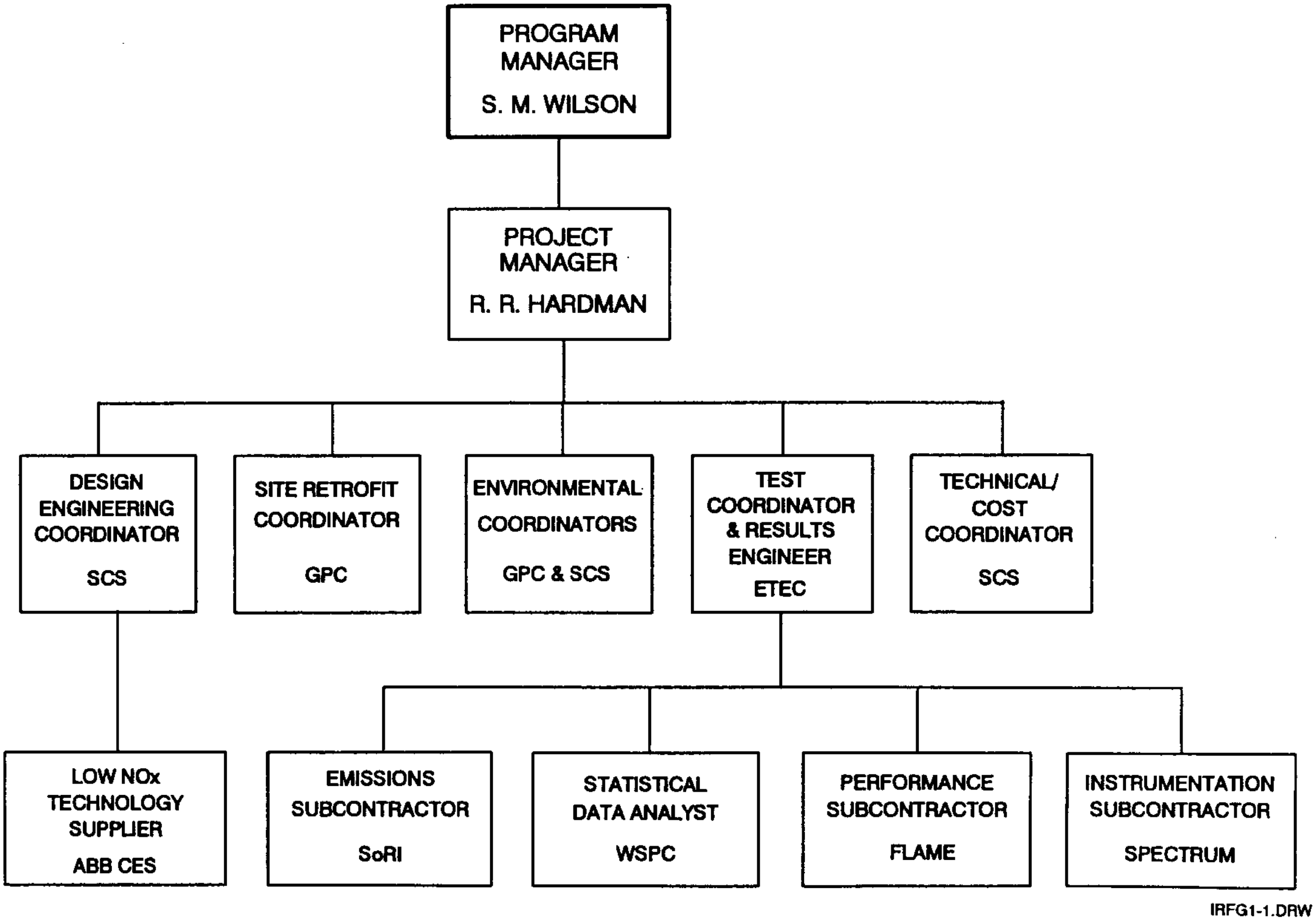
Energy Technology Consultants, Inc. Energy Technology Consultants (ETEC) has responsibility for the on-site testing and analysis of the data obtained for all phases of the project. This responsibility falls under the TEST COORDINATOR & RESULTS ENGINEER functional area under Southern Company Services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

Spectrum Systems, Inc. Spectrum provides a full-time, on-site instrument technician who is responsible for operation and maintenance of the data acquisition system (DAS) housed within the Instrument Control Room. The DAS was newly constructed for this project. During the Short-Term Characterization and Short-Term Verification activities, Spectrum personnel continuously man the instrumentation control room during the daily test periods and collect and record all data transmitted to the instrumentation control room. For the full duration of the program (Short-Term Characterization, Long-term Characterization and Short-Term Verification for all four phases), Spectrum maintains and repairs, as necessary, the instrumentation system and monitors the function of the data acquisition system (DAS) on a daily basis.

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

Flame Refractories, Inc. Flame Refractories, Inc. (Flame) is responsible for activities related to fuel/air input parameters and furnace output temperature measurements during the performance testing portion of the Short-Term Characterization for all four phases. During this period, Flame provides all manpower and equipment to perform the following tests: primary air flow, pulverizer outlet air/fuel ratios, coal fineness, coal pipe dirty air velocity, coal pipe clean air velocity and

FIGURE 1-1 SMITH PROJECT ORGANIZATION



secondary air flows at the windbox entrance and furnace gas temperature and species measurements.

W. S. Pitts Consulting, Inc. W. S. Pitts, Inc. (WSPC) is responsible for data analysis of the emission and performance data for the Long-Term Characterization Phases of the program. WSPC activities include reduction and statistical analysis of the Long-Term emissions data, review of the Experimental Design of Short-Term Characterization activities and definition of quality assurance measures for the Continuous Emission Monitor and gas analysis system data. During the Phase I Short-Term Characterization, each of the test and analysis subcontractors reporting to ETEC provided written material describing the results of their activities during the Phase I activities. Both raw and reduced data are archived by the subcontractors as well as ETEC for future reference.

1.3 Lansing Smith Unit 2 Description

Plant Lansing Smith Unit 2 is an ABB CES tangentially-fired boiler originally rated at 180 MWe but capable of firing at 200 MWe with design steam conditions of 1875 psig and 1000/1000 °F superheat/reheat temperatures, respectively. Table 1-1 provides information on the design parameters for Unit 2. Figure 1-2 illustrates the side-view of Lansing Smith Unit 2. Five CE 623 RPS mills provide pulverized eastern bituminous coal for delivery to five burner elevations. Individual windboxes are located at the four corners of the furnace. Each windbox contains the five burner elevations as illustrated in Figure 1-3.

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

1.4 Report Organization

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

TABLE 1-1 LANSING SMITH UNIT 2 BASELINE DESIGN SPECIFICATION

Design Pressure.......	2200 psig
Operation Pressure ...	1875 psig
Furnace Volume........	98,790 ft^3
Furnace Type..........	Hopper Bottom
Furnace Width.........	40' - 0"
Furnace Depth.........	25' - 11 3/8"
Superheater Type......	Multistage with Platen
Reheater Type.........	Single Stage
Economizer Type.......	CFS - 72W x 16H x 39' - 10" LG
Air Heater Type.......	24½ VI x 63
Air Heater Make.......	Ljungstrom
Fuel Burning Equipment	C - E Tilting Tangential Burners 5-623 RPS
Fuel..................	Eastern Bituminous Coal
C.....................	66.6%
H2....................	4.7%
S.....................	3.7%
N2....................	1.2%
O2....................	6.8%
ash...................	6.8%
moisture..............	8.5%
Ash Fusion Temp.......	2000 °F
Grindability..........	45
HHV...................	12,000

PREDICTED PERFORMANCE

	Control Pt.	MCR
Evaporation (lb,hr)	653,000	1,306,000
Feedwater Temperature (°F)	400	469
Superheater Outlet Temperature (°F)	1,000	1,000
Superheater Outlet Pressure (psig)	1,819	1,875
Superheater Pressure Drop (psi)	45	180
Reheater Flow (lb/hr)	575,243	1,132,650
Reheater Inlet Temperature (°F)	571	696
Reheater Inlet Pressure (psig)	255	513
Reheater Outlet Temperature (°F)	1,000	1,000
Reheater Outlet Pressure (psi)	14	27
Economizer Pressure Drop (psi)	7	25
Gas Drop, Furnace to Econ. Outlet (wg)	1.3	3.4
Gas Drop, Econ. Outlet to A.H. Outlet (wg)	1.6	4.8
Gas Temp. Entering Air Heater (°F)	530	670
Gas Temp. Leaving Air Heater, Uncorr. (°F)	249	279
Gas Temp. Leaving Air Heater, Corr. (°F)	238	268
Air Temp. Entering Air Heater (°F)	122	92
Air Temp. Leaving Air Heater (°F)	477	566
Air Press Entering Air Heater (wg)	7.55	17.5
Ambient Air Temperature (°F)	80	80
Excess Air Leaving Economizer (%)	18	18
Fuel Fired (lb/hr)	78,200	142,600
Efficiency (%)	90.4	89.1

FIGURE 1-2 SMITH UNIT 2 SIDE VIEW

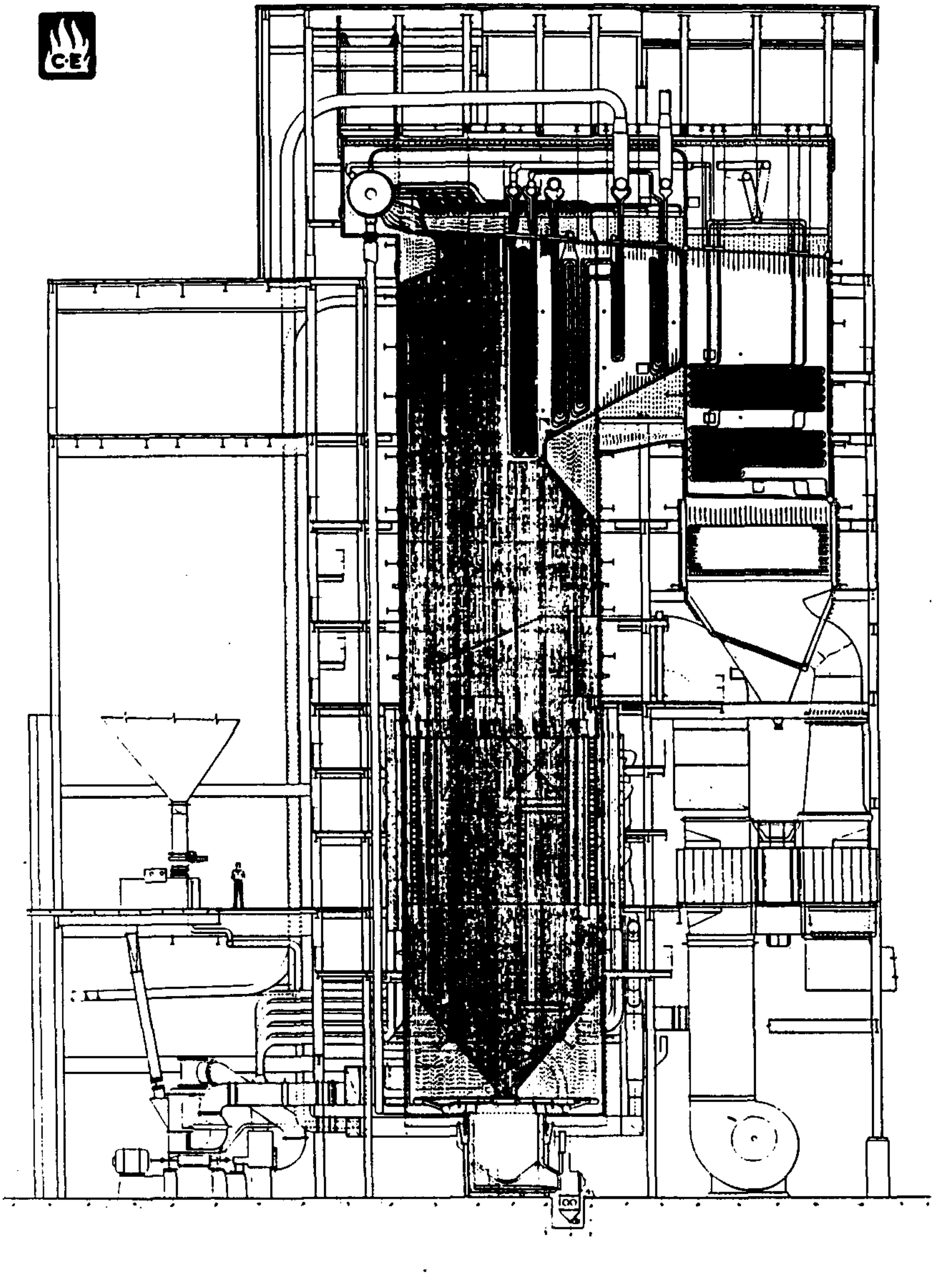
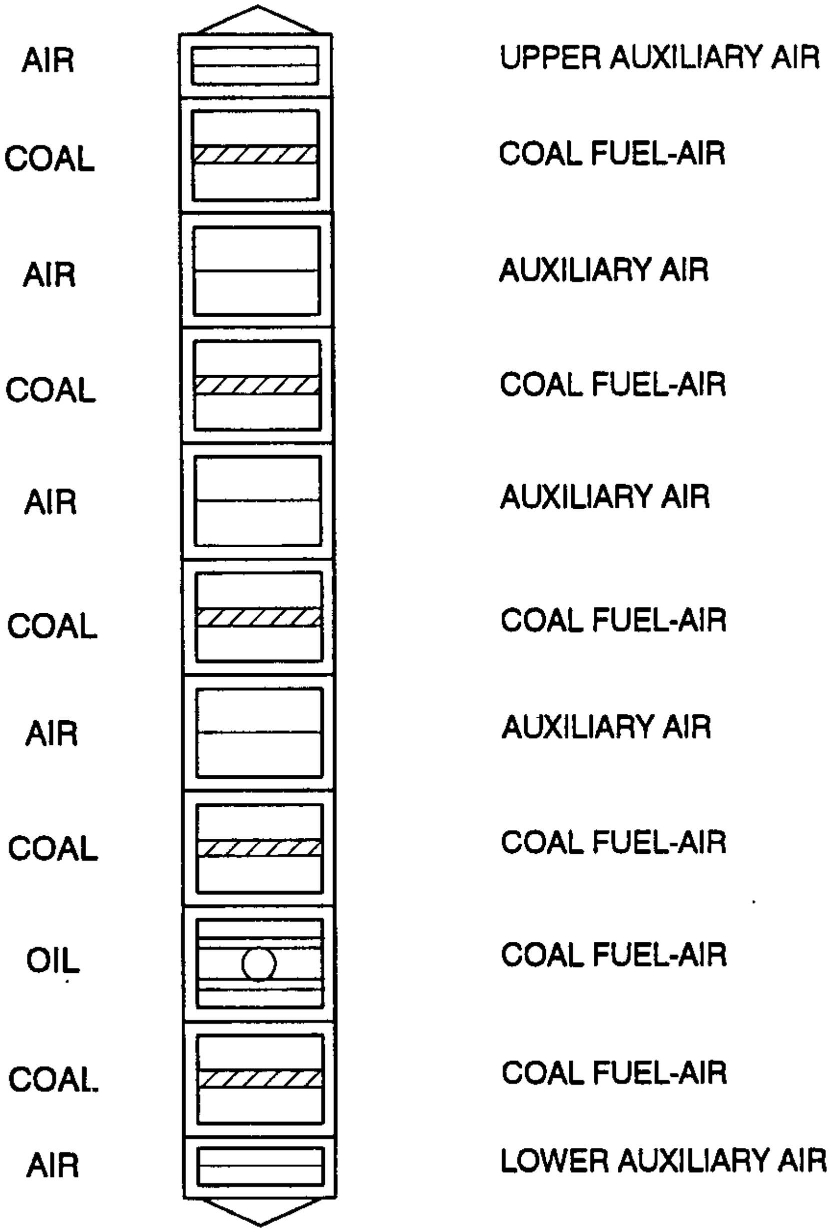
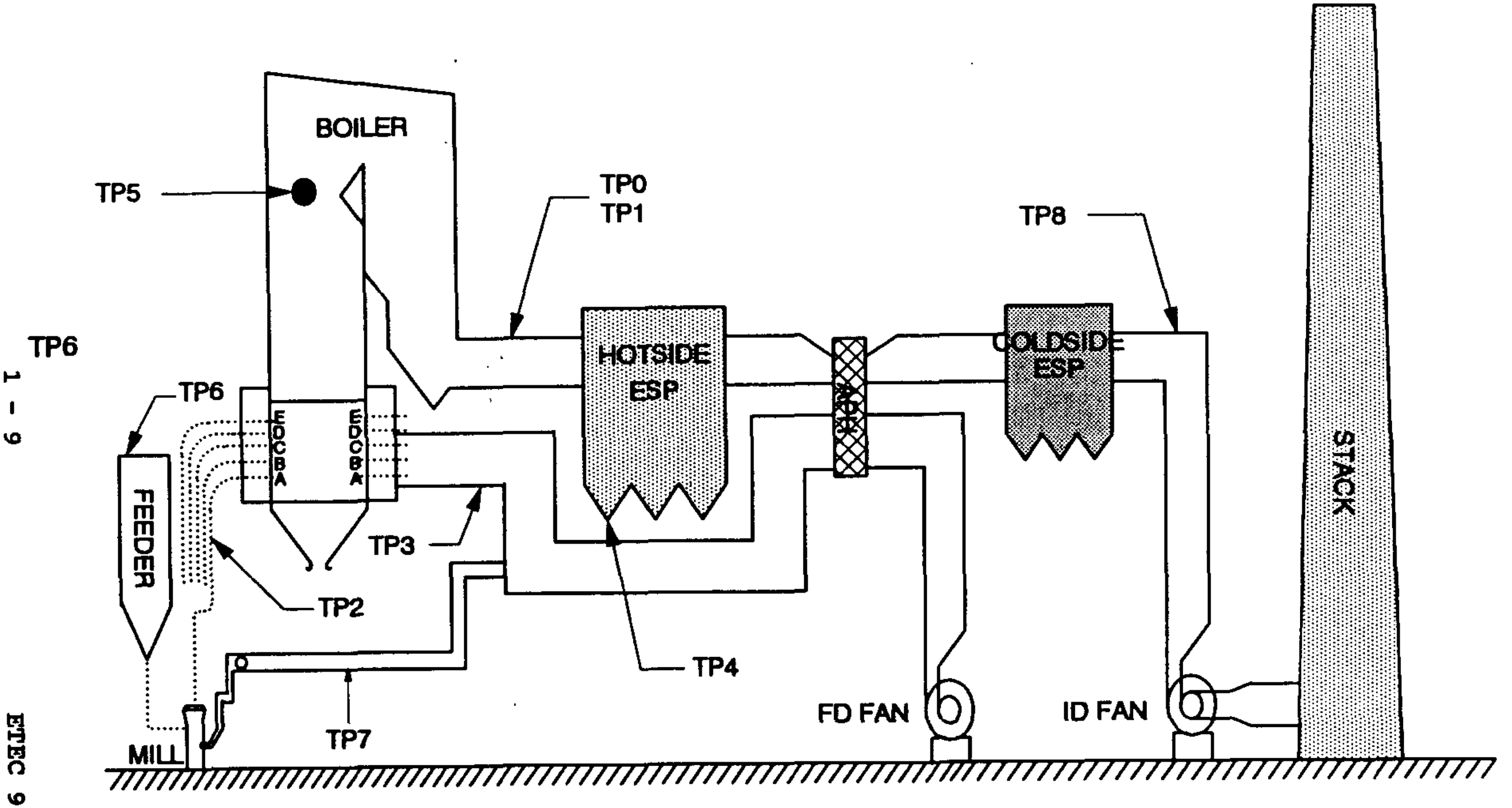


FIGURE 1-3 BASELINE BURNER/WINDBOX CONFIGURATION



IRFG1-3.DRW

FIGURE 1-4 SMITH UNIT 2 TEST SITE LOCATIONS



IRFG1-4.DRW

TABLE 1-2 LANSING SMITH UNIT 2 TEST POINT DESCRIPTION

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

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 which 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 tangentially-fired utility boiler.

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

2.1 Technology Background

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

1) Low NOx Bulk Furnace Staging (LNBFS),
and 2) Low NOx Concentric Firing System (LNCFS) Levels I, II, and III.

Each of the technologies will eventually be compared to the baseline configuration to ascertain the NOx reduction effectiveness. Southern Company Services has contracted with ABB CES to provide and install the burner hardware on the Lansing Smith Unit 2.

The baseline configuration evaluation is the subject of this report and is defined as the "as found" configuration of the unit. The "as found" configuration is further defined as the configuration under which the unit has operated in the recent past. 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 LNBFS and LNCFS retrofits as they will be subsequently incorporated into Unit 2.

2.1.1 Low NOx Bulk Furnace Staging (LNBFS).

The standard offering of overfire air ports incorporates partial combustion air bypass to ports located above the main burner windbox. This bypassed secondary combustion air will be extracted from the secondary air ducts. The portion of the combustion air diverted away from the burners drives the primary combustion stoichiometry toward a fuel rich condition. The secondary combustion air diverted above the burner windbox to the overfire air ports provides sufficient air to complete combustion before the products reach the convective pass. Because of the diversion of air, the primary coal combustion zone may operate under a fuel rich condition, which facilitates reduction of NOx.

Studies by EPRI and boiler manufacturers have shown that the standard overfire air (OFA) offerings do not result in optimum NOx reduction due to inadequate mixing of the secondary air with the partially combusted products from the fuel rich burner zone. This inadequate mixing can limit the effectiveness of the OFA technique. The separated overfire air ports to be provided by ABB CES incorporate separate (from the burner windbox) injection ports and duct system that are designed to provide increased secondary air penetration. The separated overfire air ports designed by ABB CES for this project 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. A limited evaluation of this low NOx combustion concept will be undertaken during Phase II of the project.

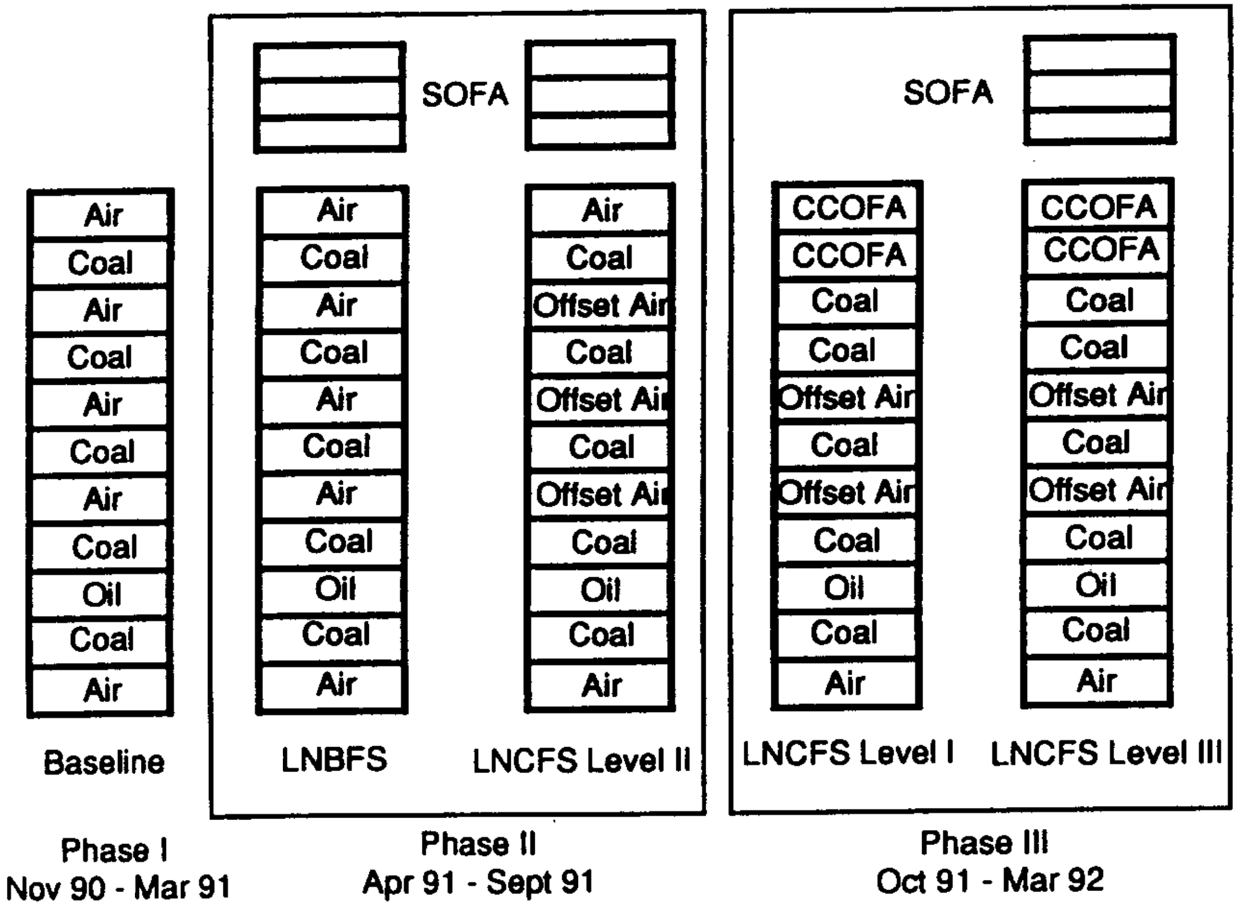
2.1.2 Low NOx Concentric Firing System

ABB CES will supply their Low NOx Concentric Firing System (LNCFS) for retrofit into the existing four corner wall penetrations of the original five tier burner configuration on Unit 2. The LNCFS is offered in three configurations - Level 1 with CCOFA and clustered coal nozzles, Level 2 with SOFA and Level 3 incorporating all of these technologies. Levels 2 and 3 require additional wall penetrations above the existing main windbox.

This Low NOx concept was originally developed in the mid-1970s and demonstrated on the Utah Power & Light's Hunter Unit 2 located in Emery County, Utah. Subsequent to that development effort, modifications of the system have been incorporated into a number of existing utility boilers. Figure 2-1 illustrates the basic design features of the current ABB CES offerings of the LNCFS concept.

As with all of the manufacturers of new low NOx ~~burners~~ burner systems, ABB CES's system utilizes the principle of separating the fuel and air streams in the primary combustion zone. Unique design features of the system allow low NOx operation with OFA that protects the walls from reducing atmospheres that are normally associated with the use of OFA ports. This low NOx combustion system will be evaluated during Phases II, and III of the project. The LNCFS Level 2 and LNBFS concepts will be evaluated during Phase II. The LNCFS Levels 1 and 3 will be evaluated during Phase III.

FIGURE 2-1 ABB-CE LOW NOx CONFIGURATIONS



2.2 Program Test Elements

One of the underlying premises for the structure of the testing efforts in all of the phases of this project is that short-term tests cannot adequately characterize the true emissions of a utility boiler. As a consequence, 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. The determination of relative effectiveness will be accomplished by performing statistical analyses of the long-term data. A description of the purpose and sequence for each of three types of testing involved in all phases of the project follows.

2.2.1 Short-Term Characterization

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

Diagnostic testing involves characterizing the gaseous emissions under three to four load conditions over the range of operating parameters which might normally be encountered on Unit 2 as well as excursions about these normal conditions. The primary parameters that are used for characterization are excess oxygen, mill pattern, and mill bias. Testing at each of the selected conditions is accomplished during a one to three hour period with the unit in a fixed configuration while it is off of System Load Dispatch to better control the operation of the boiler.

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

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

2.2.2 Long-Term Characterization

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

2.2.3 Short-Term Verification

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

2.3 Phase I Test Plan

The Smith Unit 2 Phase I testing effort was completed on March 19, 1991 after four months of uninterrupted testing. The following briefly describes the test sequence during this period.

2.3.1 Short-Term Characterization Testing

The test plan for Phase I Short-Term Characterization incorporated four load points ranging from 70 to 180 MWe which were identified as being representative of normal operating points where mill changes occurred. The initial test plan for the Short-Term Characterization testing is shown in Table 2-1 and includes the following Diagnostic tests:

LOAD	MILL PATTERN	NO. TESTS
180 MWe	All Mills-in-Service	7
180	Alternate Mill Pattern	2
135	Primary MOOS* Pattern	7
135	Alternate MOOS Pattern	3
115	Primary MOOS Pattern	6
115	Alternate MOOS Pattern	3
95	Primary MOOS Pattern	6
95	Alternate MOOS Pattern	3

* Mills-Out-Of-Service

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

Table 2-1 includes the initial test plan for the performance portion of the Short-Term Characterization tests. The performance tests were executed as planned and no make-up tests were necessary; however, an additional high O_2, 180 MWe test was performed at the end of the planned testing. A discussion of the performance test results can be found in Section 5.2.

2.3.2 Long-Term Characterization Testing

Long-Term Characterization testing began in mid-December 1990 and was completed by the end of March 1991. During this period, a significant amount of continuous emission data was collected. During the four month period the unit was on-line all but six days due to unscheduled outages. Due to difficulties with the Continuous Emission Monitoring systems, some information was lost; however, it did not compromise the statistical analysis of the data. A discussion of the results of the long-term data and the analyses can be found in Section 6.0 along with a comparison of the long- and short-term test results.

2.3.3 Verification Testing

Verification testing was completed during the week of March 19, 1991. Twenty Two tests were performed during this period - 14 at 180 MWe, four at 135 MWe and five at 115 MWe. The trends exhibited by this data indicated that no significant changes occurred during the long-term test effort. A discussion of the results of the verification testing can be found in Section 5.5.

TABLE 2-1 PRELIMINARY PHASE I TEST MATRIX

	TEST DAY	TEST CONDITIONS	LOAD MWe	MOOS[1] PATTERN	O2 LEVEL, %
CHARACTERIZE THE EFFECTS OF VARIOUS PARAMETERS ON EMISSIONS AND OPERATION	10/30	OPERATIONAL RANGE	175	AMIS[2]	3-5
	"	"	135	A-MOOS	3-5
	10/31	"	115	A,B-MOOS	4-6
	"	"	95	A,B,E-MOOS	4-6
	11/01	HI LOAD O2 VARIATION	175	AMIS	3
	"	"	175	"	4
	"	"	175	"	5
	11/02	MID LOAD O2 VARIATION	135	A-MOOS	3
	"	"	135	"	4
	"	"	135	"	5
	11/03	MID LOAD O2 VARIATION	115	A,B-MOOS	3
	"	"	115	"	4
	"	"	115	"	5
	"	"	115	"	6
	11/04	LOW LOAD O2 VARIATION	95	A,B,E-MOOS	3
	"	"	95	"	4
	"	"	95	"	5
	"	"	95	"	6
	11/05	MID LOAD MILL VARIATION	135	A-MOOS	4
	"	"	135	B-MOOS	3
	"	"	135	"	4
	"	"	135	"	5
	11/06	MID LOAD MILL VARIATION	115	A,B-MOOS	4
	"	"	115	A,C-MOOS	4
	"	"	115	"	5
	"	"	115	"	6
	11/07	LOW LOAD MILL VARIATION	95	A,B,E-MOOS	5
	"	"	95	B,C,E-MOOS	5
	"	"	95	B,C,E-MOOS	5
	"	"	95	A,B,D-MOOS	5
REPEAT TESTS TO CONFIRM AND SUPPLEMENT DATA	11/08	LOW LOAD NOMINAL CONDITIONS	95	A,B,E-MOOS	5
	"	"	95	"	6
	"	MID LOAD NOMINAL CONDITIONS	115	A,C-MOOS	4
	"	"	115	"	5
	"	MID LOAD NOMINAL CONDITIONS	135	A-MOOS	4
	"	"	135	"	5
	11/09	HI LOAD NOMINAL CONDITIONS	175	AMIS	3
	"	"	175	"	4
	"	"	175	"	5
	"	HI LOAD MILL BIAS CONDITIONS	175	AMIS	4
	"	"	175	AMIS	4
DOCUMENT BASELINE EMSSIONS AND PERFORMANCE	11/28	ENVIR. & PER. CHARACTERIZATION	175	AMIS	4
	11/29	ENVIR. & PER. CHARACTERIZATION	175	AMIS	4
	11/30	ENVIR. & PER. CHARACTERIZATION	135	A-MOOS	4
	12/01	ENVIR. & PER. CHARACTERIZATION	135	A-MOOS	4
	12/02	ENVIR. & PER. CHARACTERIZATION	115	A,C-MOOS	4
	12/03	ENVIR. & PER. CHARACTERIZATION	115	A,C-MOOS	4
	12/04	ENVIR. & PERF. MAKEUP	TBD	TBD	TBD
	12/05	"	TBD	TBD	TBD
	12/06	"	TBD	TBD	TBD

[1] Mills-Out-of-Service

[2] All-Mills-in-Service

TAB2-1.WK3

3.0 TEST PROCEDURES AND MEASUREMENTS

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

1) Manual Boiler Data Collection

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

2) Automated Boiler Data Collection

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

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

3) Combustion System Tests

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

4) Solid/Sulfur Emissions Tests

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

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

3.1 Manual Boiler Data Collection

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

3.1.1 Boiler Operating Data

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

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

The Diagnostic, or parametric, tests were performed over periods of from 1 to 3 hours, beginning after the desired operating conditions had been established and the unit had been stabilized for up to an hour. Steady operating conditions were maintained to the extent possible during the test. Typically, data were recorded manually at the beginning and end of the total test duration and approximately one-hour intervals in between in cases of longer test durations.

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

TABLE 3-1 BOILER OPERATIONAL DATA

Operating Parameters	Units
Gross Load	MW_e
Main Steam Flow	MMlb/hr
Throttle Pressure	psig
Main Steam SH & RH Temperatures	degrees F
SH Spray Flow (upper/lower)	lb/hr
Turbine Back Pressure	in. Hg
Coal Mills (A-F)	
Feeder Set Point	%
Feeder Coal Flow	Klb/hr
Supply Pressure	in. H_2O
Mill Differential Pressure	in. H_2O
Mill Motor Current	amp
Mill Outlet (PA) Temperature	degrees F
Combustion Air Flow	MMlb/hr
FD/ID Fan Currents	amp
Windbox Pressure (front/rear)	in. H_2O
Furnace Draft	in. H_2O
Boiler exit excess O_2 (A/B)	%
Secondary APH Gas/Air, In/Out Temps (A/B)	degrees F
Primary APH Gas/Air, In/Out Temps (A/B)	degrees F
Stack Opacity	%
Boiler Controls	**Position of Set Pt.**
Boiler Master Set Pt.	%
Boiler Pressure Set Pt.	psig
Fuel Master Pos.	%
Combustion Air	
FD/ID Inlet Vane Pos	%
ID Bias Set Pt. (B/C)	%
Steam	
Main Steam Temp Set Pt.	degrees F
SH Spray Pos (upper/lower, right/left)	%
SH Damper Pos.	%
RH Temp. Set Pt.	degrees F
RH Spray Valve Pos.	%
RH Damper Pos.	%
Pulverizer Feeder Readings	
Change Over Measured Time	100 lb increments

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

The greatest variation experienced during the tests was in excess O_2, as the FD fan output changed due to variations in ambient air temperature. For the most part the excess O_2 varied within ± 0.3 percent of the average for individual tests. In order to monitor the stability of the test parameters during the performance tests, readings of the parameters shown in Table 3-1 were recorded at the beginning and end of the test period and at roughly 2-hour intervals in between.

The normal regimen for soot-blowing on the unit calls for IR and IK soot blowing (furnace walls and convective pass tubing, respectively), as needed to maintain proper steam temperature balances, and air preheater (APH) blowing about once per shift to prevent pluggage of the APH baskets. During the performance and emissions sampling periods of each characterization test, no soot-blowing was allowed. Air preheaters were blown clean at times during mid-day breaks in the emissions sampling routine. APH blowing was stopped at least 1/2 hour prior to resumption of emissions testing.

3.1.2 Material Samples

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

TABLE 3-2 MATERIAL SAMPLE TIMES

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

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

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

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

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

3.2 Automated Boiler Data Collection

A data acquisition system (DAS) was designed and installed for the Plant Lansing Smith Unit 2 ICCT II project. It is a custom designed, microcomputer based system used to collect, format, calculate, store, and transmit data derived from power plant mechanical, thermal, and fluid processes. The extensive process data selected for input to the DAS has a relationship in common with either boiler performance or boiler exhaust gas properties.

3.2.1 Data Acquisition System Description

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

Instrumentation and Process Inputs

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

TABLE 3-3 Automated Boiler Data List

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

New instrumentation is incorporated into the DAS to provide specific data for the evaluation of the boiler's combustion process and for the monitoring of boiler exhaust gases being discharged to the atmosphere. The special data requirements for the ICCT project necessitated the installation of 1) Extractive Continuous Emissions Monitor (ECEM), 2) Acoustic Pyrometer, 3) Flux Domes and 4) Oxygen Monitor, which are described in greater detail below:

Data Acquisition Package

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

Hardware

The system uses a 20 MHz 80386 PC class computer. The PC is configured with a 80387 numeric co-processor, 4 MB of RAM, and 40 MB hard disk. An IBM ARTIC co-processor card is installed and is used to perform background scanning. The PC is located in the instrument room. Data is collected by two local processing units (LPU) supplied by Kaye Instruments. One LPU, located in the instrument building, is currently configured to allow up to 96 analog inputs. Inputs include new instrumentation installed around the air heaters, the KVB ECEM, flux domes and the acoustic pyrometers. The other LPU, located in the Unit 2 control room, has 64 analog input channels. Inputs to this LPU, primarily from the feedwater and steam paths, include both existing plant instrumentation and newly installed transmitters and thermocouples. There are no analog outputs or digital inputs or outputs in the system.

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

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

The analog scanners accept inputs from thermocouples, high-level signals (0-12 VDC) and current inputs (using a 40 to 20 mA shunt resistor).

Software

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

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

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

Historical Trending

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

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

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

Reports

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

Instrumentation Building

Much of the instrumentation is located in a temperature-controlled building on the turbine floor of the boiler house of the Unit 2 boiler. This location was chosen to minimize instrument cable lengths. The building serves as the central test facility for this project. The following equipment is located inside this building:

1) Data acquisition computer and operator interface
2) One of the two data acquisition front ends
3) Acoustic pyrometer display and control equipment
4) Extractive continuous emission monitoring equipment
5) Oxygen analyzer monitoring and control equipment.

3.2.2 Extractive Continuous Emissions Monitor (ECEM)

A principal objective of this ICCT project is to evaluate the long term effectiveness of the installation of low NOx combustion equipment with regards to the reduction of NOx emissions in the boiler exhaust gas. The Extractive Continuous Emissions Monitor (ECEM) was purchased from KVB to aid in the evaluation of combustion modifications. The system provides the means of extracting gas samples for automatic chemical analysis of NOx, CO, O_2, SO_2 and THC from sample points at strategic locations in the boiler exhaust ducts. The ECEM is equipped with a manual valving system that permits the DAS technician to select the extraction of gas samples from any ECEM probe or combination of probes. The extraction points are in the following locations:

TABLE 3-4 GASEOUS SAMPLE EXTRACTION POINTS

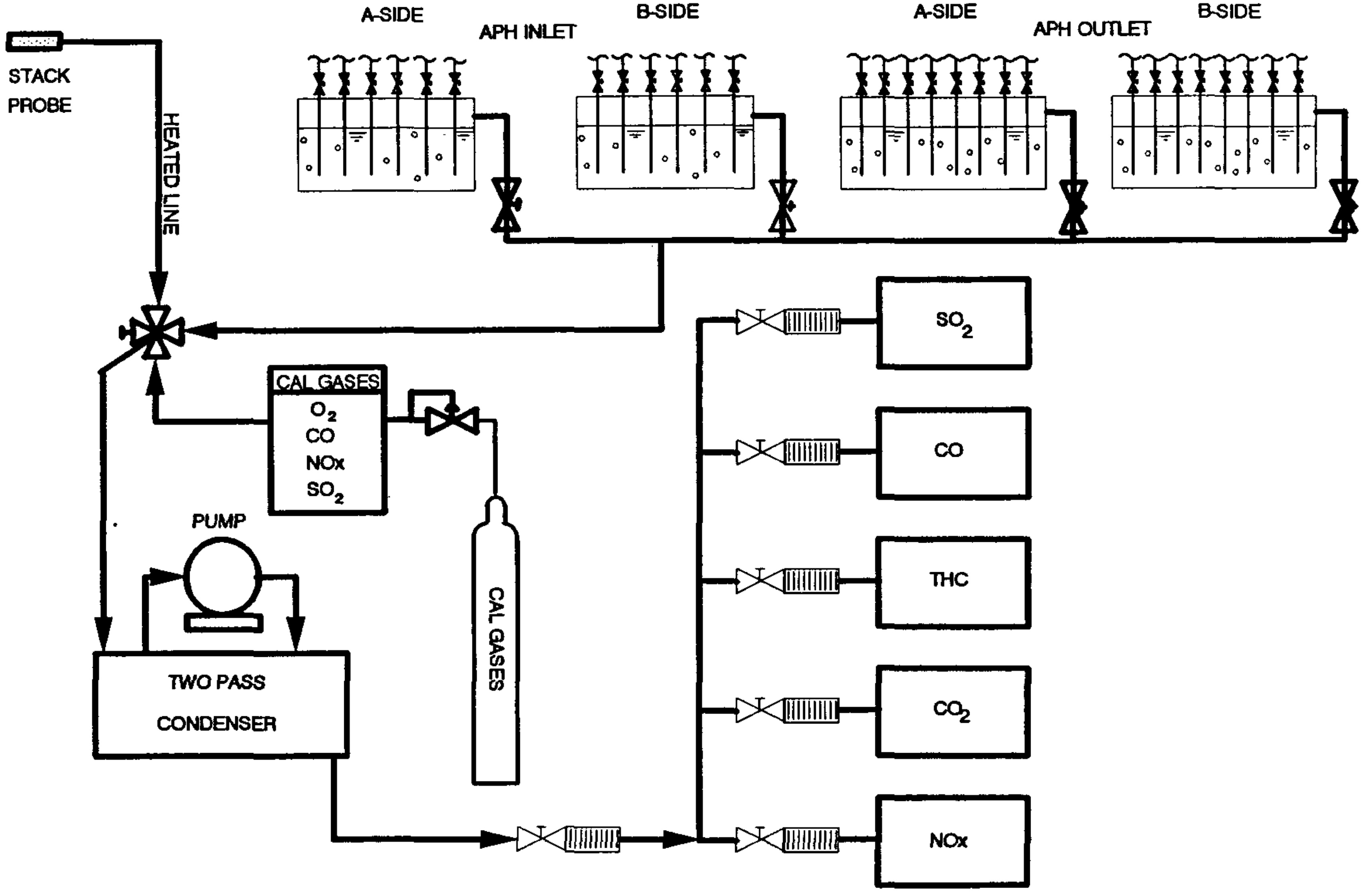
Location	Number of Extraction Points	Arrangement of Sample Probes
Economizer Outlet/ Secondary Air Heater Gas Inlet Ducts A & B	3 sets of 2 probe assemblies per duct (total 12)	3 across x 2 deep matrix
Secondary Air Heater Gas Outlet/Precipitator Inlet Ducts A & B	4 sets of 2 probes per duct (total 16)	4 across x 2 deep matrix
Duct to Stack	1 probe	Single point

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

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

With the exception of the continuous stack monitor probe line, all sample lines lead to individual flow control valves which are part of a sample distribution manifolding system, included in Figure 3-1. This arrangement allows the test personnel to sample selectively from any one probe, or any combination of probes, for analysis of the exhaust gases. The sample distribution bubblers act as simple flowmeters to ensure

FIGURE 3-1 SMITH UNIT 2 ECEM FLOW SCHEMATIC



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equal flow from each probe sampled. The use of the bubblers invalidates any SO_2 or THC readings from the duct probes due topartial solubility in the bubbler water. The valid SO_2 and THC data are acquired only through the heated stack probe/line.

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

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

3.2.3 Acoustic Pyrometer

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

The acoustic pyrometer package provides furnace gas temperature data for the analysis of variations in the combustion process. The Acoustic Pyrometer is a micro-computer controlled system that transmits and receives sonic signals through the hot furnace gas from multiple locations around the girth of the boiler furnace. The velocity of sonic pulses along multiple paths across the furnace can be computed and processed to provide an isothermal contour map of furnace temperatures at the level where the acoustic pyrometer transceivers are installed around the furnace. On Smith Unit 2, the horizontal plane that includes the transceivers is at the 101 foot elevation approximately 34 feet above the uppermost elevation of burners. The acoustic pyrometer's six furnace wall transceivers are located as described below.

- 2 transceivers at equal thirds across the North wall,

- 2 transceivers at equal thirds across the West wall,
- 2 transceivers at equal thirds across the East wall.

Transducers were not installed on the south wall due to interference with the nose of the boiler.

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

3.2.4 Fluxdome Heat Flux Sensors

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

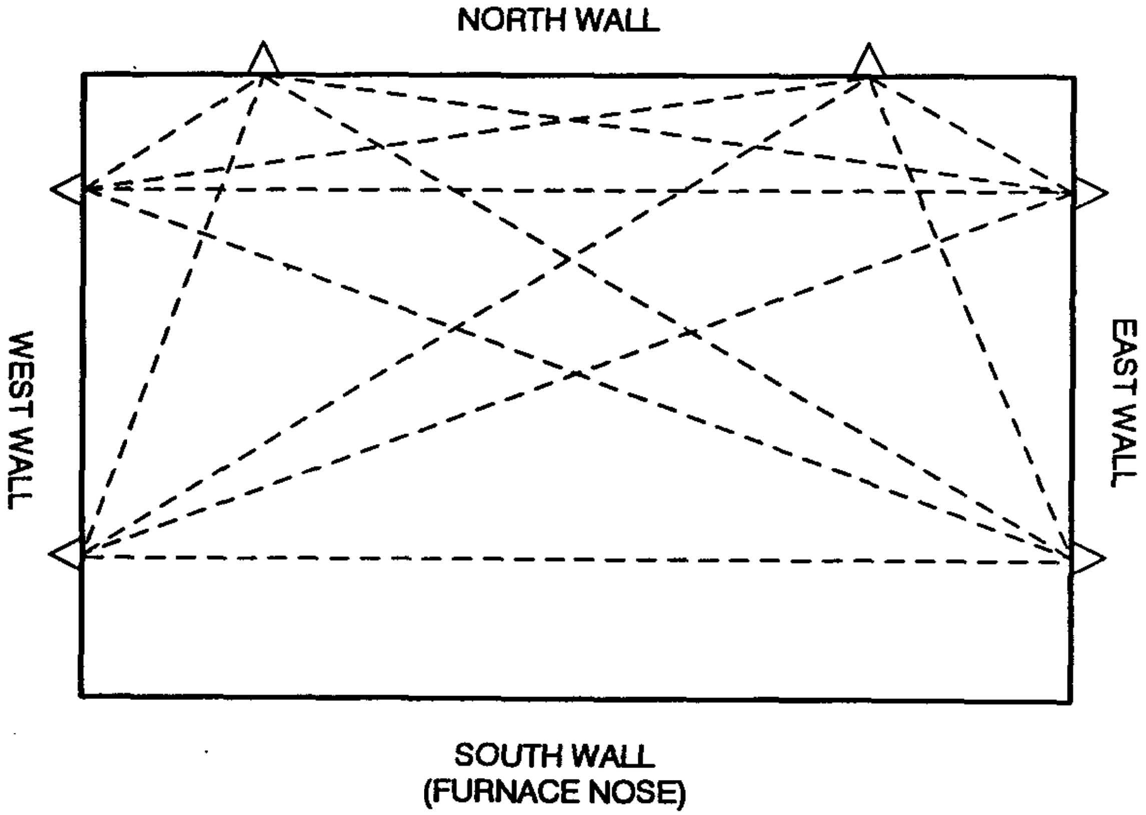
The Fluxdome sensors consist of small metal cylinders welded to the fire side surface of a boiler tube. The shape, size and weld specifications of each cylinder are carefully controlled to assure exact dimensions in order to provide a specified heat path from the furnace/tube interface into the boiler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

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

3.2.5 In-Situ Flue Gas O_2 Instrumentation

In order to continuously monitor the excess oxygen levels at the economizer outlet and the air preheater outlet, in-situ monitors were installed in these locations. The purpose of

FIGURE 3-2 ACOUSTIC PYROMETER LOCATIONS AND PATHS



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monitors was to allow detection of air preheater leakage through the seals and to provide accurate excess oxygen data for the long-term data collection effort.

The excess oxygen monitoring system uses zirconium oxide measuring cells located in the flue gas path. The zirconium oxide O_2 monitors used at the Smith plant are commonly used in power plant applications and provide an accuracy of ± 0.25 percent O_2.

The Smith Plant installation includes four monitors at the economizer outlet and four monitors at the air preheater outlet.

3.2.6 CEGRIT Ash Collectors

CEGRIT ash sample collectors are located on the east and west walls of the boiler at the economizer exit location. The system utilizes the pressure difference between two sections of the economizer to force ash laden flue gas to flow a collection nozzle. The fluegas/ash then passes through a cyclone where the ash is extracted into a collection bottle. The clean gas returns to the downstream or low pressure location in the economizer. The CEGRIT collectors penetrate approximately ten feet into the economizer gas stream from each side-wall (east and west).

The CEGRIT samples from the east and west locations allow LOI characterization to be made with respect to various operating conditions. The samples are not collected isokinetically and they represent only one location within each duct. For this reason, the ash analyses from the CEGRIT samplers are used to establish trends in LOI. The absolute LOI characterizations are obtained from the mass train samples described previously.

3.3 Combustion System Tests

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

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

- Secondary Air Supply
  - Secondary air flow, east/west

- Furnace Combustion Gases
  - Gas temperatures near furnace exit
  - Gas species near furnace exit

- Boiler Efficiency
  - Exit gas temperatures
  - Exit gas excess O_2
  - Unburned carbon losses

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

3.3.1 Primary Air/Fuel Supply Measurements

These tests were performed to characterize the quantity and properties of coal fuel and its transport air flow (primary air) supplied to each burner under several firing rates. The purpose of these tests is to correlate combustion conditions, boiler thermal performance, slagging/fouling characteristics and emissions (particulates, fly ash properties, NOx,) with the fuel supply. In that way, the effects of the subsequent modifications to the burners and air supply (e.g. OFA) may be discriminated from effects due to any changes in the fuel supply characteristics. The principal fuel supply measurements were of the coal mass distribution to each burner and the particle size distribution within each burner supply pipe. Supporting measurements were made to determine the primary air/coal velocity profile in each supply pipe and the primary air flow provided at each mill inlet. Duplicates of each measurement were made on successive days at load levels of 180 and 210 MWe.

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

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

Measurements were made along two perpendicular axes for each pipe. A dustless connection was used to prevent coal leakage around the velocity probe. The connection employs air

FIGURE 3-3 SMITH UNIT 2 COMBUSTION SYSTEM TEST LOCATIONS

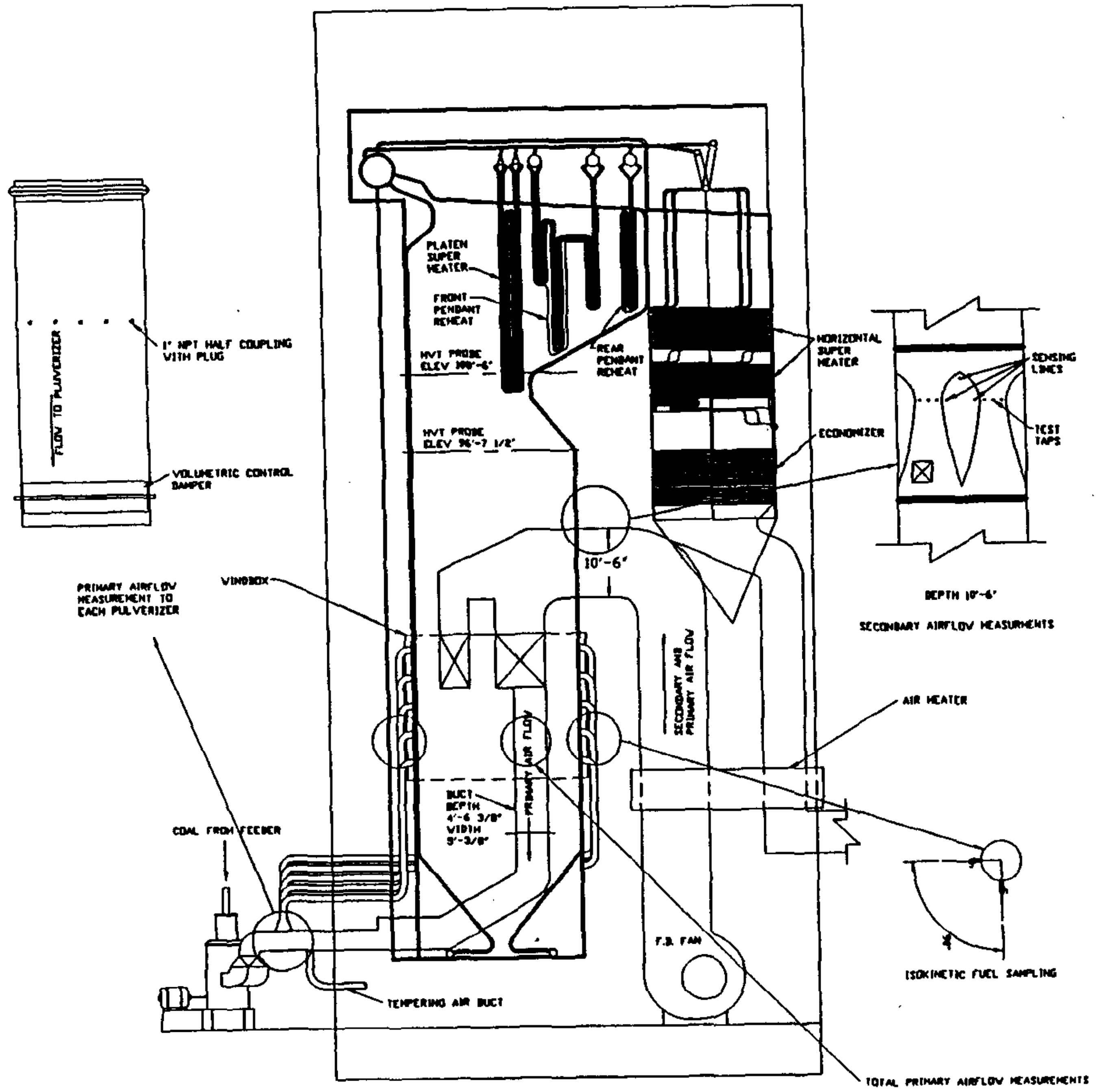
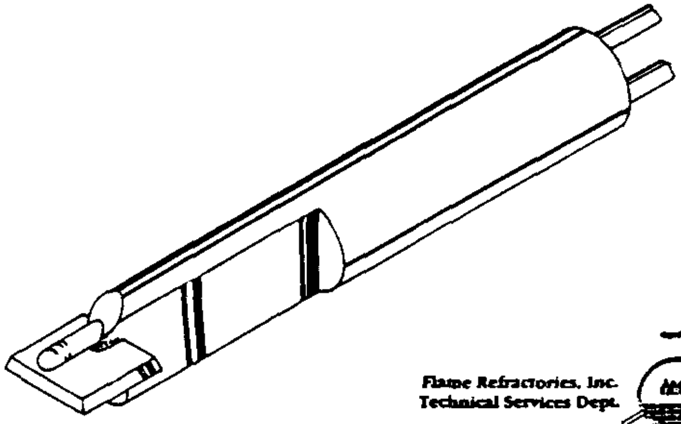


FIGURE 3-4 COAL PIPE VELOCITY APPARATUS

A. DIRTY AIR VELOCITY PROBE



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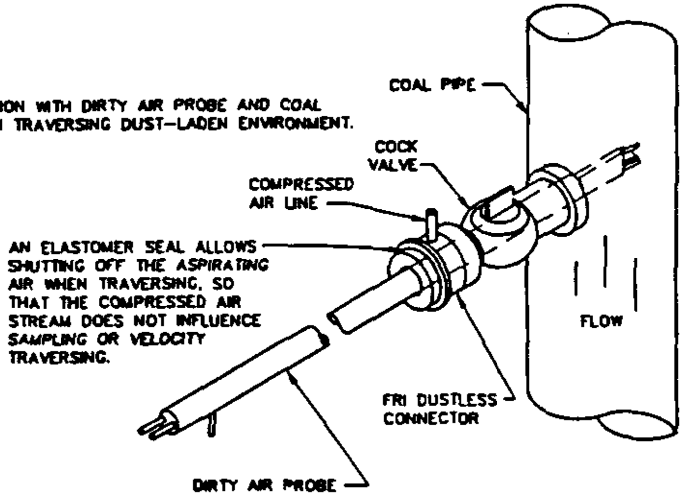
B. DUSTLESS CONNECTION

USED IN CONJUNCTION WITH DIRTY AIR PROBE AND COAL SAMPLER TO AID IN TRAVERSING DUST-LADEN ENVIRONMENT.



aspiration to counteract the pipe internal pressure as the cock valve is opened and the velocity probe inserted. During velocity measurement the aspirating air is turned off to avoid undue influence on the velocity measurements.

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

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

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

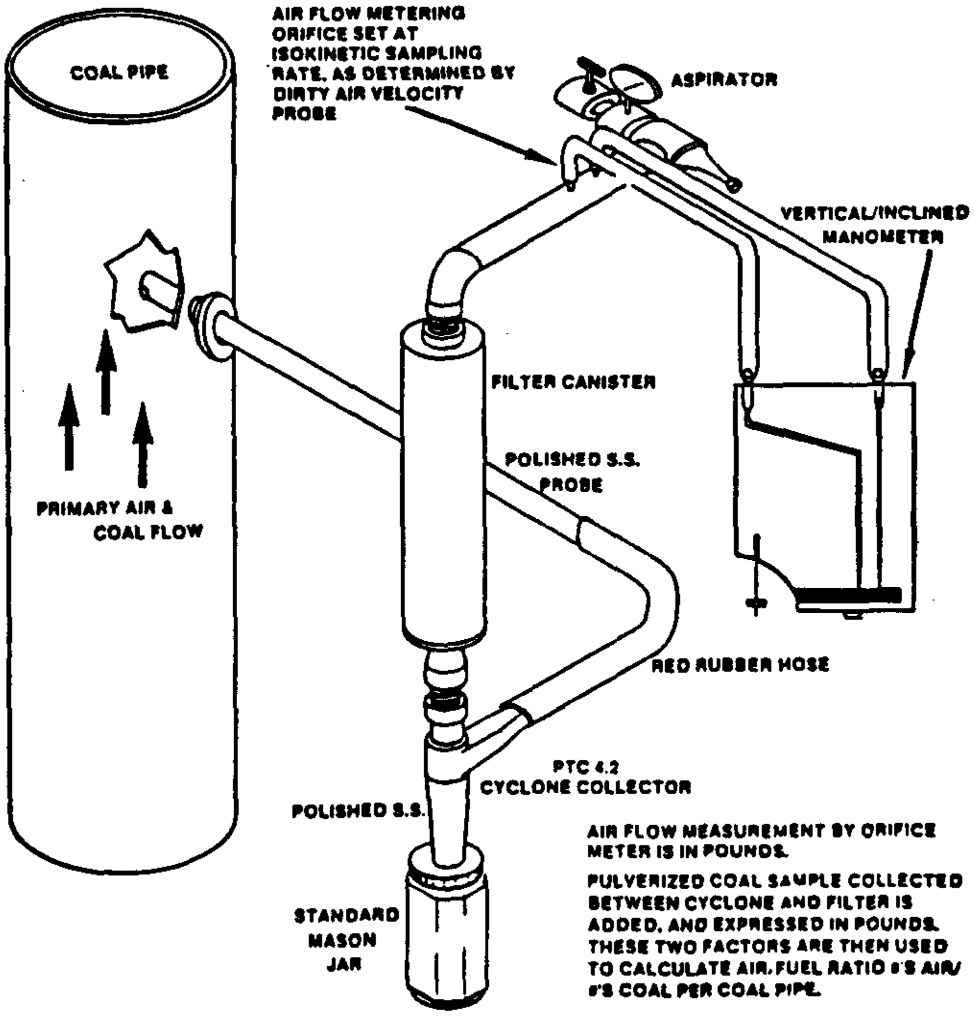
Following the determination of total weight collected, each sample was sieved at the test site using a combination of 50, 100 and 200 mesh U.S. Standard sieves and a shaker machine. The weight percent remaining on each sieve and passing the 200 mesh sieve was determined and plotted on a Rosin and Rammler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

As a final documentation of mill performance, Flame Refractories measured the inlet primary air flow rate to each mill under several operating conditions (firing rate). The measurements were made using a standard type S pitot, a vertical/inclined manometer, a type K thermocouple and a Fluke digital thermometer.

3.3.2 Secondary Air Supply Measurements

Heated combustion air is supplied to the boiler through two ducts, one on either side of the boiler (east and west). Each supply duct contains a two-dimensional venturi section with pressure taps to measure air flow rate. Secondary air flow rates (velocity) were measured at the east and west venturi throats at four depths at six test ports (see Figure 3-3). Both modified Type S and Fecheimer pitot probes were used along with a vertical/inclined manometer and a type K thermocouple with a digital thermometer readout to measure air flows.

FIGURE 3-5 COAL PIPE SAMPLING APPARTUS



AIR FLOW MEASUREMENT BY ORIFICE METER IS IN POUNDS.

PULVERIZED COAL SAMPLE COLLECTED BETWEEN CYCLONE AND FILTER IS ADDED, AND EXPRESSED IN POUNDS. THESE TWO FACTORS ARE THEN USED TO CALCULATE AIR/FUEL RATIO #'S AIR/ #'S COAL PER COAL PIPE.

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3.3.3 Furnace Gas Measurements

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

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

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

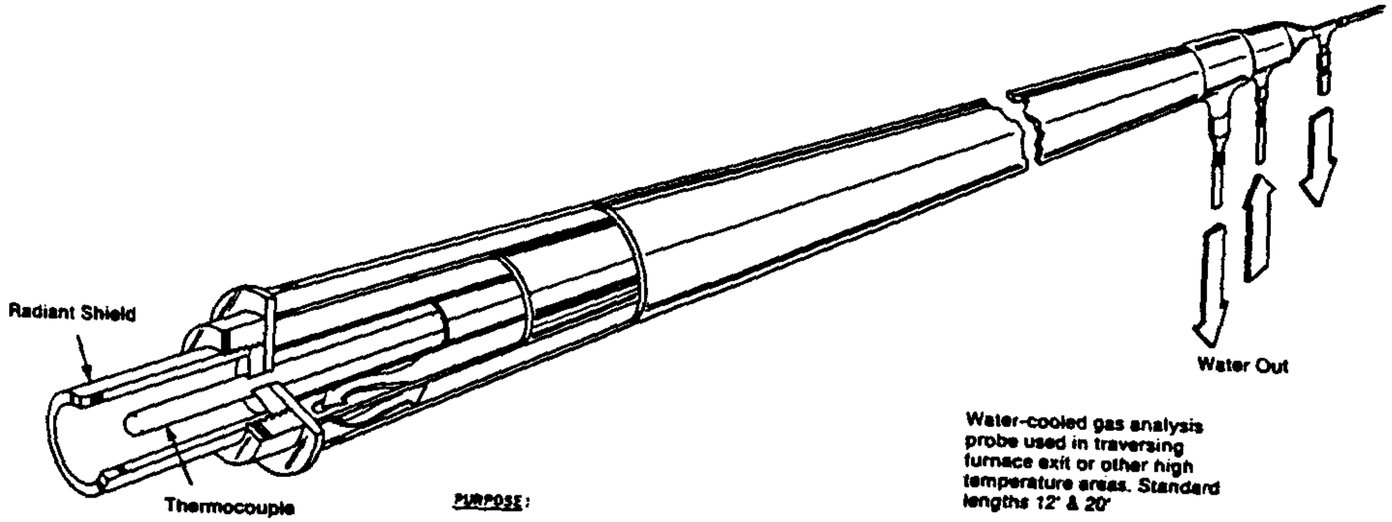
The probe was inserted through existing view ports at the 7th and 8th floor elevations, in the proximity of the furnace "nose." Figure 3-7 shows the plan view of the measurement locations, representing a total of 80 distinct points at the 8th Floor and 20 additional points at the 7th floor.

3.3.4 Boiler Efficiency

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

Calculations were made of the boiler thermal efficiency using the ASME PTC 4.1 Short Form Heat Loss Method. Flue gas exhaust flow was calculated based upon the fuel ultimate analysis and the measured excess oxygen and CO at the boiler exit. The boiler efficiency was calculated as 100 percent minus the percentage of fuel input energy discharged in the form of dry combustion gas heat content, combustion gas moisture heat content (latent and vaporization heat), energy lost through unburned

FIGURE 3-6 HVT PROBE



Water-cooled gas analysis probe used in traversing furnace exit or other high temperature areas. Standard lengths 12' & 20'

PURPOSE:

FURNACE EXIT GAS TRAVERSES TO DETERMINE THE EXCESS OXYGEN AND TEMPERATURE LEVELS AT THE SUPERHEATER INLET.

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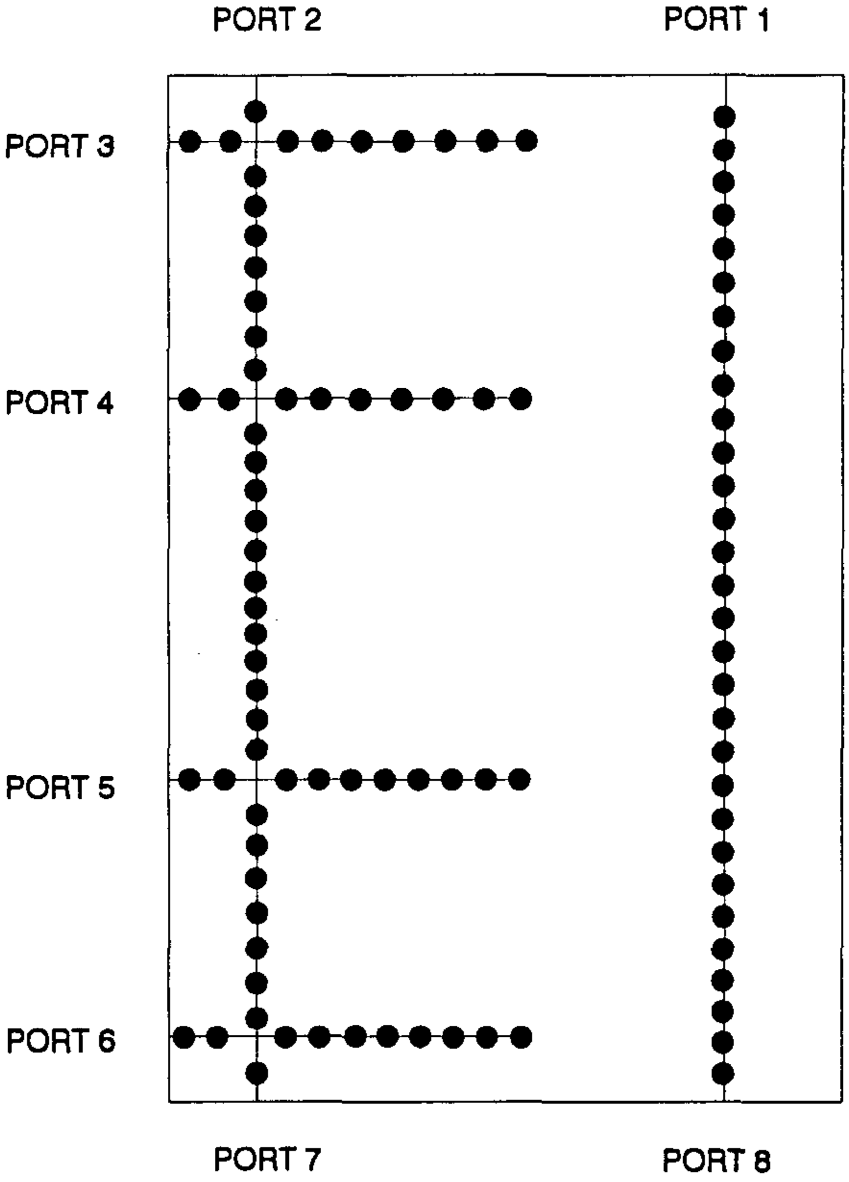
FIGURE 3-7 HVT TEST LOCATIONS



PLAN VIEW - 7 TH and 8 TH FLOOR

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carbon in the fly ash, carbon in bottom ash, blowdown heat loss, minor electrical power losses, and soot blowing steam.

Boiler exhaust gases were sampled through a matrix of the four in-situ O_2 probes located across the air preheater exit ducts. It was originally intended to utilize the 16 DAS distribution manifold probes supported by the Extractive Continuous Emission Monitoring system; however, as explained in Section 5, difficulties were encountered with this system. Excess oxygen using the Yokagawa and carbon monoxide utilizing the ECEM were measured and used in the Heat Loss Method efficiency calculations.

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

3.4 SOLID/SULFUR EMISSIONS TESTS

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

The solid/sulfur emissions tests were conducted to measure both the total mass emissions and the characteristics of the particulate matter as they might affect the ability of downstream control equipment to prevent emissions to the atmosphere. Tests were conducted at 180, 135 and 115 MWe nominal load levels.

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

3.4.1 Total Particulate Emissions

Particulate mass emissions were measured using EPA Method 17 procedures and equipment. Triplicate samples were obtained for each test sequence except a special test at 180 MWe at high O_2. Prior to each sequence at different loads the velocity profile at the test points was determined and the sampling conditions established (nozzle size and sampling rate). The sample probe with in-stack filter was traversed horizontally during the sampling. A total of 24 discrete sample points were used, in a matrix of three depths at each of four test ports across the width of the North and South flue gas ducts, as shown in Figure 3-8.

3.4.2 Particle Size

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

The apparatus chosen for the current program to collect and analyze the fly ash particles is a Brink Cascade Impactor with a pre-cut cyclone provided to remove the majority of large particles (over 100 micron). The purpose of the pre-cut cyclone is to improve the performance of the Brink Impactor with respect to small particle collection and discrimination by preventing overloading of the impactor stages with large quantities of big particles. Figures 3-9 and 3-10 illustrate the general testing apparatus and the configuration of the Brink Impactor, respectively.

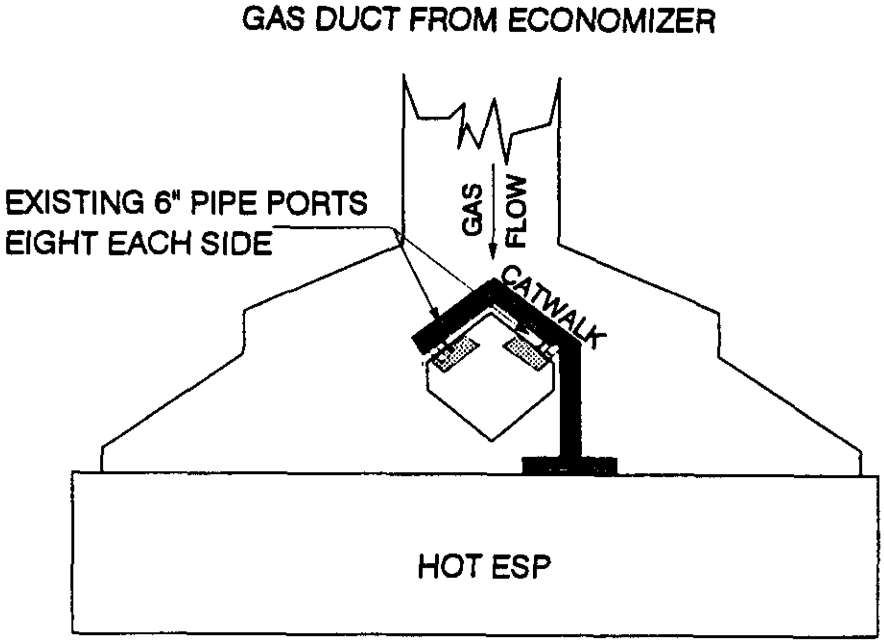
Eight impactor runs were obtained for each of the three test conditions (180, 135 and 115 MWe) during the baseline test series. For each complete sample at a load condition, the impactor was inserted in a different port for each of four repetitions of the sample. The probe was inserted at three depths in each port. Glass fiber substrates were used in each impactor stage to minimize particle bounce. The substrate material was pre-washed with sulfuric acid to reduce interaction with flue gases and particulates. Six separate impactors were used each day plus a seventh blank impactor subjected to conditions identical to the sampling impactors. Each of the impactor runs for each test was made in a different port and the results were averaged. Data were obtained in ports 2, 4, 6 NS 8 (Figure 3-8). The impactor data were reduced using a computer program developed at SoRI under EPA sponsorship and described in the publication "A Computer-Based Cascade Impactor Data Reduction System", EPA- 600/7-78-042, March, 1978.

3.4.3 Ash Resistivity

Measurements of the electrical resistivity of the dust entering the Smith hot side ESP could not be made due to the high temperatures in the location between the economizer exit and the hot-side ESP. Instead, laboratory measurements were made using ash samples from the total particulate matter tests. During the Phase I baseline testing, resistivity measurements were made on material gathered from both ducts leading to the ESP.

FIGURE 3-8 ECONOMIZER EXIT SOLIDS SAMPLING LOCATION

TEST POINT # 1
HOT ESP INLET DUCT



TEST PORT DETAIL

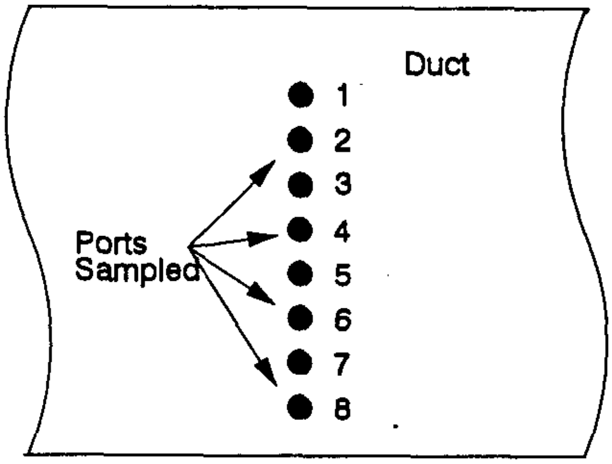


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FIGURE 3-9 CASCADE IMPACTOR SAMPLE APPARATUS

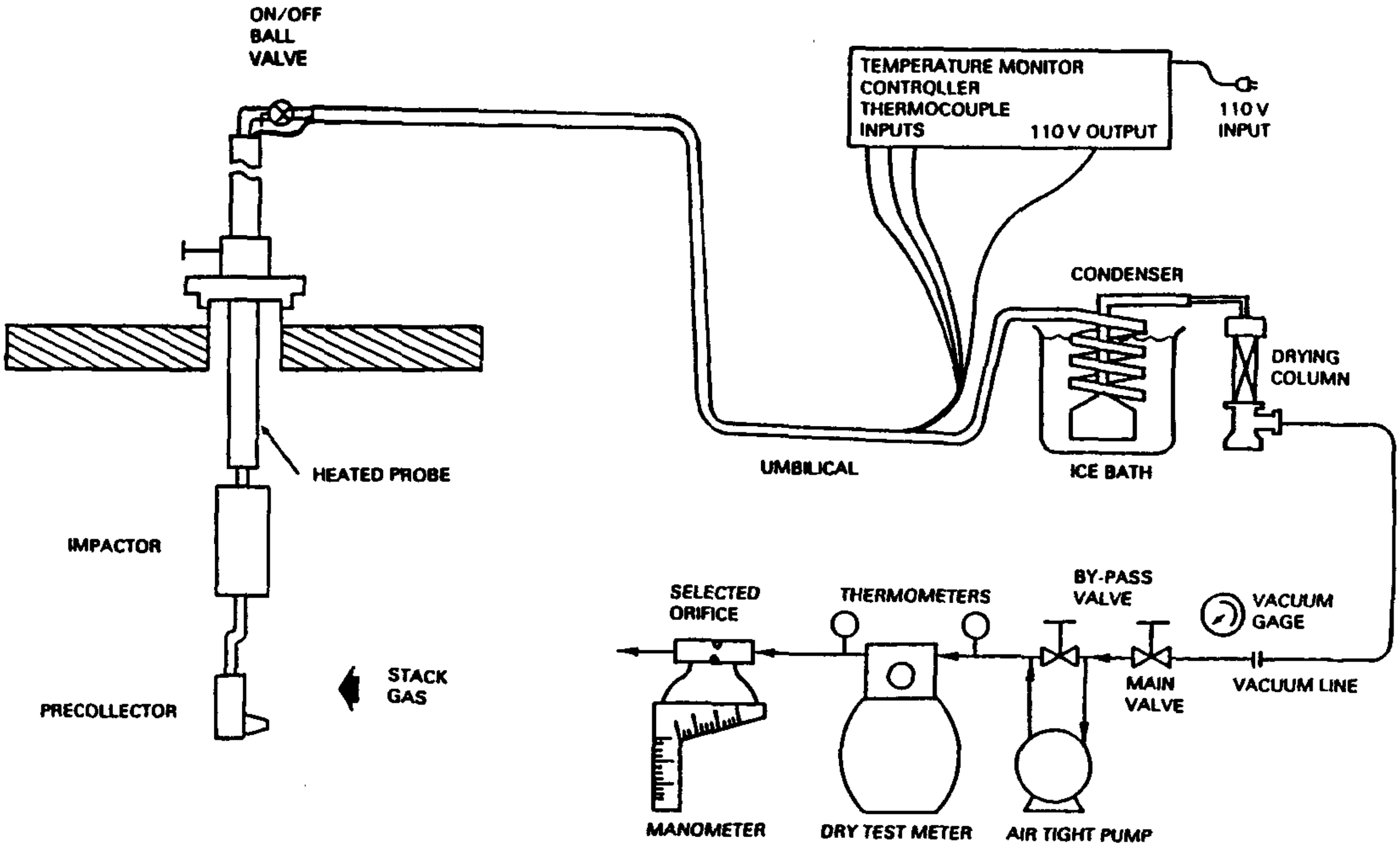
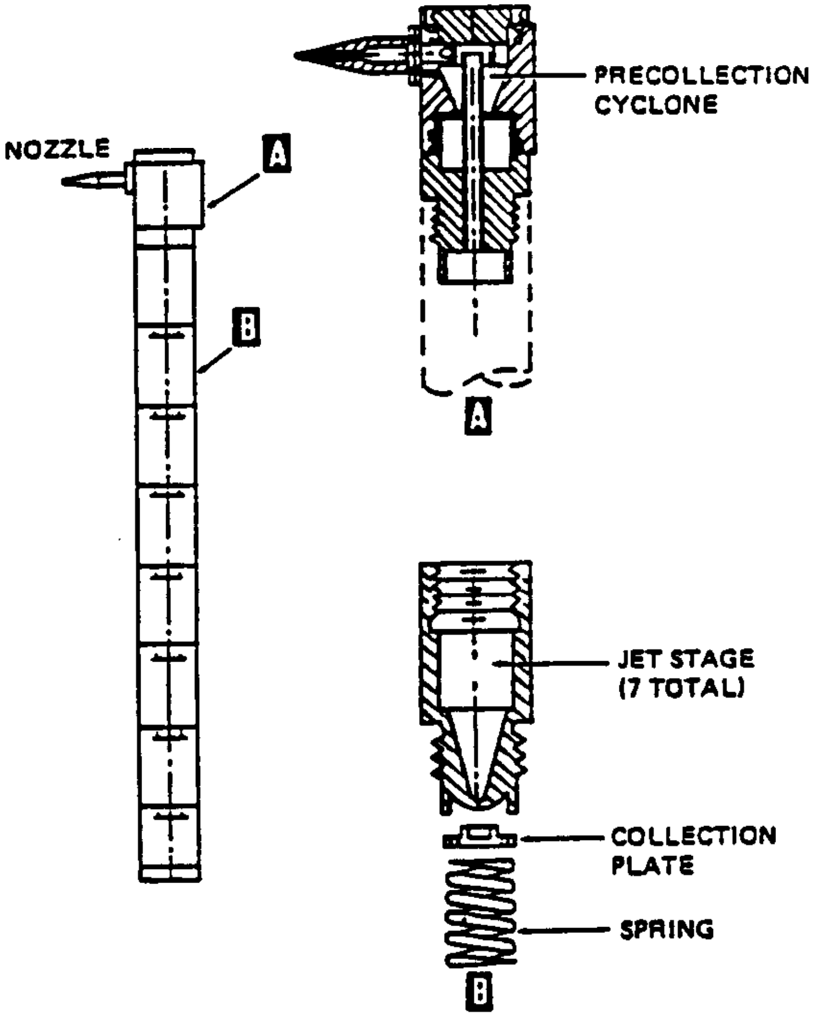


FIGURE 3-10 BRINK MODEL C IMPACTOR



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

3.4.4 SO_3/SO_2 Tests

Sulfur trioxide is either a vapor or a solid depending upon temperature. It has electrical properties that can substantially affect the net average resistivity of the fly ash, and therefore the collection efficiency of ESP's. The degree to which sulfur is oxidized to SO_3 or to SO_2 is dependent upon many combustion factors including stoichiometry and temperature histories in the boiler. Tests were performed by SoRI to determine the emissions of SO_3 and SO_2 for the three load conditions (180, 135 and 115 MW_e).

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

3.4.5 ESP Performance Prediction

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

4.0 DATA ANALYSIS METHODOLOGY

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

4.1 Short-Term Characterization Data Analysis

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

4.1.1 Diagnostic Data

The emphasis of the Diagnostic testing was to determine the NOx characteristics although much more information was obtained for use during other phases of the project. As explained in Section 3.2.2, the NOx, O_2, CO, THC and SO_2 are automatically recorded every five minutes and stored in the historic files on an IBM PC-compatible computer located in the instrumentation room. The NOx measurements of interest during this element of the short-term testing are those obtained from the Sample Flow Distribution Manifold (See Figure 3-1, Section 3.2.2). The manifold allows sampling from individual probes or combinations of probes located in the economizer exit prior to the air preheaters. Depending upon the probe groupings, the composite emission measurements over the entire economizer exit (average of 12 probes) for the period of a Diagnostic test represents a single data point for one configuration.

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

TABLE 4-1 TYPICAL ONE MINUTE AVERAGE EMISSION MEASUREMENTS

VALUE	A-SIDE OUTLET	B-SIDE OUTLET
CO EMISSIONS		
Current	19.0 ppm	21.0
Average	19.7	21.5
Maximum	21.0	22.0
Minimum	19.0	21.0
Std. Dev.	0.75	0.50
NOx EMISSIONS		
Current	405 ppm	410
Average	408	407
Maximum	412	410
Minimum	405	404
Std. Dev.	2.6	2.8
O_2 EMISSIONS		
Current	5.0 %	5.6
Average	5.1	5.5
Maximum	5.1	5.6
Minimum	5.0	5.0
Std. Dev.	0.04	0.11

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

A matrix of tests was established to allow trending and engineering evaluations of the short-term NOx emissions data. During the Diagnostic testing attempts were made to gather three sequential data points (either increasing or decreasing excess oxygen level) at each load level (or mill pattern). With three data points on one day with a minimum variation of the other influencing parameters, the general trend of NOx versus load (or mill pattern) could be determined. Test points which were not sequential (different loads or mill patterns on the same day) were used to indicate the potential variability about the trend lines. It is assumed that the trends for these single, non-sequential data points is similar to that determined for sequential data and that families of curves exist. This assumption was tested and found to be true by obtaining several days of sequential data at the same operating conditions. Figure 4-1 illustrates the type of trending that was obtained using this methodology. All NOx trend data are presented in ppm as dry corrected to 3 percent O_2 to correct for dilution. Where possible, general equations that represent the trend are developed. It should be pointed out, however, that in most cases, only three points were available to describe the trend. As was mentioned above, insufficient data at each condition was available to perform meaningful statistical analyses of these data.

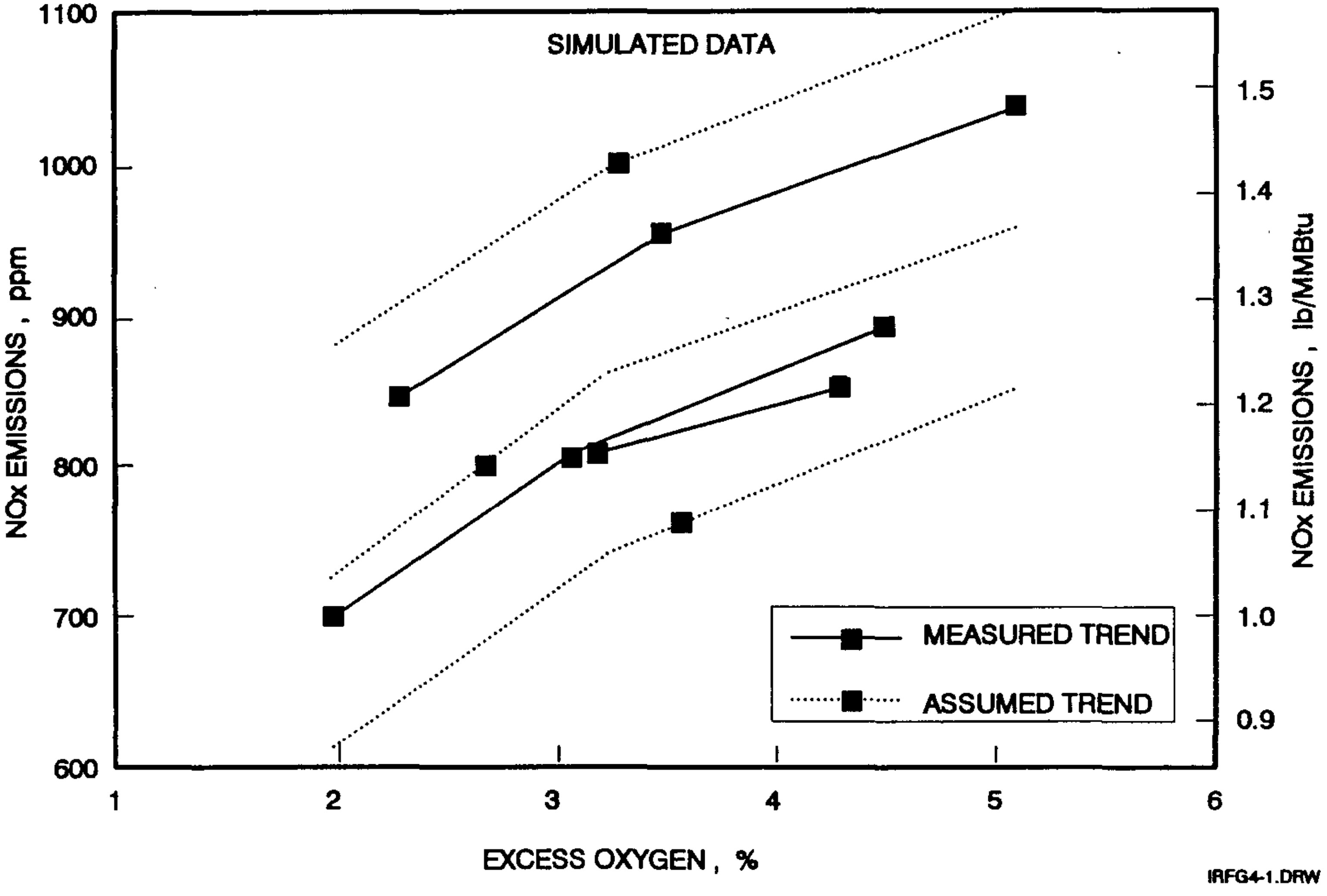
4.1.2 Performance Data

One purpose of performance tests was to establish baseline evaluation criteria for ABB CES's LNCFS retrofits. These criteria are related to the impact of the retrofits on the boiler efficiency, particle matter changes (size, amount and resistivity) and the retrofit NOx reduction effectiveness. Another equally important purpose of these performance tests was to quantify the boiler characteristics for comparison with other phases of the program and for comparison with the population of similar utility boilers. In addition, the performance NOx emission data was used for comparison against the results of the Phase I Diagnostic trends.

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

The boiler efficiency was determined utilizing the Short Form PTC 4.1 methodology described in the ASME Power Test Codes for Steam Generators. Section 5.2.8 provides a discussion of these efficiency calculations. Data for these calculations were obtained utilizing the gaseous samples from the Sample Flow Distribution Manifold (Figure 3-1) and Yokagawa in-situ O_2 analyzers along with other logged information on the DAS. Air preheater leakage was also calculated using these data. The performance tests were segregated into inlet (fuel and air) and

FIGURE 4-1 TYPICAL TRENDING CURVES



complete load and emissions data. Seventy-five valid days of data were collected during the Phase I long-term test program.

Daily Average Emissions

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

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

4.2.2 Data Analysis Procedures

Five-minute Average Emission Data

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

Hourly Average Emission Data

The purpose of hourly average emission analyses was to assess the hour-to-hour variation in NOx, O_2, and load during the long-term test period, and the within-day variation of NOx, O_2, and load. The hour-to-hour variation in NOx, O_2, and load are simply time ordered graphical presentations of the hourly averages. These graphical presentations are used to establish general trends The within-day data analyses are performed by sorting the hourly averages by hour of the day (01:00, 02:00, ..., 24:00) and computing the average NOx, O_2, and load for these periods. The statistical properties for these hourly periods and the 95 percentile uncertainty band were computed for each hourly data subset.

Daily Average Emission Data

The daily average emission data are used primarily to establish the trends in NOx, O_2 and load, and to calculate the 30-day rolling NOx emission levels for the entire long-term period. The daily average emissions data were analyzed both graphically and statistically. The graphical analyses consist of a series of plots to depict the daily variations in NOx, 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 package (UNIVARIATE and AUTOREG) procedures were used to perform the statistical analyses.

Achievable Emission Rate

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

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

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

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

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

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

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

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 I 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 if significant changes occurred during the long-term test effort.

The Phase I Short-Term Characterization testing was begun on October 30, 1990 and was completed on March 19, 1991. A total of 55 Diagnostic tests were performed during this period. An additional 18 tests were performed during the verification test effort at the end of the Phase I effort. The following paragraphs describe the Diagnostic, Performance and Verification testing performed during the Phase I effort.

5.1 Diagnostic Tests

The Phase I Diagnostic effort consisted of characterizing emissions under "as found" conditions before any subsequent repairs or retrofits had been implemented. Fifty-five tests were performed at nominal loads of 70, 115, 135 and 180 Mwe during the period from October 30 through December 6, 1990. The Diagnostic test efforts were interrupted to accomplish the performance testing due to scheduling conflicts. Diagnostic testing was completed after the performance testing was completed. Immediately before the Diagnostic testing effort began, exploratory tests were performed to establish the general boiler operating characteristics and to establish steam, fuel and air condition stabilization times. Generally, changes between test conditions 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 air 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. As a result, more tests were accomplished than originally planned.

Table 5-1 presents the "as tested" conditions during the Diagnostic portion of the testing. Eleven days of testing were planned and executed comprising the 55 individual tests at various excess oxygen, mill pattern and load conditions. Since load dispatch allowed testing at any of the four load points, it was possible to obtain approximately equal numbers of tests at each of the test loads. While it was planned for no more than four test points per test day, it was possible to accomplish as many as seven test conditions on some test days which accounted for the large number of Diagnostic tests performed.

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 NOx, CO, O_2, SO_2 and total hydrocarbons (THC) from 28 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) B-side economizer outlet, 3) A-side APH outlet and 4) B-side 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 B-side 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 I effort are shown in Figures 5-1 and 5-2. The conditions represented in these figures include excess oxygen variation, mill-out-of-service variation and mill biasing. All NOx data are corrected to 3 percent excess oxygen for all figures and tables.

TABLE 5-1 PHASE 1 DIAGNOSTIC TEST DATA

TEST NO.	DATE	LOAD MWe	MOOS PATTERN	O2 %	NO ppm	CO ppm
1-1	10/30/90	181	None	4.0	483	11
1-2	10/30/90	180	None	2.9	422	11
1-3	10/30/90	179	None	2.0	376	80
2-1	10/31/90	179	None	4.1	474	14
2-2	10/31/90	135	A	4.9	472	11
2-3	10/31/90	135	A	3.9	438	12
2-4	10/31/90	135	A	3.0	398	11
2-5	10/31/90	113	AB	5.9	468	12
2-6	10/31/90	113	AB	5.0	429	12
2-7	10/31/90	112	AB	3.3	364	13
3-1	11/01/90	180	None	4.3	517	9
3-2	11/01/90	180	None	3.7	492	10
3-3	11/01/90	180	None	2.9	454	8
3-4	11/01/90	181	None	2.2	422	8
4-1	11/02/90	136	A	4.6	457	7
4-2	11/02/90	134	A	3.4	404	9
4-3	11/02/90	133	A	2.6	377	10
4-4	11/02/90	135	A	2.5	388	9
5-1	11/03/90	115	AB	5.7	436	9
5-2	11/03/90	116	AB	4.7	415	7
5-3	11/03/90	116	AB	3.6	378	7
5-4	11/03/90	116	AE	3.7	349	6
5-5	11/03/90	116	AE	4.6	385	6
5-6	11/03/90	117	AE	5.6	422	7
6-1	11/04/90	72	ABE	5.9	397	6
6-2	11/04/90	70	ABE	5.3	368	9
6-3	11/04/90	69	ABE	4.6	340	7
6-4	11/04/90	72	ABE	6.5	410	9
7-1	11/05/90	75	ABE	6.7	409	10
7-2	11/05/90	76	ABE	5.7	378	9
7-3	11/05/90	74	ABE	4.8	348	9
8-1	11/06/90	116	AE	5.7	401	12
8-2	11/06/90	115	AE	4.1	343	10
8-3	11/06/90	115	AE	3.0	298	9
9-1	11/09/90	180	E	3.3	454	6
9-2	11/09/90	179	E	2.8	432	4
9-3	11/09/90	181	E	2.1	383	3
9-4	11/09/90	180	E	3.5	483	5
9-5	11/09/90	180	E25	3.6	417	5
9-6	11/09/90	181	E40	3.8	407	6
9-7	11/09/90	181	E15	3.5	455	5

IRTAB5-1.WK3

TABLE 5−1 PHASE 1 DIAGNOSTIC TEST DATA (Cont.)

TEST NO.	DATE	LOAD MWe	MOOS PATTERN	O2 %	NO ppm	CO ppm
10−1	11/28/90	183	None	3.6	467	20
10−3	11/28/90	185	None	3.6	516	6
10−4	11/28/90	184	None	4.5	575	6
11−1	11/29/90	180	None	2.2	384	10
14−1	12/02/90	114	A, B	4.7	409	10
14−2	12/02/90	113	A, B	3.6	368	8
14−3	12/02/90	112	A, B		358	7
17−1	12/05/90	134	A,B	6.1	521	10
17−2	12/05/90	133	A,B	5.2	289	9
17−3	12/05/90	136	A,B	4.2	433	8
18−1	12/06/90	67	A,B,C	7.7	424	9
18−2	12/06/90	67	A,B,C	6.3	367	9
18−3	12/06/90	69	A,B,C	4.8	317	9
18−4	12/06/90	70	A,B,C	6.6	371	9
18−5	12/06/90	71	A,B,C	7.8	424	9

IRTAB5−1.WK3

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

TEST NO.	DATE	GROSS LOAD (MWe)	PLANT O2 E ECON OUTLET (PCT)	PLANT O2 W ECON OUTLET (PCT)	CEM O2 AVERAGE OUTLET (PCT)	CEM COMPOSITI AVG NO (PPM)	STACK OPACITY (PCT)	SAPH A OUT TEMP (°F)	SAPH B OUT TEMP (°F)	STEAM FLOW (°F)	SH TEMP (°F)	SH SPRAY FLOWS LOWER SPRAY (KLB/HR)	SH SPRAY FLOWS UPPER SPRAY (KLB/HR)	HOT RH TEMP (°F)	PULVERIZER FLOW MILL A	MILL B	MILL C (KLB/HR)	MILL D	MILL E
1-1	10/30/90	180	5.9	4.7	4.0	463	-	317	313	1299	999	46.7	43.9	997	20.1	26.6	23.6	24.7	30.2
1-2	10/30/90	180	4.5	3.5	2.9	422	-	-	-	1299	1000	22	30.6	991	20.6	20.7	23.7	27.6	29.6
1-3	10/30/90	180	3.6	2.6	2.0	376	-	313	206	1300	993.5	7.6	0	979	20.7	27.2	23.7	27.3	29.7
2-1	10/31/90	180	5.7	4.3	4.1	474	2.9	309	304	1295	1001	44.7	49	992	27.2	27	26.3	26.2	26.1
2-2	10/31/90	135	6	5	4.9	472	1.9	297	292	944	1001	51	59.6	974	0	20.6	25.1	25.1	25.2
2-3	10/31/90	135	5	3.9	3.9	436	1.7	299	293	940	1002	37.6	50.2	976	0	21.4	25.4	25.1	25.5
2-4	10/31/90	135	4.2	3	3.0	396	1.6	299	292	935	1001	27.8	40.4	973	0	20.6	24.8	24.7	25
2-5	10/31/90	113	6.9	6	5.9	466	2.5	263	279	772	992	76.9	56.9	945	0	0	27	27	27.3
2-6	10/31/90	113	5.9	5.1	5.0	429	2.7	263	277	776	1001	29	31.4	934	0	0	25.8	25.6	25.9
2-7	10/31/90	112	4.4	3.5	4.0	379	1.9	262	276	780	986.5	12.5	0.8	926	0	0	27.2	26.6	27.3
3-1	11/01/90	180	4.7	6.2	4.3	517	5.65	314	310	1267	999	94.5	74.9	1005	26.6	26.5	25.4	25.3	25.2
3-2	11/01/90	180	4.1	5.6	3.7	492	2.7	317	312	1265	1000	44.3	59.2	997	26.2	26.1	25.5	24.7	24.5
3-3	11/01/90	180	3.3	4.6	2.9	454	2.5	317	312	1297	1001	48.2	56	1001	26.6	26.9	25.9	25.6	25.5
3-4	11/01/90	180	4.3	2.9	2.2	422	2.2	319	314	1299	999	39.6	48.2	1002	26.5	26.9	25.7	25.5	25.2
4-1	11/02/90	135	5.5	4.6	4.6	457	2.2	286	283	956	1001	51	61.6	997	0	24.7	24.3	25.4	25.9
4-2	11/02/90	135	4.4	3.6	3.4	404	1.9	294	287	941	1001	32.9	45.9	975	0	24	23.4	24.6	25
4-3	11/02/90	135	3.9	3	2.6	377	1.3	295	289	936	999	34.5	43.1	974	0	23.7	23.2	24.7	24.3
4-4	11/02/90	135	3.6	2.8	2.5	366	5.75	297	290	951	1001	42	47.6	974	0	23.6	23.4	24.5	24.3
5-1	11/03/90	115	6.7	5.9	5.7	436	1.6	270	264	801	999	41.2	46.3	927	0	0	27.6	28.1	27.5
5-2	11/03/90	116	5.6	4.6	4.7	415	1.4	276	269	806	999	35.3	37.6	926	0	0	28.1	29	27.6
5-3	11/03/90	116	4.9	3.6	3.6	376	1.4	281	275	810	1000	27.1	32.5	927	0	0	27.1	27.3	27.1
5-4	11/03/90	116	5.1	3.9	3.7	349	1.2	281	269	806	1000	16.3	10.6	922	0	26.7	27.3	28.4	0
5-5	11/03/90	116	5.6	4.7	4.6	365	5.3	281	273	804	996	35.7	41.6	926	0	27.2	27.5	28.3	0
5-6	11/03/90	117	6.6	5.7	5.6	422	1.9	283	275	804	996	57.3	58.6	932	0	28	28.2	29.4	0
6-1	11/04/90	72	6.6	5.9	5.9	397	1.5	253	246	-	996	11	1.6	902	0	0	26.6	27.6	0
6-2	11/04/90	70	6.2	5.3	5.3	366	1.1	253	247	503	966	1.2	1.6	867	0	0	26	26.4	0
6-3	11/04/90	69	5.5	4.6	4.6	340	1.35	258	250	506	945	2	1.6	836	0	0	25.6	26.4	0
6-4	11/04/90	72	7.5	6.6	6.5	410	1	256	250	506	994	7.5	1.6	869	0	0	27.3	27.1	0
7-1	11/05/90	75	7.5	6.8	6.5	404	20.7	252	240	535	1002	12.5	0.6	891	0	0	27.6	29.4	0
7-2	11/05/90	76	6.6	5.7	5.7	378	6.6	257	250	551	964.5	1.2	0	857	0	0	27.4	29.3	0
7-3	11/05/90	74	5.7	4.6	4.6	348	6.1	256	249	554	945	1.2	0	843	0	0	27.6	29.5	0
8-1	11/08/90	116	6.6	5.9	5.7	401	5.7	255	246	624	996	16.6	1.6	904	0	27.1	28.3	29.3	0
8-2	11/08/90	115	5.3	4.3	4.1	343	4.6	267	256	636	974	1.2	0	861	0	27.1	28.2	29.1	0
8-3	11/08/90	115	4.3	3.1	3.3	303	4.1	270	261	646	950	1.2	0	854	0	26.4	28.4	29.1	0
9-1	11/09/90	180	5.5	4.2	3.3	454	6.3	293	290	1344	996	6.3	0	936	31.6	33.6	28.6	36.5	0
9-2	11/09/90	179	4.9	3.7	2.6	432	1.6	299	295	1334	994	10.2	0	946	31.7	33.6	29.1	36.1	0
9-3	11/09/90	161	4.2	3	2.1	363	9.1	297	293	1359	976	2	0	934	31.5	33.5	28.5	36.1	0
9-4	11/09/90	180	5.7	4.4	3.5	463	11	299	295	1313	999	33.3	34.1	966	31.7	33.6	28.9	36.1	0
9-5	11/09/90	180	5.9	4.5	3.6	417	22	302	296	1322	1002	24.7	11	962	31.5	33.7	29.2	36.2	0
9-6	11/09/90	161	5.6	4.5	3.6	407	9.9	302	299	1325	999	25.9	11	960	31.9	33.7	28.9	35.7	0
9-7	11/09/90	161	5.7	4.3	3.5	465	24.1	302	300	1325	1000	30.2	29.6	967	31.6	33.9	28.9	36.5	0

TABLE 5–2 SUMMARY OF PHASE 1 DIAGNOSTIC TESTS OPERATING AND EMISSION DATA (cont.)

			PLANT O2		CEM O2	CEM						SH SPRAY FLOWS			PULVERIZER FLOW				
TEST NO.	DATE	GROSS LOAD (MWe)	E ECON OUTLET (PCT)	W ECON OUTLET (PCT)	AVERAGE OUTLET (PCT)	COMPOSITI AVG NO (PPM)	STACK OPACITY (PCT)	SAPH A OUT TEMP (°F)	SAPH B OUT TEMP (°F)	STEAM FLOW (°F)	SH TEMP (°F)	LOWER SPRAY (kLB/HR)	UPPER SPRAY (kLB/HR)	HOT RH TEMP (°F)	MILL A	MILL B	MILL C (kLB/HR)	MILL D	MILL E
10–1	11/28/90	183	5.8	4.3	3.8	467	10	301	300	1349	998	0	16.1	973	20.3	28.8	26.4	25.2	28.7
10–3	11/28/90	185	5.5	4.1	3.6	516	10	319	315	1326	1000	67	59	1005	27.5	28.3	25.8	23.7	27.5
10–4	11/28/90	184	6.8	5.1	4.5	575	10	319	314	1323	1002	88	98	998	27.7	28.4	26.2	24.3	27.5
11–1	11/29/90	180	3.9	2.7	2.2	384	10	299	295	1324	998	1.8	1.2	959	27	27.5	28.3	24.3	24
12–1	11/30/90	133	4.8	3.5	1.1	348	10	285	279	925	1001	35	33	965	0	23.5	22.9	22.8	25.1
14–1	12/02/90	114	5.5	4.7	4.7	409	10	271	268	763	1002	33	35	945	0	0	26.9	26.1	26.1
14–3	12/02/90	112	4	2.7		358	–	263	278	777	1000	36.5	34.1	943	0	0	27.3	26.6	26.7
17–1	12/05/90	134	7.2	6.3	6.1	521	–	264	280	949	1000	52.2	49.8	950	0	0	34.2	29.6	33.6
17–2	12/05/90	133	6.3	5.4	5.2	289	–	263	282	939	1000	42.4	42	946	0	0	34.3	29.5	33.5
17–3	12/05/90	136	5.3	4.3	4.2	433	–	285	276	961	1002	36.9	35.9	950	0	0	35.3	29.8	33.6
18–1	12/06/90	67	7.9	7.4	7.7	424	–	263	258	471	927	44.3	52.5	927	0	0	0	24.3	28
18–2	12/06/90	67	8.5	6.2	6.3	367	–	259	258	471	998	1.8	22.4	910	0	0	0	23.5	27
18–3	12/06/90	69	5.3	4.6	4.8	317	–	258	250	491	961	0	1.2	889	0	0	0	24.4	27.7
18–4	12/06/90	70	6.7	6.4	6.6	371	–	247	240	489	984	32.2	52.5	917	0	0	0	26.1	29.5
18–5	12/06/90	71	8	7.5	7.8	424	–	244	238	491	990	67	98	927	0	0	0	24.4	28.3

FIGURE 5-1 SMITH UNIT 2 OXYGEN LEVELS TESTED

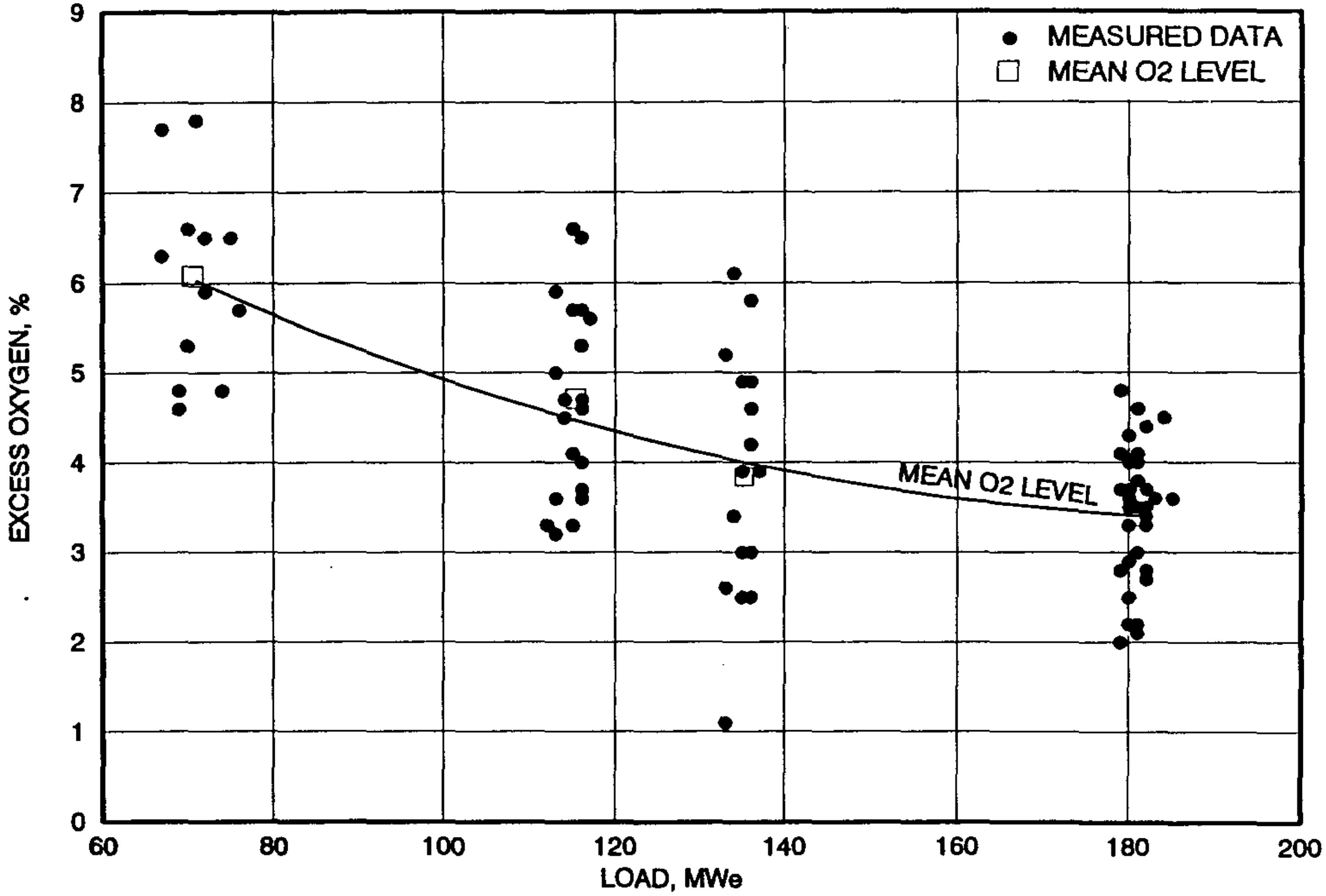


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FIGURE 5-2 SMITH UNIT 2 NITRIC OXIDE MEASUREMENTS

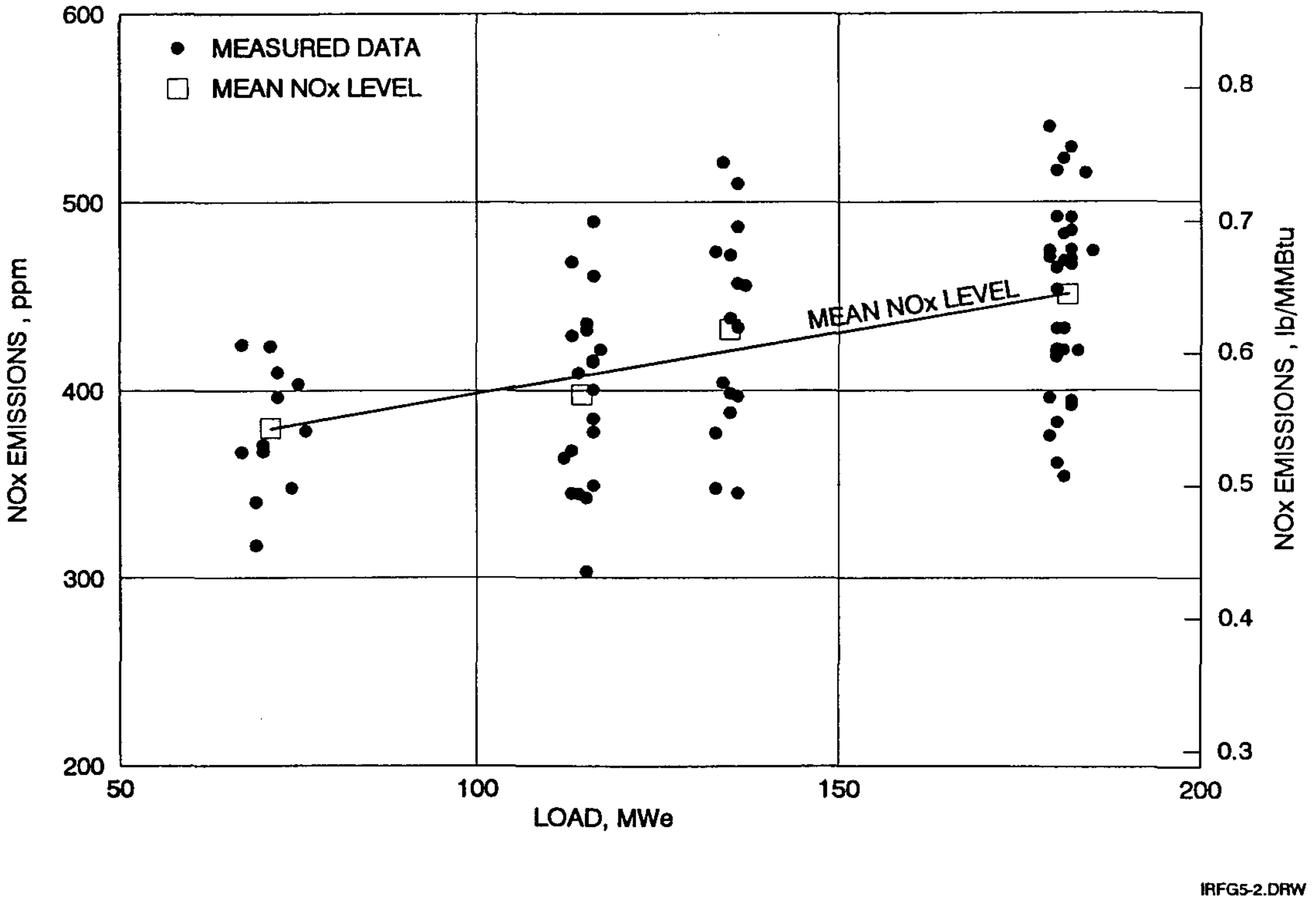

Figure 5-1 serves to illustrate that the testing was performed over a wide range of excess oxygen levels. The solid curve represents the mean level of the data sample at each given load. During System Dispatch control of the unit, excursions to these levels are frequently experienced during transient 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 that different configurations are represented. The mean NOx line shown in Figure 5-2 for loads from 70 to 180 MWe indicate that, at least for this set of data, the trend is increasing NOx with increasing load. It should be pointed out that with more NOx data the slope of the trend may change slightly. It should be pointed out 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.

On Plant Smith Unit 2, short-term characterizations 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 - 70, 115, 135 and 180 MWe. The legend for each data point indicates the mill configuration (where appropriate) and the test day for the particular data point.

Figure 5-3 shows the NOx data for the 180 MWe test point. At this load, the most commonly used mill pattern is with all mills-in service (AMIS) with the E mill-out-of-service (MOOS) used on occasion when conditions dictate. 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 50 ppm/percent O_2 for the two mill patterns tested.

NOx data for the 135 MWe test point is shown in Figure 5-4 primarily for two mill patterns - A-MOOS and AB-MOOS. According to plant personnel these were the most commonly used mill patterns at this load. The NOx increased at a rate of approximately 40 ppm/percent O_2 at this load over a wider excess oxygen excursion (2.5 to 6.0 percent) than the 180 MW load point.

At 115 MWe, the oxygen range could be tested over the same excursion range as the 135 MW test point. For the two mill patterns tested at this load point (AB and AE MOOS), the NOx trends appeared to be similar but exhibited a greater level of

FIGURE 5-3 180 MWe LOAD SUMMARY

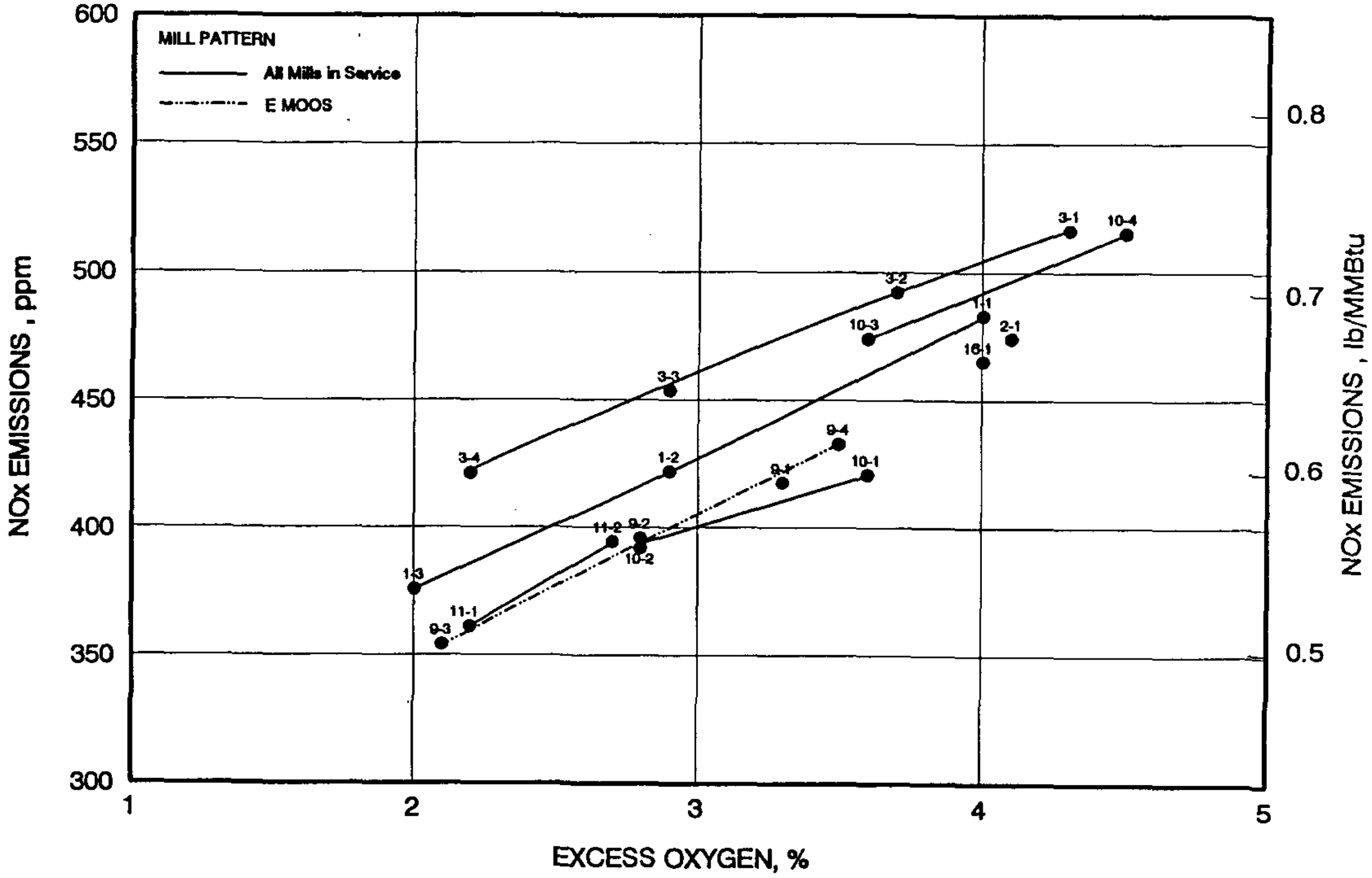

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FIGURE 5-4 135 MWe LOAD SUMMARY

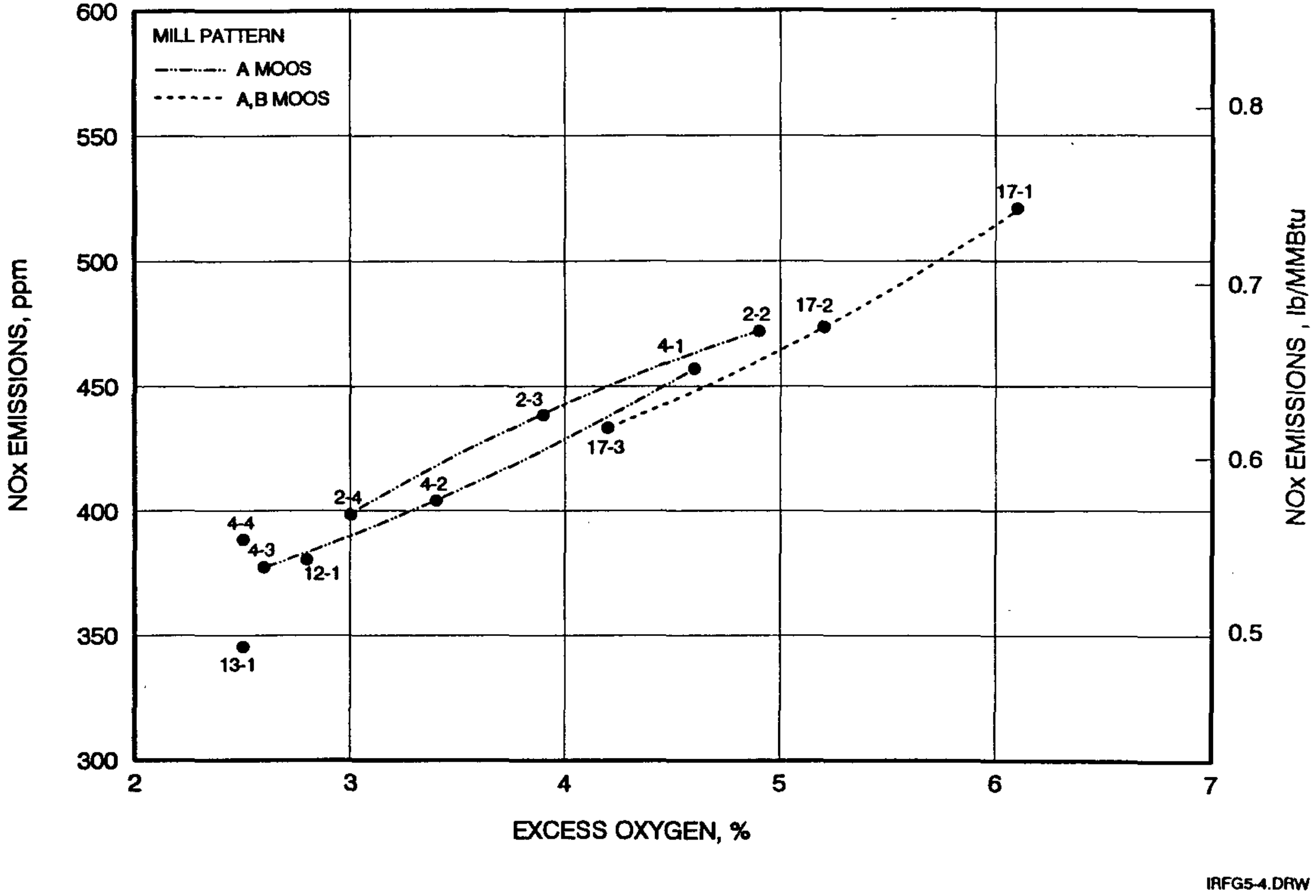


FIGURE 5-5   115 MWe LOAD SUMMARY

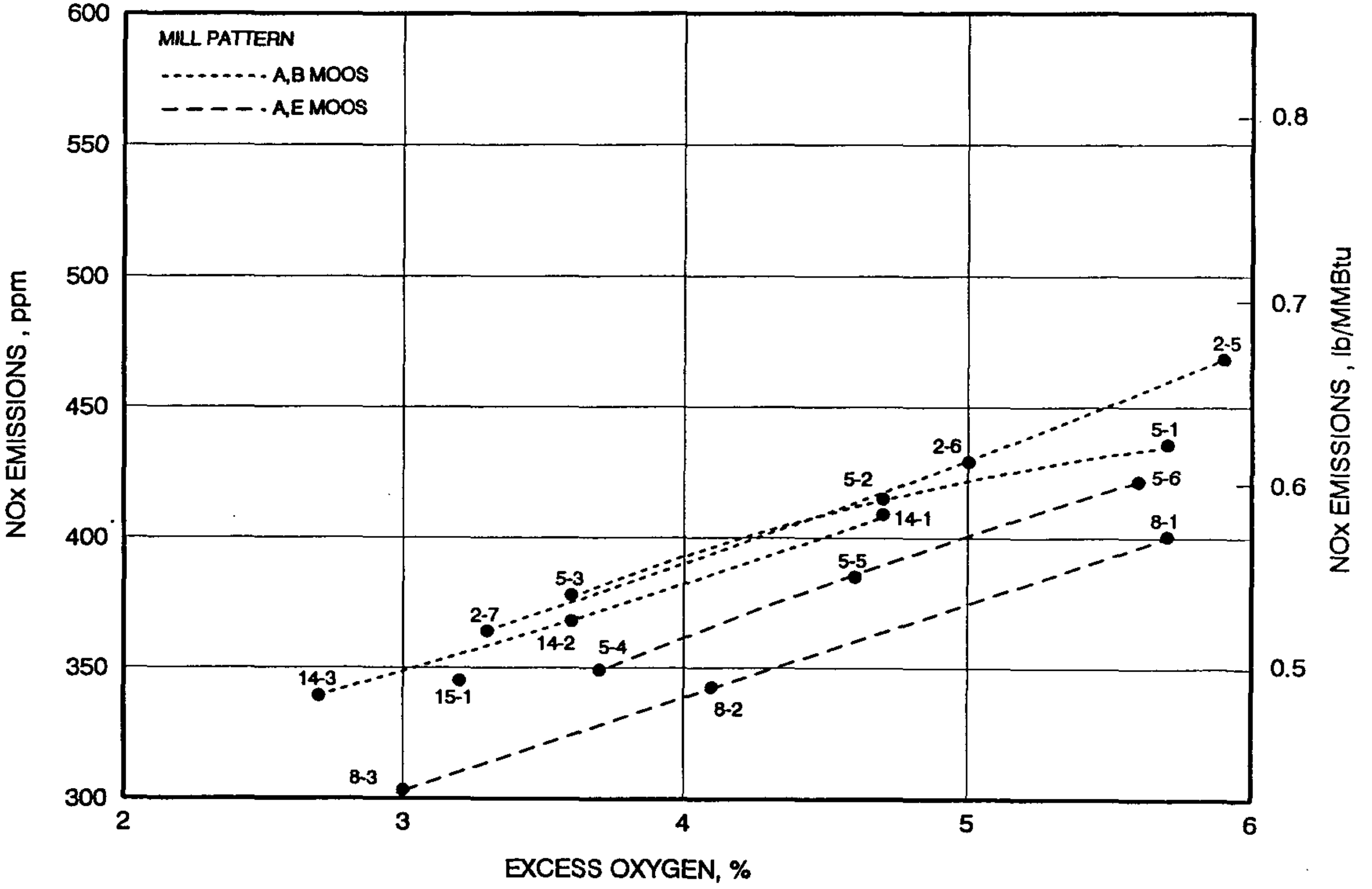
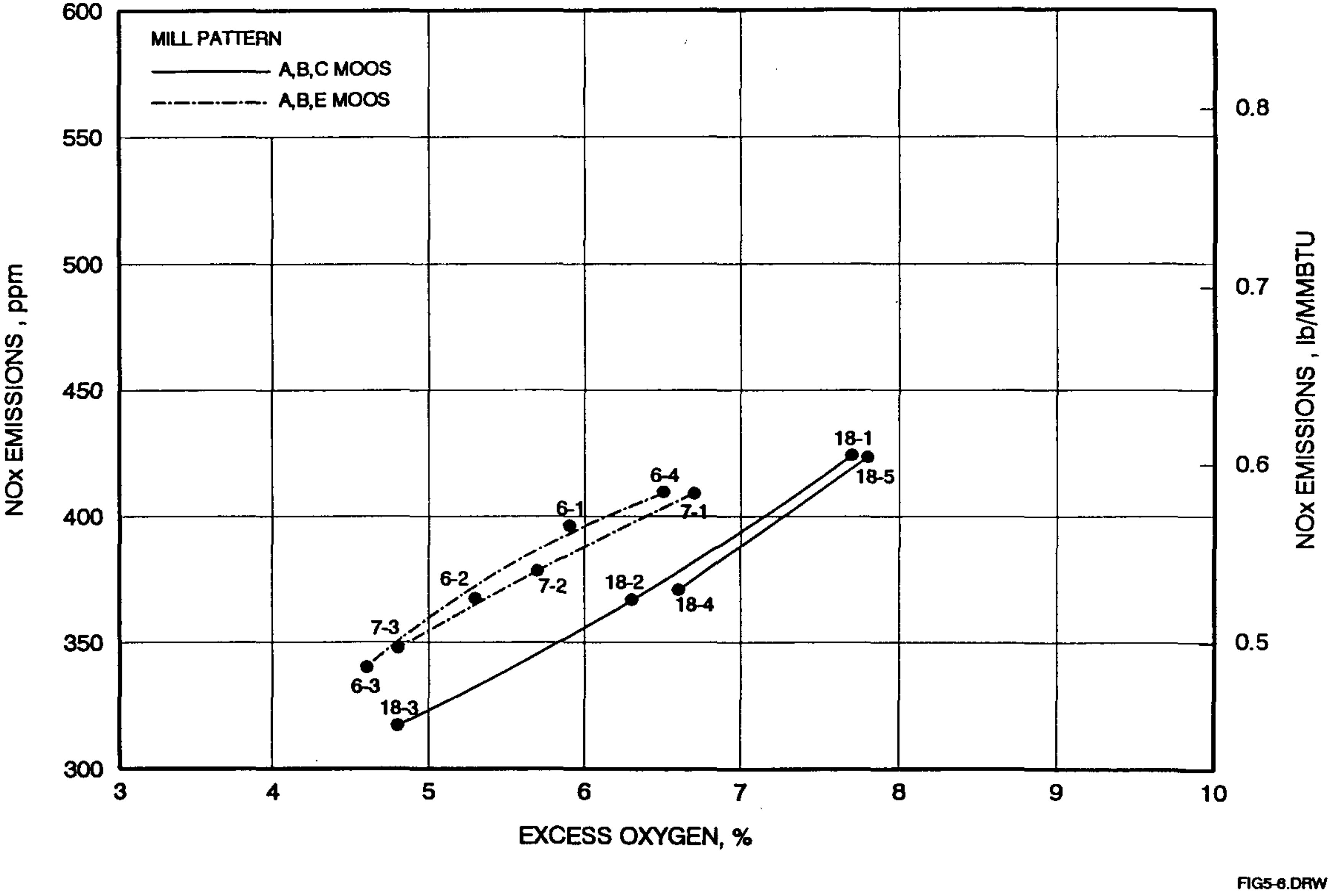


FIGURE 5-6 70 MWe LOAD SUMMARY



variability than at the higher loads as shown in Figure 5-5. On average the NOx increased at a rate of approximately 40 ppm/percent O_2 over the excess oxygen excursion range.

Figure 5-6 shows the data for two MOOS patterns (ABE and ABC) at the 70 MW test point. For both mill patterns, the trend characteristics agreed well but the ABE MOOS pattern resulted in slightly higher NOx levels. Both patterns exhibited a nominal 33 ppm/percent O_2 slope.

From these figures it is evident that the trends (NOx vs O_2) determined on the same day are similar and that the slope of the NOx versus O_2 decreases as the load is decreased. The sensitivity decreases nearly linearly as load is decreased from 180 (50 ppm NOx/percent O_2) to 70 MWe (33 ppm/percent O_2).

5.1.3 Coal and Ash Analyses

Coal samples were taken on three days during the Diagnostic testing. The results of these analyses are shown in Table 5-3 for test day 6 (Tests 6-1 through 6-4) and for two subsequent days when tests were not in progress. These data show that the coal properties were relatively constant for these days.

Due to the short times required to perform the testing at each load point, insufficient time was available to collect ash samples in the Cegrit Samplers. The data collected with the Cegrit Samplers is insufficient for establishing meaningful trends. Sufficient time was available during the performance testing to collect samples for analyses. These data will be presented in Section 5.2.6.

5.2 Performance Tests

Seven performance tests were conducted at nominal gross loads of 180, 135 and 115 MWe. 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, and ambient temperature. A supplemental test was performed at the 180 MWe load point to determine the impact of an increase in excess oxygen on the total particulate matter. Each total performance test covered a period of from ten to twelve hours during which time manual and automated boiler operational data were recorded, fuel and ash samples acquired, gaseous and solid emissions measurements made and the engineering performance tests conducted.

5.2.1 Unit Operating Data

For each performance test, the desired test conditions were established and allowed to stabilize at least one hour prior to commencement of testing. To the extent possible the active coal

TABLE 5-3 BASELINE DIAGNOSTIC TESTS COAL ANALYSIS

Date	Ultimate Analyses, (%)									HHV BTU/lb	VM %	Fixed Carbon %
	H_2O	C	H	N	Cl	S	Ash	O	TOTAL			
11/06/90	8.46	67.03	4.62	1.42	0.23	2.73	9.45	6.29	100.00	12056	35.79	46.30
11/07/90	8.25	67.33	4.61	1.40	0.24	2.73	9.51	6.17	100.00	12045	35.66	46.57
11/08/90	8.33	67.25	4.63	1.39	0.25	2.81	9.35	6.24	100.00	12067	36.21	46.11

TAB5-3.WK3

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 adjustments to the air flow over the day.

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

At each nominal load level, at least two tests were performed over a two- day period to accommodate all of the specific test measurements desired. A third test was performed at 180 MWe after discovering that the KVB O_2 monitor was potentially reading incorrectly during tests 10-2 and 11-2 which may have resulted in testing at a lower excess oxygen level than desired. Table 5-4 summarizes the conditions of each of the seven performance tests for ease of reference. Table 5-5 presents a summary of important operating parameters recorded on the DAS during this test series. The values shown in this table represent average over the duration of the test segment during the day.

TABLE 5-4

SUMMARY OF PERFORMANCE TESTS

Test No.	Date	Gross Load MWe	MOOS	O_2 Percent	NOx ppm
10-2	11/28	182	None	2.8	420
11-1	11/29	180	None	2.2	384
11-2	11/29	182	None	2.7	425
12-1	11/30	133	A	1.1	348
13-1	12/01	136	A	2.5	345
14-2	12/02	113	A,B	3.6	368
15-1	12/03	113	A,B	3.2	345
16-1	12/04	180	None	4.0	465

5.2.2 Gaseous Emissions

During the performance tests gaseous emissions were measured with the ECEM operating in the manual mode. At various times

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

TEST NO.	DATE	GROSS LOAD MWe	PLANT O2 E ECON OUTLET PCT	PLANT O2 W ECON OUTLET PCT	CEM O2 AVERAGE OUTLET PCT	CEM COMPOSITE AVG NO PPM	STACK CO (ppm)	STACK OPACITY PCT	SAPH A OUT TEMP °F	SAPH B OUT TEMP °F	STEAM FLOW mmLB/HR	SH TEMP °F	SH SPRAY FLOWS LOWER SPRAY kLB/HR	SH SPRAY FLOWS UPPER SPRAY kLB/HR	HOT RH TEMP °F	PULVERIZER FLOW MILL A kLB/HR	PULVERIZER FLOW MILL B kLB/HR	PULVERIZER FLOW MILL C kLB/HR	PULVERIZER FLOW MILL D kLB/HR	PULVERIZER FLOW MILL E kLB/HR
10-2	11/28/90	184	4.4	3	2.8	420	8	10	308	305	1329	999	37	33	995	27.8	26.5	25.4	23.9	27.9
11-2	11/29/90	180	4.8	3.2	2.7	425	7	10	301	298	1323	1000	11	25.1	984	27.3	27.8	26.9	24.7	26.3
13-1	12/01/90	136	3.8	2.7	2.5	345	10	10	295	290	966	1000	14	26	948	0	24	23.6	22.6	25.2
14-2	12/02/90	113	4.8	3.7	3.6	368	8	10	278	273	782	1000	11.8	27.1	931	0	0	26.3	25.7	25.9
15-1	12/03/90	113	4.5	3.2	3.2	345	8	10	277	272	794	994	1.2	17.3	914	0	0	26.6	25.5	25.1
16-1	12/04/90	180	5.8	4.5	4.0	465	8	-	298	288	1312	1002	32	34	974	26.9	24.6	25.6	24.9	26.1

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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. It was discovered early in the performance testing that the primary DAS O_2 was malfunctioning and was measuring higher than actual excess oxygen levels. For this reason, the backup Yokagawa in-situ probes upstream and downstream of the air preheater were used to obtain composite readings. These in-situ probes did not allow determination of the spatial distributions at the economizer exit. Table 5-6 lists the composite average values of O_2, CO and NOx measured over a several hour period for each test condition.

Based upon these results it can be seen that, for the most part, the NOx emissions on different days repeated fairly well.

TABLE 5-6
SUMMARY OF GASEOUS EMISSIONS TEST DATA

Test No.	Gross Load MWe	O_2 %	CO ppm	NOx ppm
10-2	182	2.8	8	420
11-2	182	2.7	7	425
12-1	133	2.8	5	348
13-1	136	2.5	8	345
14-2	113	3.6	8	368
15-1	113	3.2	8	345
16-1	180	4.0	9	465

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 before the air preheater (see Figure 3-8). The following paragraphs describe the results from these measurements.

Total Mass Emissions Total mass emissions reflect both a fraction of the total coal ash injected into the furnace (100 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 5-7 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 4.7

percent of isokinetic. The results shown for each load level represent the average of three replicate tests. For all tests, the data were remarkably consistent. Within each replicate series the standard deviation of mass loading was less than 3 percent of the mean value. The test repeatability as well as the test to test repeatability was surprisingly good during this performance test series.

TABLE 5-7

SUMMARY OF SOLID MASS EMISSIONS TESTS

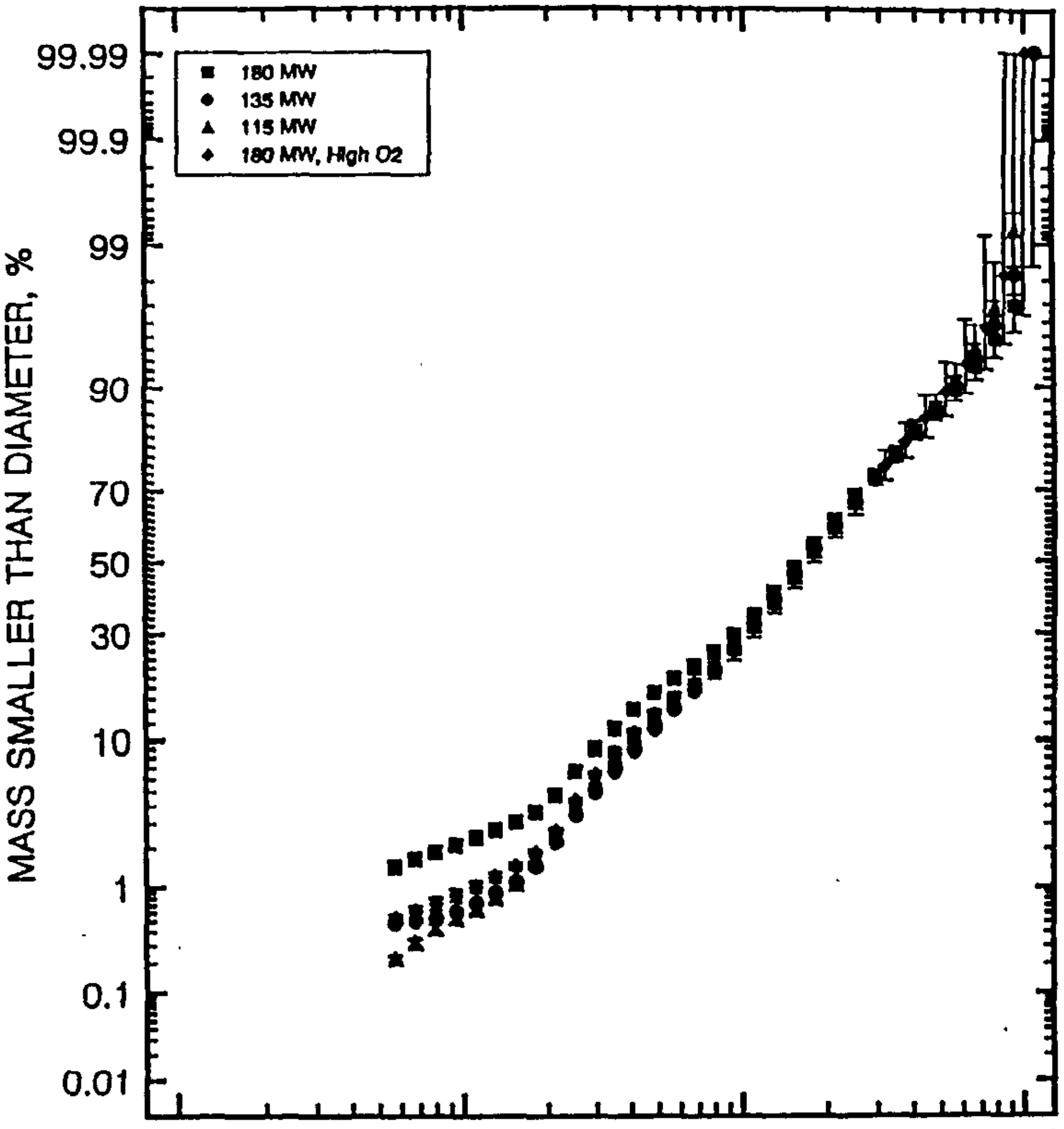
TEST No	LOAD MWe	O_2 %	LOADING gr/dscf	GAS FLOW dscfm	CARBON %	LOI %
11-2	180	2.7	3.10	815800	8.3	8.71
12-1	135	2.8	2.69	532000	3.6	4.22
14-2	115	3.6	2.77	465000	3.8	4.04
16-1	180	4.0	4.08	901300	4.8	5.02

As a measure of the degree of completeness of combustion, the ash collected in the cyclone portion of the Method 17 train for each test was analyzed by two separate methods for carbon content and Loss On Ignition (LOI). The LOI is considered to represent carbon content along with volatile solids (sulfates, chlorides, etc.) driven off in the analysis procedure. The close agreement between the carbon and LOI analyses for all samples provides a measure of confidence in the reliability of the results. The principal use of the Phase I performance carbon and LOI analyses is as a reference for comparison with ash samples acquired during subsequent 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 condition. Figure 5-7 shows the particle size distributions for all test conditions as the total percentage of cumulative mass (4-axis comprising particles smaller than the aerodynamic diameter D_{50}). 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 tests under common conditions and also the relatively minor effect of load on the ash particle size distribution. The one exception to this is the low excess oxygen

FIGURE 5-7 INLET PERCENT MASS DISTRIBUTION



test at 180 MWe performed during Test 10-2. From Fig. 5-7 the mass-median diameter is about 17 microns for all tests. The geometric standard deviation (assuming log-normal distribution) is 3.6 microns for all data. These results compare closely with EPRI data base predictions of 16.3 micron, 3.4 std. dev. (J.L. DuBard and R.S. Dahlin, Precipitator Performance Estimation Procedure, EPRI CS-5040, Feb. 1987).

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 subsequent phases of the program with these Phase I data and will highlight any significant changes in particle size distribution and potential effects 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 5-7). The ESP hopper samples (North and South composites separately) were analyzed for mineral composition. Table 5-8 presents these data and allow a comparison of carbon and LOI between the economizer exit (Method 17) and the ESP hopper chemical analysis.

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

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

Ash Resistivity One of the most important properties affecting ESP performance is the resistivity of the ash particles. Ash resistivity is a measure of the ash's ability to retain an electrical charge which allows it to migrate and adhere to the ESP plates. The results of laboratory resistivity measurements are presented in Table 5-9. Since the unit is equipped with a Hot-Side ESP, in-situ resistivity measurements could not be made. Laboratory measurements of the resistivity of ESP hopper samples from the different test conditions are shown in Figures 5-9 and 5-10.

FIGURE 5-8 INLET DIFFERENTIAL MASS DISTRIBUTION

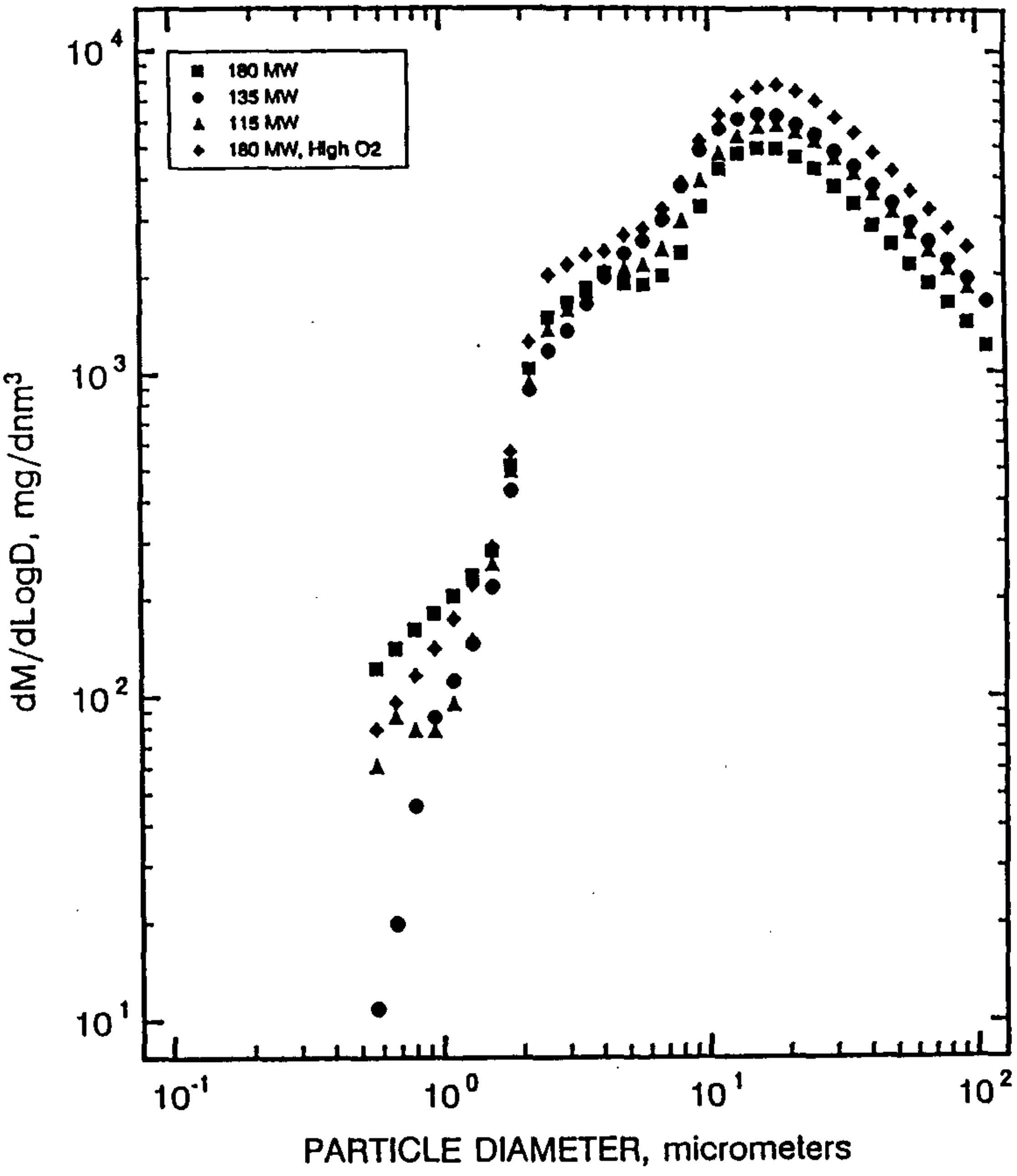


TABLE 5-8 CHEMICAL ANAYLSES OF HOPPER SAMPLES IN WEIGHT PERCENT

	180 MWe 11/28/90		135 MWe 11/30/90		115 MWe 12/02/90		180 MWe, HIGH O_2 12/04/90	
OXIDE	NORTH DUCT	SOUTH DUCT	NORTH DUCT	SOUTH DUCT	NORTH DUCT	SOUTH DUCT	NORTH DUCT	SOUTH DUCT
Li_2O	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Na_2O	0.70	0.57	0.72	0.59	0.66	0.54	0.81	0.61
K_2O	2.7	2.5	2.8	2.5	2.5	2.4	2.8	2.4
MgO	0.99	0.97	1.1	0.99	0.99	0.93	0.97	0.95
CaO	5.3	6.6	5.1	5.7	5.0	5.9	5.3	7.8
Fe_2O_3	17	18	16	16	18	19	17	19
Al_2O_3	20.5	20	21	20	21	20	20	18
SiO_2	51	50	51	51	49	50	50	49
TiO_2	1.2	1.1	1.2	1.2	1.2	0.90	1.3	1.0
P_2O_5	0.22	0.23	0.24	0.20	0.25	0.21	0.24	0.22
SO_3	0.79	1.0	1.5	0.72	0.81	0.94	0.84	1.1
LOI	8.2	12.8	2.9	7.5	2.9	8.9	3.7	11
AVG LOI		10.5		5.2		5.9		7.3
TOTAL LOI (flyash)		8.3		3.6		3.8		4.8

TAB5-9.WK3

TABLE 5–9 LABORATORY AND MODEL RESISTIVITY FOR HOT–SIDE ESP

DATE	LOAD (MWe)	DUCT	TEMP (° F)	LABORATORY RESISTIVITY (ohm–cm)	PREDICTED RESISTIVITY (ohm–cm)	SODIUM DEPLETED RESISTIVITY (ohm–cm)
11/28/90	180	NORTH	658	2×10^9	1×10^9	1×10^{10}
		SOUTH		2×10^9	3×10^9	2×10^{10}
11/30/90	135	NORTH	591	5×10^9	4×10^9	4×10^{10}
		SOUTH		4×10^9	6×10^9	5×10^{10}
12/02/90	115	NORTH	568	7×10^9	6×10^9	5×10^{10}
		SOUTH		7×10^9	9×10^9	9×10^{10}
12/04/90	180, HI O_2	NORTH	665	1×10^9	1×10^9	8×10^9
		SOUTH		1×10^9	2×10^9	2×10^{10}

TAB5–9.WK3

FIGURE 5-9 ESP HOPPER ASH RESISTIVITY

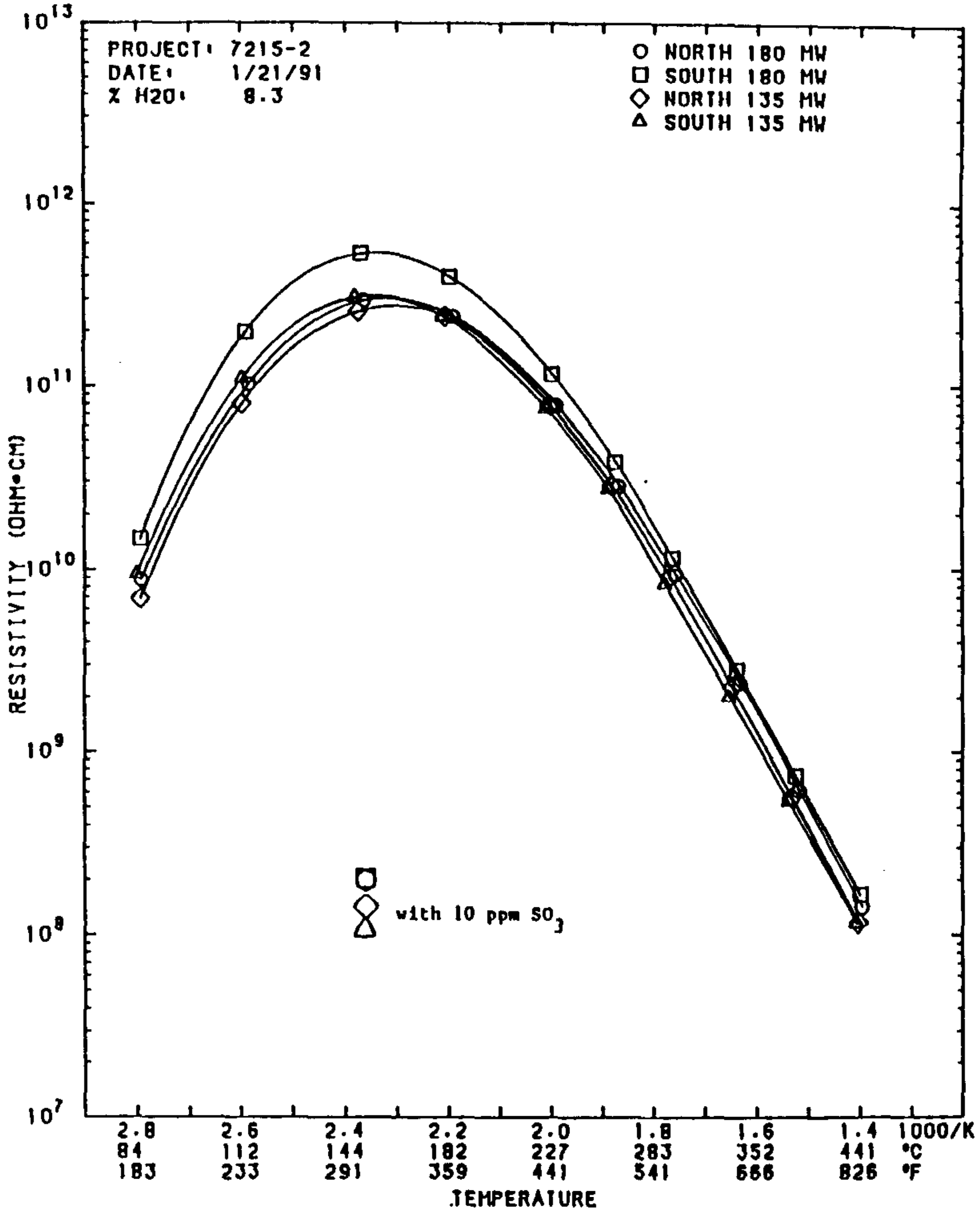
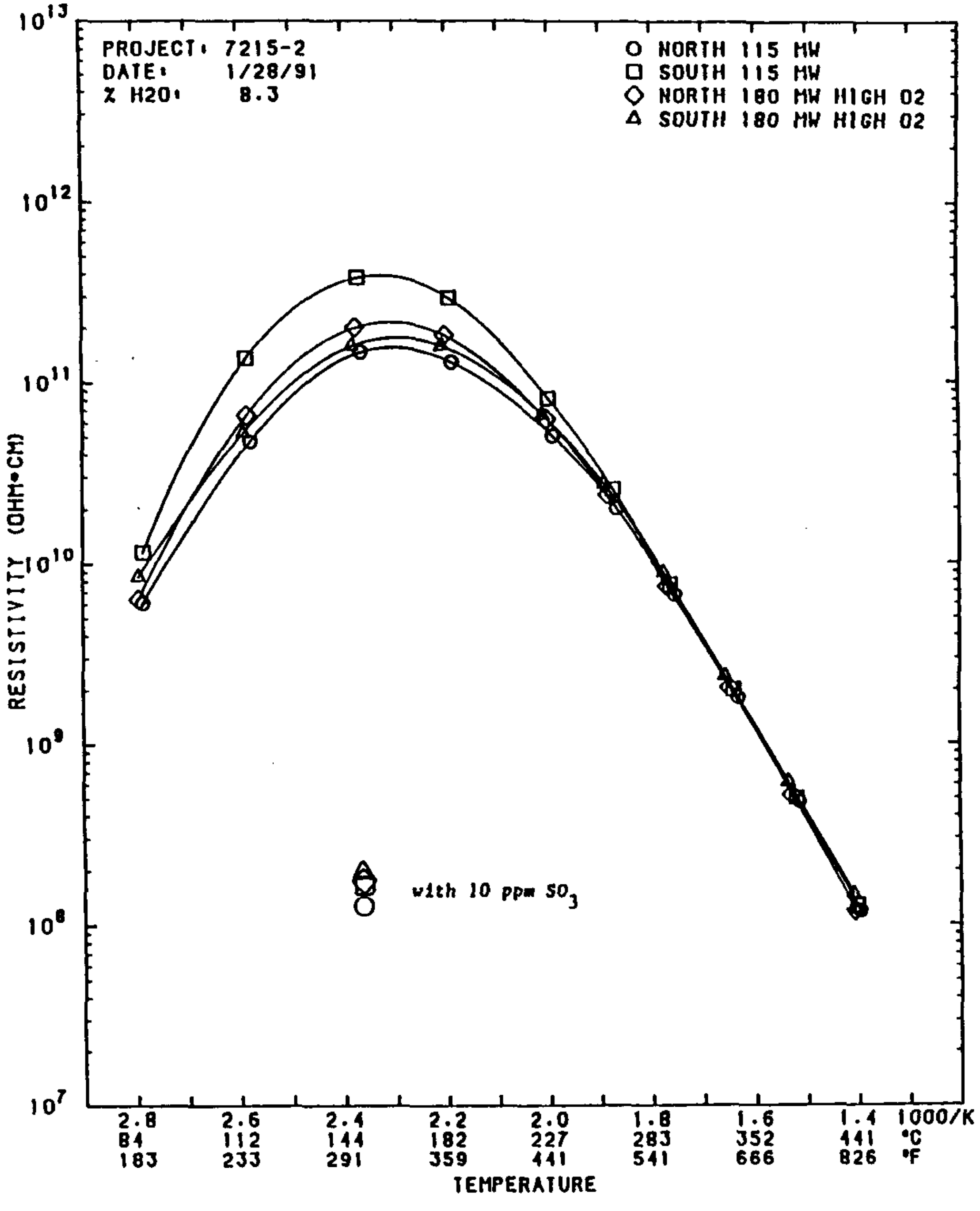


FIGURE 5-10 ESP HOPPER ASH RESISTIVITY



The resistivity of the ESP hopper samples was calculated using their chemical compositions (Table 5-9) and a mathematical model of fly ash resistivity (Bickelhaupt, "A Study to Improve a Technique for Predicting Fly Ash Resistivity with Emphasis on the Effect of Sulfur Trioxide", EPS-600/7-86-010, 1985). The curves (Figures 5-9 sand 5-10) showing these calculated resistivities for typical ash compositions during the Plant Smith tests are for an assumed 10 ppm SO_3 level.

Because the laboratory measurement of resistivity with acid vapor is run for an extended period of time in order to reach an equilibrium condition, the resulting values of resistivity with some ashes can be lower than could realistically be achieved at a power plant. This over-conditioning effect does not appear to be related to ash compositions similar to that at Lansing Smith, but the lack of a developed correlation for the effect suggests caution in the interpretation of laboratory data. However, even if the resistivity data were more than an order of magnitude to low, the actual resistivity would still be low enough not to impede ESP operation.

5.2.4 SO_2/SO_3 Tests

The concentration of SO_2 and SO_3 (as separate species) was measured in both the north and south ducts at the air preheater exit for every performance test load condition. Table 5-10 presents the results of the tests for the three load points. From the table some important observations related to the SO_2 can be made. First, the SO_2 value is relatively constant for any particular test sequence (e.g., Test 10-2 or 11-2) which indicates good repeatability. Second,the SO_2 varied by only approximately five percent between sampling periods.

The measured SO_2 variations, however, do not correlate with the average coal sulfur values (average of 2 to 5 samples from Table 5-13) for the corresponding test day. Since the coal samples were acquired during the testing period from the mill inlet chutes, very little time delay should have passed between coal sampling and combustion in the furnace (a few minutes at most). The exact reason for the variation is unexplained at this time, however, the fact that SO_2 measurements were made at only a single point in one duct tends to favor the conclusion that SO_2 was stratified within the boiler.

5.2.5 Combustion System Tests

Combustion performance tests were performed at each of the three load levels to document the specific performance parameters related to the fuel and air combustion systems. During subsequent phases of the program that involve changes to the air supply system, comparisons will be made to ascertain potential influences of these changes on the NOx emissions.

<u>Mill Performance</u> The air flow to each mill and the particle size and mass flow distributions of coal to each burner were

TABLE 5−10 SULFUR OXIDE EMISSION RESULTS

DATE	LOAD (MWe)	TEST NUMBER	DUCT LOCATION	APH GAS TEMP (° F)	SULFUR TRIOXIDE ppm[1]	SULFUR DIOXIDE ppm[1]
11/28/90	180		SOUTH	339	10	2206
				337	11	2222
				338	12	2236
				339	12	2240
11/29/90	180		NORTH	301	7	2315
				304	8	2253
				305	9	2225
				305	9	2218
AVERAGE ± 1				321 ± 18	10 ± 2	2239 ± 34
11/30/90	135		SOUTH	309	10	2132
				310	9	2164
				308	10	2192
				308	10	2171
12/01/90	135		NORTH	282	6	2254
				283	6	2245
				284	7	2258
				287	7	2257
AVERAGE ± 1				296 ± 13	8 ± 2	2209 ± 50
12/02/90	115		SOUTH	299	10	2066
				300	12	2080
				302	12	2076
				301	12	2082
12/03/90	115		NORTH	276	6	2139
				277	7	2131
				276	7	2151
				276	7	2150
AVERAGE ± 1				288 ± 13	9 ± 3	2109 ± 37
12/04/90	180/High O_2		SOUTH	330	16	2084
				331	18	2092
				334	19	2080
				335	19	2071
AVERAGE ± 1				333 ± 3	18 ± 1	2082 ± 9

[1] Actual Concentration at stack conditions.

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measured as described in Section 3.3. Duplicate tests were performed at all three load levels (180, 135 and 115 MWe). Table 5-11 summarizes the results of these tests. From Table 5-11 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 2.3 to 3.0 over the load range.

During these mill tests the coal fineness was found to be below 70 percent through 200 mesh on all mills. This could potentially cause the NOx emissions to be lower than for a condition with 70 percent through a 200 mesh screen.

It should be noted that the results of the mill performance were those obtained by measurement within a straight section of pipe which is at a location different from that normally used by the plant personnel. ABB CES recommends obtaining these fineness near the mill outlet which is the location normally used by the plant and CE. When measurements are taken near the mill outlet, fineness is in the 70 percent through 200 mesh range.

Secondary Air Supply The secondary combustion air flow was measured at two locations as described in Section 3.3. Table 5-12 presents the results of the flow measurements for tests 10 through 15. 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.

TABLE 5-12
COMBUSTION AIR DISTRIBUTION

TEST	LOAD MWe	O_2 %	SECONDARY MMlb/Hr	%	PRIMARY	%
10-2	180	2.8	1.110	74.4	0.382	25.6
11-2	182	2.7	1.066	73.9	0.377	26.1
12-2	133	2.8	0.739	70.0	0.317	30.0
13-1	136	2.5	0.808	71.9	0.315	28.1
14-2	113	3.6	0.684	71.5	0.273	28.5
15-1	113	3.2	0.707	66.8	0.351	33.2
16-1	180	4.0	1.117	74.7	0.378	25.3

Furnace Measurements Measurements were made of combustion gas temperatures and species concentrations (O_2 and CO) at eight locations within the boiler furnace at the 7th and 8th floor levels (See Figure 3-7). At each port approximately 10 measurements were made of temperature, excess oxygen and carbon

TABLE 5-11
SMITH UNIT 2 SUMMARY OF MILL PERFORMANCE TESTS

PARAMETER	MILLS				
	A	B	C	D	E
<u>TEST 10-2 180 MWe</u>					
MEASURED COAL FLOW, Klb/hr	31.3	29.5	32.3	23.8	27.8
MEASURED PA FLOW, Klb/hr	74.4	70.6	77.0	70.5	73.0
A/F RATIO	24	2.4	2.4	3.0	29.0
AVG. PASSING 200 MESH, PCT	60.6	57.4	58.6	60.0	58.0
AVG. PASSING 50 MESH, PCT	98.3	97.9	97.1	97.2	96.3
<u>TEST 11-2 182 MWe</u>					
MEASURED COAL FLOW, Klb/hr	31.3	30.0	30.4	23.2	28.8
MEASURED PA FLOW, Klb/hr	72.9	70.2	75.3	68.0	72.1
A/F RATIO	2.3	2.3	2.5	2.9	2.5
AVG. PASSING 200 MESH, PCT	60.0	57.6	59.0	64.7	59.4
AVG. PASSING 50 MESH, PCT	98.4	97.9	96.6	97.4	97.5
<u>TEST 12-1 133 MWe</u>					
MEASURED COAL FLOW, Klb/hr	—	23.7	25.5	22.8	26.1
MEASURED PA FLOW, Klb/hr	—	70.9	75.0	67.2	69.6
A/F RATIO	—	3.0	2.9	2.9	2.66
AVG. PASSING 200 MESH, PCT	—	60.1	60.7	62.1	21.5
AVG. PASSING 50 MESH, PCT	—	98.4	97.5	98.1	97.6
<u>TEST 13-1 136 MWe</u>					
MEASURED COAL FLOW, Klb/hr	—	26.9	28.6	22.7	28.5
MEASURED PA FLOW, Klb/hr	—	69.0	75.6	67.0	70.5
A/F RATIO	—	2.6	2.7	3.0	2.5
AVG. PASSING 200 MESH, PCT	—	58.3	60.7	65.3	59.2
AVG. PASSING 50 MESH, PCT	—	98.1	97.4	97.9	97.1
<u>TEST 14-2 113 MWe</u>					
MEASURED COAL FLOW, Klb/hr	—	—	30.7	28.6	30.2
MEASURED PA FLOW, Klb/hr	—	—	75.7	28.0	70.6
A/F RATIO	—	—	2.5	2.3	2.3
AVG. PASSING 200 MESH, PCT	—	—	61.8	61.2	57.0
AVG. PASSING 50 MESH, PCT	—	—	96.9	97.4	96.3
<u>TEST 15-1 113 MWe</u>					
MEASURED COAL FLOW, Klb/hr	—	—	30.4	27.1	29.4
MEASURED PA FLOW, Klb/hr	—	—	74.6	66.2	70.0
A/F RATIO	—	—	2.5	2.4	2.4
AVG. PASSING 200 MESH, PCT	—	—	65.2	63.5	57.1
AVG. PASSING 50 MESH, PCT	—	—	96.8	97.7	96.5

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monoxide at loads of 180, 135 and 115. As mentioned previously, difficulties in the excess oxygen measurement were discovered late in the performance testing which resulted in lower than desired levels during most of the test runs. An additional test was made at 180 MWe at a higher level of excess oxygen to determine the impact of these low excess oxygen levels.

Figures 5-11, 5-12 and 5-13 show the distribution of temperature and excess oxygen at the 180 MWe nominal load point. Tests 10-2 and 11-2 were made at low excess oxygen levels while Test 16-1 was made at a level approximately 1.2 percent higher. 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 to 2.0 percent for the low O_2 tests and from 0 to 4.0 percent for the high O_2 test. One reason for this maldistribution is the non-uniformity of the coal flows to the corners. Figure 5-14 graphically illustrates this maldistribution for one of the low O_2 tests (Test 11-2). For this test, the flows to the individual corners ranged from 18 to 30 percent of the total flow. The low flow area (right rear corner) corresponded to the high O_2 points in Figures 5-12 and 5-13.

Figures 5-15 through 5-18 illustrate the temperature and excess oxygen distributions for the 135 and 115 MWe load test conditions. These figures exhibit the same general excess oxygen maldistribution as that for the 180 MWe condition. This may indicate that the coal flows to the corners may also be maldistributed in the same manner as that shown in Figure 5-15.

5.2.6 Coal and Ash Analyses

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

The coal samples were analyzed for proximate and ultimate composition, colorific value, grindability and ash fusion properties. Table 5-13 presents the results of these analyses. These analyses show that the coal properties remained very consistent over the duration of the testing and is consistent with the analyses obtained during the Diagnostic test effort (Table 5-3).

The results of the Cegrit furnace ash and the furnace bottom ash analyses are shown in Table 5-14. In general the Cegrit LOI values were lower than the bottom ash samples. This may have been due to the difficulties experienced in obtaining Cegrit samples in the sampling location for these devices.

FIGURE 5-11 FURNACE EXIT HVT AND OXYGEN DISTRIBUTIONS

TEST 10-2 180 MWe

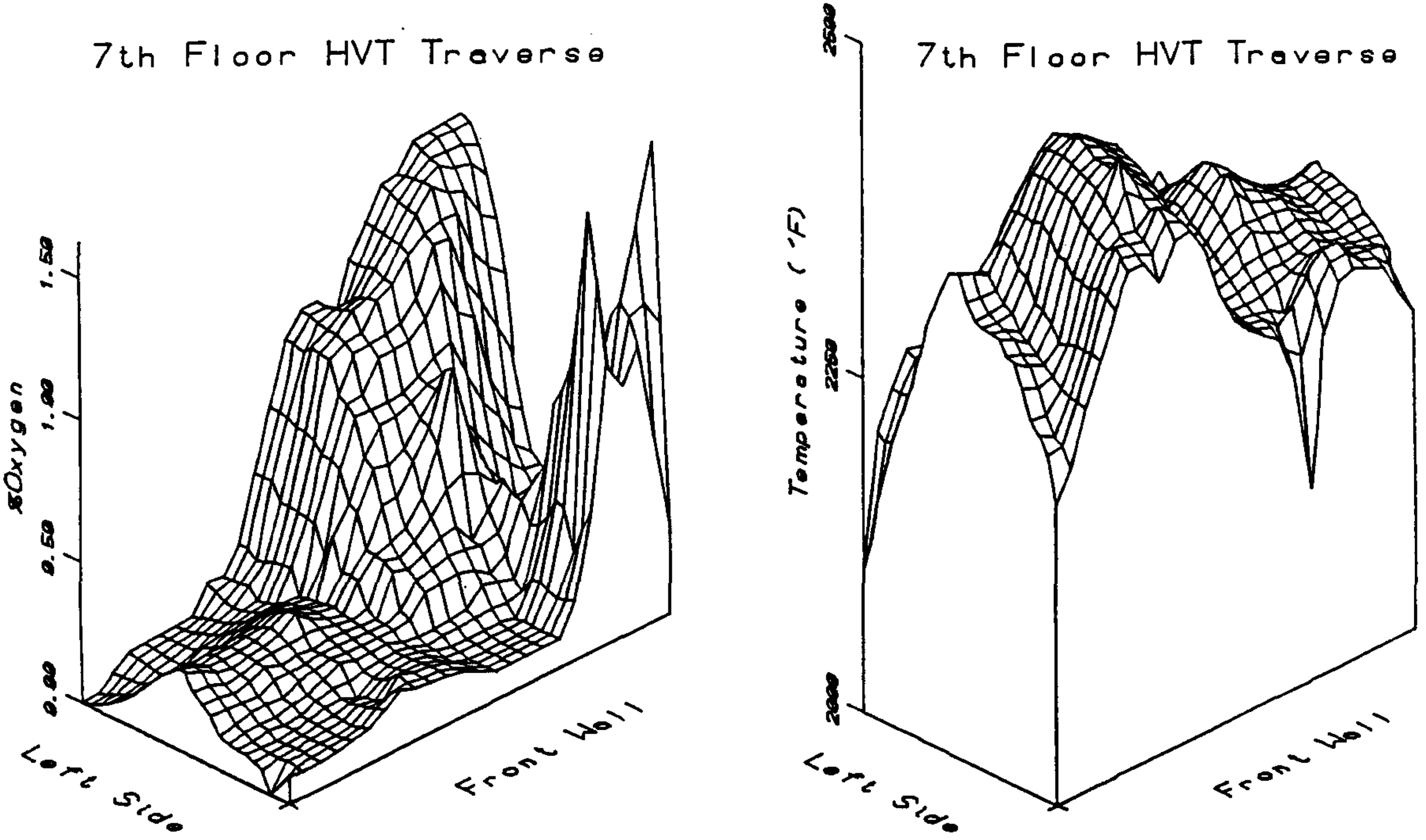


FIGURE 5-12 FURNACE EXIT HVT AND OXYGEN DISTRIBUTIONS

TEST 11-2 180 MWe

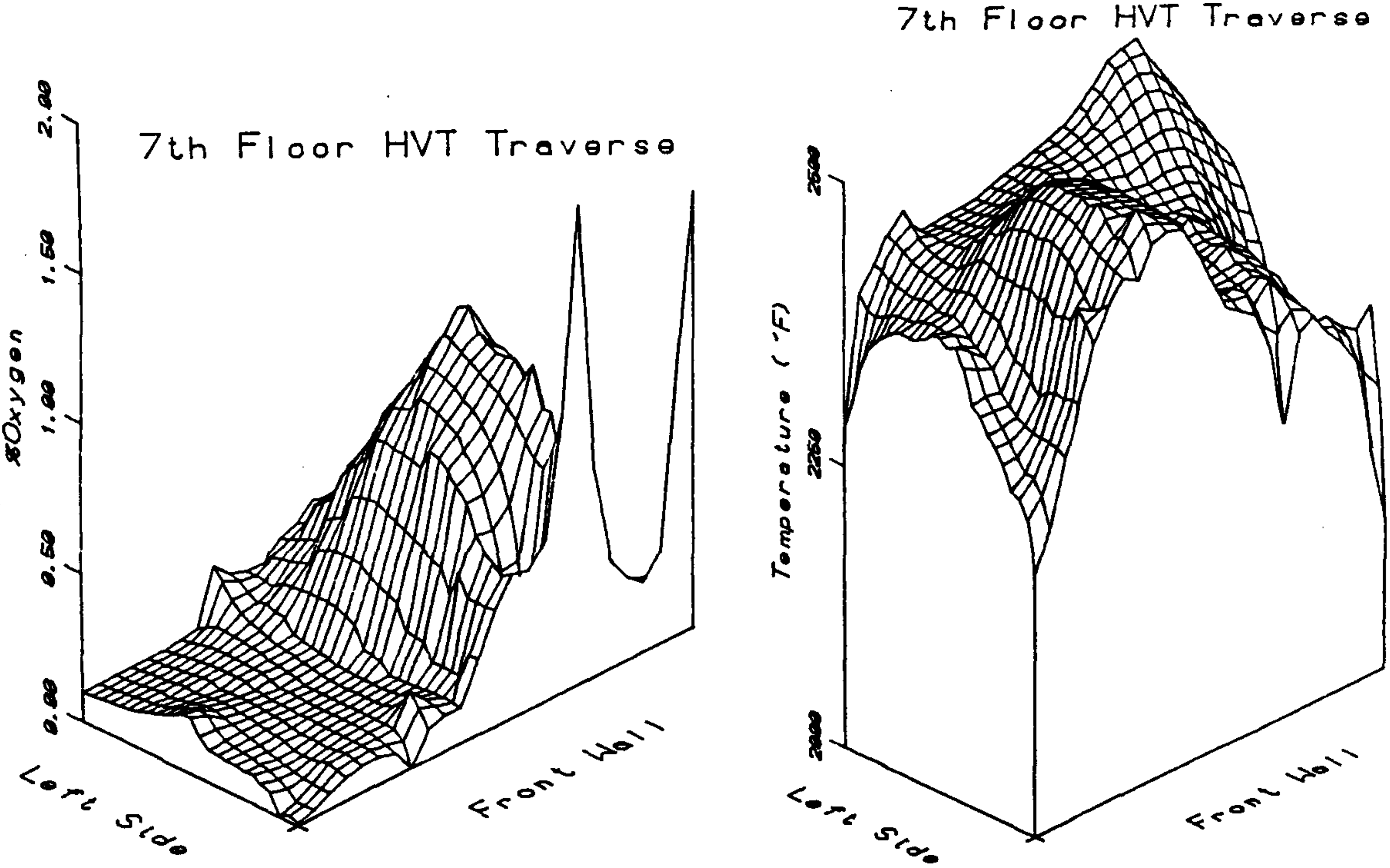


FIGURE 5-13 FURNACE EXIT HVT AND OXYGEN DISTRIBUTIONS

TEST 16-1 180 MWe

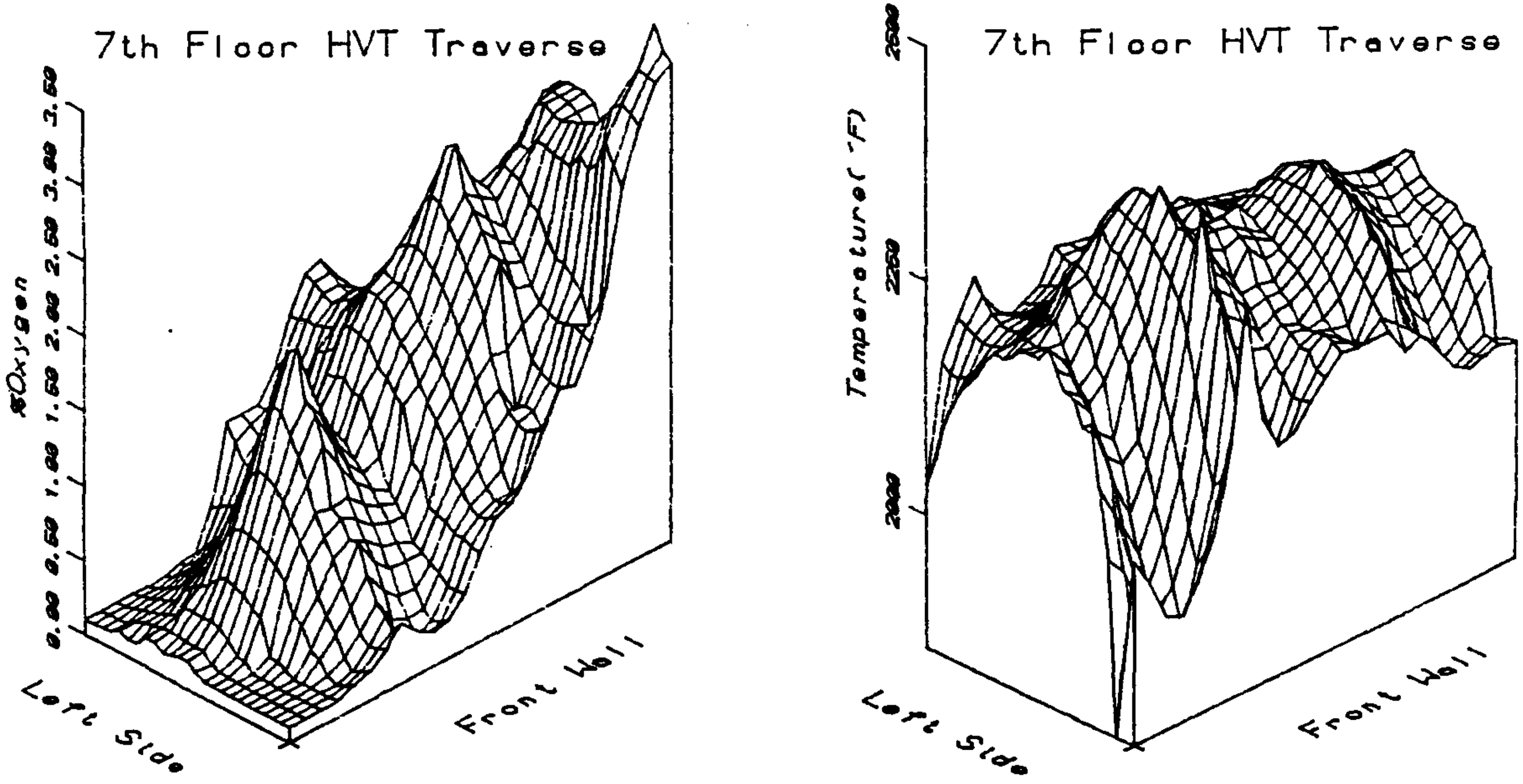
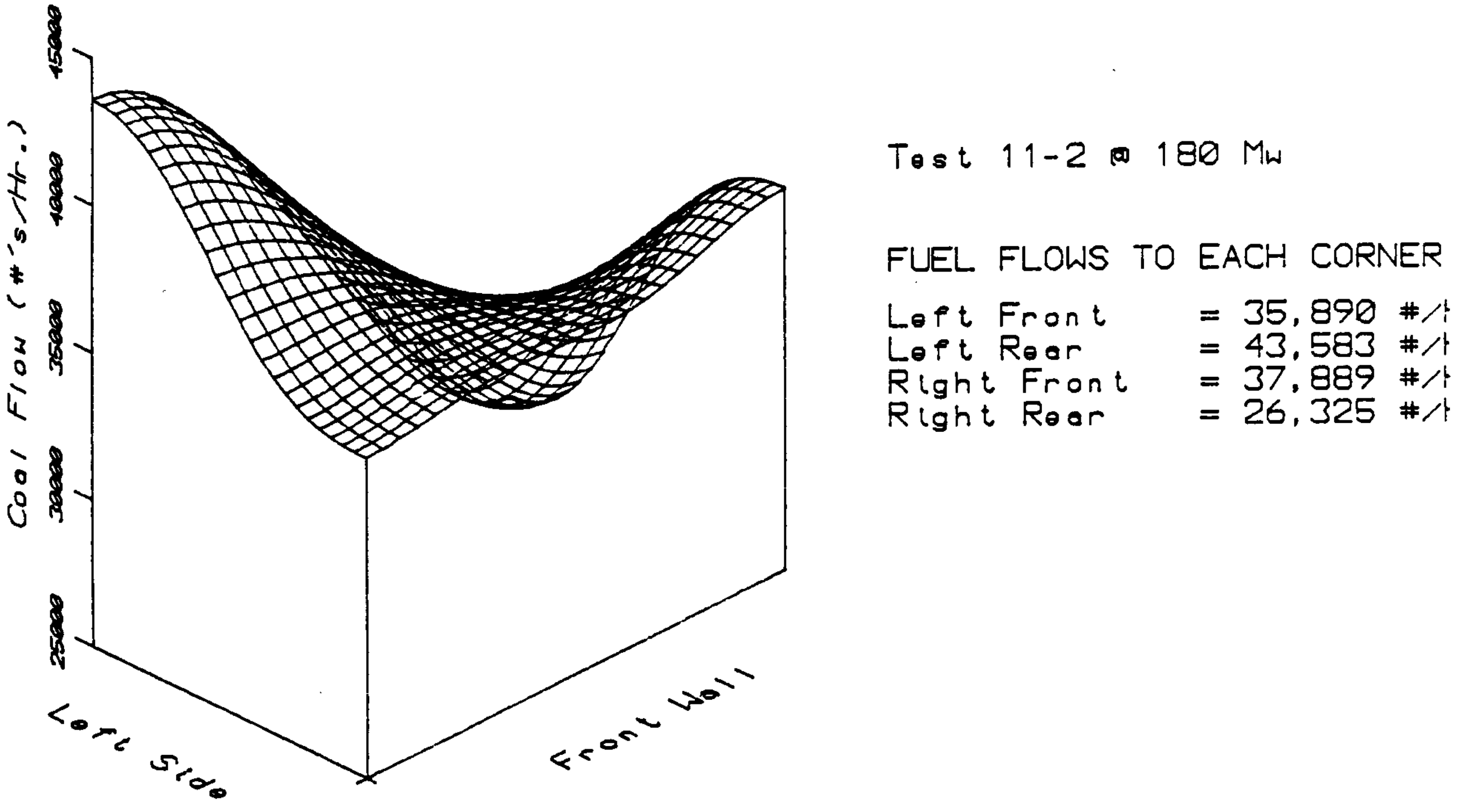


FIGURE 5-14 COAL FLOW DISTRIBUTION

TEST 11-2 180 MWe



Test 11-2 @ 180 Mw

FUEL FLOWS TO EACH CORNER

Left Front = 35,890 #/
Left Rear = 43,583 #/
Right Front = 37,889 #/
Right Rear = 26,325 #/

FIGURE 5-15 FURNACE EXIT HVT AND OXYGEN DISTRIBUTIONS

TEST 12-1 135 MWe

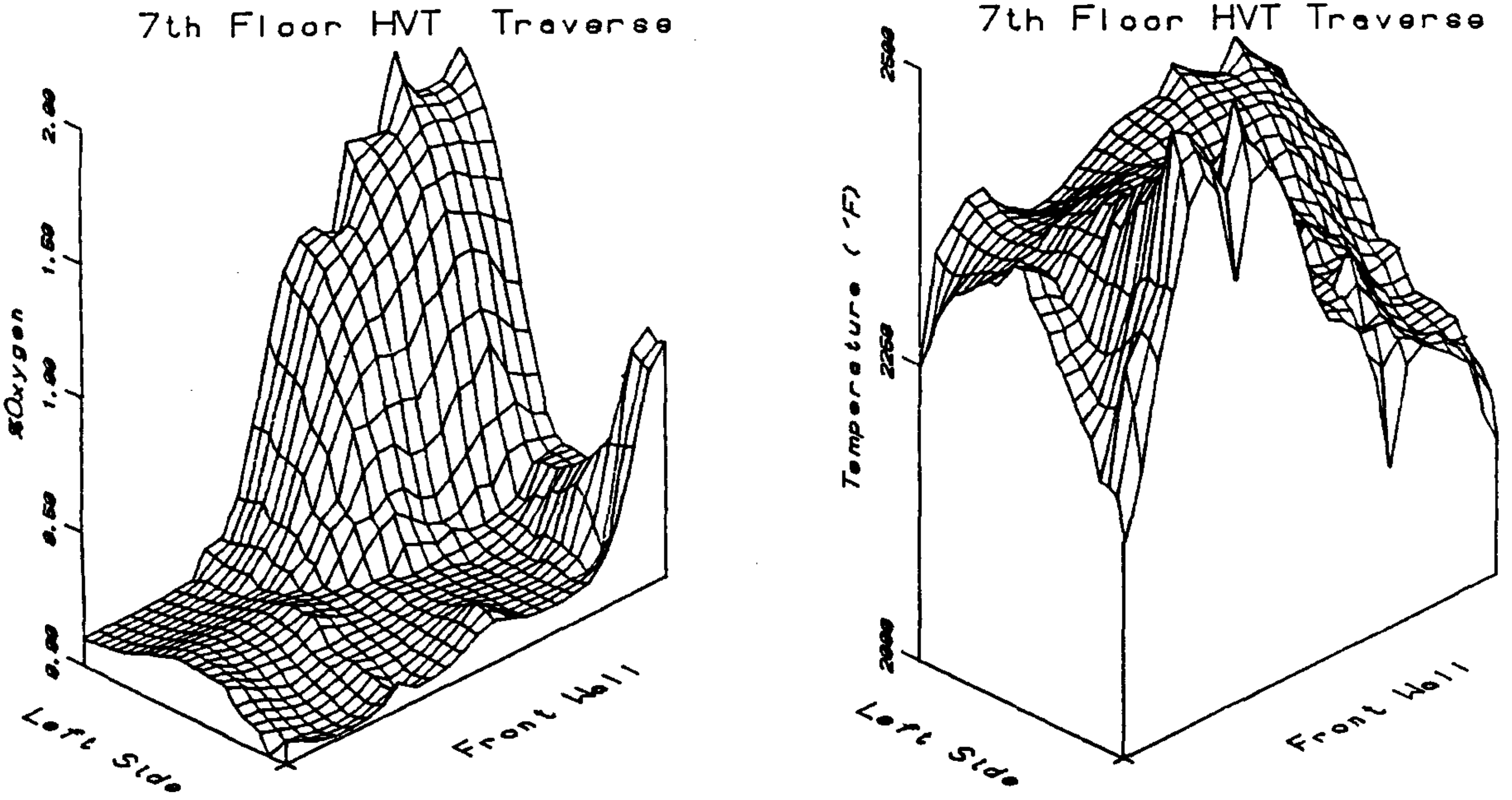


FIGURE 5-16 FURNACE EXIT HVT AND OXYGEN DISTRIBUTIONS

TEST 13-1 135 MWe

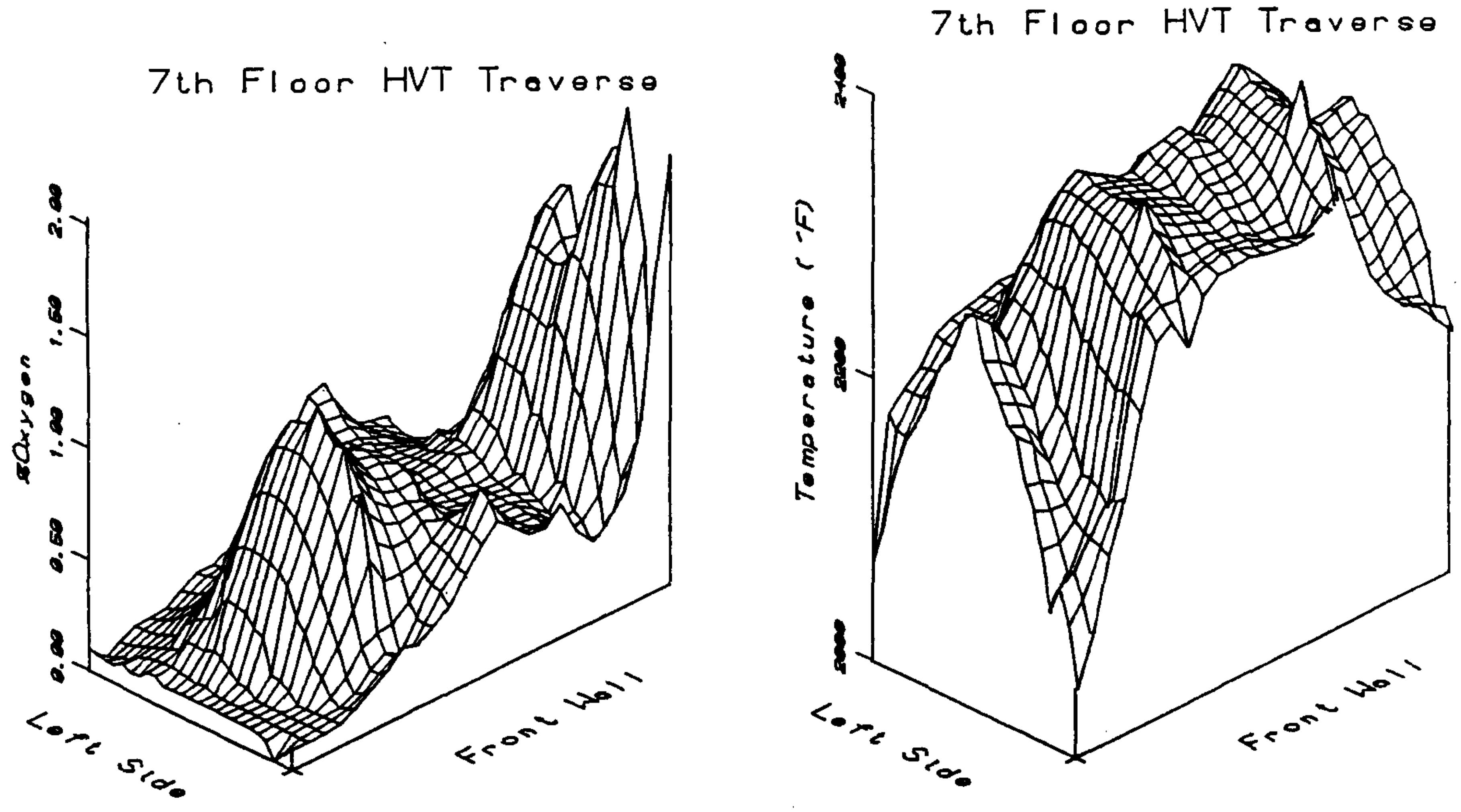
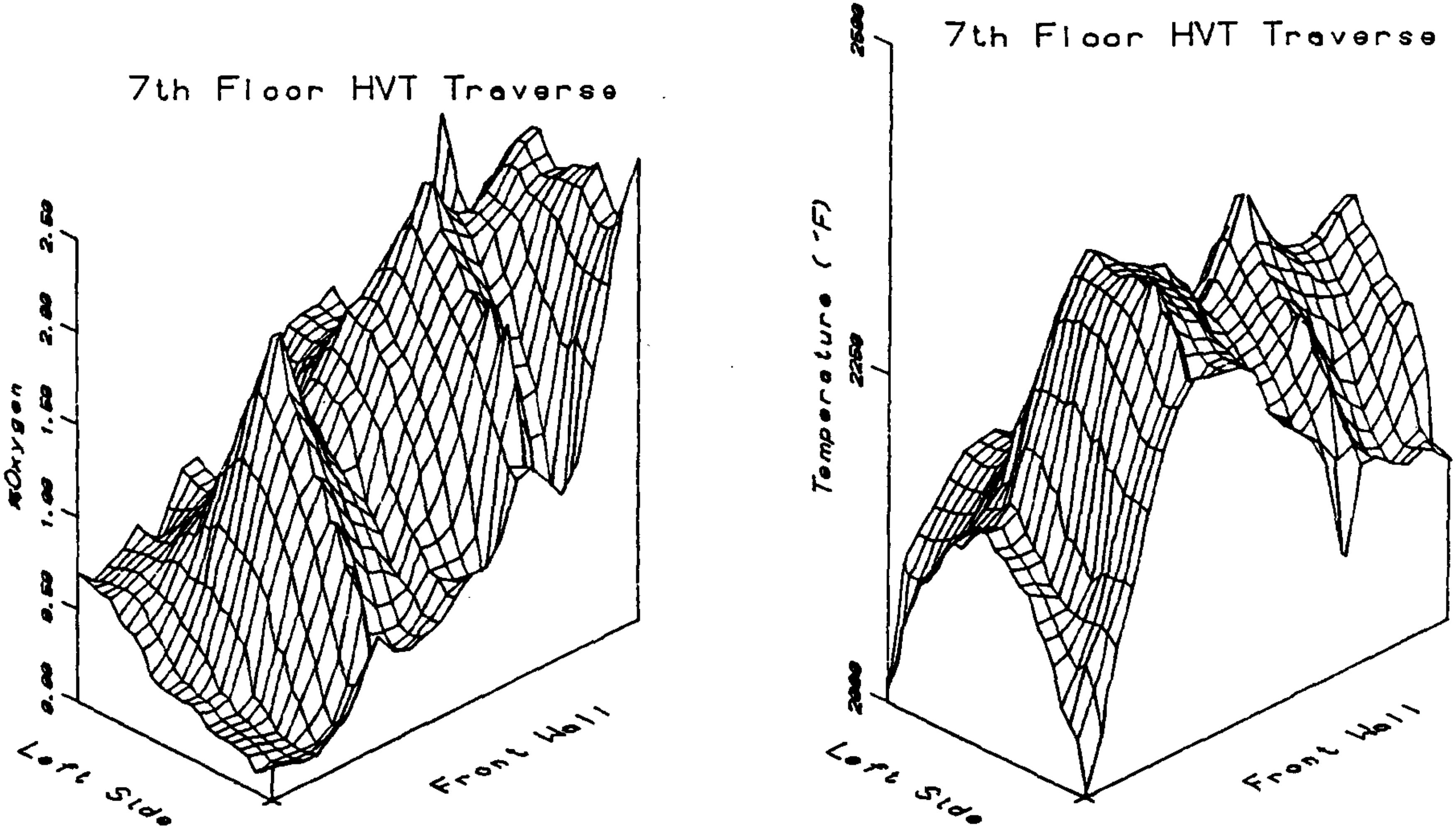


FIGURE 5-17 FURNACE EXIT HVT AND OXYGEN DISTRIBUTIONS

TEST 14-2 115 MWe



7th Floor HVT Traverse

7th Floor HVT Traverse

FIGURE 5-18 FURNACE EXIT HVT AND OXYGEN DISTRIBUTIONS

TEST 15-1 115 MWe

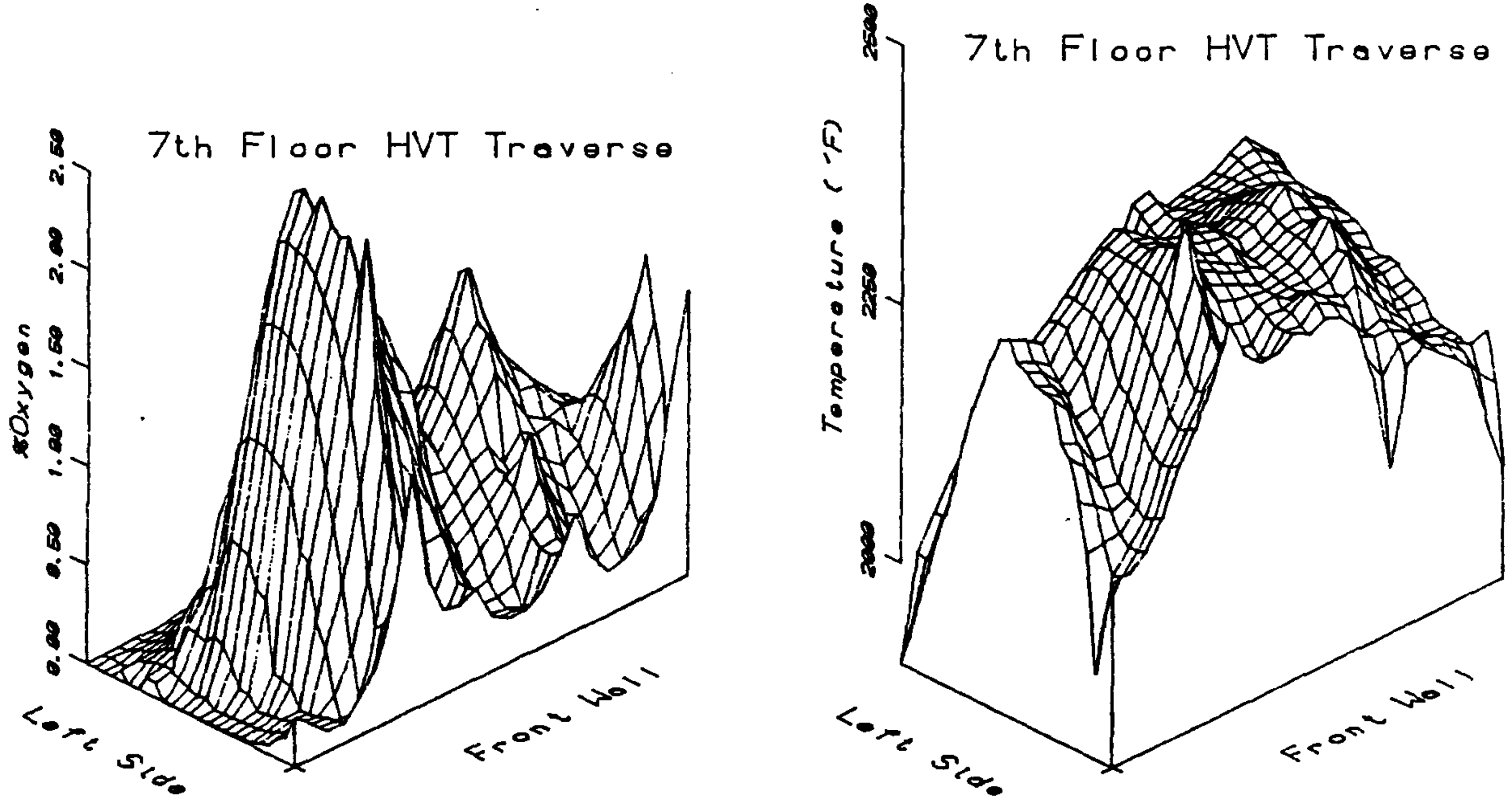


TABLE 5–13 BASELINE PERFORMANCE TESTS COAL ANALYSIS

Date	Time	Ultimate Analyses, (%) H_2O	C	H	N	Cl	S	Ash	O	TOTAL	HHV BTU/lb	VM %	Fixed Carbon %
11/28/90	0900	6.90	68.72	4.89	1.39	0.24	2.90	9.27	5.93	100.00	12311	37.00	46.83
11/28/90	0900	6.67	69.17	4.69	1.50	0.13	2.93	8.90	6.14	100.00	12389	36.86	47.57
11/28/90	1300	7.45	68.92	4.69	1.43	0.21	2.80	8.89	5.81	99.99	12288	36.35	47.30
11/28/90	1600	7.26	68.29	4.77	1.39	0.21	2.97	9.28	6.04	100.00	12266	36.80	46.66
11/29/90	0900	8.07	67.81	4.68	1.40	0.20	2.88	9.17	5.99	100.00	12125	37.08	45.67
11/29/90	1300	7.14	68.60	4.74	1.39	0.20	2.76	9.07	6.30	100.00	12328	36.78	47.01
11/29/90	1600	7.22	68.99	4.65	1.45	0.20	2.84	8.85	6.00	100.00	12335	36.65	47.28
11/30/90	1000	6.80	69.44	4.81	1.47	0.16	2.81	8.77	5.90	100.00	12411	37.76	46.67
11/30/90	1300	7.21	69.40	4.81	1.42	0.16	2.77	8.21	6.18	100.00	12402	36.93	47.65
11/30/90	1600	7.36	69.07	4.73	1.42	0.19	2.78	8.87	5.76	99.99	12308	37.04	46.73
12/01/90	0900	7.31	69.03	4.82	1.37	0.17	2.86	8.57	6.04	100.00	12343	37.05	47.07
12/01/90	1300	7.41	68.51	4.83	1.42	0.14	2.92	9.04	5.88	100.01	12259	36.37	47.18
12/01/90	1300	7.21	68.51	4.66	1.57	0.09	3.00	8.81	6.24	100.00	12276	36.41	47.57
12/01/90	1600	6.98	69.08	4.84	1.38	0.14	3.00	8.62	6.11	100.01	12369	37.30	47.10
12/02/90	0900	7.54	68.81	4.85	1.40	0.15	2.84	8.66	5.90	100.00	12323	36.84	46.96
12/02/90	1300	7.43	68.90	4.67	1.38	0.17	2.93	8.76	5.94	100.01	12311	37.09	46.72
12/02/90	1600	7.65	68.63	4.69	1.38	0.19	2.85	8.64	6.16	100.00	12275	37.11	46.60
12/04/90	0900	8.13	68.21	4.73	1.44	0.19	2.79	8.78	5.91	99.99	12207	36.81	46.27
12/04/90	1300	7.83	68.43	4.65	1.36	0.24	2.82	8.62	6.29	100.00	12274	36.85	46.70
12/04/90	1600	8.08	68.31	4.69	1.41	0.27	2.87	8.68	5.97	100.01	12213	36.99	46.25
12/05/90	–	9.86	66.91	4.54	1.42	0.23	2.77	8.97	5.53	100.00	11917	36.04	45.13
	AVERAGE	7.50	68.65	4.73	1.42	0.18	2.86	8.83	6.00	100.00	12282	36.86	46.81
	STD DEV	0.66	0.56	0.08	0.05	0.04	0.07	0.25	0.18	0.01	105	0.36	0.60
	VARIANCE	0.43	0.31	0.01	0.00	0.00	0.01	0.06	0.03	0.00	11046	0.13	0.36

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TABLE 5-14 SMITH UNIT 2 CEGRIT AND BOTTOM ASH LOI ANALYSES

Test No.	Date	Time	Load MWe	Excess Oxygen %	CEGRIT		BOTTOM ASH	
					A-Side LOI %	B-Side LOI %	Sample Time	Composite LOI %
10-2B	11/28/90	1000-1051	182	2.8	4.14	2.91		
10-2C	11/28/90	1055-1500	183	2.8	3.29	2.12	1300	7.61
10-2D	11/28/90	1500-1750	184	2.8	2.82	2.30		
		AVERAGES:	183	2.8	3.42	2.44		
11-2A	11/29/90	0640-1005	182	2.7	4.09	2.53		
11-2B	11/29/90	1005-1330	182	2.7	2.90	2.15	1230	8.11
11-2C	11/29/90	1426-1727	183	2.7	2.65	1.99		
		AVERAGES:	182	2.7	3.21	2.22		
12-1A	11/30/90	0949-1130	133	2.8	1.88	2.76		
12-1B	11/30/90	1140-1500	132	2.8	2.84	1.91	1300	3.93
12-1C	11/30/90	1517-1830	133	2.8	2.67	2.00		
		AVERAGES:	133	2.8	2.46	2.22		
13-1A	12/01/90	0845-1023	136	2.5	3.74	2.70		
13-1B	12/01/90	1045-1400	136	2.5	4.22	3.43	1200	5.45
13-1C	12/01/90	1405-1706	136	2.5	3.45	2.90		
		AVERAGES:	136	2.5	3.80	3.01		
14-2A	12/02/90	0847-1100	113	3.6	2.86	2.55		
14-2B	12/02/90	1218-1516	113	3.6	2.56	2.79	1230	4.60
14-2C	12/02/90	1542-1756	113	3.6	2.52	2.93		
		AVERAGES:	113	3.6	2.65	2.76		
15-1A	12/03/90	0750-0946	113	3.2	5.53	4.21		
15-1B	12/03/90	1011-1220	113	3.2	5.24	-	1315	4.81
15-1C	12/03/90	1241-1619	114	3.2	3.19	3.16		
		AVERAGES:	113	3.2	4.65	2.46		
16-1A	12/04/90	0742-0933	180	4.0	2.09	1.73		
16-1B	12/04/90	0939-1140	180	4.0	1.87	1.80		
16-1C	12/04/90	1327-1506	180	4.0	2.07	1.78	1330	4.91
		AVERAGES:	180	4.0	2.01	1.77		

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5.2.7 Boiler Efficiency

During selected Performance Tests at each load point, measurements were recorded of the flue gas temperatures and gaseous species, both upstream and downstream of the air preheaters, using the DAP and the ECEM for the purpose of calculating the Heat Loss Efficiency. Over several hours of each test the Yokagawa 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 5-15.

The purpose of the Boiler Efficiency calculations is to document the Phase I boiler efficiencies at specific operating conditions for comparison to the ~~subsequent~~ efficiencies 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 upon the measured calorific value, moisture and chemical composition of the as-fired fuel samples taken during each test.

TABLE 5-15

LANSING SMITH UNIT 2 ASME PTC 4.1 BOILER EFFICIENCY

TEST NO.	LOAD (MWe)	O_2 (%)	EFFICIENCY AS MEASURED (%)	EFFICIENCY NORMALIZED (%)
11-2	182	2.6	90.09	89.70
12-1	133	2.8	91.19	90.73
14-2	113	3.5	91.50	90.94
16-1	180	4.0	90.11	89.72

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 test were performed during the week of March 14, 1991. During this period, twenty tests were performed from high to medium loads (180, 135 and 115MWe).

Table 5-16 presents a summary of the data taken during the verification testing. Thirteen tests were performed at the 180 MWe load point and the remaining nine tests were performed at the mid- to low-load points. During the last two days of testing at high loads, the excess oxygen distribution through the furnace was measured by Flame Refractories which indicated that significant in-leakage of air was occurring prior to the economizer inlet.

Figure 5-19 presents a comparison of the verification test results (Tests 21 and 22 only) with those for the Diagnostic testing (See Figure 5-3) for the 180 MWe load point. From Figure 5-21 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 5-20 presents a comparison of the verification test results with those for the Diagnostic testing (See Figure 5-4) for the 135 MWe load point. Testing at the 135 MWe load point was with only one (A MOOS) of the two mill patterns used during the Diagnostic testing. From Figure 5-20 it is evident that the verification trends and the absolute levels of NOx were remarkably similar to those for the Diagnostic test results.

Figure 5-21 presents the comparison for the 115 MWe test point. These data illustrate that the trends were similar and the verification tests bounded the data from the diagnostic tests.

All of the tests during the verification testing indicated that no significant changes in operation occurred during the long-term testing period.

TABLE 5-16 PHASE 1 VERIFICATION TEST RESULTS

TEST NO.	DATE	LOAD	MOOS PATTERN	O2 %	NO ppm	CO ppm
19-1	03/14/91	116	AB	4.0	416	6
19-2	03/14/91	116	AB	5.3	461	8
19-3	03/14/91	116	AB	6.5	490	9
19-4	03/14/91	115	AE	6.6	432	7
19-5	03/14/91	114	AE	4.5	345	7
20-1	03/15/91	136	A	3	397	7
20-2	03/15/91	137	A	3.9	456	6
20-3	03/15/91	136	A	4.9	487	7
20-4	03/15/91	136	A	5.8	510	9
21-1	03/16/91	180	None	2.2	383	10
21-2	03/16/91	181	None	3.0	433	10
21-3	03/16/91	181	None	4.1	469	13
22-1	03/17/91	179	None	4.8	540	9
22-2	03/17/91	179	None	3.7	471	7
22-3	03/17/91	180	None	2.5	421	8
23-1	03/18/91	182	None	3.4	475	7
23-2	03/18/91	182	None	3.3	467	7
23-3	03/18/91	182	None	3.4	470	8
23-4	03/18/91	182	None	3.7	485	8
23-5	03/18/91	182	None	3.5	492	7
24-1	03/19/91	181	None	4.6	523	7
24-2	03/19/91	182	None	4.4	529	7

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FIGURE 5-19 VERIFICATION TEST CHARACTERIZATION
180 MWe NOMINAL LOAD

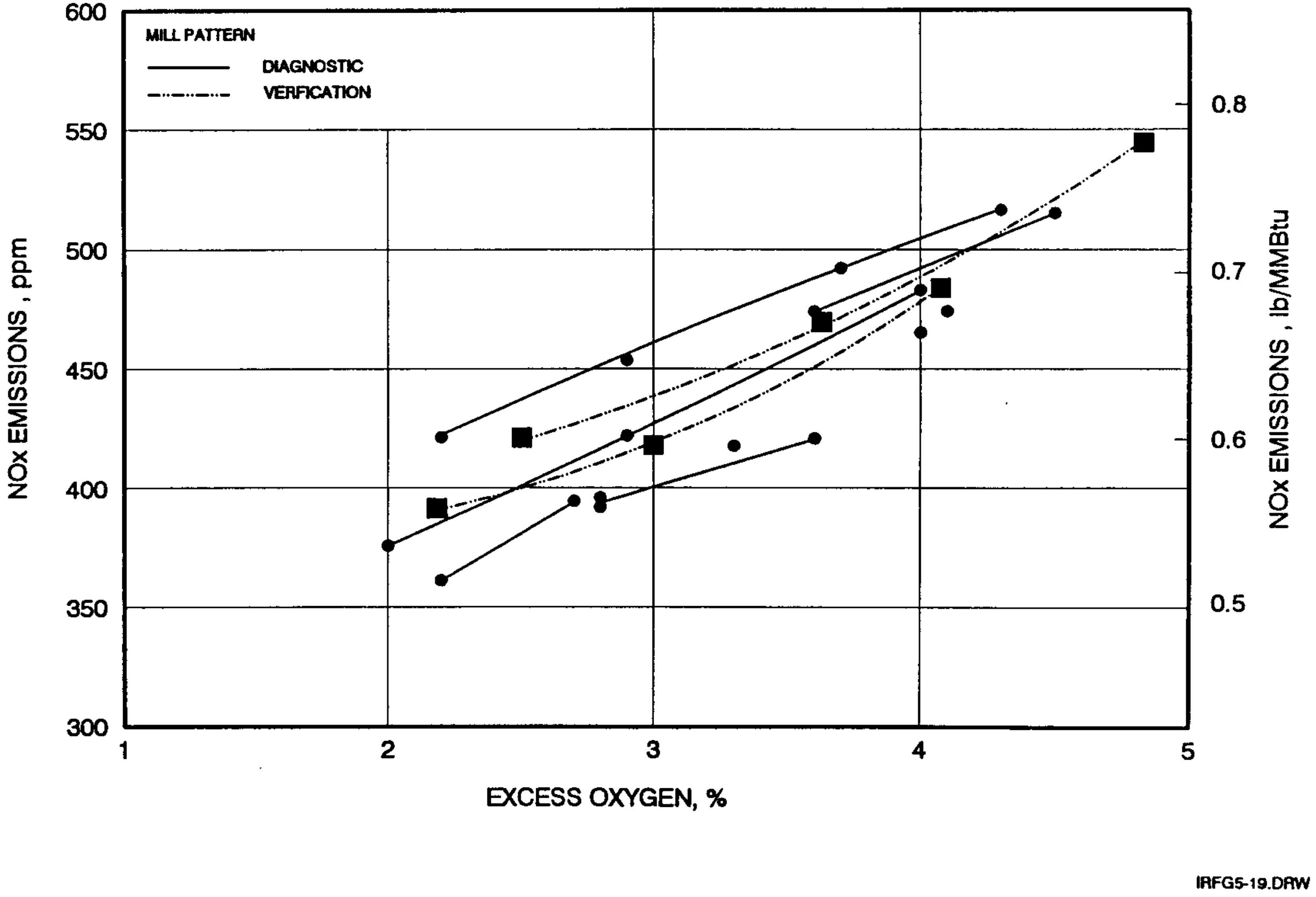


FIGURE 5-20 VERIFICATION NOx CHARACTERIZATION

135 MWe NOMINAL LOAD

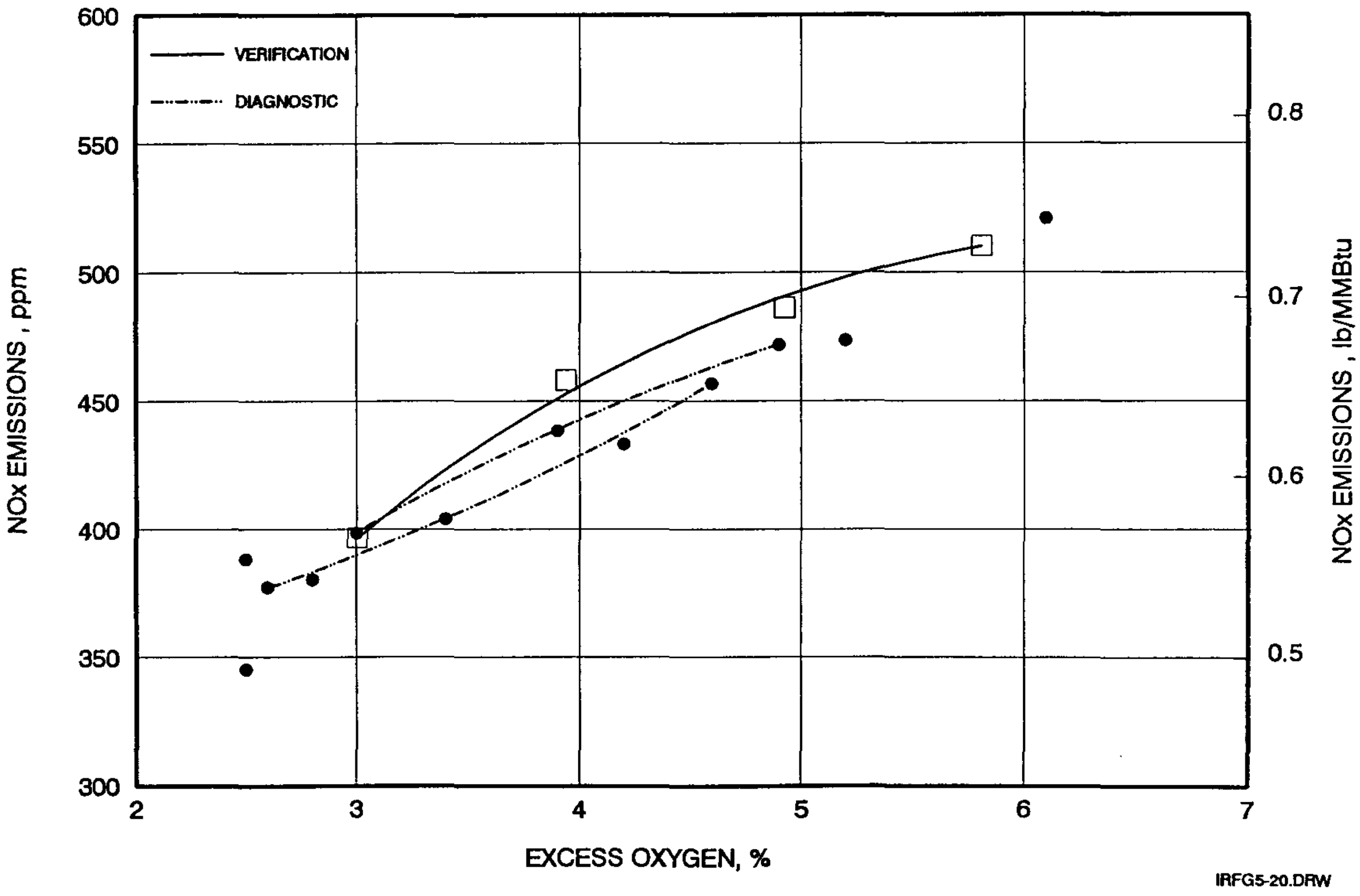
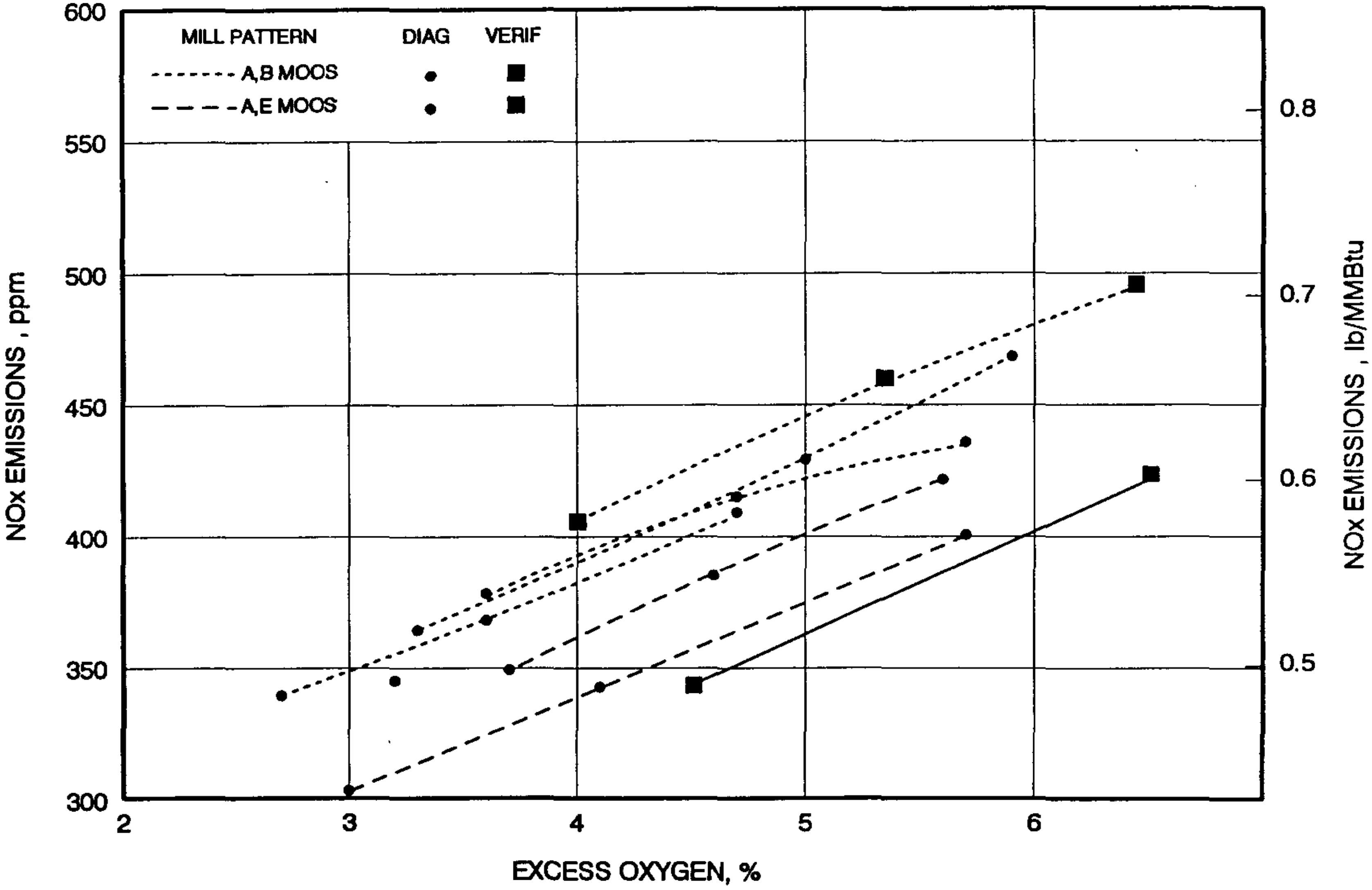


FIGURE 5-21 VERFICATION NOx CHARACTERIZATION
115 MWe NOMINAL LOAD



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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 mid December 1990 through the end of March 1991. During this period two unit outages were experienced. The data capture during this three and one half month period was 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 O_2 and mill patterns for all five-minute ECEM data,

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

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

and 5) Comparison of long-term results to short-term results.

The following paragraphs describe the results of these analyses.

6.1 Unit Operating Characteristics

Figure 6-1 illustrates the NOx emissions variation for the load scenario during the month of January 1991 for the long-term testing. This months characteristic is representative of the mode of operation during the other months of data collection. From Figure 6-1 it can be seen that the five-minute average NOx emissions generally varied from approximately 0.70 to 0.50 lb NOx/MMBtu during the month of January. 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 (70 MWe) to the maximum continuous operating load (200 MWe) during the entire long-term test period.

From the data for the long-term testing, the daily averages of load and NOx were determined and are shown in Figure 6-2. These daily average data were determined using the EPA criteria for valid data explained in Section 4.2.1. Only days with at least 18 hours of data are presented in this figure. These data are used to determine the 30-day rolling averages and the achievable emission levels discussed in later sections. It is evident that during the long-term testing that the average daily

FIGURE 6-1 HOURLY AVERAGE CHARACTERISTICS

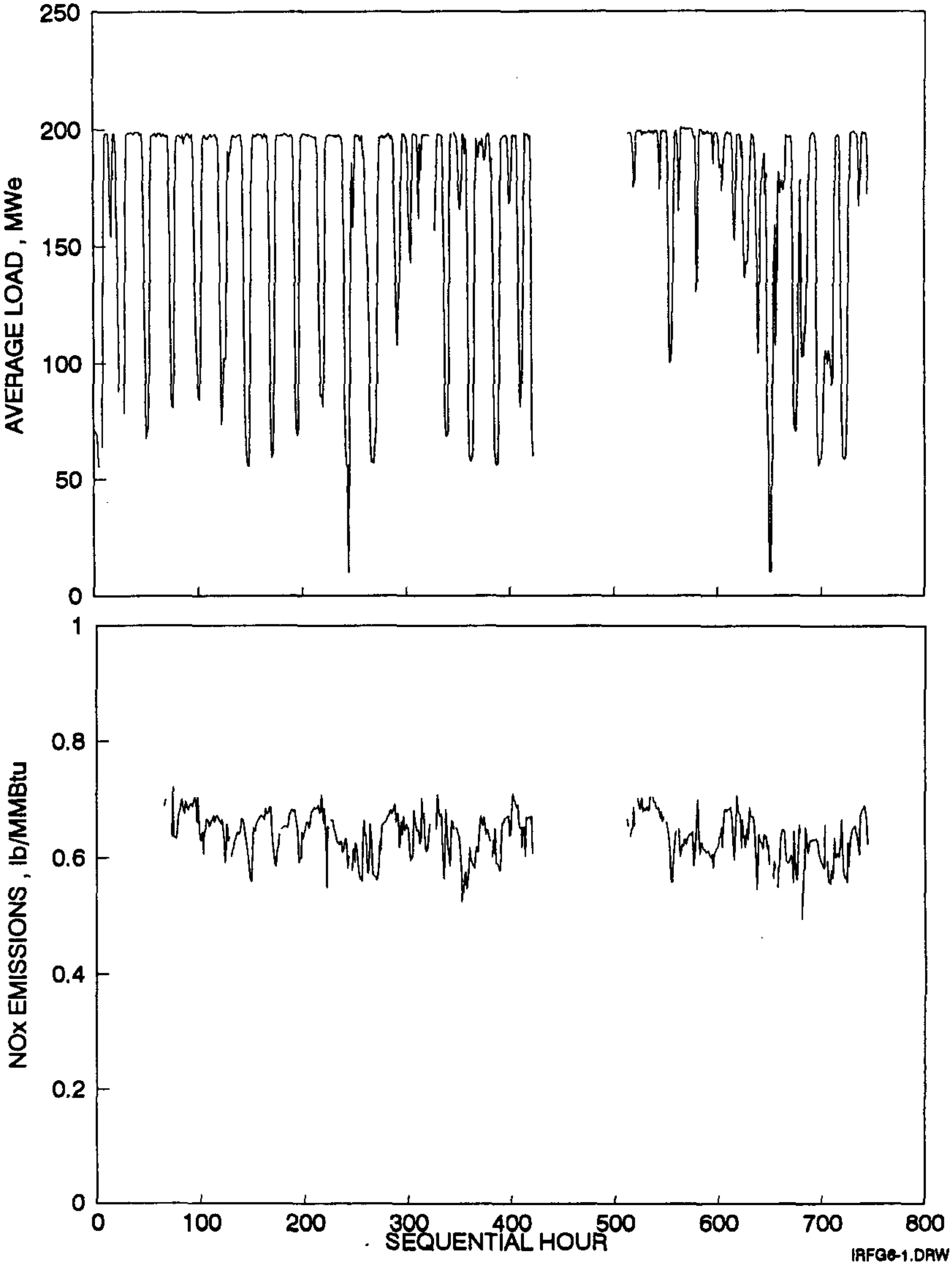
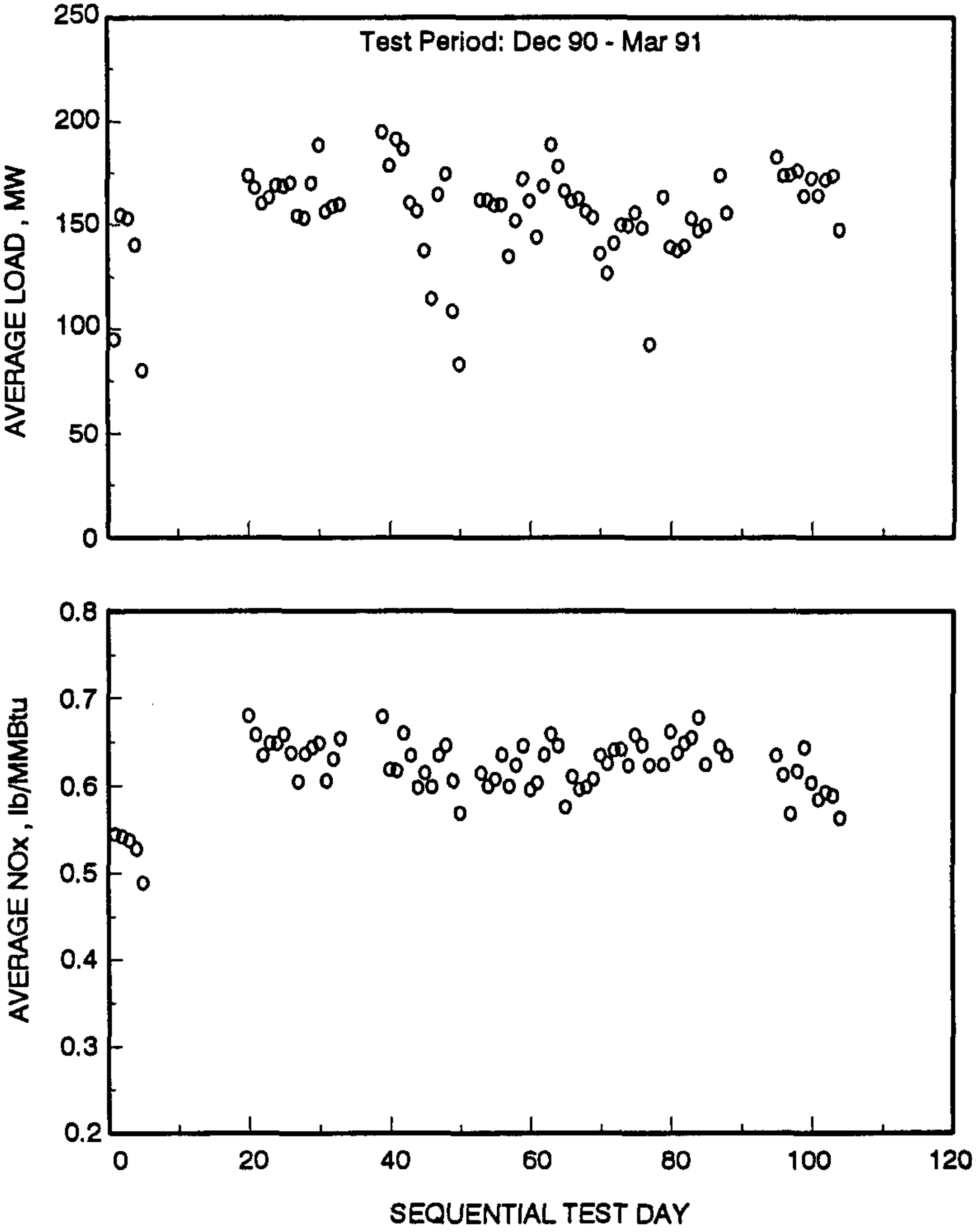


FIGURE 6-2 DAILY AVERAGE CHARACTERISTICS



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load was in excess of 150 MWe. Only four days were at a load below 100 MWe. For this long-term period, the daily average emissions fell within a very narrow range from approximately 0.50 to 0.70 lb NOx/MMBtu.

One method of characterizing the boiler operating characteristics during the long-term testing is to examine the within-day variation of load and NOx. This was accomplished by segregating the data by hour of the day, i.e., 0100, 0200,...2400. For these segregated data, the mean load and NOx were computed. In addition, the hourly values representing the lower 5 percent and upper 95 percent confidence intervals (CI) of all values were determined. Figure 6-3 illustrates the daily trend for load and NOx emissions over the entire long-term test period. The figure illustrates that the unit was operated as a base loaded unit for most of the day (on average 14 hours were near 180 MWe). It is evident from this figure what characteristics the NOx versus load exhibit. 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 10 MW wide load ranges. Table 6-1 provides the results for this segregation of the data for the entire long-term data set. The population for each load range, as well as the mean lower five percentile and upper ninety-five percentile are shown for both load and NOx emission values. Figure 6-4 illustrates the NOx versus load trend for these data.

Figure 6-4 exhibits a bi-modal NOx versus load characteristic. The general characteristic is increasing NOx with increasing load except in the 100 to 150 MWe range. This bi-modal characteristic was most likely due to the mill patterns generally used in this load range. Overall, the mean NOx varied from a low of 0.54 to a high of 0.65 lb/MMBtu. The 95 percent confidence interval, however, varied from a low of 0.43 to a high of 0.72 lb/MMBtu.

The effect of operating O_2 on NOx emissions for certain mill patterns was examined for load ranges that corresponded to those tested during the short-term test portion of the Phase I test effort. These short-term ranges were the 180-190, 130-140, 110-120 and 65-75 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

FIGURE 6-3 WITHIN DAY AVERAGE CHARACTERISTICS

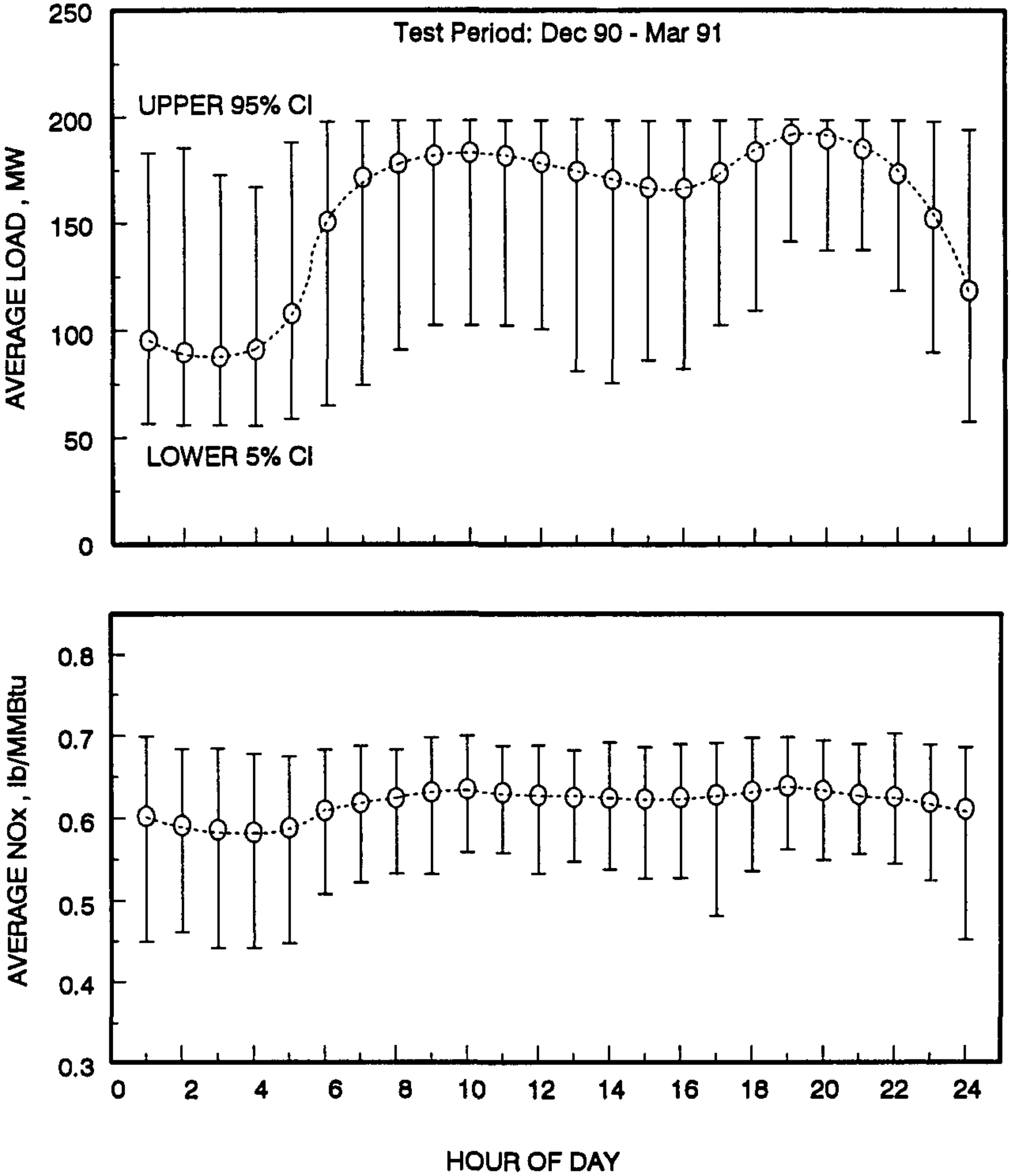

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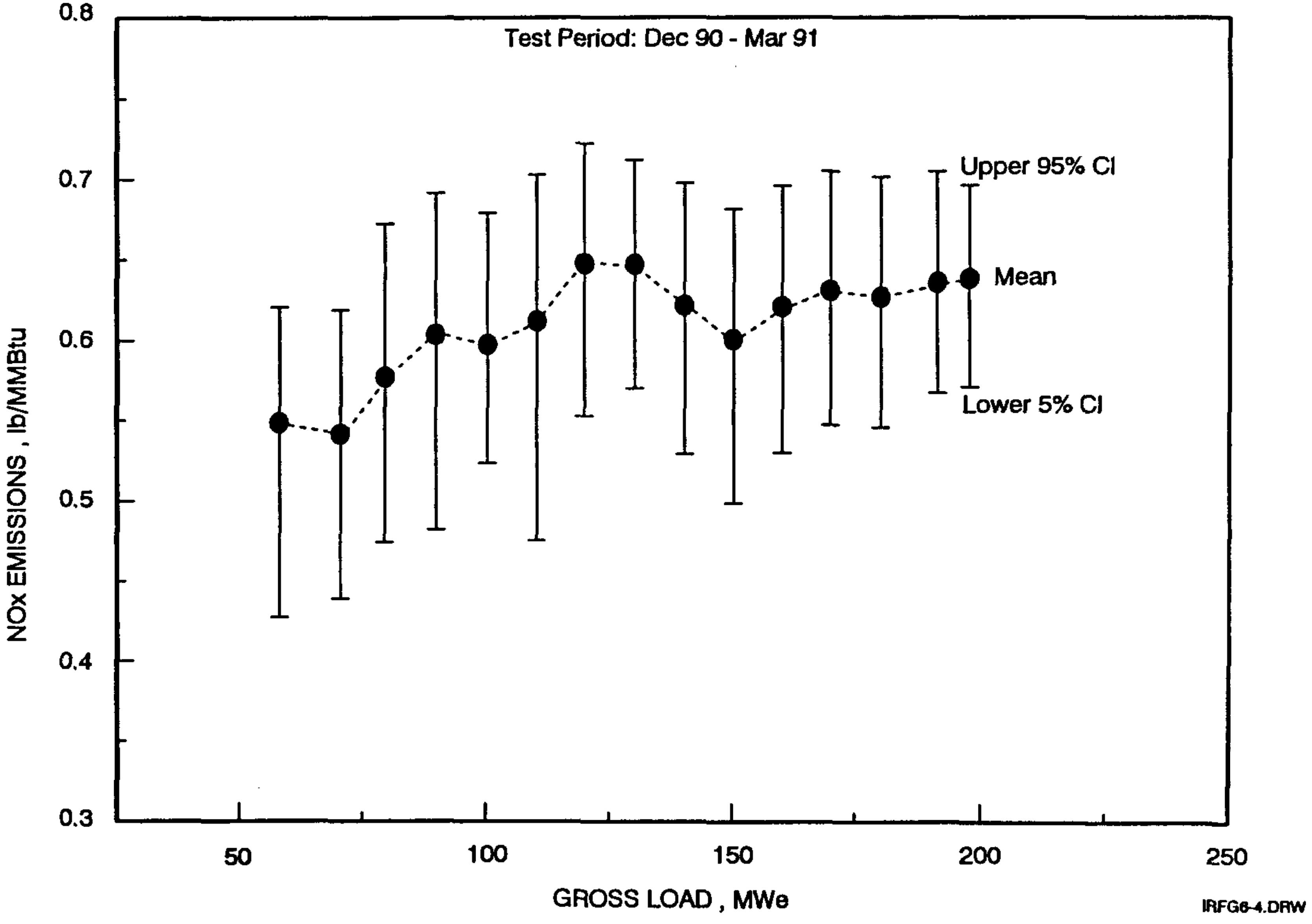
TABLE 6-1 BASELINE TEST LOAD SEGREGATION

PLANT SMITH BASELINE TESTING PHASE I: DECEMBER 1990 - MARCH 1991
AVERAGE BY LOAD RANGE
5 MINUTE DATA

		Load			O2			NOx		
Load Range	n	Lower 5%	Average	Upper 95%	Lower 5%	Average	Upper 95%	Lower 5%	Average	Upper 95%
55-65	1892	55.5	58.0	61.5	7.85	9.38	10.35	0.427	0.549	0.621
65-75	892	66.5	70.4	74.5	7.05	8.59	9.65	0.439	0.542	0.619
75-85	763	75.5	79.4	84.5	6.85	8.26	9.35	0.474	0.577	0.672
85-95	609	85.5	89.8	94.5	6.45	8.05	9.25	0.482	0.604	0.691
95-105	696	95.5	100.3	104.5	6.35	7.68	8.75	0.524	0.598	0.679
105-115	772	105.5	110.4	114.5	6.15	7.56	8.75	0.475	0.612	0.703
115-125	611	115.5	120.0	124.5	6.25	7.60	8.55	0.553	0.648	0.722
125-135	721	125.5	130.1	134.5	6.25	7.38	8.35	0.570	0.647	0.712
135-145	771	135.5	140.2	144.5	5.75	6.85	7.95	0.529	0.622	0.698
145-155	812	145.5	150.1	154.5	4.95	6.31	7.55	0.498	0.601	0.682
155-165	840	155.5	160.1	164.5	5.05	6.23	7.25	0.530	0.621	0.696
165-175	987	165.5	169.8	174.5	5.05	6.15	7.15	0.547	0.631	0.705
175-185	1085	175.5	180.0	184.5	4.85	5.91	6.85	0.546	0.627	0.701
185-195	1762	185.5	191.2	194.5	4.65	5.69	6.75	0.567	0.636	0.705
195-200	9192	195.5	197.5	199.5	4.55	5.45	6.25	0.571	0.639	0.696

FIGURE 6-4 BASELINE LOAD CHARACTERISTICS



to determine the most frequently used patterns the frequency distribution of the mills in service (AMIS) pattern was determined. Table 6-2 presents the frequency distribution for the two most commonly used mill patterns for the load ranges tested during short-term testing. the patterns are dictated by the operational requirements of the unit, i.e., slag minimization and steam temperature control.

TABLE 6-2 MILL PATTERN USE FREQUENCY

Load Cell (MW)	MOOS	Sample Size	Average Load (MW)	Average NOx (lb/MMBtu)	Average O_2 %
175-185	NONE	991	179.6	0.61	6.4
	E	36	180.6	0.64	6.6
130-140	A	555	135.1	0.60	6.5
	AB	44	132.7	0.64	7.0
110-120	AB	521	114.6	0.63	6.5
	ABE	92	113.7	0.55	6.6
65-75	ABC	843	70.6	0.50	7.9
	ABE	23	70.9	0.49	8.5

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.

All of the valid five-minute load data were 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. These long-term results will be compared to the short-term results for the same mill patterns in Section 6.5.

6.3 Thirty-day Rolling Averages

The NSPS Subpart Da and Db standards are based upon compliance on a thirty-day rolling average. While this unit is not required to comply with these standards, it is of some value to evaluate the data for Phase I on a thirty-day rolling average basis and later compare it to the results from subsequent phases. Thirty-day rolling average load, NOx, and O_2 were computed using the valid hourly data as defined by the EPA criteria explained in Section 4.2.2. These thirty-day rolling averages are shown in Figure 6-9 for the 95 (66 rolling averages) valid days (by EPA criteria) of data.

It should be pointed out that the thirty-day rolling average results shown in Figure 6-9 are only representative of the load scenario that was experienced by the unit during this long-term test period. During other periods when the load might be significantly different, the rolling averages would be expected to be somewhat different. For this particular period, it can be seen that there was an increase in the daily load as the testing began and stabilized to a level of approximately 150 MWe after the first month of monitoring.

It was shown in the Figure 6-4 the NOx emissions have a non-linear relationship with increasing load with two peaks in NOx emissions at 125 and 200 MWe. The average load increased over the long-term test period and passed through the peak at 125 MWe and subsequently stabilized at the 150 MWe average load point. This 150 MWe load point corresponds to a minimum NOx emission point between the two peaks (125 and 200 MWe). Based upon this, it is not surprising that the rolling average NOx emissions decreased 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 1977 NSPS 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

FIGURE 6-5 70 MWe EXCESS OXYGEN CHARACTERISTICS

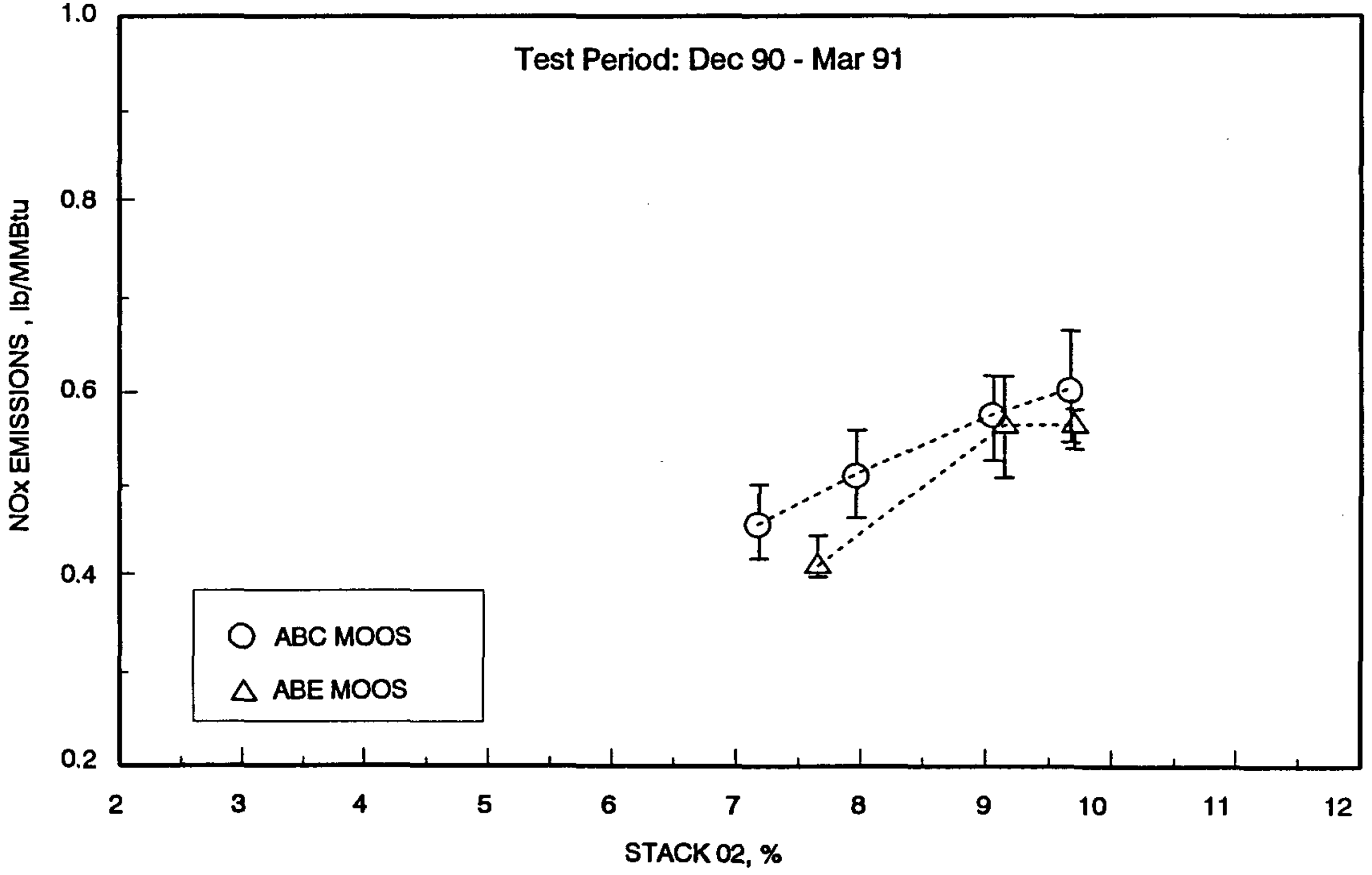


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FIGURE 6-6 115 MWe EXCESS OXYGEN CHARACTERISTICS

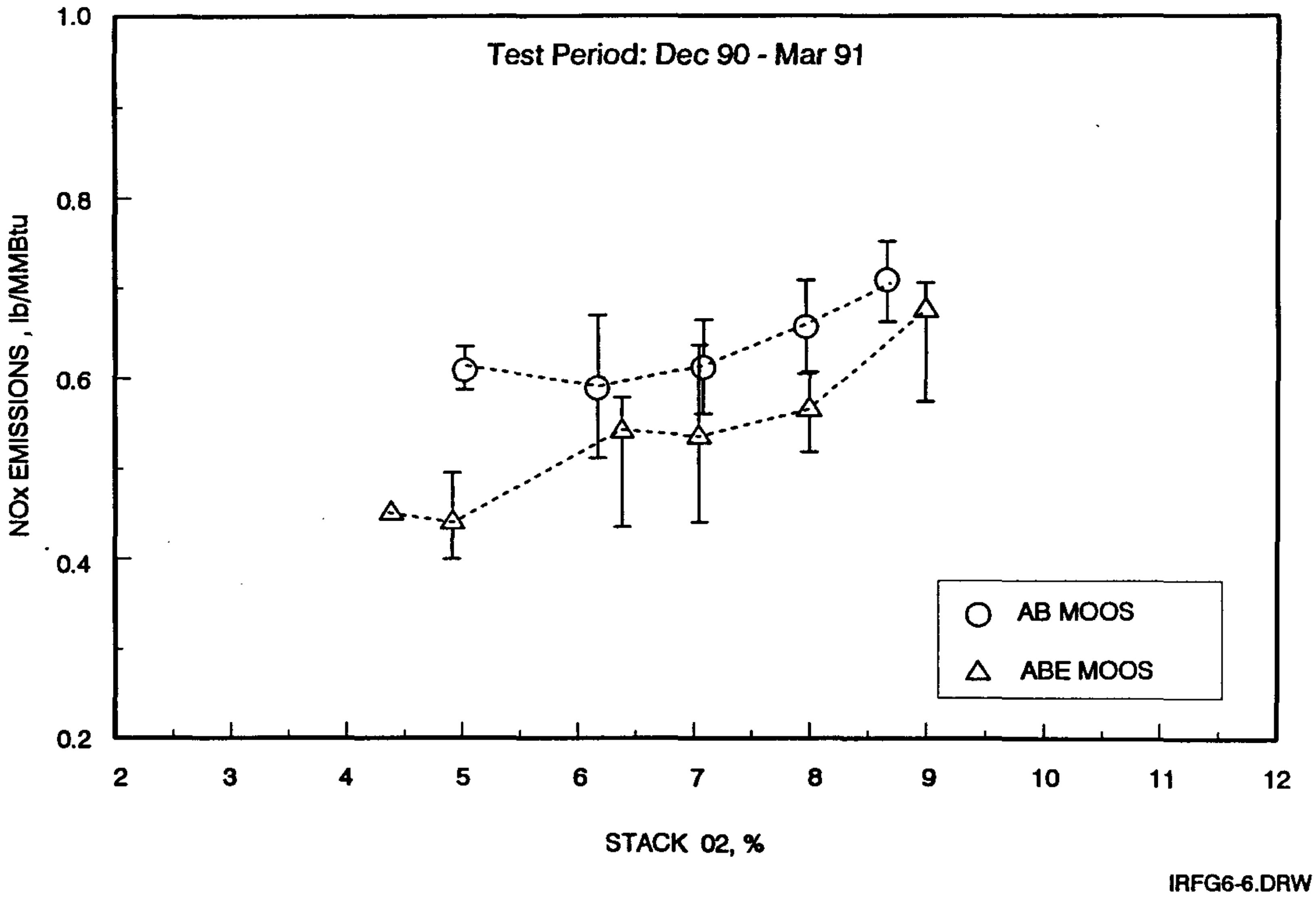

FIGURE 6-7 135 MWe EXCESS OXYGEN CHARACTERISTICS

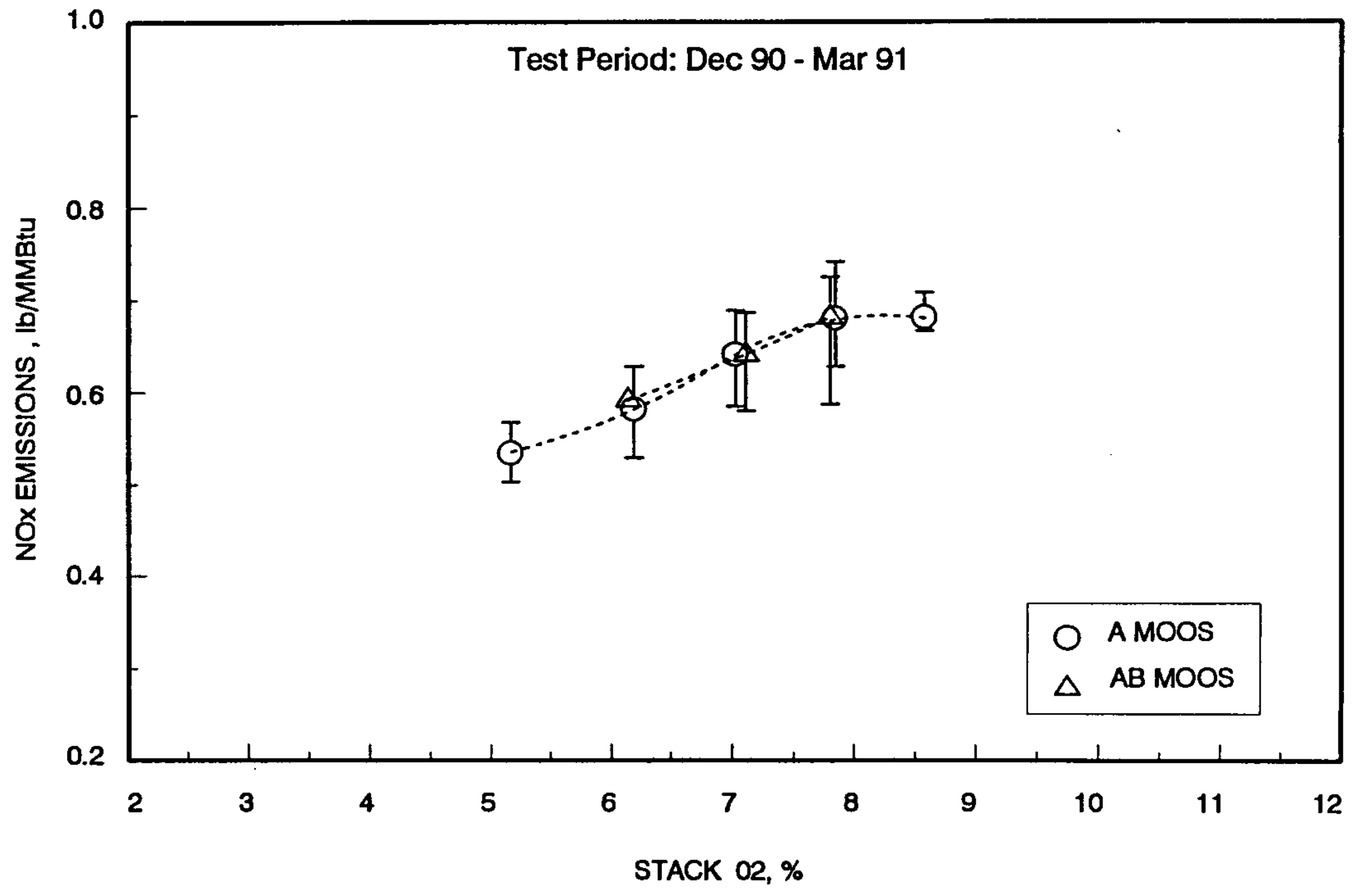

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FIGURE 6-8 180 - 200 MWe EXCESS OXYGEN CHARACTERISTICS

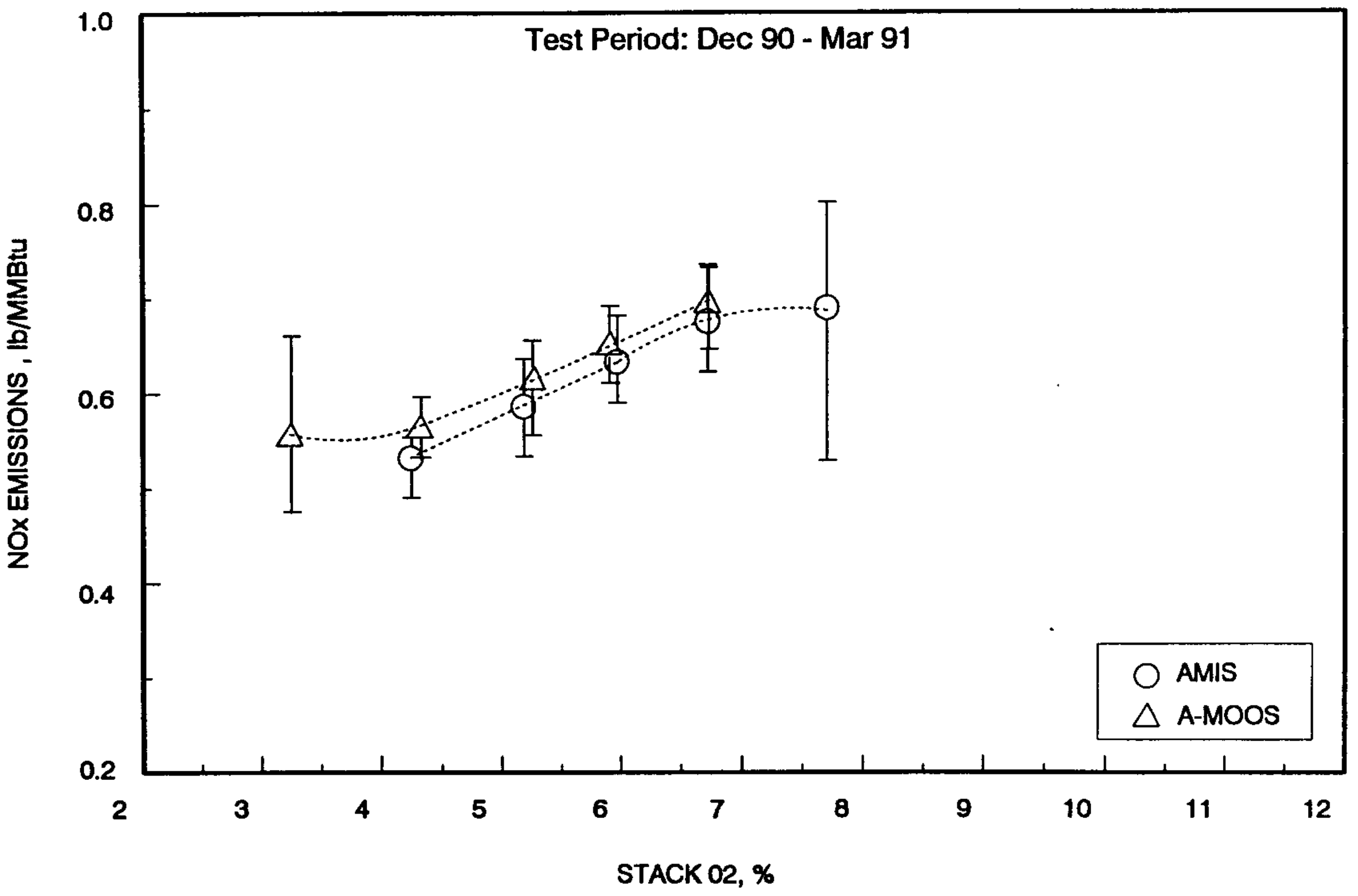

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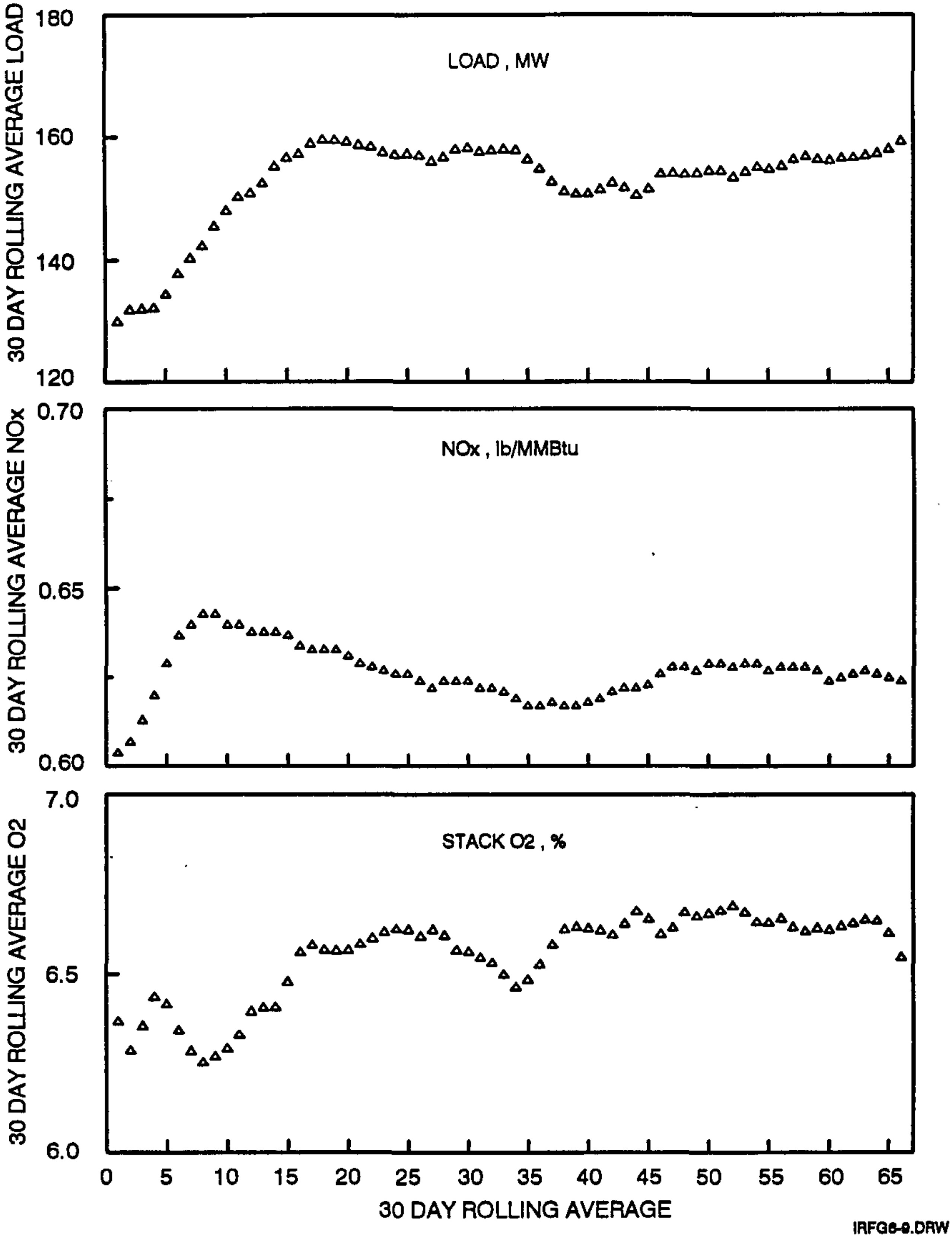
FIGURE 6-9 30-DAY ROLLING AVERAGE CHARACTERISTICS



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	75
Average Emissions (lbNOx/MMBtu)	0.62
Standard Deviation (lbNOx/MMBtu)	0.036
Distribution	Normal
First Order Autocorrelation (ρ)	0.75
Standard Error of Autocorrelation	0.09

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 and the hourly average values used to calculate these averages. The achievable emission levels are calculated for both the 30-day rolling average criteria for NSPS units and for the proposed requirements for an annual average for pre-NSPS units subject to the Clean Air Act Amendments of 1990. The achievable NOx emission limits shown in this table, are computed for two conditions - no autocorrelation (ρ=0) and the estimated value of 0.75 (which indicates a highly time dependent data set). The assumption in this table is that Lansing Smith Unit 2 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 and the annual averages would be different and therefore the achievable emission levels would also be different.

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

Autocorrelation Coefficient	Achievable Emission Limit (lb NOx/MMBtu)	
	30-Day	Annual
$\rho = 0$	0.64	0.62
$\rho = 0.75$	0.68	0.63

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

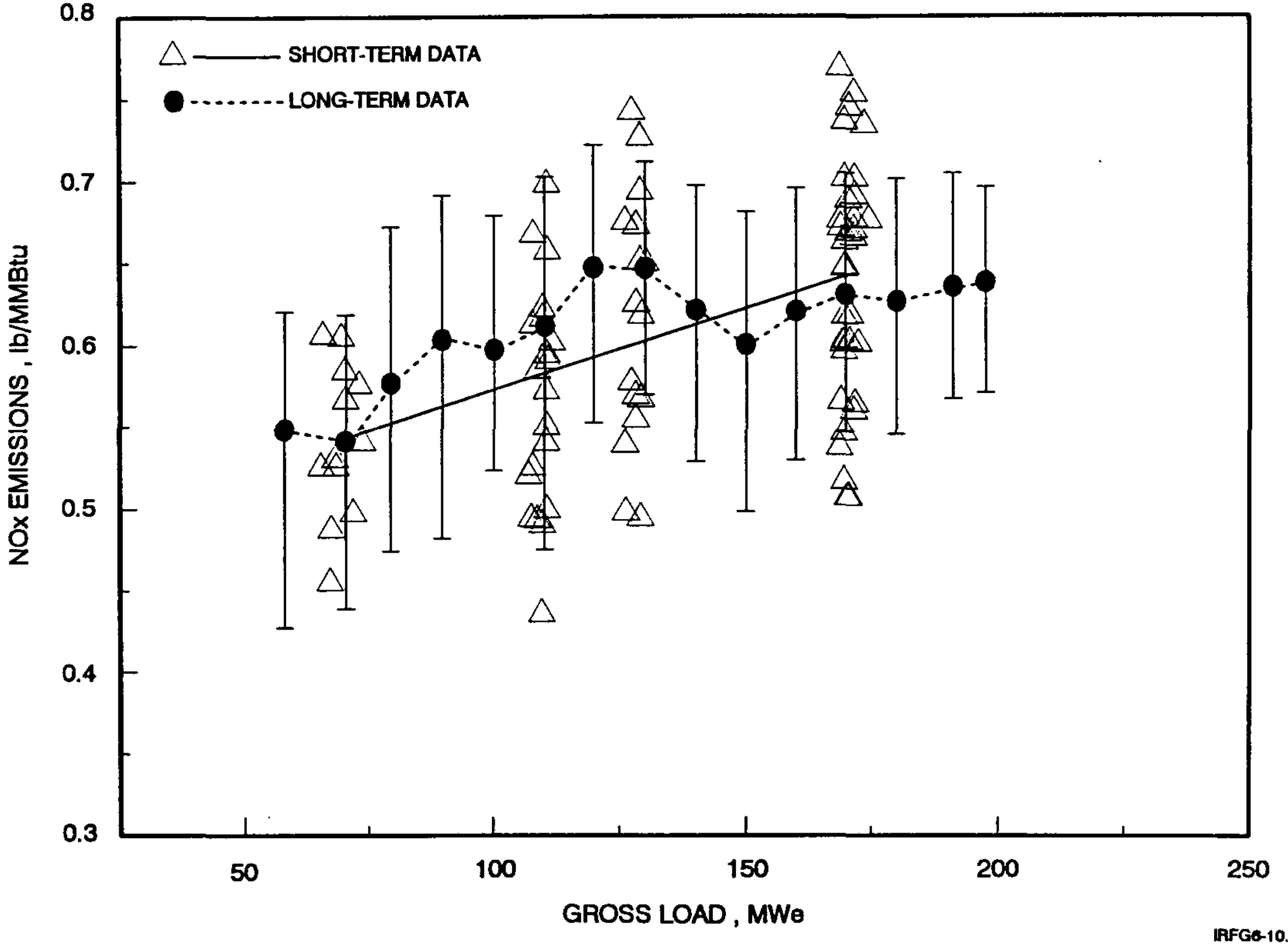
6.5 Comparison of Long- and Short-Term NOx Data

Section 5.1 presented short-term data for the load characteristics (See Figure 5-3 to 5-6). 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 long-term testing from mid December 1990 through the end of 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, outside the confidence interval particularly at the high load points. The exact explanation for this is not certain, however, it was pointed out in Section 5.1 that the conditions selected for short-term testing encompassed the outer limits of the excess oxygen ranges that might be expected during long-term testing. If the outer limits of the short-term NOx emissions were used to make estimates of the characteristic unit emissions, they would be severely overestimated. An interesting outcome of the comparison is that for this particular set of short-term data, the trends for the mean levels for both the long- and short-term data agree reasonably well. It is difficult to say if the same outcome would occur if the mix of configurations (MOOS patterns) used in the short-term effort were the same as that experienced during the long-term effort.

The short-term testing at the 180 MWe test point was performed with two mill configurations - all-mills-in-service and E mill-out-of-service . The AMIS configuration is the normal configuration and is the configuration that would be experienced most frequently during long-term testing. A comparison can be made between the long- and short-term data as a function of the

FIGURE 6-10 COMPARISON OF LONG- AND SHORT-TERM NOx DATA

ALL EXCESS OXYGEN LEVELS



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operating excess oxygen. The long-term data was obtained from the ECEM after the air preheater. As a result of this, the air preheater leakage was included in the oxygen measurement at this point. The short-term Diagnostic results were obtained at the economizer exit and consequently did not include the APH leakage. Before the comparisons could be made, the long-term data had to be adjusted for the APH leakage based upon the best fit of the leakage data, i.e., not on an individual test point basis. Figure 6-11 shows the comparison for data obtained from Figure 5-4 for short-term data and Figure 6-8 for long-term data. This comparison again points out that most of the NOx data from the short-term effort falls within the confidence band, however some of the data is outside the band. For the most part, the trends were quite similar for this particular set of short-term data. It should be pointed out that the true trend is represented by the long-term data mean values since short-term test data are collected under fixed steady-state conditions.

During the short-term Diagnostic testing at 135 MWe, the A- and AB-MOOS patterns were tested. At this load the A-MOOS pattern was the predominate mill pattern used during long-term testing (See Table 6-2). Figure 6-12 provides a comparison of the short-term data from Figure 5-6 and the long-term data from Figure 6-6. Again, due to the preheater leakage, the long-term excess oxygen had to be adjusted. From Figure 6-12 it can be seen that the available short-term data at this load point falls within the confidence band. In addition, the trends appear to agree reasonably well for both long- and short-term data.

The comparisons of the long- and short-term data indicate that, for the most part, the measured data falls within the confidence band determined for the long-term emissions. It is evident from the comparison that the true characteristics are provided by the long-term data. The short-term data do, however, provide some insight into the <u>general</u> characteristics of the NOx emissions.

FIGURE 6-11 COMPARISON OF LONG- AND SHORT-TERM NOx DATA
180 MWe NOMINAL LOAD

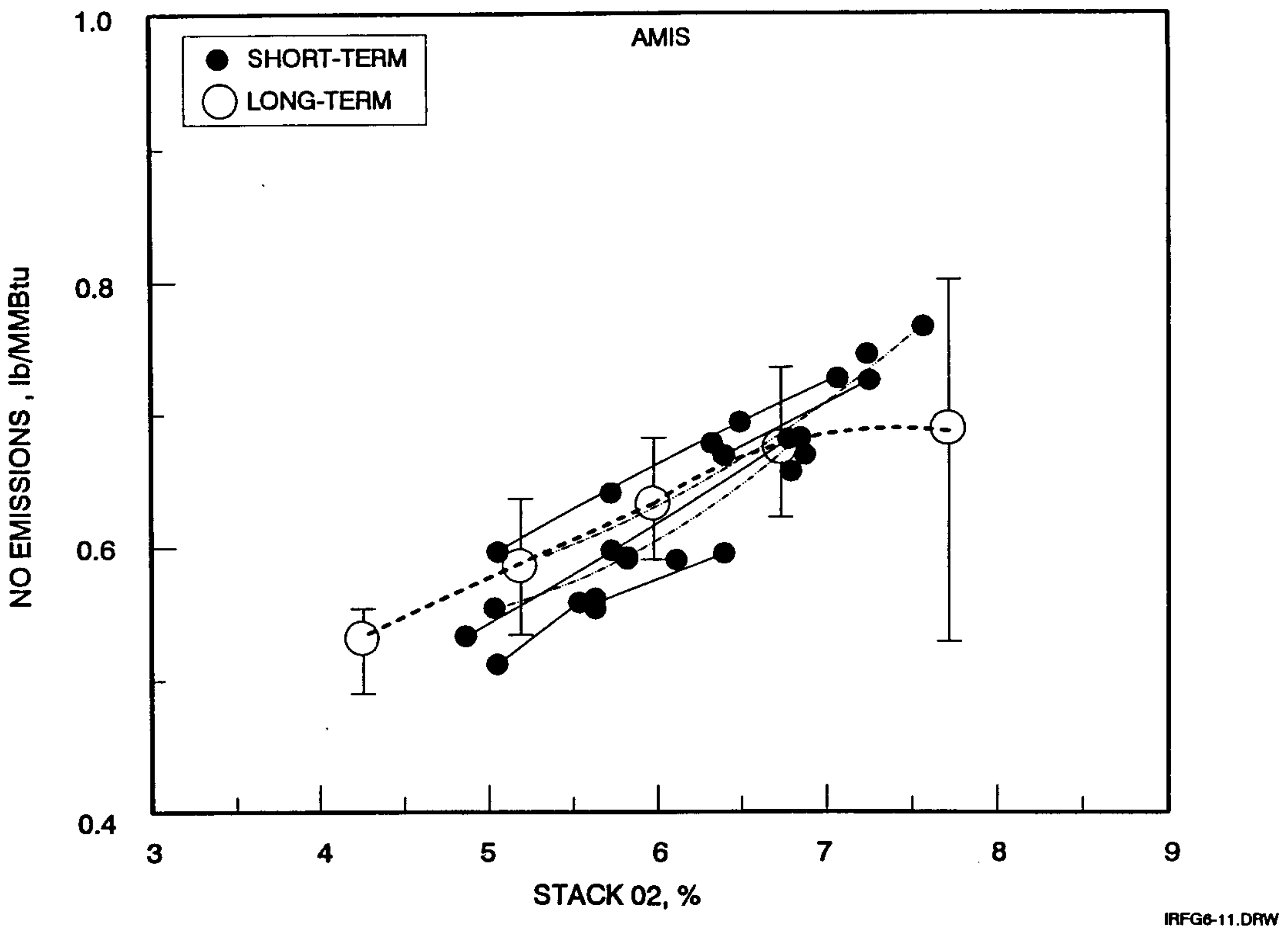
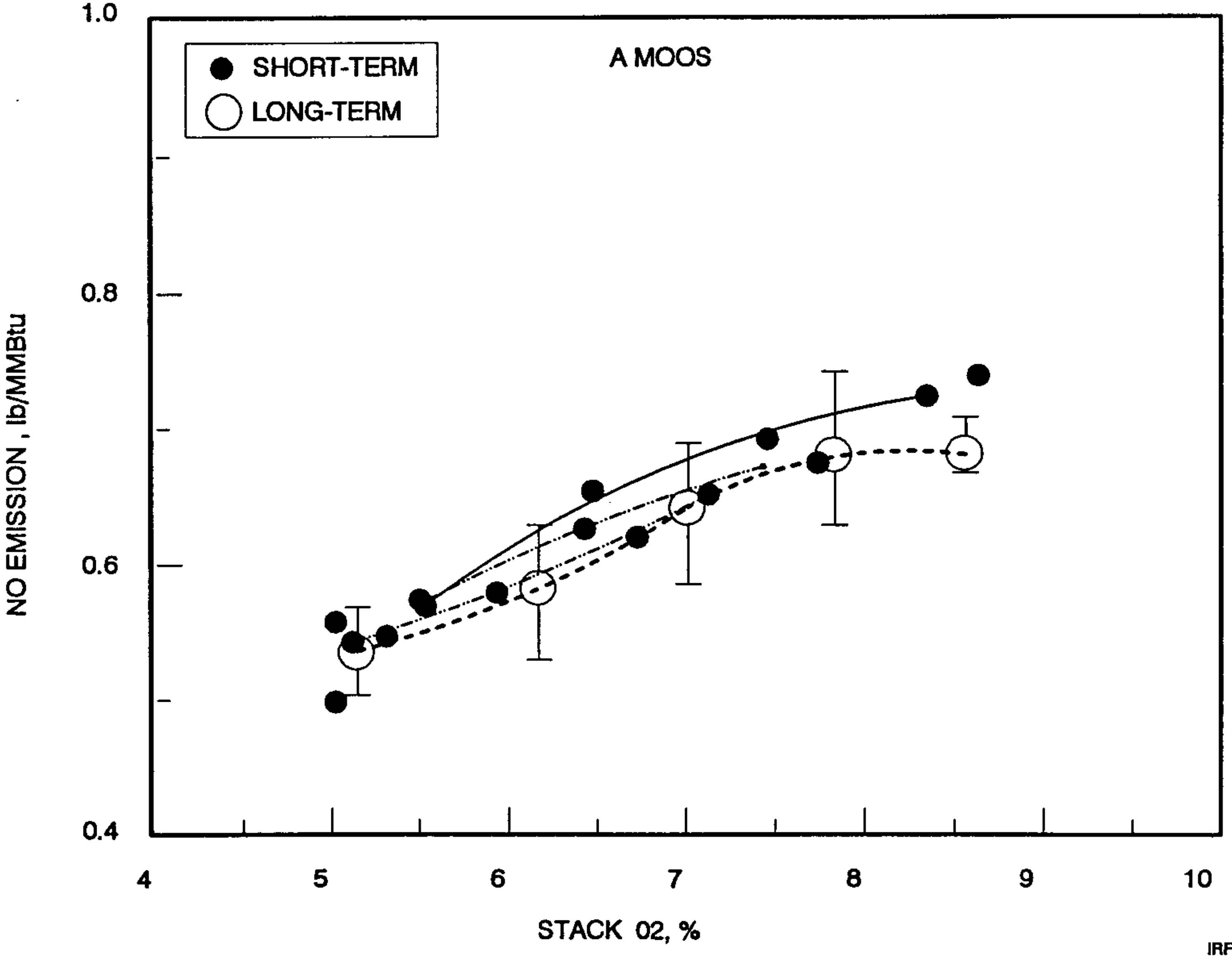


FIGURE 6-12 COMPARISON OF LONG- AND SHORT-TERM NOx DATA
135 MWe NOMINAL LOAD



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7.0 CONCLUSIONS

The primary objective of the Phase I test effort was to document the existing condition of Unit 2 and to establish the "as-found" NOx emissions under short-term well controlled conditions and under long-term normal System Load Dispatch conditions. In addition, other important performance data related to the present operation of the boiler were documented for comparison to those measured during subsequent phases after retrofit of low NOx combustion control techniques. A secondary objective of this phase was to establish protocols for data collection and instrumentation operation for subsequent phases of the demonstration.

The following paragraphs provide brief discussions of the conclusions that can be drawn from the short-term and the long-term test results. Conclusions related to the comparison of the short- and long-term results are also presented. After the completion of Phase II (and subsequent phases), comparative analyses will be performed to assess the effectiveness of the individual NOx control techniques with respect to the Baseline emissions. Conclusions for these comparative analyses will be presented at that time.

7.1 Short-Term Characterization Tests

During both the Diagnostic and Performance portions of this test effort, the coal supply remained relatively constant and no significant difficulties with Unit 2 equipment were experienced. The initial test plan was established based upon the characteristics of the unit as they were known at the beginning of the program. Upon initiation of the test effort it was discovered that considerably less time was required to establish satisfactory test conditions than was anticipated. This resulted in greater than anticipated tests being performed (30 initially planned versus 56 performed) in the time allotted for the Diagnostic test portion of the testing. This ability to perform relatively large numbers of tests in a test day will be incorporated into the plans for subsequent phases of the project.

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

7.1.1 Diagnostic Test Conclusions

The conclusions for the Diagnostic portion of the testing are based primarily upon testing performed at 180, 135, 115 and

70 MWe at approximately the same frequency. The major conclusions for the Diagnostic testing are:

1) The variability of the short-term data was found to be relatively low. In general, conditions and NOx data could be repeated with little data scatter.

2) NOx emissions were very well behaved showing the maximum data scatter of ± 7 percent at the 180 MWe load point and to less than ± 2 percent at the lower loads.

3) All of the trends for all loads and mill patterns exhibited increasing NOx with increasing O_2; however, the slopes were different for the different loads. The slope varied from 50 ppm/ percent O_2 at 180 MWe to 33 ppm/ percent O_2 at 70 MWe;

4) NOx emissions increased slightly with increasing load. On average, the NOx increased by approximately 0.7 ppm/MWe over the load range of 180 to 70 MWe.

7.1.2 Performance Test Conclusions

The Performance tests documented the unit characteristics at nominal loads of 180, 135 and 115 MWe. Over the 10 to 12 hour period of the individual performance tests, the unit operated under extremely stable normal operating conditions. Due to difficulties with the ECEM O_2 analyzer, the initial tests at the 180, 135 and 115 MWe test points were at actual excess oxygen levels some 1.0 to 1.5 percent lower than normal. One test at the end of the performance testing was performed at an excess oxygen level above the normal operational level. The 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) O_2 spatial distributions within the furnace exit showed non-uniformities in the excess oxygen to the burner corners. Mill coal flow measurements indicated that the coal flow was non-uniform resulting in the excess oxygen maldistribution.

3) Coal fineness was from 58 to 65 percent through a 200 mesh screen based upon the samples taken in the coal pipes. Sampling at the mill outlet showed mill fineness of approximately 70 percent through 200 mesh. The measured fineness through a

50 mesh screen was from 96 to 98 percent for samples taken in the coal pipes.

4) Peak furnace exit gas temperatures were generally below 2400 °F near the nose. Some locations exceeded 2600 °F during the low O_2 180 MWe test condition.

6) ESP entrance particle size was within the range predicted by the EPRI Database Predictions for Precipitator Performance. The mass-median diameter was 17 υ with a standard deviation of 3.6 υ.

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

8) LOI was nominally two to five percent as expected. The LOI measurements indicated that LOI increased with decreasing excess oxygen. Carbon in ash was very close to the LOI data and was generally five percent lower than the LOI.

7.1.3 Verification Test Conclusions

Based upon the results of 22 verification tests at loads of 180, 135 and 115 MWe performed subsequent to the long-term testing, it can be concluded that no significant changes in NOx characteristics occurred during the long-term test period.

7.2 Long-Term Characterization Tests

Long-term testing took place from mid December 1990 through late March 1991. During this period the KVB Extractive Continuous Emission Monitor (ECEM) was operated 24 hours per day except during periods of repair and calibration. Sufficient data was collected to perform meaningful statistical analyses for both engineering and regulatory purposes.

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

1) Data confirmed that the unit typically operates uniformly over the useful load range for the majority of it's on-line time. The unit would be classified as a cycling unit on this basis.

2) Daily average NOx emission levels ranged from approximately 0.57 to 0.68 lb/MMBtu while the daily average load ranged from 70 to 150 MWe.

3) Data for the various mill patterns indicated that NOx increased with increasing O_2. The 95 percent confidence intervals for NOx emissions at high

load mill patterns was in the order of ± 0.06 lb/MMBtu about the mean.

4) The mean load characteristics showed that NOx generally increased as load increased from 70 to 180 MWe but that there were two NOx peaks (125 and 150 MWe). Mean emissions ranged from 0.54 to 0.65 lb/MMBtu over the load range. The 95 percent confidence intervals for NOx emissions over the load range was in the order of ± 0.07 lb/MMBtu about the mean.

5) Based upon 30-day rolling averages, the data showed that the average load slowly increased from 130 to 160 MWe over the first two months of testing. 30-day rolling average NOx generally stabilized between approximately 0.65 and 0.62 lb/MMBtu.

6) Statistical analyses indicated that the data were autocorrelated with a correlation coefficient of $\rho = 0.75$. The data are therefore were highly autocorrelated (time dependent).

7) Non-time dependent ($\rho = 0$) analyses resulted in an achievable emission level of 0.64 lb/MMBtu for the load scenario experienced during the long-term testing. Time dependent ($\rho = 0.75$) analyses resulted in an achievable emission limit of 0.68 lb/MMbtu which was moderately higher than the non-time dependent analysis.

8) Based upon annual average autocorrelated analyses the achievable annual average emission limit is 0.63 lb/MMBtu.

7.3 Short-Term/Long-Term Comparison Conclusions

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

1) The NOx trends were very similar for both short- and long-term data. The slopes (NOx vs O_2) agreed remarkably well for all test loads.

2) At all load conditions the emissions for the short-term data fit within the 95 percent confidence band for the long-term data. Few short-term data points fell outside this confidence band.

3) The good agreement between the short- and long-term data trends and absolute values demonstrates that Unit 2 is a well behaved unit and does not exhibit significant influence from "undefined parameters".