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

Topical Report
LNCFS Levels I and III Tests Results

DOE Contract Number:
DE-FC22-90PC89653

SCS Contract Number
C-91-000028

Prepared by:

Southern Company Services, Inc.
800 Shades Creek Parkway
Birmingham, Alabama 35209

Cleared by DOE Patent Counsel on August 17, 1993

LEGAL NOTICE

EXECUTIVE SUMMARY

This report presents results from the third phase of an Innovative Clean Coal Technology (ICCT) project demonstrating advanced tangentially-fired combustion techniques for the reduction of nitrogen oxide (NOx) emissions from a coal-fired boiler. The purpose of this project was to study the NOx emissions characteristics of ABB Combustion Engineering's (ABB CE) Low NOx Concentric Firing System (LNCFS) Levels I, II, and III. These technologies were installed and tested in a stepwise fashion at Gulf Power Company's Plant Lansing Smith Unit 2.

The project sponsors include the U. S. Department of Energy (DOE), the Electric Power Research Institute (EPRI), and The Southern Company. The DOE oversees the project through the Office of Clean Coal Technology located at the Pittsburgh Energy Technology Center. EPRI provides technical input to the project management team. Southern Company Services manages the project on behalf of The Southern Company, which includes five electric operating companies serving Alabama, Georgia, Florida, and Mississippi. ABB C-E Services is co-funding the project by sharing in the cost of the low NOx combustion technology.

The objective of this report is to provide the results from Phase III. During that phase, Levels I and III of the ABB C-E Services Low NOx Concentric Firing System were tested. The LNCFS Level III technology includes separated overfire air, close coupled overfire air, clustered coal nozzles, flame attachment coal nozzle tips, and concentric firing. The LNCFS Level I was simulated by closing the separated overfire air nozzles of the LNCFS Level III system.

Based upon long-term data, LNCFS Level III reduced NOx emissions by 45 percent at full load. LOI levels with LNCFS Level III increased slightly; however, tests showed that LOI levels with LNCFS Level III were highly dependent upon coal fineness. After correcting for leakage air through the separated overfire air system, the simulated LNCFS Level I reduced NOx emissions by 37 percent. There was no increase in LOI with LNCFS Level I.

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2. Summary Report on DOE ICCT II Phase 3B for Lansing Smith Unit 2. Energy Technology Consultants (ETEC) letter report from Lowell L. Smith to Robert R. Hardman dated August 3, 1993.

Summary Report on DOE ICCT II Phase 3A for Lansing Smith Unit 2

July 12, 1993.

July 12, 1993

Mr. Robert H. Hardman
SOUTHERN COMPANY SERVICES
800 Shades Creek Pkwy
Birmingham, Al 35209

SUBJECT: Summary Report on DOE ICCT II Phase 3A for Lansing Smith Unit 2

Dear Rob:

The purpose of this letter is summarize the major findings for the Phase 3A testing on Lansing Smith Unit 2. The objective of this test effort was to evaluate the effectiveness of the ABB-CE LNCFS Level 3 retrofit. Information related to the program structure, responsibilities of the various contractors, test setup, instrumentation and the impact of effluents on ESP performance are discussed in Reference 1. While Reference 1 addresses the findings for Phase 2 (LNCFS Level 2) these sections of the program were not substantially different from that for the Phase 3A effort.

The following paragraphs will provide summary information on the emissions of gaseous and solid matter and will discuss the findings of a Special LOI test effort undertaken subsequent to the completion of Phase 3B. In addition, information related to the unit performance impacts will be discussed. Detailed information related to the mill performance and combustion air flow distribution are presented in Reference 2. Similarly, the detailed results for the ESP measurements are discussed in Reference 3. Pertinent summary results from these efforts will be summarized in this letter.

ENERGY TECHNOLOGY CONSULTANTS, INC.
One Technology Drive, Suite I-809, Irvine, CA 92718 (714) 753-9129 Fax (714) 753-1528
51 Virginia Avenue, West Nyack, NY 10994 (914) 353-0306 Fax (914) 353-0308
12337 Jones Road, Suite 400, Houston, TX 77070 (713) 894-1091 Fax (713) 894-1094

INTRODUCTION

The initial Phase 3A test effort to evaluate LNCFS Level 3 began on December 5, 1991 and was completed on March 11, 1992. This initial test effort consisted of Diagnostic tests to evaluate the short-term emissions trends, Performance tests to evaluate the short-term performance impacts, Long-Term tests to evaluate the normal transient operation and Verification tests to determine if significant changes had occurred during the Long-Term effort. A subsequent series of tests were performed to establish the impact of coal fineness on NOx and LOI. This effort began on November 17, 1992 after the completion of the Phase 3B testing. Reference 4 describes this test effort.

PHASE 3A GASEOUS EMISSION TEST RESULTS

During the Phase 3A test effort, 23 days of short-term testing was performed. Long-term testing was performed over a period of several months beginning in early January 1992 and ending in mid-March 1992. The following paragraphs will describe the gaseous emission results for these two types of testing.

Short-Term Characterization Test Results

Short-term emission result were obtained during two different segments of the characterization - LNCFS Level 3 Normal Operating Characteristics and LNCFS Level 3 Coal Fineness Characteristics.

LNCFS Level 3 Normal Operating Characterization - The three types of testing performed during the initial short-term testing effort were Diagnostic, Performance and Verification. With regard to the gaseous emissions results, data from all three types of testing are determined in a consistent manner and therefore should show the same trends and characteristics. Table 1 provides a summary of all of the LNCFS Level 3 short-term tests results performed during the initial test effort.

Figure 1 illustrates the range of excess oxygen levels that were tested during the short-term testing. Included in this figure is the average control room excess oxygen level (measured at the economizer exit) recommended by ABB-CE. Except at the lower load ranges, the excess oxygen tested provided excursions about the recommended level. At the lower load levels, the excess oxygen level ranges were limited by operational constraints. Figure 2 provides the resultant NOx levels for these excess oxygen levels tested. Included in this figure is an approximate average NOx level for all of the tests performed at the various loads at the recommended excess oxygen levels. These approximate averages were obtained from the NOx data for the individual loads discussed below.

Figures 3 through 7 illustrate the NOx versus O_2 trends for operation with the LNCFS Level 3 configuration at nominal loads of 200, 180, 135, 115 and 70 MWe. The numbers in the figures represent the test day and test numbers. Solid lines are drawn through tests performed on the same day with the same boiler setting. The curves for loads below 200 MWe show that there is a reasonable amount of data scatter at any given load. In addition, all of the figures show that the NOx emissions are relatively sensitive to excess oxygen excursions with NOx increasing with increasing excess oxygen level.

Figure 8 provides a comparison of the NOx trends for the Baseline and the Level 3 configurations at 180 MWe. While it is not possible to obtain an accurate picture of the effectiveness from the short-term data, the figure illustrates the general trend. As will be shown in the following paragraphs on Long-Term data analysis, emission reductions are the greatest at high loads and diminish as the load is decreased to the control point (80 MWe).

LNCFS Level 3 Mill Fineness Characteristics - As part of the Phase 3A effort, the effect of coal fineness was evaluated during the Special LOI testing. Table 2 provides a summary of the test results performed during the Special LOI test effort. This effort was initiated after the LNCFS Level 1 test effort was completed. The during this special test effort, the Separated Overfire Air Ports were opened to the prescribed positions to configure the boiler in the Level 3 mode of operation. Detailed information related to these Special LOI tests are included in References 4 and 5. The coal fineness for this test effort was varied in three steps at a nominal load of 180 MWe. During each step in fineness, the fineness was measured by Flame Refractories using their methods (similar to ASME methods) and locations and by plant personnel using the methods recommended by ABB-CE (See Ref 4).

Figure 9 presents the results of the testing over the excess oxygen range normally experienced on the Lansing Smith Unit 2. Fineness values are shown in this and subsequent figures for both FRI and Plant measurements. Figure 10 shows that these data are consistent with data taken during the initial Phase 3A test effort and exhibits the same degree of data scatter. Figures 11 and 12 illustrate that while the LOI is a strong function of coal fineness, the NOx emissions are, for all intents and purposes, insensitive to the fineness in the range of fineness normally experienced on this boiler.

Long-Term Characterization Test Results

During the long-term testing, virtually no intervention by the test team members was made to adjust the operation. Instructions provided by ABB-CE were utilized to provide guidance to the plant personnel on the proper mode of operation in the LNCFS Level 3 configuration. The most illustrative data from the long-term testing is the emission characteristics over the load range. Table 3 provides a summary of the long-term average NOx, economizer O_2 and the CO emissions. This table includes the data for the upper 95 percent and the lower 5 percent of the data variation. Data in this table illustrates that the data scatter for long-term data is significant. This scatter is a result of the normal variation of numerous parameters such as coal properties, mill settings, burner settings, etc.

Figures 13 through 16 show the average trends for the Phase 3A NOx, economizer O_2 and CO compared to those for the Baseline configuration. As shown in Figure 13, over the useful load range (200 to 70 MWe) the average NOx levels for the LNCFS Level 3 configuration were below those of the Baseline configuration. As the load approached the lowest automatic control load point (70 MWe), the NOx emission reduction effectiveness began to approach the Baseline levels. This decreased effectiveness is illustrated in Figure 14 which shows that below 140 MWe, the effectiveness decreases significantly until at approximately 70 MWe the NOx reduction is below 10 percent.

Operationally the LNCFS Level 3 configuration generally required a higher level of excess oxygen. This is illustrated in Figure 15 which shows that over the load range the long-term LNCFS Level 3 excess oxygen was higher than during Baseline operation. At loads above 150 MWe, the excess oxygen was 0.5 to 0.75 percent higher for the LNCFS Level 3 configuration. In spite of the increased excess oxygen levels for LNCFS Level 3, the carbon monoxide emissions were higher than Baseline particularly at loads above 150 MWe as is shown in Figure 16. The average CO levels experienced during long-term LNCFS Level 3 operation were, however, well within the range of safe and efficient operation.

Data from the long-term testing was used to estimate the achievable emission limitations. The achievable emission limitations were calculated for 30-day averages and for an annual average. The following compares the Baseline levels with those obtained from the Level 3 testing.

AVERAGING PERIOD	BASELINE	LEVEL 3
30-Day Average	0.68	0.44
Annual Average	0.63	0.40

These achievable emission results were based upon the load scenarios that were experienced during the Baseline and Level 3 test periods. An indication of the load scenarios during these phase can be obtained from the data utilized to calculate the achievable emission limitations. Figure 17 shows the percent of time at each load that was experienced during both long-term test periods. The two load scenarios are very similar but are different in the fact that the Baseline configuration spent more time at the top load. The load scenario is an important factor in determining the achievable emissions. Further analyses would be necessary to assess the achievable emission limitations under the same load scenarios.

PHASE 3A PERFORMANCE TEST RESULTS

During the Phase 3A test effort, testing was performed to evaluate the impact of the LNCFS Level 3 retrofit on steaming characteristics, ash characteristics and unit efficiency. Most of these evaluations were made using short-term test data, however, the impact on steaming characteristics were evaluated using long-term data.

Steaming Characteristics

A summary of the average long-term superheat and reheat temperatures and the burner tilts are presented in Table 4. Additional data on the steaming characteristics is provided in Reference 6. This table shows the Baseline values compared to the Phase 3A values for these parameters. It should be pointed out that during the Baseline tests the tilts were fixed in the horizontal position due to mechanical problems. During the LNCFS Level 2 retrofit (Phase 2), the linkages were repaired and the tilts became completely operational. During the Phase 3A testing the linkages began to bind which did not permit the full range of operation of the tilts. The tilts were, however, partially functional during this test phase.

Figures 18 through 20 provide a comparison of the superheat and reheat temperatures, and the burner tilts. As shown in Figure 18 the superheat temperature was not affected by the Level 3 retrofit at the top load however as load was decreased below 150 MWe the temperature began to sag. This depression in temperature occurred even with the ability to utilize the tilts to compensate as shown in Figure 20.

A similar depression in temperature is shown in Figure 19 for the reheat temperature comparisons. The conclusion from this evaluation is that the Level 3 configuration impacted the ability to maintain the superheat and reheat temperature. Utilization of the tilts could not compensate for the impact on temperatures.

Loss-On-Ignition and Boiler Efficiency Characteristics

LOI was determined during the initial testing of Phase 3A and during the Special LOI testing. In both series of tests Southern Research Institute performed EPA Method 17 testing to gather the particulates. This particulate matter was analyzed to determine the LOI and the resulting data is presented in Table 2 for the Special LOI testing and in Table 5 for the Performance tests. Tables 2 and 5 also include information on the mill fineness through 200 mesh and remaining on 50 mesh.

Figure 21 provides a comparison of the Baseline and the Phase 3A LOI results from the Performance testing. This figure illustrates that there is a substantial increase in the LOI for the LNCFS Level 3 configuration. This impact on LOI not only affects the boiler efficiency but could affect the ability to sell the flyash.

During the Performance testing of each Phase of the program sufficient data were gathered to calculate the boiler efficiency using the ASME PTC 4.1 Short Form method. Table 5 presents the results of the PTC 4.1 analysis for the Performance test data for both the Baseline and the LNCFS Level 3 configurations. Figure 22 illustrates that their was a net efficiency loss ranging from 0.6 percent at low loads to 0.3 percent at high loads. A decrease of 0.6 percent is measurable using PTC 4.1 and therefore indicates that the efficiency is decreased a low loads. An efficiency difference of 0.3 percent is not within the accuracy of the PTC 4.1 method and therefore it cannot be said that the efficiency decreased at full load.

CONCLUSIONS

The major conclusions for the Phase 3A testing of the LNCFS Level 3 retrofit are briefly delineated below.

- NOx reductions ranging from as high as 47 percent at high loads to as low as 10 percent a low loads were measured based upon long-term data.
- Increases of Loss-on-ignition ranging from 2.7 percentage points at low loads to approximately one percentage point at high load were measured.
- Boiler efficiency was reduced at lower loads. High load efficiency changes were not discernable from the Baseline level.
- Superheat temperatures were unchanged over the load range. Reheat temperatures were reduced at lower loads.
- Coal fineness affected the LOI significantly. As fineness was increased, LOI decreased.
- Coal fineness had virtually no affect on NOx emissions.

More thorough conclusions will be provided in the final report which discusses the comparison of all four program phases.

If you have any questions concerning these analyses, please do not hesitate to contact me.

Sincerely,

Lowell L. Smith

ATTACHMENTS
References
Tables 1 through 5
Figures 1 through 22

REFERENCES

1. "180 Mwe Demonstration of Advanced Tangentially-Fired Combustion Techniques for the Reduction of Nitrogen Oxide (NOx) Emissions form Coal-Fired Boilers", Innovative Clean Coal Technology DOE Contract Number DE-FC22-90PC89653, Prepared by Southern Company Services, Jan 1992.

2. "Phase III Parametric Testing", Service Report No. 1991, Contract No. 5459-036, Prepared by Flame Refractories, Inc., Feb 1992.

3. "ESP Performance Analysis During Phase IIIa of the 180 MWe Demonstration of Advanced Tangentially-Fired Combustion Techniques for the Reduction of Nitrogen Oxide Emissions form Coal-Fired Boilers - Volume 1 - Results and Analysis", SCS Contract No. 196-90-107, Prepared by Southern Research Institute, Dec 1992.

4. Letter to R. H. Hardman (SCS) from L. L. Smith (ETEC), "Effects of Coal Fineness on NOx Emissions and Loss on Ignition for Lansing Smith Unit 2 Testing", Dated Jan 18, 1993.

5. Letter to R. H. Hardman (SCS) from L. L. Smith (ETEC), "Correction to Figures in Smith Special LOI Report dated January 18, 1993", dated June 15, 1993.

6. Letter to R. H. Hardman (SCS) from L. L. Smith (ETEC), "Summary of Steam Temperature and Tilt Profiles for All Phases of Lansing Smith DOE ICCT II Program" dated March 26, 1993.

TABLE 1
LANSING SMITH PHASE IIIa TEST SUMMARY

TEST NO.	DATE	LOAD MWe	MOOS	UCCOFA	LCCOFA	USOFA	MSOFA	LSOFA	BURNER TILT	CR O2 %	STK O2 %	DAS O2 %	NOC ppm	NOx lb/MMB	CO ppm
69-1	12/20/91	199	NONE	100	20	100	100	100	-1.1	4.4	6.1	3.8	234	0.318	13
69-2	12/20/91	200	NONE	100	20	100	100	100	-1.1	4.2	6.0	3.5	229	0.312	16
55-1	12/05/91	179	None	82	30	100	100	100	8.7	5.2	6.8	5.4	257	0.350	26
55-2	12/05/91	180	None	82	20	100	100	100	8.7	4.9	6.6	5.1	248	0.338	58
55-3	12/05/91	180	None	82	20	100	100	100	8.7	5.4	7.0	5.8	264	0.360	15
55-4	12/05/91	180	None	82	20	100	100	100	8.7	5.8	7.7	6.8	300	0.409	5
55-5	12/05/91	179	None	82	20	100	100	100	8.7	6.7	8.4	7.5	323	0.440	7
55-6	12/05/91	180	None	83	20	100	100	100	8.7	5.8	7.6	6.3	283	0.385	6
56-1	12/06/91	182	None	66	20	100	100	100	4.8	4.1	5.6	4.1	224	0.305	109
56-2	12/06/91	182	None	65	20	100	100	100	4.8	4.7	6.4	4.6	241	0.329	26
56-3	12/06/91	182	None	65	20	100	100	100	4.8	5.5	7.2	5.7	269	0.366	33
56-4	12/06/91	182	None	65	20	100	100	100	4.8	6.2	8.2	6.7	293	0.400	15
56-5	12/06/91	183	None	66	20	100	100	100	4.8	5.8	7.8	6.6	284	0.387	15
56-6	12/06/91	183	None	66	20	100	100	100	4.8	5.0	6.9	5.2	253	0.345	17
57-1	12/07/91	179	None	83	20	100	100	100	9.2	4.3	6.0	4.3	235	0.320	110
57-2	12/07/91	179	None	82	20	100	100	100	9.2	4.8	6.6	4.8	252	0.343	26
57-3	12/07/91	179	None	83	20	100	100	100	9.2	5.7	7.2	5.8	273	0.372	20
57-4	12/07/91	179	None	83	20	100	100	100	9.2	6.2	7.9	6.9	302	0.412	15
57-5	12/07/91	179	None	82	20	100	100	100	9.2	6.1	7.9	6.6	304	0.415	14
57-6	12/07/91	180	None	83	20	100	100	100	9.2	5.5	7.3	6.1	284	0.386	14
57-7	12/07/91	179	None	83	20	100	100	100	9.2	5.2	6.9	5.1	256	0.349	32
60-1	12/10/91	182	None	20	65	100	100	100	18.4	3.7	5.3	2.7	219	0.298	79
60-2	12/10/91	181	None	20	65	100	100	100	18.4	4.4	6.1	3.7	242	0.329	16
62-1	12/12/91	180	None	83	20	100	100	100	-0.8	4.5	6.3	4.0	231	0.315	15
62-2	12/12/91	182	None	82	20	100	100	100	-0.7	4.6	6.3	4.0	234	0.318	14
63-1	12/13/91	180	None	84	20	100	100	100	-1.8	4.4	6.4	4.0	222	0.302	12
63-2	12/13/91	179	None	83	20	100	100	100	-1.8	4.5	6.4	4.1	227	0.309	11
68-1	12/19/91	181	None	85	20	100	100	100	-0.8	4.4	6.4	3.9	226	0.308	17
68-2	12/19/91	180	None	82	20	100	100	100	-0.8	4.6	6.4	4.0	229	0.312	15
76-1	03/10/92	177	None	81	20	100	100	100	6	4.8	6.5	4.0	230	0.313	123
76-2	03/10/92	178	None	81	20	100	100	100	6	5.2	7.4	4.9	266	0.362	9
76-3	03/10/92	181	None	86	20	100	100	100	6	4.8		4.3	244	0.332	7
77-1	03/11/92	176	None	82	20	100	100	100	9	5.8		5.5	309	0.420	4
77-2	03/11/92	176	None	82	20	100	100	100	9	4.4		3.7	241	0.326	17
59-1	12/09/91	136	A	20	41	100	100	27	8.1	4.4	6.2	3.8	215	0.292	45
59-2	12/09/91	137	A	20	41	100	100	24	8.0	5.0	6.7	4.4	230	0.314	11
59-3	12/09/91	138	A	20	41	100	100	26	8.0	5.5	7.1	5.0	247	0.337	11
59-4	12/09/91	139	A	20	41	100	100	23	8.0	6.1	8.0	5.9	279	0.380	9
59-5	12/09/91	138	AB	20	41	100	100	25	8.0	6.3	8.1	5.9	261	0.356	11
59-6	12/09/91	138	AB	20	41	100	100	25	8.1	4.4	6.2	3.9	234	0.319	18
61-1	12/11/91	134	A	38	20	100	100	100	13.3	6.1	8.0	5.8	276	0.376	11
61-2	12/11/91	135	A	40	20	100	100	100	13.4	4.1	5.8	3.5	219	0.298	16
61-3	12/11/91	136	AB	39	20	11	100	100	13.4	4.1	6.0	3.4	250	0.340	62
61-4	12/11/91	137	AB	38	20	10	100	100	13.4	5.2	7.0	4.6	271	0.369	13
61-5	12/11/91	136	AB	38	20	12	100	100	13.4	6.5	6.2	6.0	284	0.387	11
66-1	12/17/91	135	A	43	20	31	100	100	-1.1	5.0	6.8	4.6	216	0.294	11
66-2	12/17/91	137	A	41	20	25	100	100	-1.1	5.1	6.8	4.5	216	0.294	11
67-1	12/18/91	133	A	39	20	24	100	100	-0.8	5.1	6.8	4.6	216	0.294	12
67-2	12/18/91	136	A	41	20	24	100	100	-0.8	5.1	6.7	4.4	213	0.290	10
77-3	03/11/92	135	A	38	20	100	100	10	15	6.1		6.0	302	0.412	5
77-4	03/11/92	135	A	38	20	100	100	10	15	5.1		4.9	279	0.380	5
77-5	03/11/92	135	A	38	20	100	100	10	15	3.6	5.9	3.2	234	0.319	17
58-1	12/08/91	114	AB	20	20	100	100	0	9.3	4.1	5.9	4.0	212	0.289	20
58-2	12/08/91	115	AB	20	20	100	100	0	9.3	4.2	6.1	4.2	220	0.299	11
58-3	12/08/91	115	AB	20	20	100	100	0	9.3	3.5	5.4	3.1	212	0.288	12
58-4	12/08/91	115	AB	20	20	100	100	0	9.3	4.8	6.6	4.3	234	0.319	13
58-5	12/08/91	115	AB	20	20	100	100	0	9.3	5.4	7.1	4.9	250	0.341	9
58-6	12/08/91	116	AB	20	20	100	100	0	9.3	5.8	7.6	5.6	262	0.357	9
64-1	12/14/91	111.9	A&B	20	20	-8	100	100	-1.3	5.5	7.3	5.2	229	0.312	8
64-2	12/14/91	112.55	A&B	18	20	-8	100	100	-1.3	5.5	7.4	5.2	231	0.315	7
65-1	12/15/91	113	AB	18	20	-8	100	100	-1.5	5.5	7.4	5.3	241	0.328	7
65-2	12/15/91	113	AB	18	20	-8	100	100	-1.5	5.6	7.4	5.3	238	0.324	4
76-4	03/10/92	116	AB	22	10	-8	100	100	15	6.1		5.8	290	0.395	4
76-5	03/10/92	116	AB	21	10	-8	100	100	15	5.2		4.9	281	0.383	6
76-6	03/11/92	116	AB	22	10	-8	100	100	15	4.6		4.1	266	0.363	6
74-1	01/12/92	68	A,B,C	-8	20	-8	-8	10	-0.8	5.6	8.7	5.8	330	0.450	9
74-2	01/12/92	68	A,B,C	-8	20	-8	-8	12	-0.9	5.0	8.0	4.8	300	0.409	10
74-3	01/12/92	68	A,B,C	-8	20	-8	-8	10	--	6.3	9.3	6.4	360	0.490	11
74-4	01/12/92	68	A,B,C	-8	20	-8	-8	10	-0.9	7.2	10.1	3.7	386	0.526	13
74-5	01/12/92	62	A,B,C	-8	20	-8	17	65	-1.0	5.5	6.7	5.7	233	0.317	15
75-1	01/13/92	60	A,B,C	-8	20	-8	5.9	59	-0.7	5.5	8.0	5.6	250	0.340	12
75-2	01/13/92	62	A,B,C	-8	20	-8	-8	-8	-0.7	5.7	8.2	5.6	327	0.446	11
75-3	01/13/92	69	A,B,C	-8	20	-8	-8	-8	-0.8	6.0	8.3	6.1	354	0.482	7
75-4	01/13/92	69	A,B,C	-8	20	-8	-8	10	-0.9	5.9	8.5	6.2	354	0.482	9
75-5	01/13/92	68	A,B,C	-8	20	-8	-8	40	-0.9	6.1	8.4	6.2	296	0.401	10

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TABLE 2
SUMMARY OF LOI TESTING

LANSING SMITH UNIT 2 SPECIAL LOI TESTING

ALL MILLS IN SERVICE, ZERO BURNER TILT

TEST	DATE	LOAD	CCOFA U/L	SOFA U/M/L	DAS O2 dry Pct	NOC dry ppm	NO dry lb/mmBtu	CO dry ppm	CLASSIF SETTING A/B/C/D/E	COAL FINENESS % THRU 200 MESH A/B/C/D/E	AVG LOI Pct	COMMENTS
103-1	11/17/92	181	83/20	100/100/100	2.3	206	0.279	214	3/1/1/2/3	54/53/50/49/51	11.9	LOI AT MIN XS O2, MINIMUM COAL FINENESS
103-2	11/17/92	181	83/20	100/100/100	3.2	221	0.301	22	3/1/1/2/3	54/53/50/49/51	10.8	LOI AT MED XS O2, MINIMUM COAL FINENESS
103-3	11/17/92	180	83/20	100/100/100	4.1	247	0.338	13	3/1/1/2/3	54/53/50/49/51	7.1	LOI AT HIGH XS O2, MINIMUM COAL FINENESS
104-1	11/18/92	179	83/20	100/100/100	2.4	202	0.275	209	4/2/3/3/4	57/57/58/52/56	7.8	LOI AT MIN XS O2, MEDIUM COAL FINENESS
104-2	11/18/92	180	83/20	100/100/100	3.1	220	0.303	20	4/2/3/3/4	57/57/58/52/56	5.6	LOI AT MED XS O2, MEDIUM COAL FINENESS
104-3	11/18/92	179	83/20	100/100/100	3.9	234	0.322	15	4/2/3/3/4	57/57/58/52/56	4.1	LOI AT HIGH XS O2, MEDIUM COAL FINENESS
104-4	11/18/92	179	83/20	100/100/100	3.3	216	0.297	43	4/2/3/3/4	57/57/58/52/56	6.1	LOI AT MED XS O2, MEDIUM COAL FINENESS
105-1	11/19/92	182	83/20	100/100/100	2.6	204	0.279	125	6/6/6/6/6	64/63/64/63/63	5.0	LOI AT MIN XS O2, MAXIMUM COAL FINENESS
105-2	11/19/92	182	83/20	100/100/100	3.1	215	0.293	39	6/6/6/6/6	64/63/64/63/63	3.4	LOI AT MED XS O2, MAXIMUM COAL FINENESS
105-3	11/19/92	181	83/20	100/100/100	4.2	230	0.315	13	6/6/6/6/6	64/63/64/63/63	2.4	LOI AT HIGH XS O2, MAXIMUM COAL FINENESS
105-4	11/19/92	182	83/20	100/100/100	3.0	214	0.293	21	6/6/6/6/6	64/63/64/63/63	3.2	LOI AT MED XS O2, MAXIMUM COAL FINENESS

FILE: D:\SCS\123R3\SP3ARPT\TABLE 2.WK3

TABLE 3 LNCFS LEVEL 3 LONG-TERM NOx EMISSIONS DATA

AVG LOAD MWe	LOWER5% OXYGEN Percent	AVG OXYGEN Percent	UPPER95% OXYGEN Percent	LOWER5% NOx lb/MMB	AVG NOx lb/MMB	UPPER95% NOx lb/MMB	LOWER5% CO ppm	AVG CO ppm	UPPER95% CO ppm
59	5.6	7.1	8.3	0.464	0.593	0.755	6	20	56
71	5.6	6.8	7.9	0.407	0.519	0.623	3	20	50
79	5.4	6.6	7.8	0.350	0.471	0.583	3	18	52
90	5.0	6.3	8.2	0.337	0.418	0.512	2	16	44
100	4.7	5.9	7.4	0.306	0.376	0.441	1	15	42
110	4.7	5.7	6.8	0.317	0.372	0.433	2	16	43
120	4.5	5.4	6.4	0.315	0.366	0.414	1	16	42
130	4.4	5.2	6.1	0.299	0.345	0.389	2	17	46
140	4.0	5.0	6.0	0.283	0.322	0.357	4	20	49
150	3.8	4.8	5.9	0.280	0.323	0.361	5	35	139
160	3.6	45.6	5.6	0.285	0.323	0.362	5	53	236
170	3.5	4.5	5.3	0.293	0.333	0.368	5	43	178
179	3.3	4.3	5.1	0.311	0.343	0.378	4	33	110
191	2.9	3.9	4.8	0.313	0.345	0.385	4	30	101
197	3.0	3.8	4.4	0.319	0.345	0.372	2	26	89

E:\SCS\123R3\SP3ARPT\TABLE 3.WK3

TABLE 4 COMPARISON OF BASELINE AND LEVEL 3 STEAMING CHARACTERISTICS

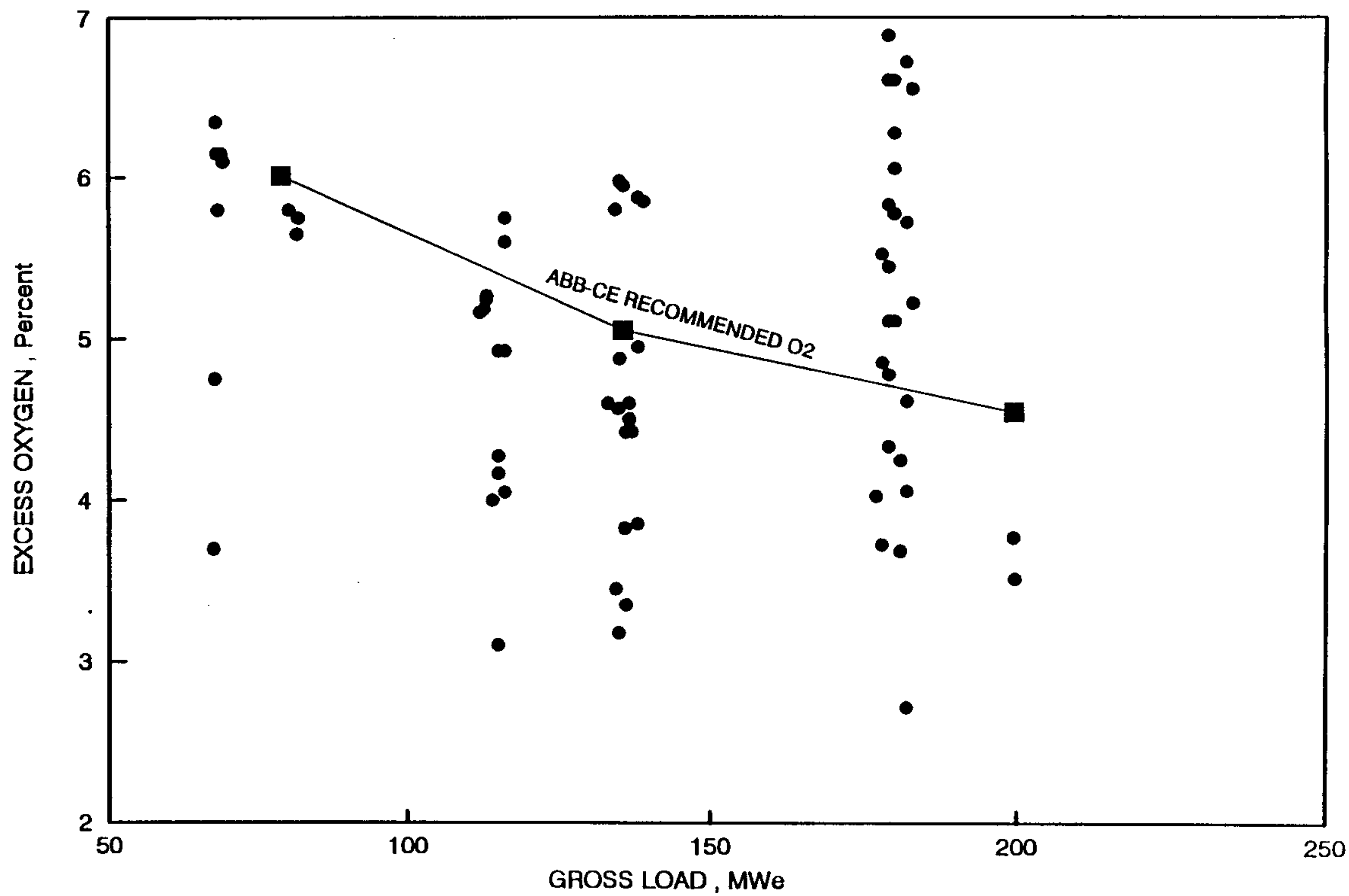
PHASE 1 Baseline				PHASE 3A LNCFS III			
LOAD MWe	SH TEMP Deg F	RH TEMP Deg F	TILT Deg	LOAD MWe	SH TEMP Deg F	RH TEMP Deg F	TILT Deg
70	998	909	0	71	990	894	5
79	999	919	0	79	981	887	6
90	999	926	0	90	983	895	7
100	1001	934	0	100	992	906	6
110	1002	940	0	110	996	915	6
120	1003	952	0	120	996	923	6
131	1003	959	0	130	998	932	6
140	1003	963	0	140	1002	941	7
150	1003	966	0	150	1003	949	7
160	1003	976	0	160	1002	960	6
170	1001	982	0	171	1004	970	5
180	1001	987	0	179	1005	981	6
191	1001	991	0	191	1004	987	4
198	1000	995	0	197	1005	993	4

E:\SCS\123R3\SP3ARPT\TABLE 4.WK3

TABLE 5 COMPARISON OF BASELINE AND LEVEL 3 PERFORMANCE PARAMETERS

	EXCESS OXYGEN		FINENESS THRU 200		FINENESS ON 50		LOSS ON IGNITION		BOILER EFFICIENCY	
NOMINAL LOAD MWe	BASELINE EXCESS OXYGEN Percent	LEVEL 3 EXCESS OXYGEN Percent	BASELINE FINENESS THRU 200 MESH Percent	LEVEL 3 FINENESS THRU 200 MESH Percent	BASELINE FINENESS ON 50 MESH Percent	LEVEL 3 FINENESS ON 50 MESH Percent	BASELINE LOI Percent	LEVEL 3 LOI Percent	BASELINE PTC 4.1 EFFICIENCY Percent	LEVEL 3 PTC 4.1 EFFICIENCY Percent
180	4.0	4.0	58.9	60.7	2.9	3.1	5.0	6.1	89.7	89.4
135	2.8	4.4	60.7	58.0	2.3	2.6	4.2	5.8	90.7	90.1
115	3.6	5.2	60.0	58.8	3.1	3.1	4.0	6.6	90.9	90.3

FIGURE 1 PHASE 3A EXCESS OXYGEN LEVELS TESTED



E:\SCS\FREE\SP3ARPT\FIG1.DRW

FIGURE 2   PHASE 3A NOx EMISSION CHARACTERISTICS

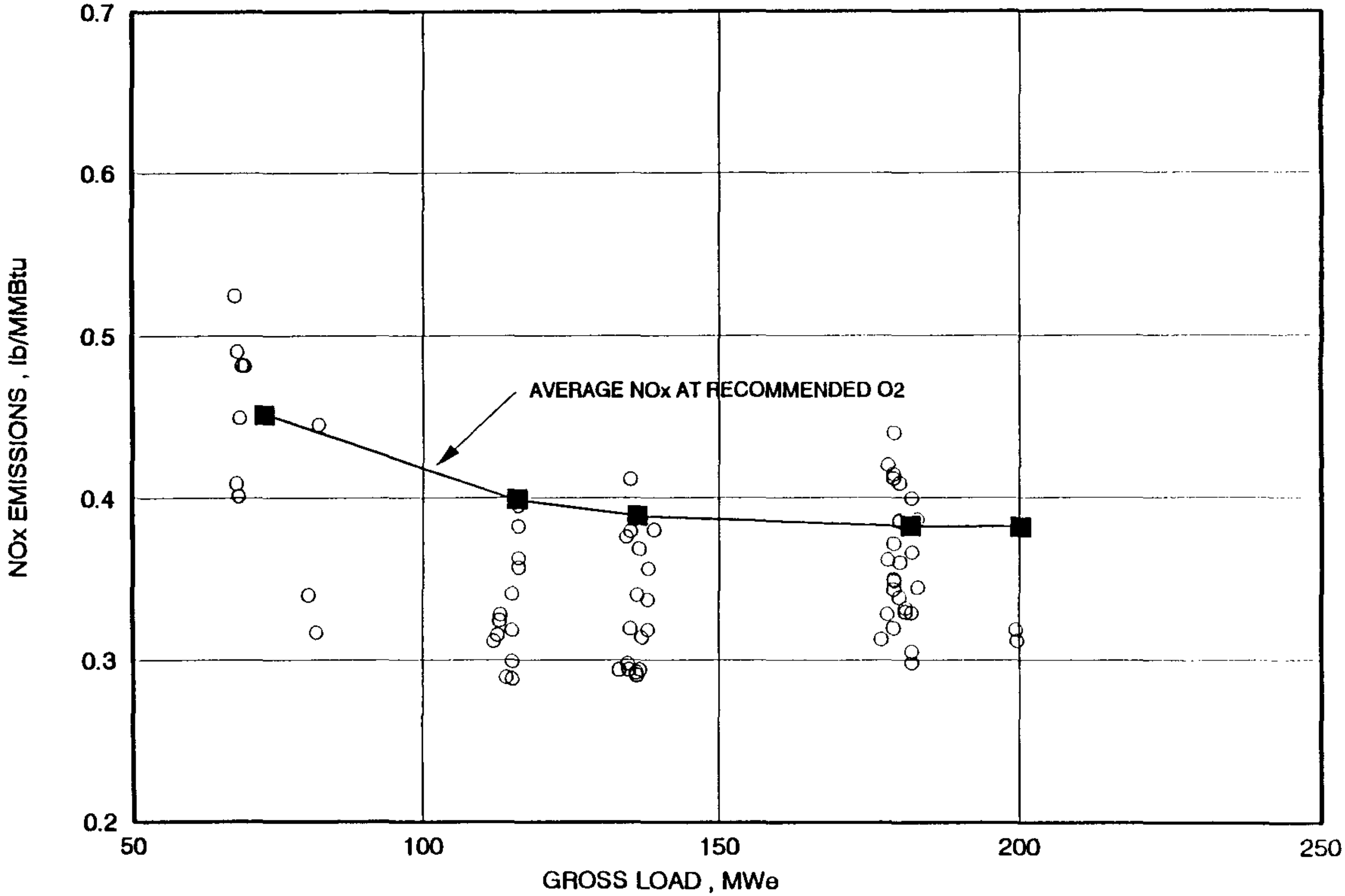


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FIGURE 3 PHASE 3A 200 MWe NOx CHARACTERIZATION

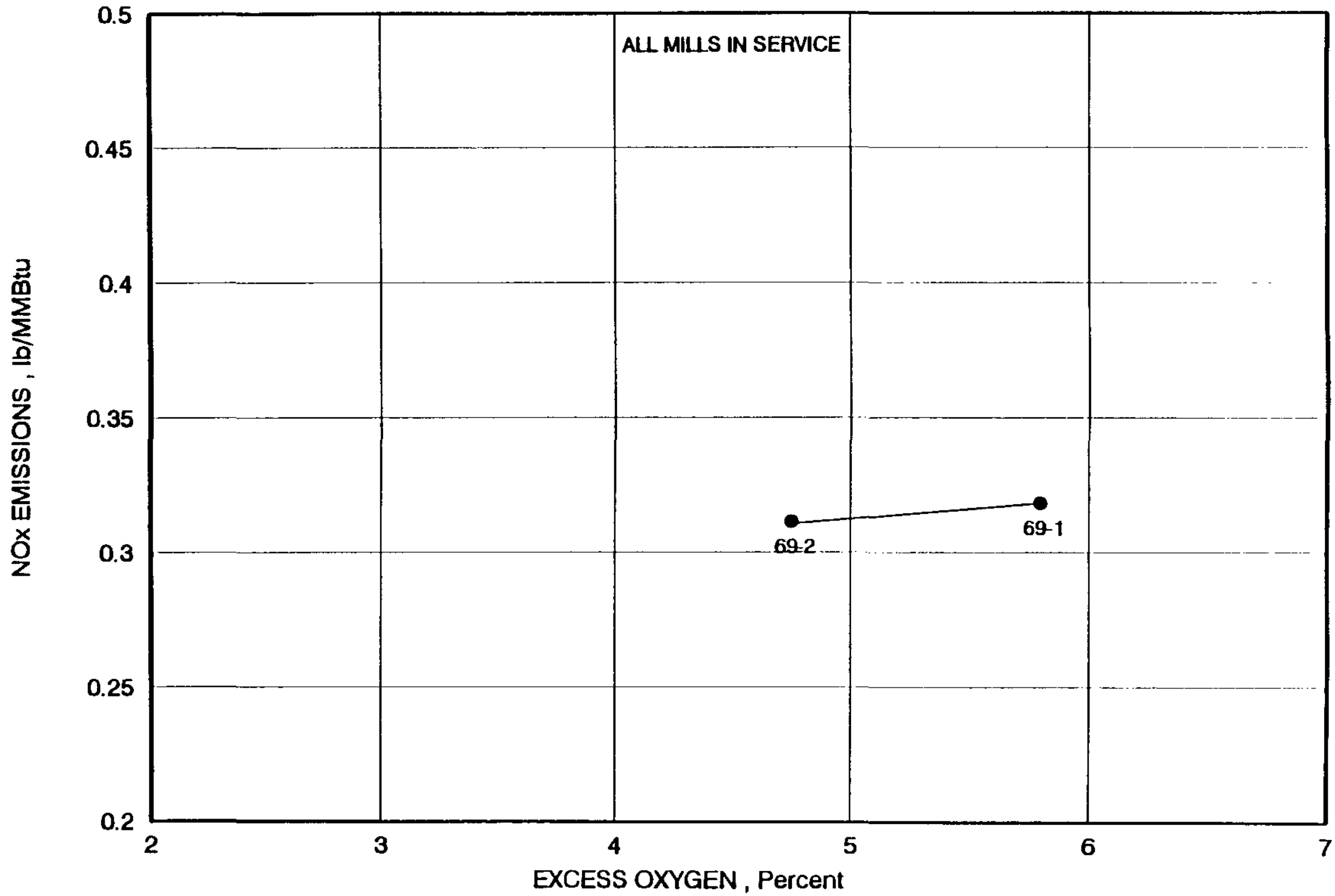

FIGURE 4   PHASE 3A 180 MWe NOx CHARACTERIZATION

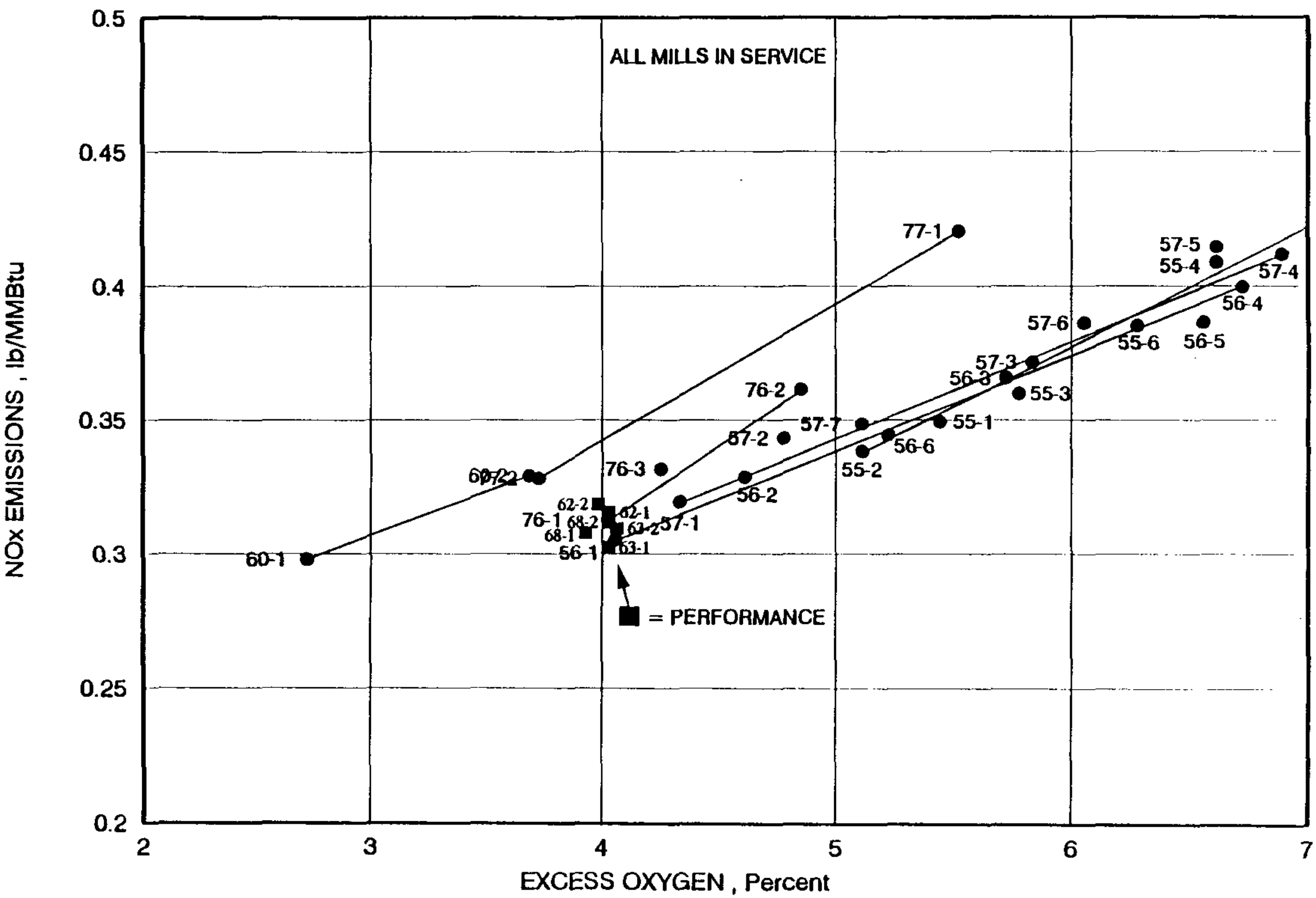

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FIGURE 5   PHASE 3A 135 MWe NOx CHARACTERIZATION

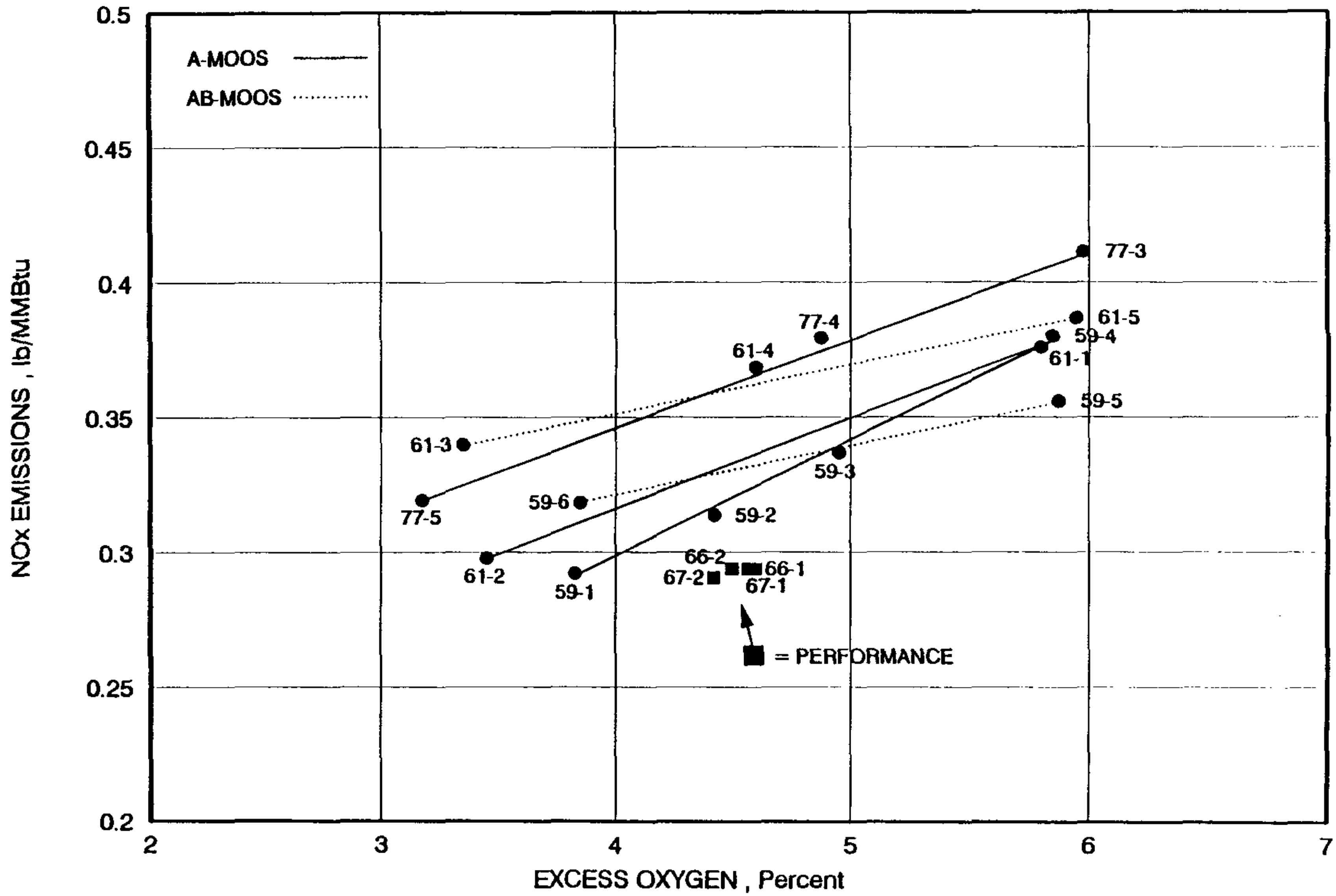

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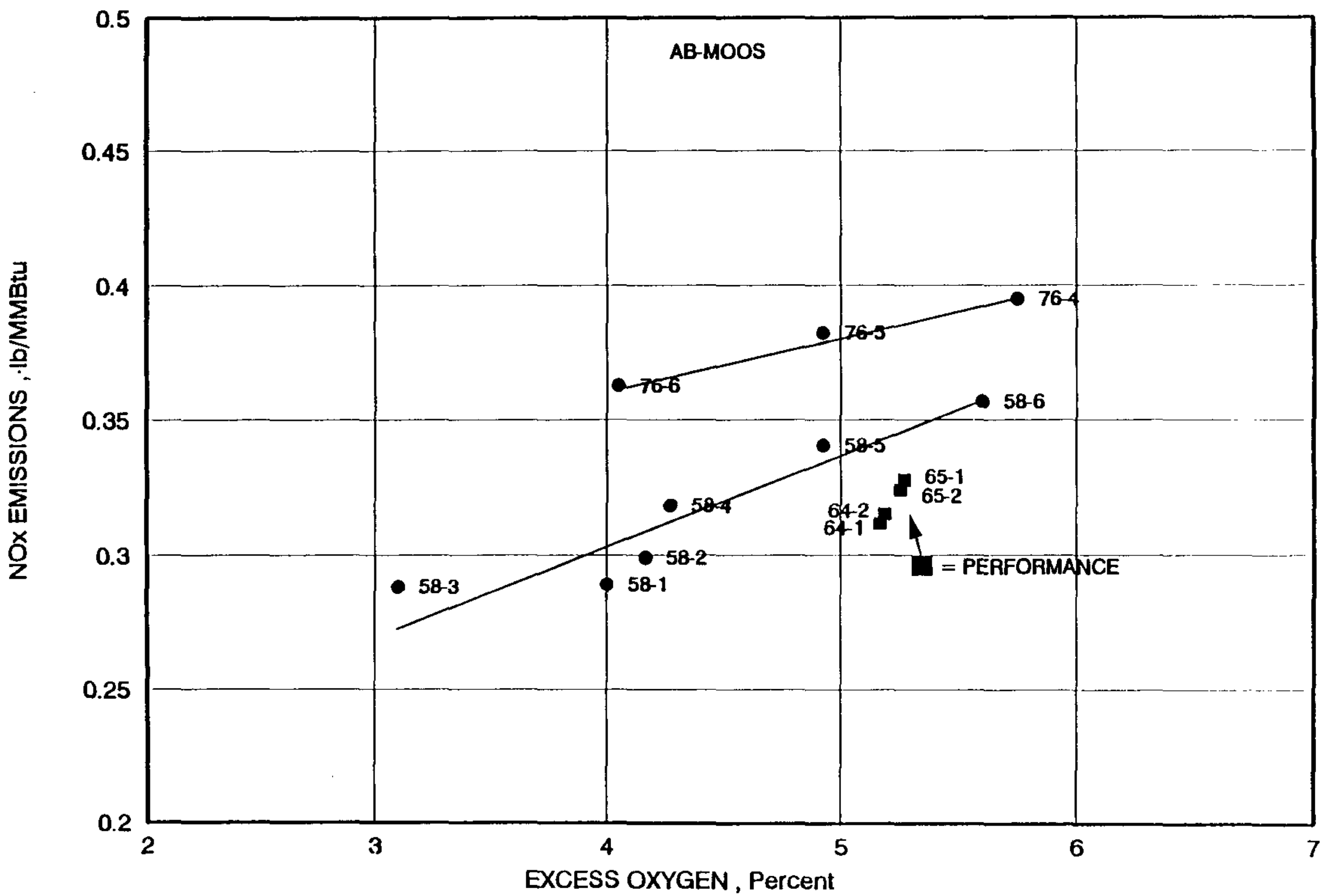
FIGURE 6   PHASE 3A 115 MWe NOx CHARACTERIZATION



ERIZATION

FIGURE 8   COMPARISON OF BASELINE AND LEVEL 3
180 MWe NOx EMISSIONS

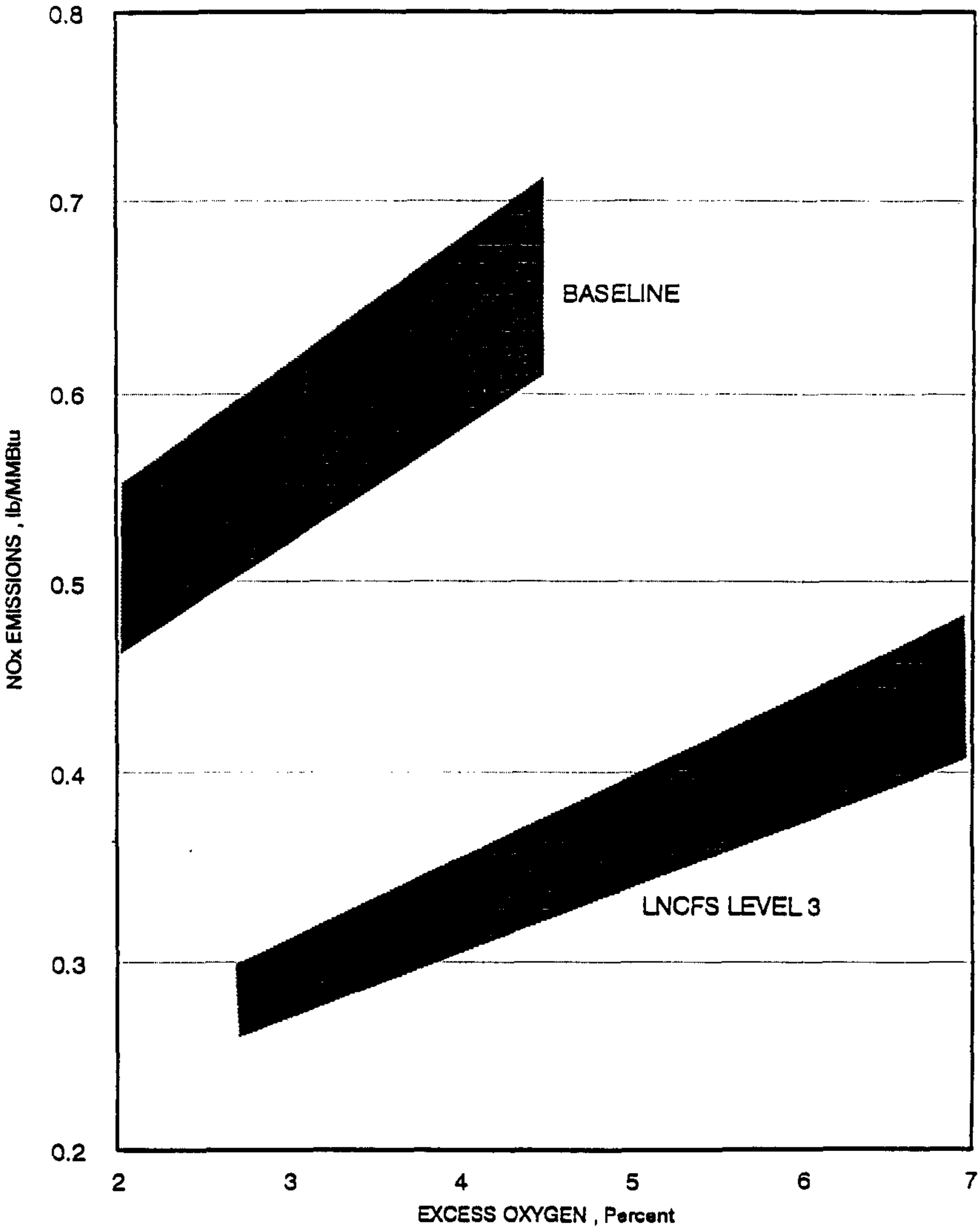


FIGURE 9
NOx CHARACTERISTICS
FULL-LOAD LNCFS LEVEL 3 CONFIGURATION

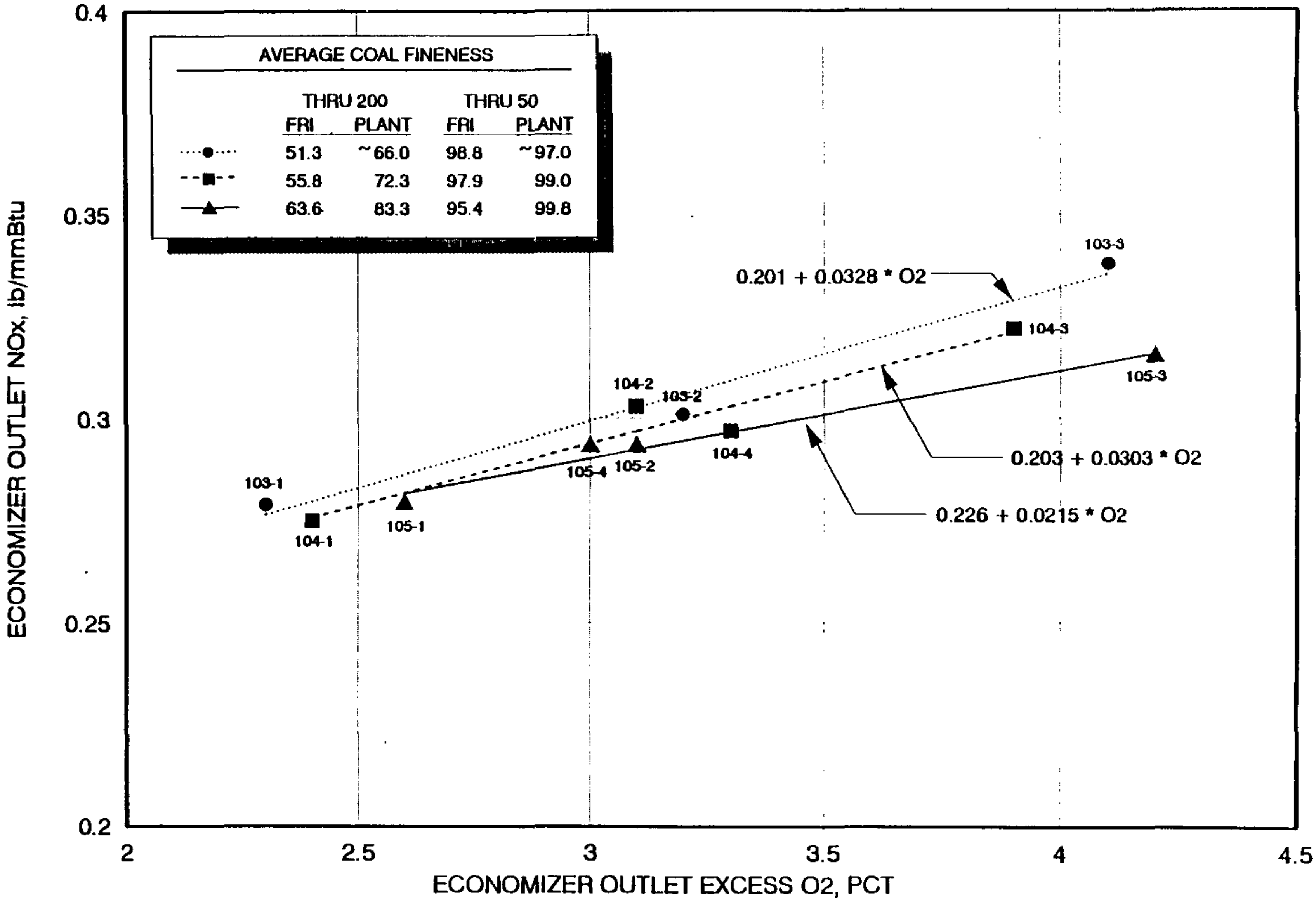


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FIGURE 10
PHASE IIIa 180 MWe NOx CHARACTERIZATION
FULL-LOAD LNCFS LEVEL 3 CONFIGURATION

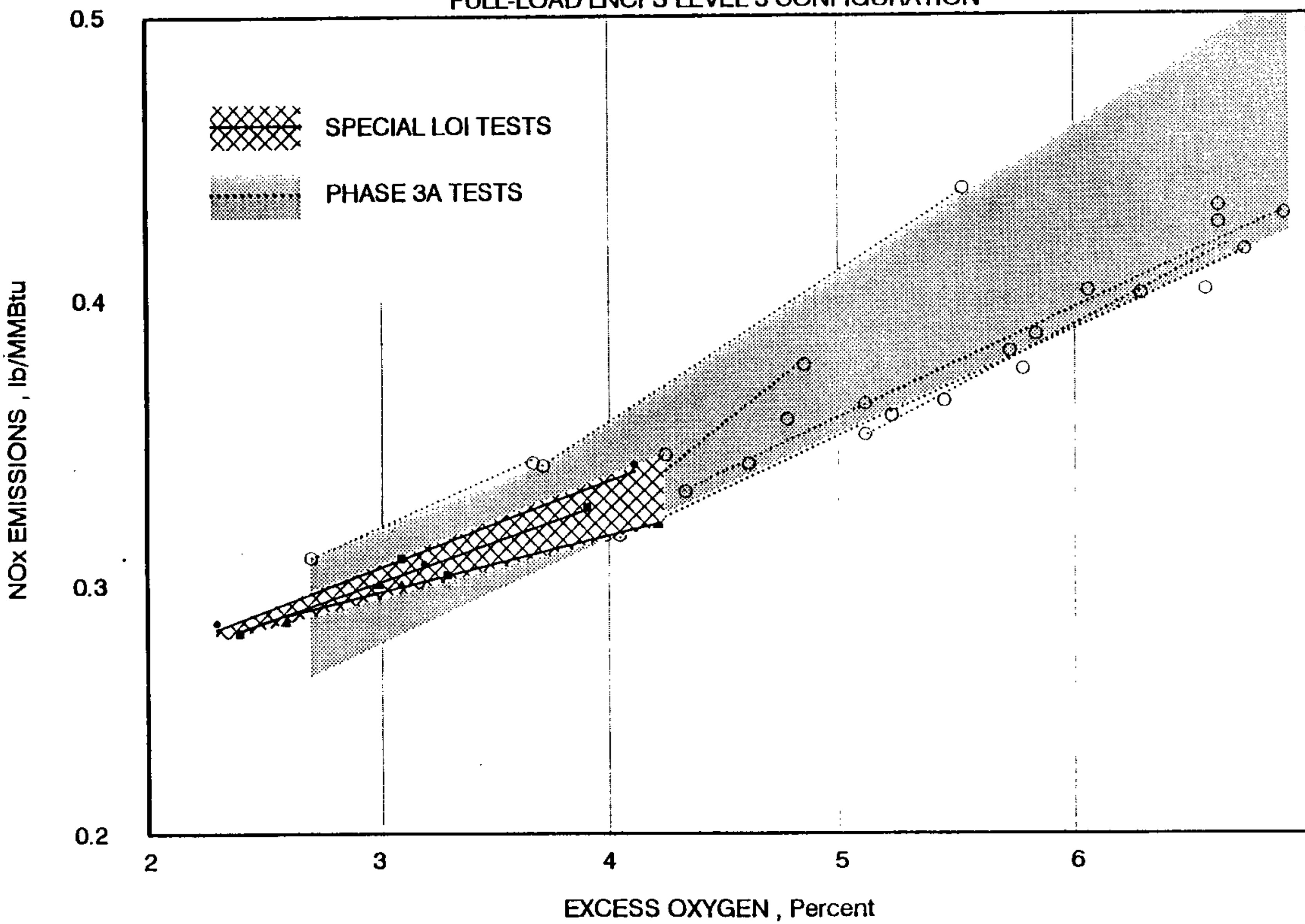

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FIGURE 11

NOx AND LOI SENSITIVITIES

FULL-LOAD LNCFS LEVEL 3 CONFIGURATION OPERATING AT 3 PERCENT O2

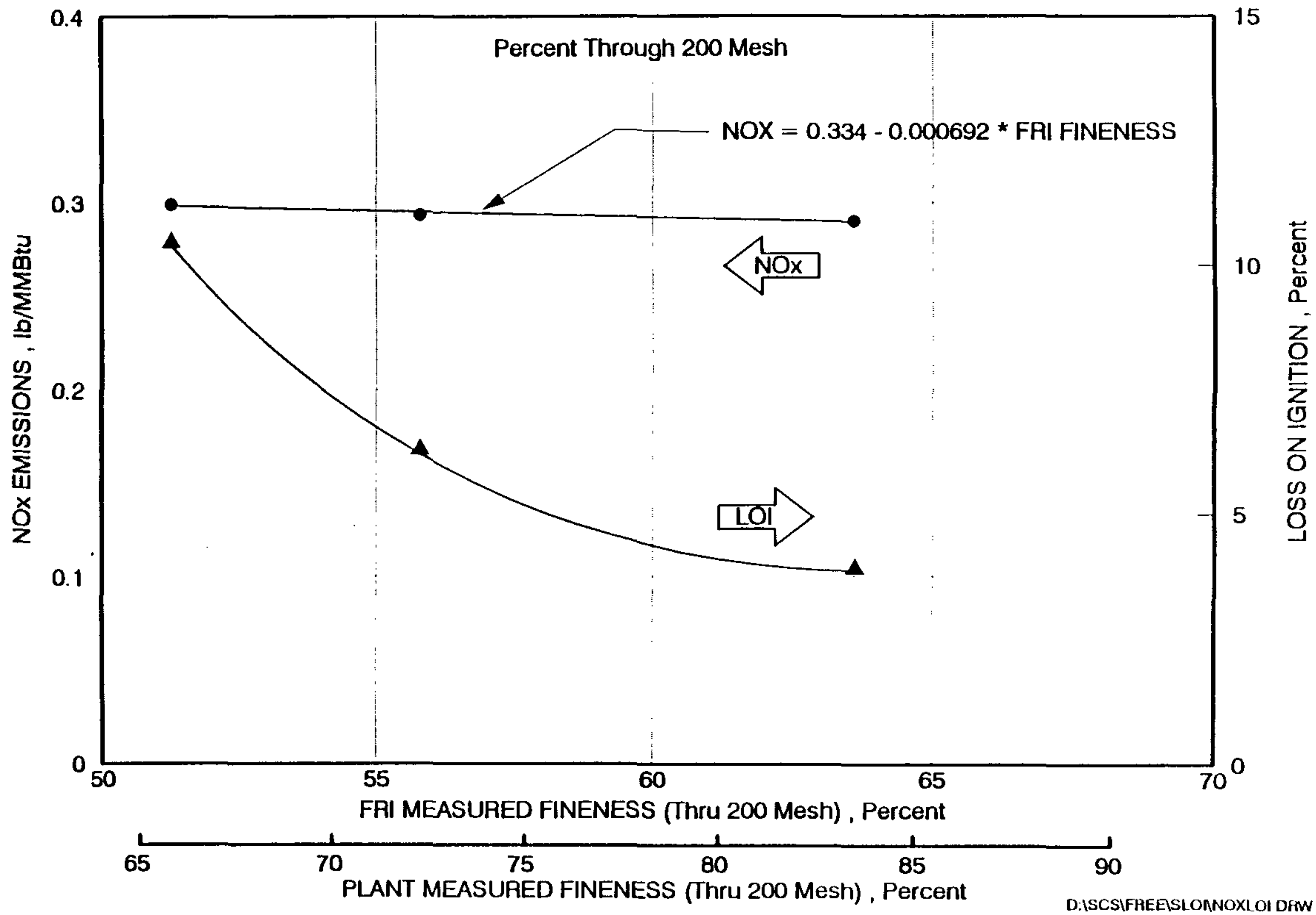

FIGURE 12
NOx AND LOI SENSITIVITIES
FULL-LOAD LNCFS LEVEL 3 CONFIGURATION OPERATING AT 3 PERCENT O2

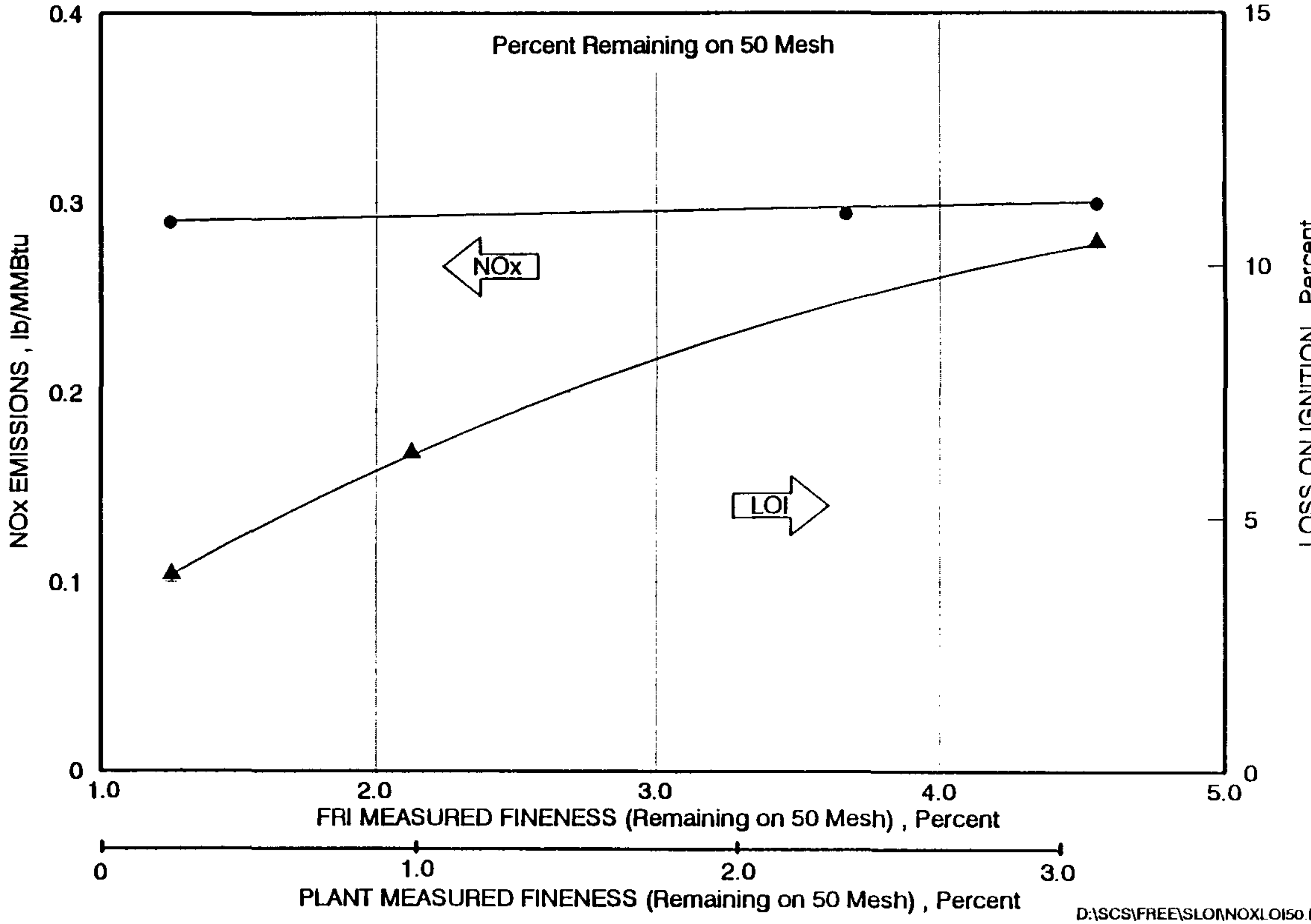

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FIGURE 13 LONG-TERM NOx EMISSION CHARACTERISTICS

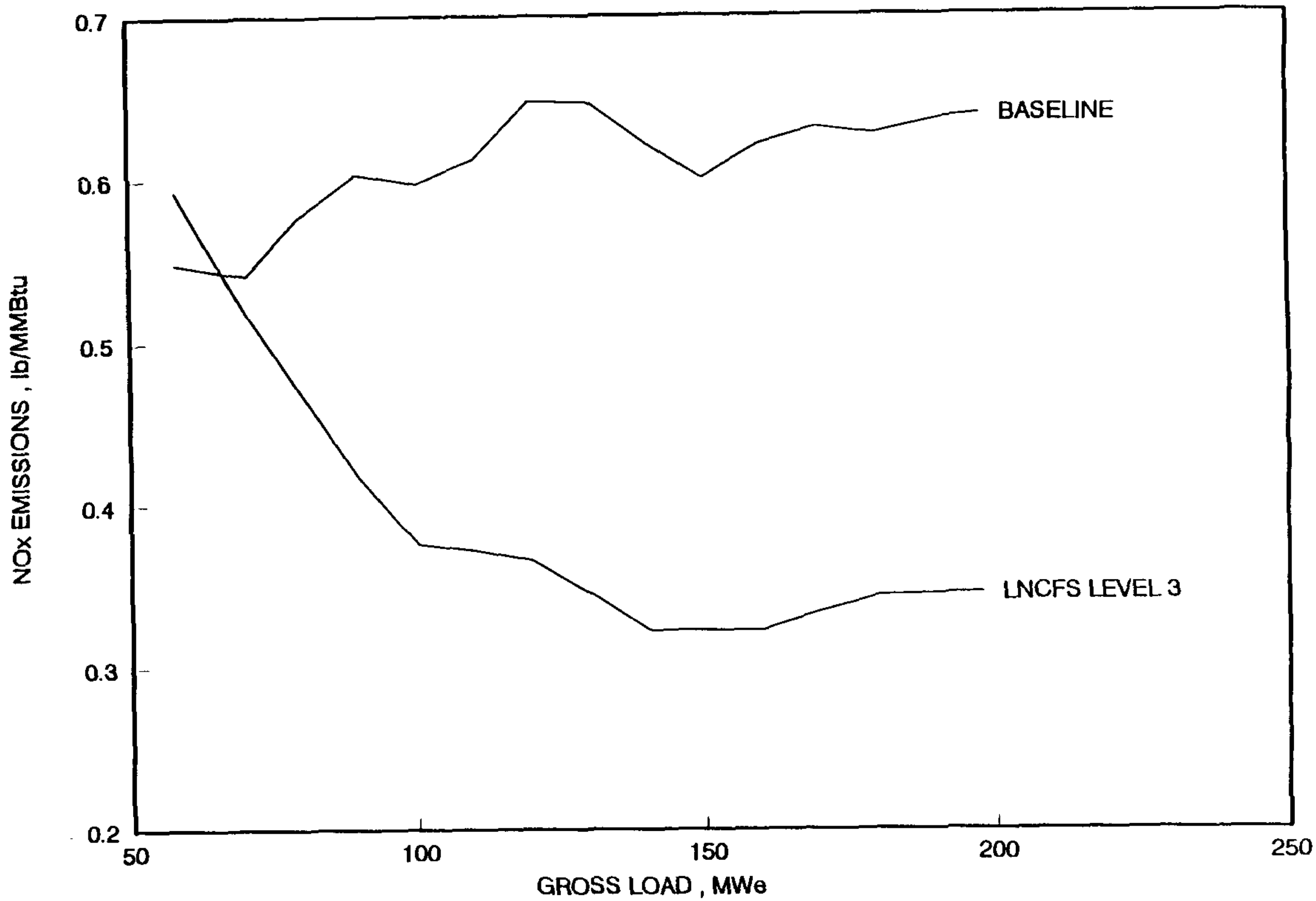


FIGURE 14 LNCFS LEVEL 3 NOx REDUCTION EFFECTIVENESS

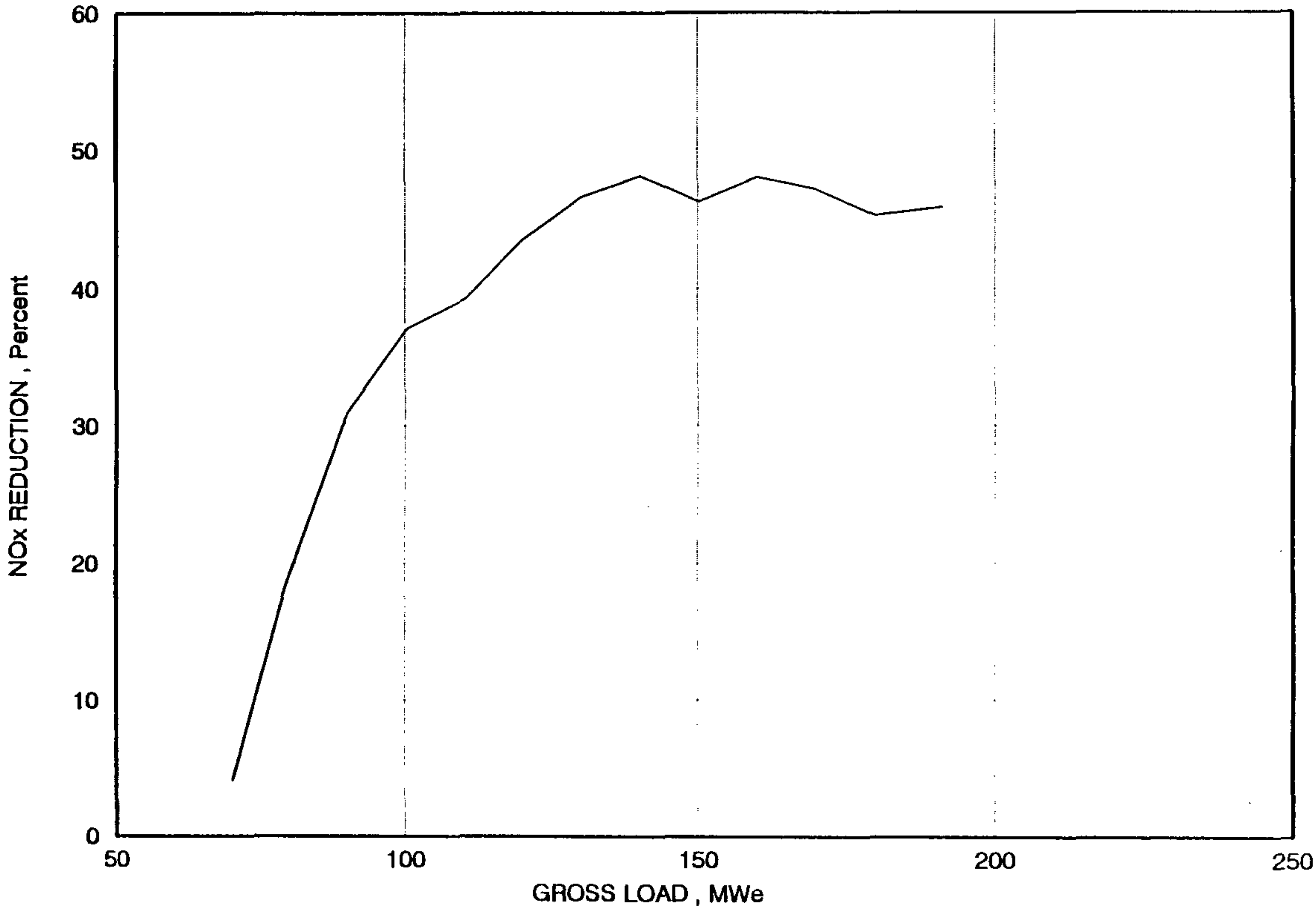


FIGURE 15 LONG-TERM EXCESS OXYGEN CHARACTERISTICS

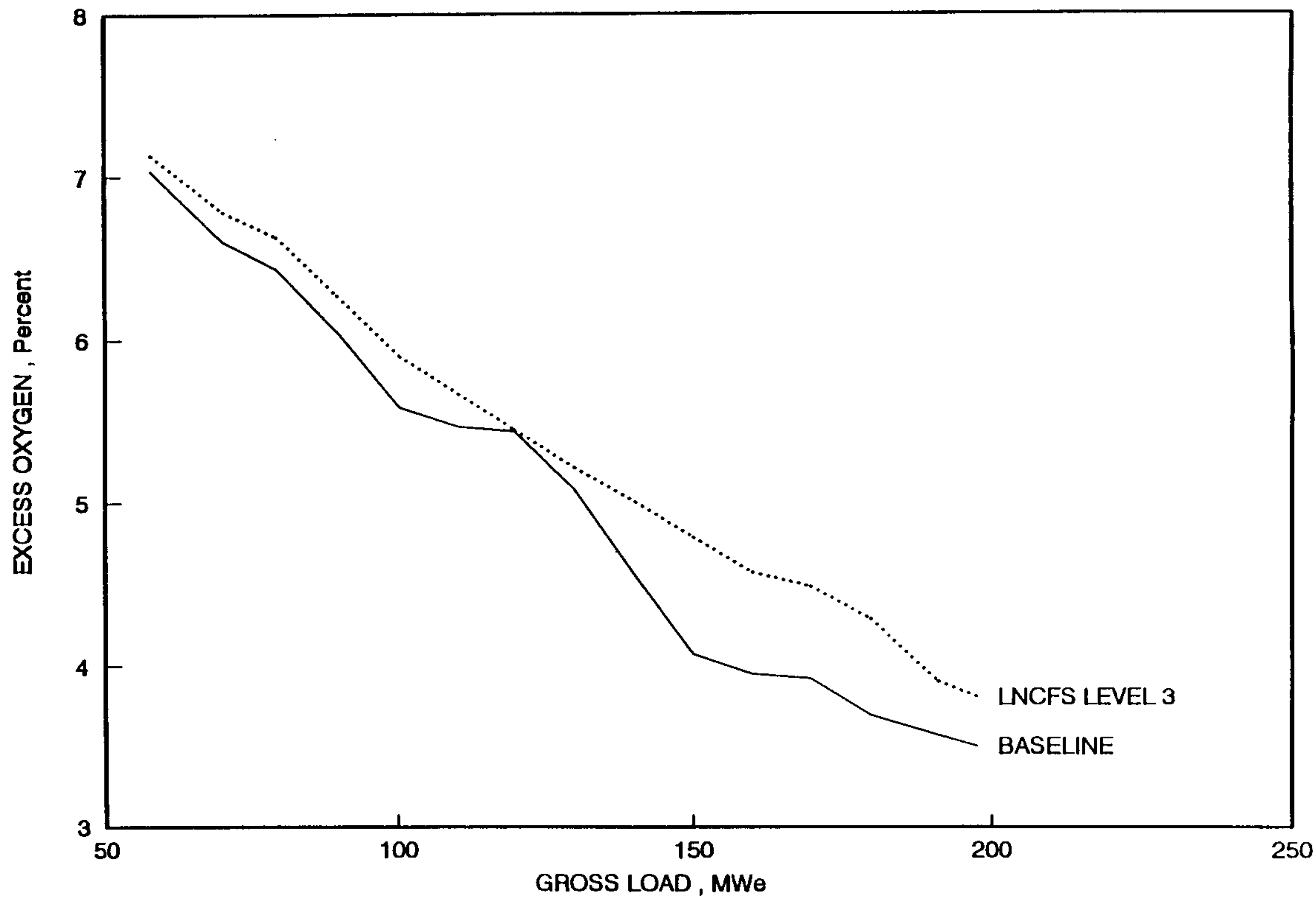


FIGURE 16 LONG-TERM CARBON MONOXIDE CHARACTERISTICS

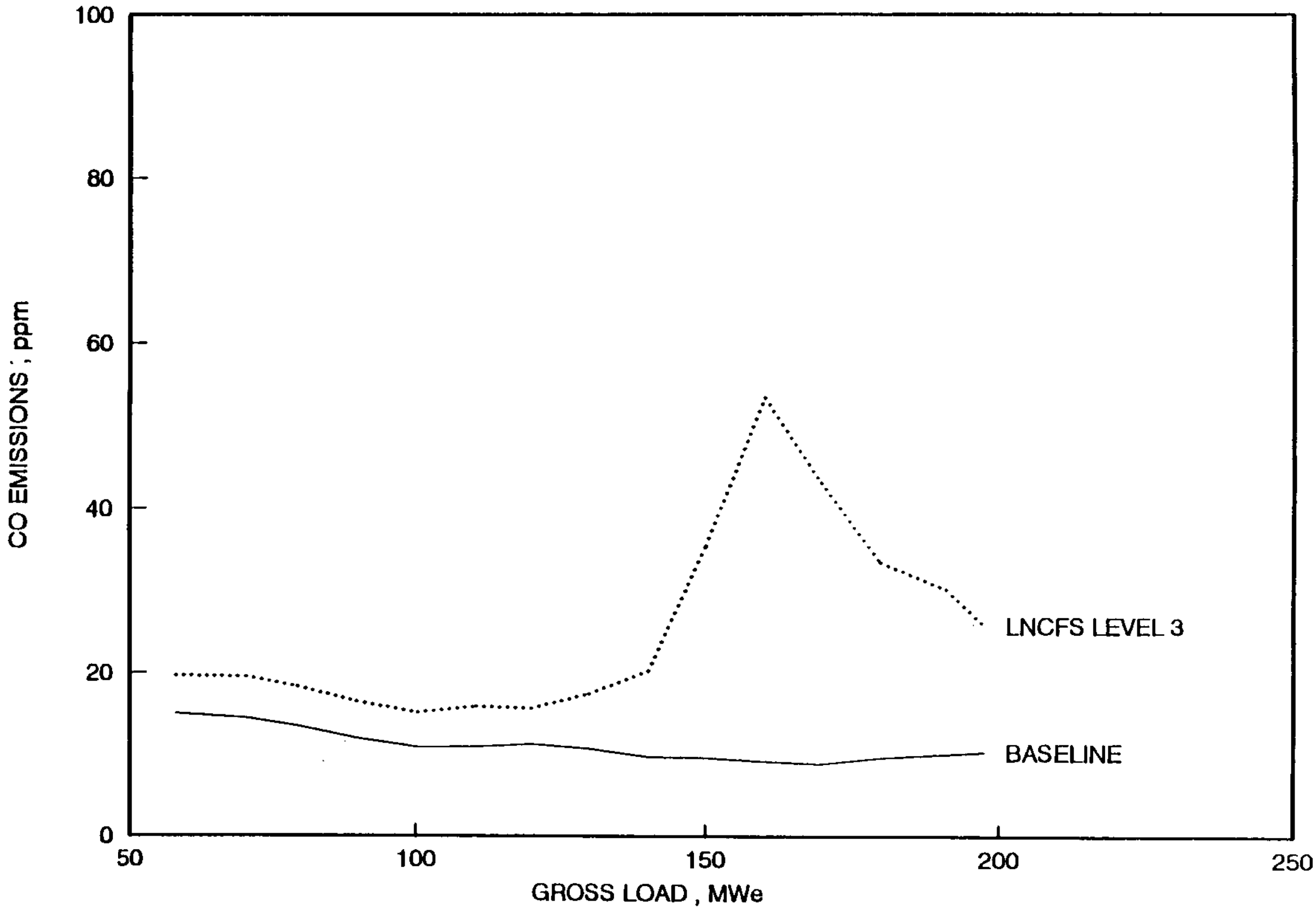


FIGURE 17 LOAD HISTORIES FOR BASELINE AND LEVEL 3 LONG-TERM TESTS

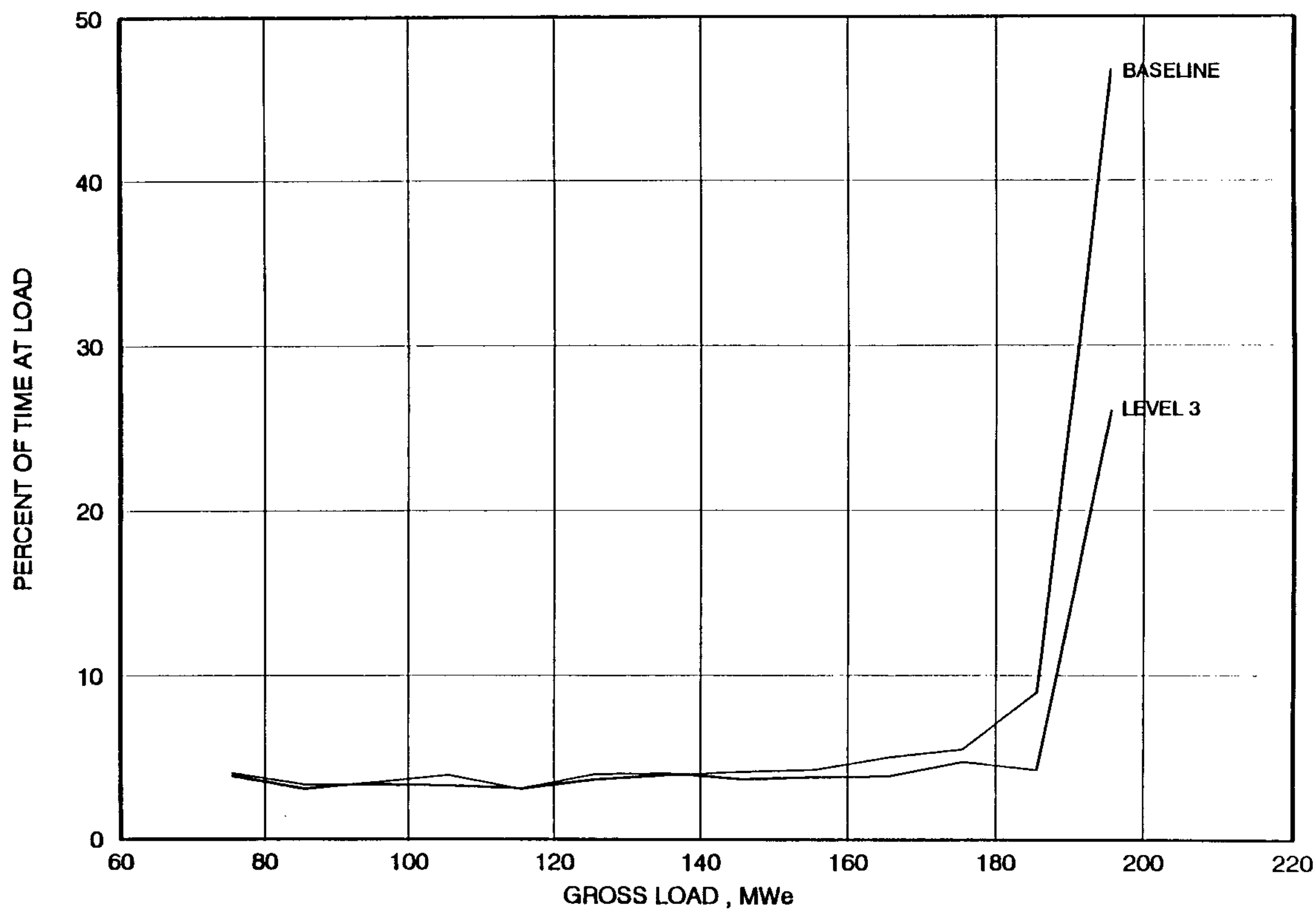


FIGURE 18 COM8ARISON OF LONG-TERM BASELINE AND LNCFS LEVEL 3 SUPERHEAT TEMPERATURES

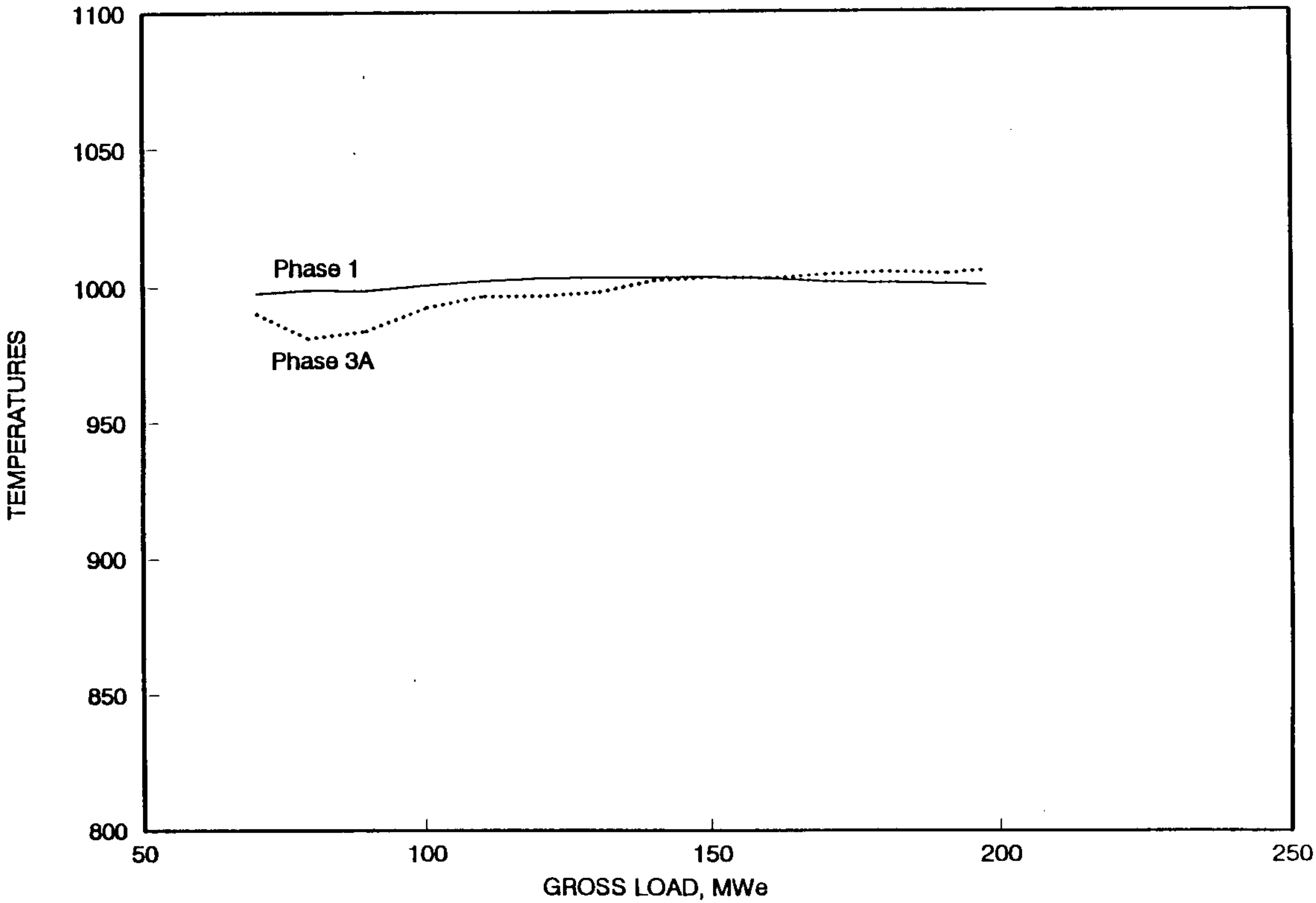


FIGURE 19 COMPARISON OF LONG-TERM BASELINE AND LNCFS LEVEL 3 REHEAT TEMPERATURES

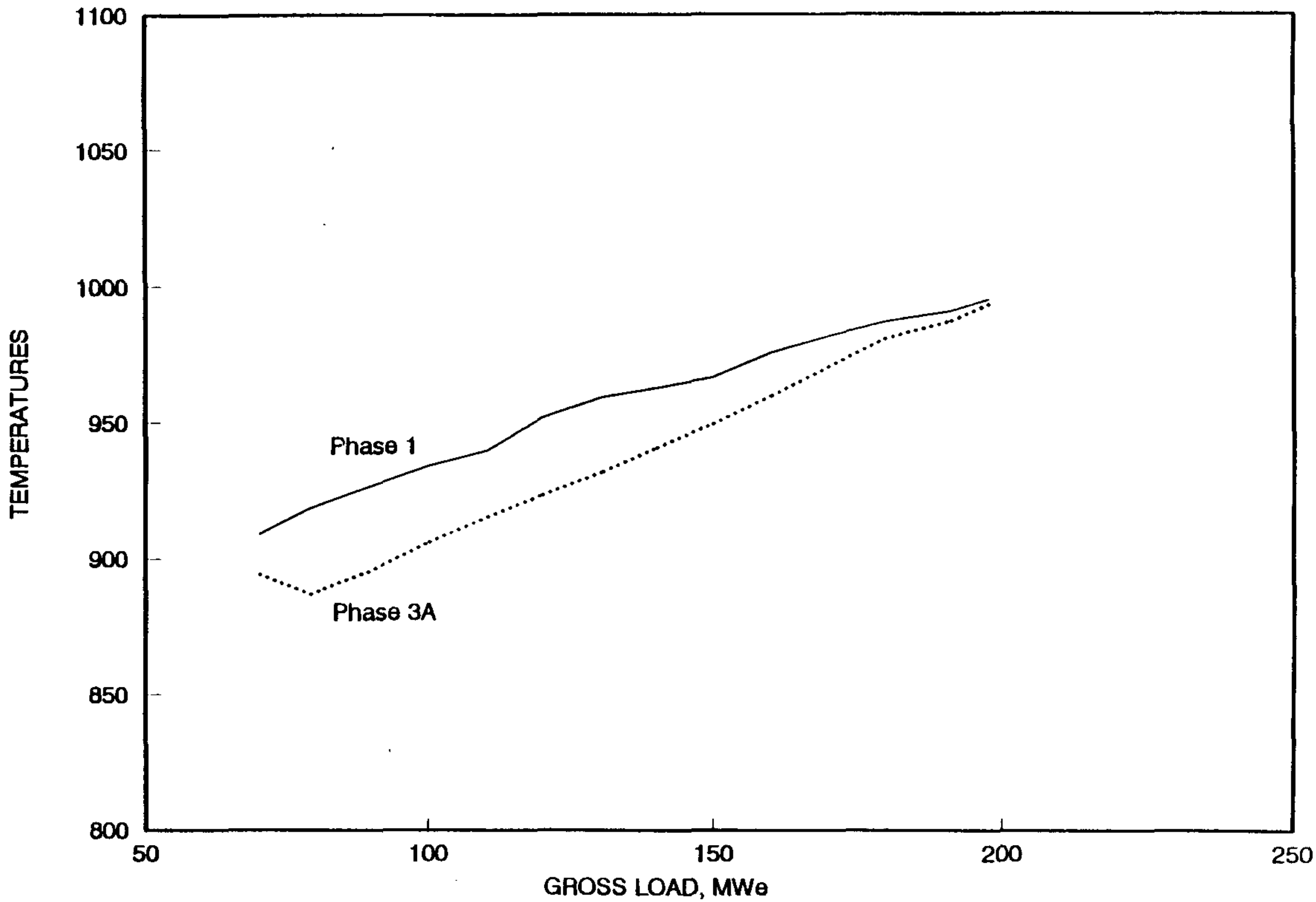


FIGURE 20 COMPARISON OF LONG-TERM BASELINE AND LNCFS LEVEL 3 BURNER TILTS

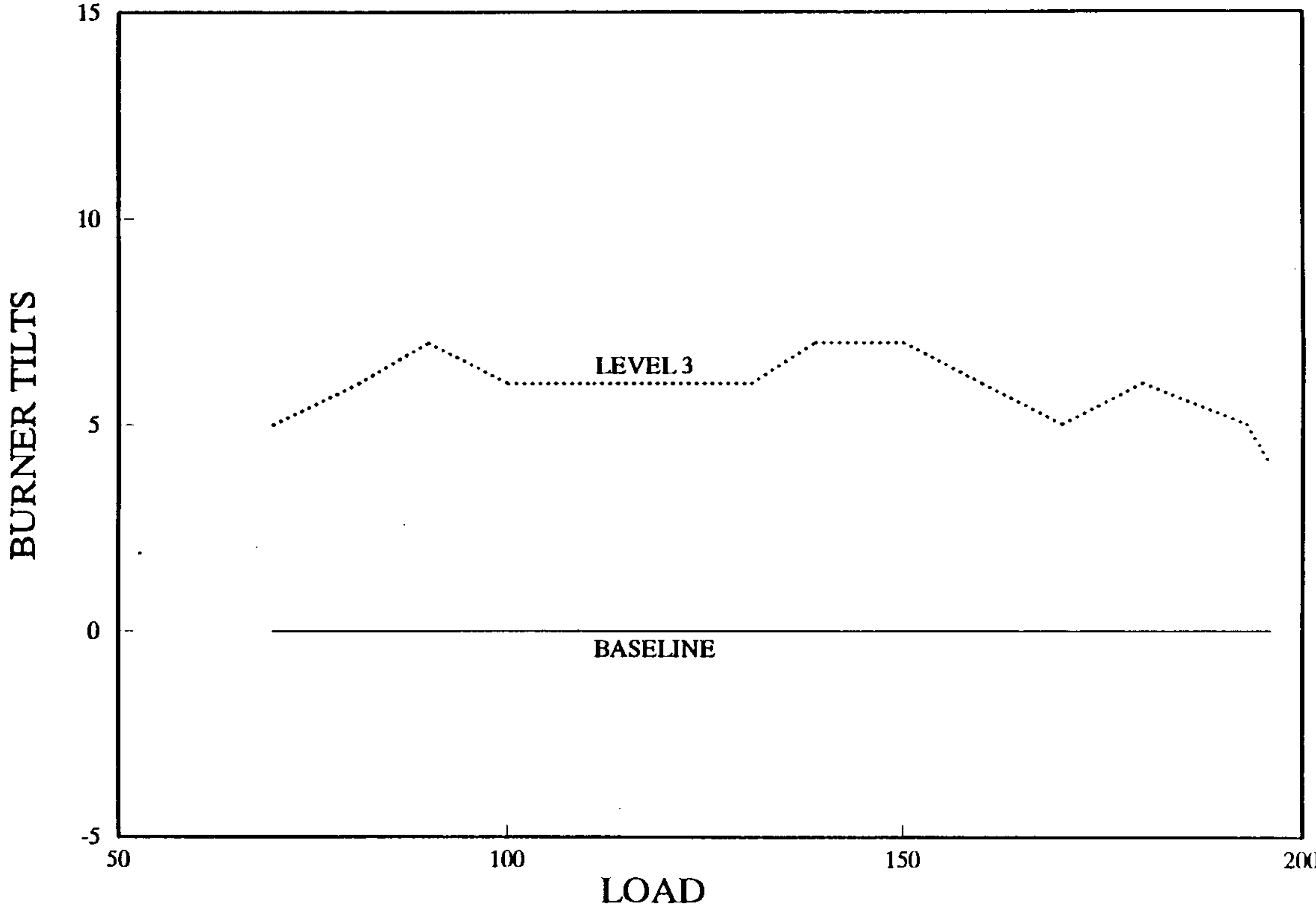


FIGURE 21 COMPARISON OF BASELINE AND LEVEL 3 LOSS ON IGNITION

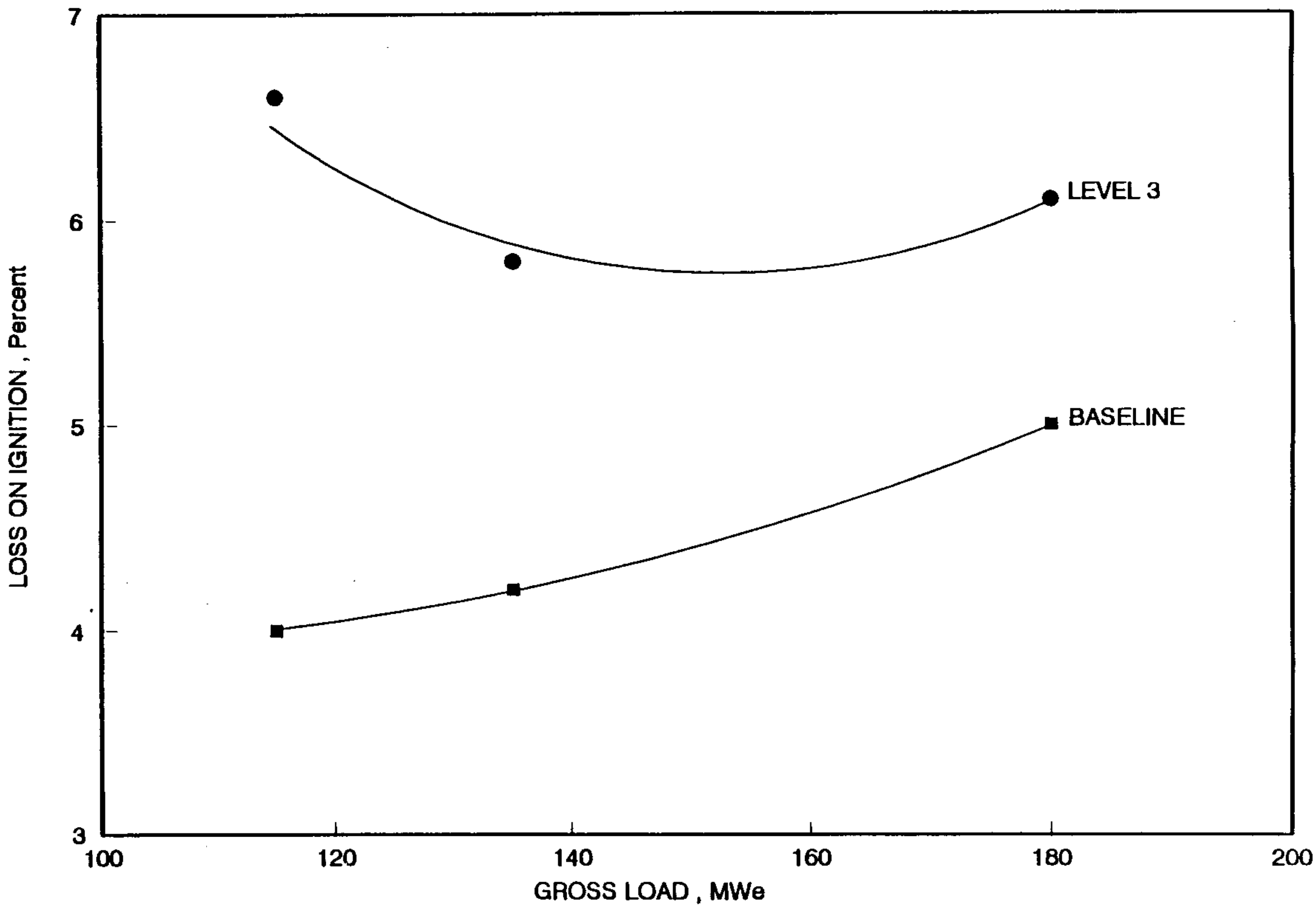
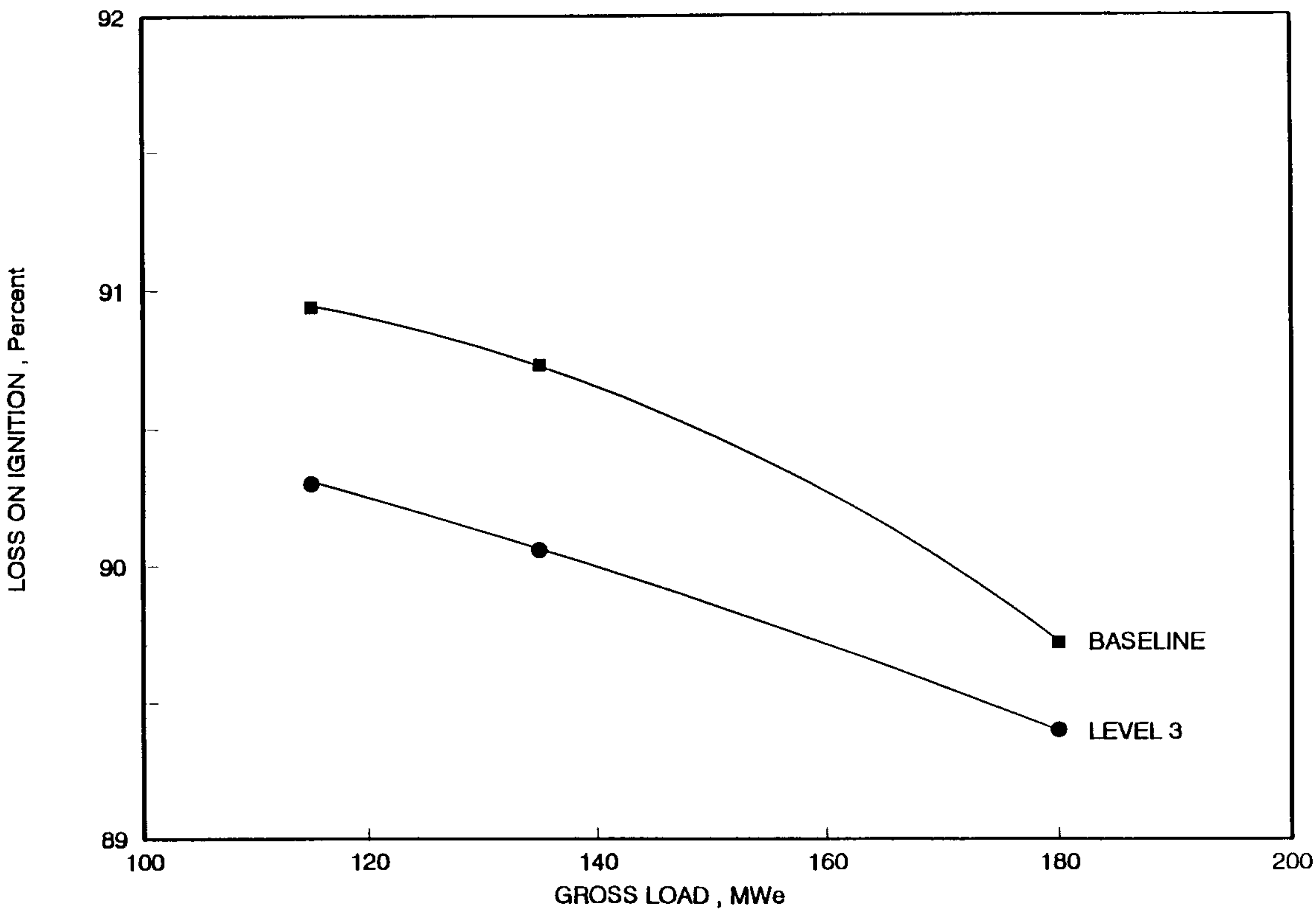


FIGURE 22 COMPARISON OF BASELINE AND LEVEL 3 PTC 4.1 BOILER EFFICIENCY



Summary Report on DOE ICCT II Phase 3B for Lansing Smith Unit 2

August 3, 1993.

August 3, 1993

Mr. Robert H. Hardman
SOUTHERN COMPANY SERVICES
800 Shades Creek Pkwy
Birmingham, Al 35209

SUBJECT: Summary Report on DOE ICCT II Phase 3B for Lansing Smith Unit 2

Dear Rob:

The purpose of this letter is summarize the major findings for the Phase 3B testing on Lansing Smith Unit 2. The objective of this test effort was to evaluate the effectiveness of the ABB-CE LNCFS Level 1 retrofit. Information related to the program structure, responsibilities of the various contractors, test setup, instrumentation and the impact of effluents on ESP performance are discussed in Reference 1. While Reference 1 addresses the findings for Phase 2 (LNCFS Level 2) these sections of the program were not substantially different from that for the Phase 3b effort.

The following paragraphs will provide summary information on the emissions of gaseous and solid matter. In addition, information related to the unit performance impacts will be discussed. Detailed information related to the mill performance and combustion air flow distribution are presented in Reference 2. Similarly, the detailed results for the ESP measurements are discussed in Reference 3. Pertinent summary results from these efforts will be summarized in this letter.

ENERGY TECHNOLOGY CONSULTANTS, INC.
One Technology Drive, Suite I-809, Irvine, CA 92718 (714) 753-9129 Fax (714) 753-1528
51 Virginia Avenue, West Nyack, NY 10994 (914) 353-0306 Fax (914) 353-0308
12337 Jones Road, Suite 400, Houston, TX 77070 (713) 894-1091 Fax (713) 894-1094

given load, however, the trends are similar between data taken on different days. In addition, all of the figures show that the NOx emissions are relatively sensitive to excess oxygen excursions with NOx increasing with increasing excess oxygen level.

Figure 8 provides a comparison of the NOx trends for the Baseline and the Level 1 configurations at 180 MWe. While it is not possible to obtain an accurate picture of the effectiveness from the short-term data, the figure illustrates the general trend. This trend prevailed over the entire load range. In general, the sensitivity of NOx to excess oxygen decreased with the addition of the Level 1 NOx control technique.

Long-Term Characterization Test Results

During the long-term testing, virtually no intervention by the test team members was made to adjust the operation. Instructions provided by ABB-CE were utilized to provide guidance to the plant personnel on the proper mode of operation in the LNCFS Level 1 configuration. The most illustrative data from the long-term testing is the emission characteristics over the load range. Table 2 provides a summary of the long-term average NOx, economizer O_2 and the CO emissions. This table includes the data for the upper 95 percent and the lower 5 percent of the data variation. Data in this table illustrates that the data scatter for long-term data is significant. This scatter is a result of the normal variation of numerous parameters such as coal properties, mill settings, burner settings, etc.

Figures 9 through 12 show the average trends for the Phase 3B NOx, economizer O_2 and CO compared to those for the Baseline configuration. As shown in Figure 9, over the useful load range (200 to 70 MWe) the average NOx levels for the LNCFS Level 1 configuration were below those of the Baseline configuration. The NOx characteristics of the Level 1 configuration were essentially flat - relatively little variation over the load range. The NOx reduction effectiveness of the Level 1 configuration is oxygen level (measured at the economizer exit) recommended by ABB-CE. As can be seen from the figure, the excess oxygen levels tested provided an excursion about the recommended level of approximately one percent excess oxygen. Figure 2 provides the resultant NOx levels for these excess oxygen levels tested. Included in this figure is an approximate average NOx level for all of the tests performed at the various loads at the recommended excess oxygen levels. These approximate averages were obtained from the NOx data for the individual loads discussed below. It should be pointed out that these data are not corrected for leakage of air through the SOFA ports.

The LNCFS Level 1 configuration tested during Phase 3B was a simulation of the ABB-CE offering of Level 1. To simulate Level 1, the SOFA ports were closed and the recommended settings for the Close Coupled Overfire Air (CCOFA) were set by ABB-CE to their recommended positions. In order to provide cooling air to the SOFA ports, stops were provided in the SOFA dampers. Tests were performed to estimate the amount of leakage through the SOFA dampers and the effect on the NOx emissions during the simulated Level 1 testing. The results of this testing indicated that only a small amount of air was escaping through the SOFA ports and it was likely that this additional OFA was channeled along the walls thus providing little further NOx reduction. The results of the SOFA leakage tests indicated that at the high loads the leakage resulted in small additional reduction in NOx over that would be provided by the CCOFA ports alone. At lower loads the effect was negligible. This SOFA leakage effect at high load has been included in the data presented in the following curves for both short- and long-term data at loads above 150 MWe.

Figures 3 through 7 illustrate the NOx versus O_2 trends for operation with the LNCFS Level 3 configuration at nominal loads of 200, 180, 135, 115 and 70 MWe. The numbers in the figures represent the test day and test numbers. Solid lines are drawn through tests performed on the same day with the same boiler setting. The curves for loads below 200 MWe show that there is a reasonable amount of data scatter at any top load. The load scenario is an important factor in determining the achievable emissions. Further analyses would be necessary to assess the achievable emission limitations under the same identical load scenarios.

PHASE 3A PERFORMANCE TEST RESULTS

During the Phase 3B test effort, testing was performed to evaluate the impact of the LNCFS Level 1 retrofit on steaming characteristics, ash characteristics and unit efficiency. Most of these evaluations were made using short-term test data, however, the impact on steaming characteristics were evaluated using long-term data.

Steaming Characteristics

A summary of the average long-term superheat and reheat temperatures and the burner tilts are presented in Table 3. Additional data on the steaming characteristics is provided in Reference 4. This table shows the Baseline values compared to the Phase 3B values for these parameters. It should be pointed out that during the Baseline tests the tilts were fixed in the horizontal position due to mechanical problems. During the LNCFS Level 2 retrofit (Phase 2), the linkages were repaired and the tilts became completely operational. During the Phase 3A testing the linkages began to bind which did not permit the full range of operation of the tilts. During the Phase 3B testing the binding had progressed to a point that only limited variation in the tilts could be achieved. The tilts were, however, partially functional during Phase 3B.

Figures 14 through 16 provide a comparison of the superheat and reheat temperatures, and the burner tilts. As shown in Figure 14 the superheat temperature was not affected by the Level 3 retrofit at the top load however as load was decreased below 120 MWe the temperature began to sag. This depression in temperature occurred even with the ability to utilize the tilts to compensate as shown in Figure 16.

illustrated in Figure 10 which shows that, the effectiveness decreases slightly at lower loads.

Operationally the LNCFS Level 1 configuration generally required approximately the same if not lower levels of excess oxygen than that for the Baseline configuration. This is illustrated in Figure 11 which shows that over the load range the long-term LNCFS Level 1 excess oxygen was equal to the Baseline levels at low loads and was lower during Baseline operation. At loads above 150 MWe, the excess oxygen was 0.5 to 0.75 percent lower for the LNCFS Level 1 configuration. For all intents and purposes, the carbon monoxide emissions were essentially the same for both the Level 1 and Baseline configurations as is shown in Figure 12. The average CO levels experienced during long-term LNCFS Level 1 and Baseline operation were well below that required for safe and efficient operation.

Data from the long-term testing was used to estimate the achievable emission limitations. The achievable emission limitations were calculated for 30-day averages and for an annual average. The following compares the Baseline levels with those obtained from the Level 1 testing.

AVERAGING PERIOD	BASELINE	LEVEL 1
30-Day Average	0.68	0.42
Annual Average	0.63	0.41

These achievable emission results were based upon the load scenarios that were experienced during the Baseline and Level 1 test periods. An indication of the load scenarios during these phase can be obtained from the data utilized to calculate the achievable emission limitations. Figure 13 shows the percent of time at each load that was experienced during both long-term test periods. The two load scenarios are very similar but are different in the fact that the Baseline configuration spent less time at the

During the Performance testing of each Phase of the program sufficient data were gathered to calculate the boiler efficiency using the ASME PTC 4.1 Short Form method. Table 4 presents the results of the PTC 4.1 analysis for the Performance test data for both the Baseline and the LNCFS Level 1 configurations. Figure 18 illustrates that their was a net efficiency loss ranging from 1.0 percent at low loads to 0.1 percent at the intermediate and high load conditions, respectively. A decrease of 1.0 percent is measurable using PTC 4.1 and therefore indicates that the efficiency is decreased at low loads. An efficiency difference of 0.1 percent is not within the accuracy of the PTC 4.1 method and therefore it can be said that the efficiency did not change at full load. Even if the efficiency decreased 1.0 percentage point at 135 MWe, the amount of time spent at this condition is negligible compared to that spent at full-load.

CONCLUSIONS

The major conclusions for the Phase 3A testing of the LNCFS Level 3 retrofit are briefly delineated below.

- NOx reductions ranging from as high as 38 percent at the high to intermediate high loads to 32 percent a low loads were measured based upon long-term data.

- Increases of Loss-on-ignition ranging from 1.0 percentage points at low loads to approximately 0.1 percentage point at high load were measured.

- Boiler efficiency was reduced at low to intermediate loads. High load efficiency changes were not discernable from the Baseline level.

- Superheat temperatures were unchanged over most of the load range but decreased slightly at lower loads. Reheat temperatures were measurably reduced at lower loads.

- Coal fineness degradations during the Level 1 testing did not appear to affect the LOI significantly.

A similar but more substantial depression in reheat temperature is shown in Figure 15. The conclusion from this evaluation is that the Level 1 configuration impacted the ability to maintain the superheat and reheat temperature. The limited ability to utilize the tilts could not compensate for the impact on temperatures.

Performance Characteristics

During the Performance tests Flame Refractories, Inc. (FRI) performed mill testing to determine amongst other things the fineness characteristics of the mills. Two locations were utilized to obtain the mill fineness data - 1) in the coal pipe lines and 2) at the mill exhauster exit as recommended by ABB-CE. For the purpose of this report, only the coal pipe data is used since this is believed to be more representative of the actual distribution. Table 4 provides a summary of the pertinent mill fineness results. Based upon these fineness data, the mills had degraded from the period between baseline testing and the retrofit of LNCFS Level 1.

These FRI fineness tests were performed simultaneously with particulate matter testing performed by Southern Research Institute (SoRI). LOI was determined during the short-term Performance testing in Phase 3B utilizing data from particulate matter tests obtained from EPA Method 17 testing. This particulate matter was analyzed to determine the LOI and the resulting data is presented in Table 4.

Figure 17 provides a comparison of the Baseline and the Phase 3B LOI results from the Performance testing. This figure illustrates that there is little change in the LOI between the Baseline and Level 1 configurations except at the intermediate load (135 MWe). At 135 MWe, the LOI appears to increase by slightly more than one percentage point. In any case, this increased level is near that for full-load and consequently may not impact the ability to sell ash based upon the amount of time spent at 135 MWe.

REFERENCES

1. "180 MWe Demonstration of Advanced Tangentially-Fired Combustion Techniques for the Reduction of Nitrogen Oxide (NOx) Emissions form Coal-Fired Boilers", Innovative Clean Coal Technology DOE Contract Number DE-FC22-90PC89653, Prepared by Southern Company Services, Jan 1992.

2. "Phase IV Parametric Testing (Level 1)", Service Report No. 1252, Contract No. 5459-036, Prepared by Flame Refractories, Inc., August 1992.

3. "ESP Performance Analysis During Phase IIIb of the 180 MWe Demonstration of Advanced Tangentially-Fired Combustion Techniques for the Reduction of Nitrogen Oxide Emissions form Coal-Fired Boilers - Volume 1 - Results and Analysis", SCS Contract No. 196-90-107, Prepared by Southern Research Institute, Draft, August 1993.

4. Letter to R. H. Hardman (SCS) from L. L. Smith (ETEC), "Summary of Steam Temperature and Tilt Profiles for All Phases of Lansing Smith DOE ICCT II Program" dated March 26, 1993.

More thorough conclusions will be provided in the final report which discusses the comparison of all four program phases.

If you have any questions concerning these analyses, please do not hesitate to contact me.

Sincerely,

Lowell L. Smith

ATTACHMENTS
References
Tables 1 through 4
Figures 1 through 18

TABLE 2 LNCFS LEVEL 1 LONG-TERM GASEOUS EMISSIONS DATA

	OXYGEN			NOx			CO		
AVG LOAD MWe	LOWER 5% OXYGEN PERCENT	AVG OXYGEN PERCENT	UPPER 95% OXYGEN PERCENT	LOWER 5% NOx lb/MMB	AVG NOx lb/MMB	UPPER 95% NOx lb/MMB	LOWER 5% CO ppm	AVG CO ppm	UPPER 95 CO ppm
61	6.0	6.7	8.2	0.229	0.399	0.542	8	31	7[illegible]
70	5.6	6.7	8.3	0.203	0.348	0.590	7	23	48
81	5.4	6.5	8.1	0.293	0.398	0.478	3	17	44
89	5.2	6.1	7.2	0.361	0.405	0.491	2	17	46
100	4.9	5.8	7.0	0.361	0.407	0.476	1	13	27
110	4.4	5.4	6.5	0.340	0.397	0.454	1	11	28
120	4.1	4.9	6.0	0.356	0.395	0.454	2	11	29
131	3.8	4.7	5.8	0.349	0.404	0.471	2	13	32
140	3.4	4.2	5.2	0.322	0.381	0.425	2	11	33
150	3.1	3.9	4.7	0.329	0.380	0.420	2	10	25
160	2.9	3.7	4.3	0.332	0.380	0.418	3	15	36
170	2.7	3.4	4.0	0.337	0.374	0.411	3	15	41
180	2.7	3.2	3.9	0.345	0.376	0.407	2	12	41
193	2.6	3.2	3.9	0.360	0.387	0.411	3	10	27
196	2.5	3.0	3.6	0.361	0.389	0.413	3	10	25

196 TO 150 MWe DATA CORRECTED FOR SOFA LEAKAGE

TABLE 1 LANSING SMITH PHASE 3B TEST SUMMARY
LNCFS LEVEL 1 DATA ONLY

TESTS				BURNER AND OFA SETTINGS						GASEOUS EMISSIONS				
TEST NO.	DATE	LOAD	MOOS	UCCOFA	LCCOFA	USOFA	CSOFA	LSOFA	BURNER TILT	CR O2 wet	STK O2 dry	DAS O2 dry	NOx lb/MMBtu	CO dry
200 MWe TESTS														
82-1	05/18	197	AMIS	100	80	0	0	0	10	5.9		4.2	0.48	17
83-1	05/19	200	AMIS	100	80	0	0	0	5	5.2		3.8	0.42	13
89-1	06/02	197	AMIS	100	100	0	0	0	3	5.1	6.6	4.0	0.40	14
89-2	06/02	200	AMIS	100	100	0	0	0	3	4.8	5.8	3.0	0.37	14
89-1	06/02	200	AMIS	100	100	0	0	0	3	4.2	5.1	2.2	0.35	18
90-1	06/08	198	AMIS	100	100	0	0	0	7	4.8	5.4	2.6	0.38	11
90-5	06/08	198	AMIS	100	100	0	0	0	7	4.8	5.5	2.7	0.37	12
180 MWe TESTS														
78-1	05/14	184	AMIS	100	80	0	0	0	2	4.0	5.3	2.3	0.35	73
78-2	05/14	184	AMIS	100	80	0	0	0	1	4.7	5.8	3.1	0.40	13
78-3	05/14	184	AMIS	100	80	0	0	0	1	5.4	6.7	4.0	0.43	14
78-4	05/14	185	AMIS	100	80	0	0	0	2	4.7	5.9	3.1	0.41	15
78-5	05/14	183	AMIS	100	80	0	0	0	1	4.9	6.2	3.1	0.39	16
79-1	05/15	180	AMIS	100	80	0	0	0	3	5.2	6.9	4.3	0.43	12
79-2	05/15	180	AMIS	100	80	0	0	0	3	5.0	6.5	3.6	0.42	12
79-3	05/15	181	AMIS	100	80	0	0	0	3	4.0	5.9	3.0	0.39	11
79-4	05/15	180	AMIS	100	80	0	0	0	3	3.5	5.3	2.3	0.36	40
80-1	05/16	184	AMIS	100	80	0	0	0	5	5.4	6.9	4.1	0.43	13
80-2	05/16	185	AMIS	100	80	0	0	0	5	4.2	5.9	3.0	0.39	12
80-3	05/16	186	AMIS	100	80	0	0	0	5	3.5	5.1	2.0	0.35	34
80-4	05/16	185	AMIS	100	80	0	0	0	5	3.8	5.5	2.5	0.37	12
84-1	05/20	185	AMIS	100	80	0	0	0	-1	4.7		3.6	0.36	10
84-2	05/20	192	AMIS	100	80	0	0	0	-1	4.2		2.8	0.36	
85-1	05/29	187	AMIS	100	80	0	0	0	3	4.5	5.6	3.0	0.36	38
86-1	05/30	181	AMIS	100	100	0	0	0	4	4.5	5.9	3.2	0.37	8
88-1	06/01	183	AMIS	100	100	0	0	0	6	4.5	5.8	3.1	0.37	8
92-1	06/10	182	AMIS	100	100	0	0	0	2	4.7	5.7	3.1	0.36	10
92-2	06/10	181	AMIS	100	100	0	0	0	2	4.7	5.6	3.0	0.36	9
92-3	06/10	181	AMIS	100	100	0	0	0	2	4.8	5.7	3.0	0.37	9
93-1	6/11	182	AMIS	100	100	0	0	0	4	4.6	5.7	2.9	0.37	7
93-2	6/11	180	AMIS	100	100	0	0	0	4	4.7	5.9	3.0	0.36	8
94-1	6/12	184	AMIS	100	20	100	100	100	0	5.3	6.2	3.6	0.29	22
94-2	6/12	184	AMIS	100	20	100	100	100	0	5.2	6.2	3.6	0.30	19
100-1	9/15	182	AMIS	100	100	0	0	0	0	5.5	7.2	4.0	0.39	6
100-2	9/15	183	NONE	100	100	0	0	0	0	4.6	6.5	3.1	0.36	6
100-3	9/15	184	AMIS	100	100	0	0	0	0	3.9	5.9	2.3	0.37	13
135 MWeTESTS														
83-2	05/19	132	A	100	78	0	0	0	11	5.7	7.7	5.1	0.40	9
83-3	05/19	133	A	100	78	0	0	0	12	4.7	6.6	3.9	0.36	10
83-4	05/20	134	A	100	78	0	0	0	12	3.5	5.3	2.4	0.31	11
85-3	05/29	134	A	100	100	0	0	0	3	5.8	7.6	5.2	0.35	6
85-4	05/29	134	A	100	100	0	0	0	3	4.9	6.6	4.0	0.32	6
85-5	05/29	136	A	100	100	0	0	0	3	3.9	5.6	2.9	0.29	22
97-1	6/15-6/16	136	A	100	100	0	0	0	8	5.4	6.8	4.2	0.36	6
97-2	6/15-6/16	137	A	100	100	0	0	0	8	5.3	6.9	4.2	0.36	7
98-1	6/19-6/20	136	A	100	100	0	0	0	7	5.4	6.6	4.1	0.36	7
98-2	6/19-6/20	137	A	100	100	0	0	0	7	5.4	6.9	4.1	0.36	6
102-1	9/17	132	A	100	100	0	0	0	0	4.2	6.5	3.0	0.31	11
102-2	9/18	135	A	100	100	0	0	0	0	5.1	7.2	3.9	0.33	7
102-3	9/18	133	A	100	100	0	0	0	0	6.0	6.0	4.8	0.34	7
115 MWe TESTS														
82-2	05/18	113	AB	100	80	0	0	0	10	6.5	8.5	6.1	0.41	13
82-3	05/18	112	AB	100	80	0	0	0	10	5.4	7.7	4.7	0.37	13
82-4	05/18	112	AB	100	80	0	0	0	10	4.5	6.3	3.7	0.35	13
83-5	05/20	116	AB	100	78	0	0	0	12	5.3		4.6	0.36	11
86-2	05/30	117	AB	100	100	0	0	0	4	6.3	8.2	6.0	0.39	6
86-3	05/30	119	AB	100	100	0	0	0	4	5.5	7.5	4.9	0.36	5
86-4	05/30	118	AB	100	100	0	0	0	4	4.4	6.5	3.7	0.33	10
95-1	6/13-6/14	116	AB	100	100	0	0	0	7	5.7	7.1	4.6	0.34	9
95-2	6/13-6/14	117	AB	100	100	0	0	0	7	5.6	7.1	4.6	0.35	8
95-3	6/13-6/14	117	AB	100	100	0	0	0	7	5.5	7.1	4.6	0.35	7
96-1	6/14-6/15	114	AB	100	100	0	0	0	7	5.7	7.1	4.6	0.35	5
96-2	6/14-6/15	113	AB	100	100	0	0	0	7	5.6	7.0	4.8	0.36	4
101-1	9/16	121	AB	78	100	0	0	0	0	4.7	7.1	4.0	0.33	6
101-2	9/17	118	AB	78	100	0	0	0	0	6.4	8.2	5.2	0.34	4
101-3	9/17	117	AB	80	100	0	0	0	0	6.9	8.6	5.9	0.34	5
80 MWe TESTS														
81-4	05/17	79	ABC	100	80	0	0	0	3	7.0	9.5	7.3	0.41	7
81-5	05/17	74	ABC	100	80	0	0	0	3	5.8	8.2	5.7	0.37	7
81-6	05/17	75	ABC	100	50	0	0	0	3	4.7	7.3	4.2	0.33	8
87-1	05/31	82	ABC	100	55	0	0	0	7	7.5	9.7	7.4	0.43	10
87-2	05/31	82	ABC	100	55	0	0	0	7	5.8	8.1	5.6	0.36	9
87-3	06/01	80	ABC	100	55	0	0	0	7	5.0	7.2	4.5	0.34	9

200 AND 180 MWe DATA NOT CORRECTED FOR SOFA LEAKAGE

TABLE 4 COMPARISON OF BASELINE AND LEVEL 1 PERFORMANCE PARAMETERS

	EXCESS OXYGEN		FINENESS THRU 200		FINENESS ON 50		LOSS ON IGNITION		BOILER EFFICIENCY	
NOMINAL LOAD MWe	BASELINE EXCESS OXYGEN Percent	LEVEL 1 EXCESS OXYGEN Percent	BASELINE FINENESS THRU 200 MESH Percent	LEVEL 1 FINENESS THRU 200 MESH Percent	BASELINE FINENESS ON 50 MESH Percent	LEVEL 1 FINENESS ON 50 MESH Percent	BASELINE LOI Percent	LEVEL 1 LOI Percent	BASELINE PTC 4.1 EFFICIENCY Percent	LEVEL 1 PTC 4.1 EFFICIENCY Percent
180	4.0	2.8	58.9	53.7	2.9	2.6	5.0	4.6	89.7	89.6
135	2.8	3.9	60.7	54.6	2.3	2.7	4.2	5.3	90.7	89.7
115	3.6	4.2	60.0	53.2	3.1	2.7	4.0	4.0	90.9	90.1

TABLE 3 COMPARISON OF BASELINE AND LEVEL 1 STEAMING CHARACTERISTICS

PHASE 1 BASELINE				PHASE 3B LNCFS I			
LOAD MWe	SH TEMP Deg F	RH TEMP Deg F	TILT Deg	LOAD MWe	SH TEMP Deg F	RH TEMP Deg F	TILT Deg
70	998	909	0	70	931	830	3
79	999	919	0	81	966	870	4
90	999	926	0	90	978	886	3
100	1001	934	0	100	991	905	5
110	1002	940	0	111	995	925	5
120	1003	952	0	120	994	929	4
131	1003	959	0	131	994	936	3
140	1003	963	0	139	994	939	4
150	1003	966	0	150	995	950	3
160	1003	976	0	160	993	958	3
170	1001	982	0	170	994	965	3
180	1001	987	0	180	996	980	2
191	1001	991	0	193	995	985	2
198	1000	995	0	196	996	992	3

FIGURE 2 PHASE 3b MEASURED NOx LEVELS

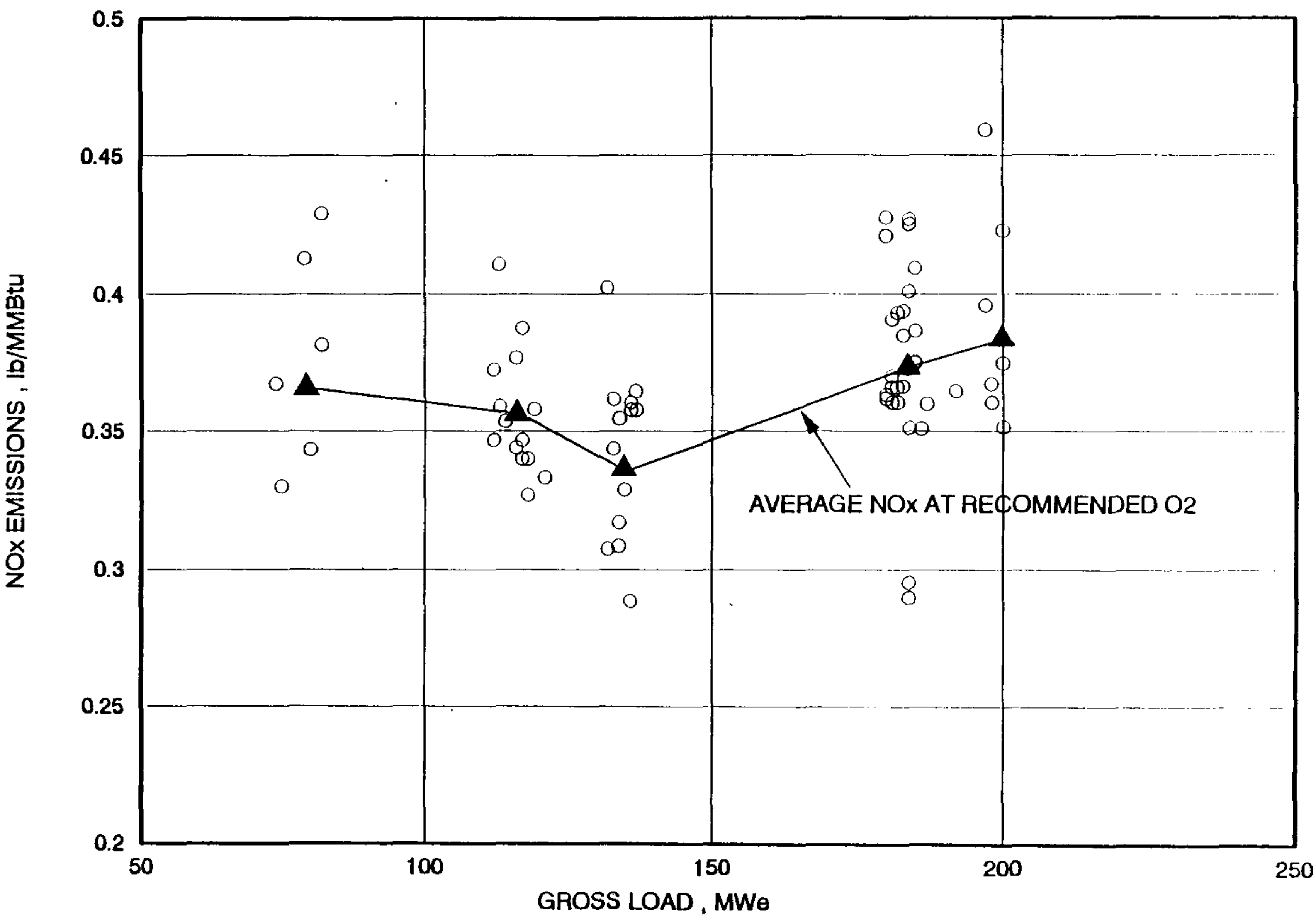


FIGURE 1 PHASE 3b OXYGEN LEVELS TESTED

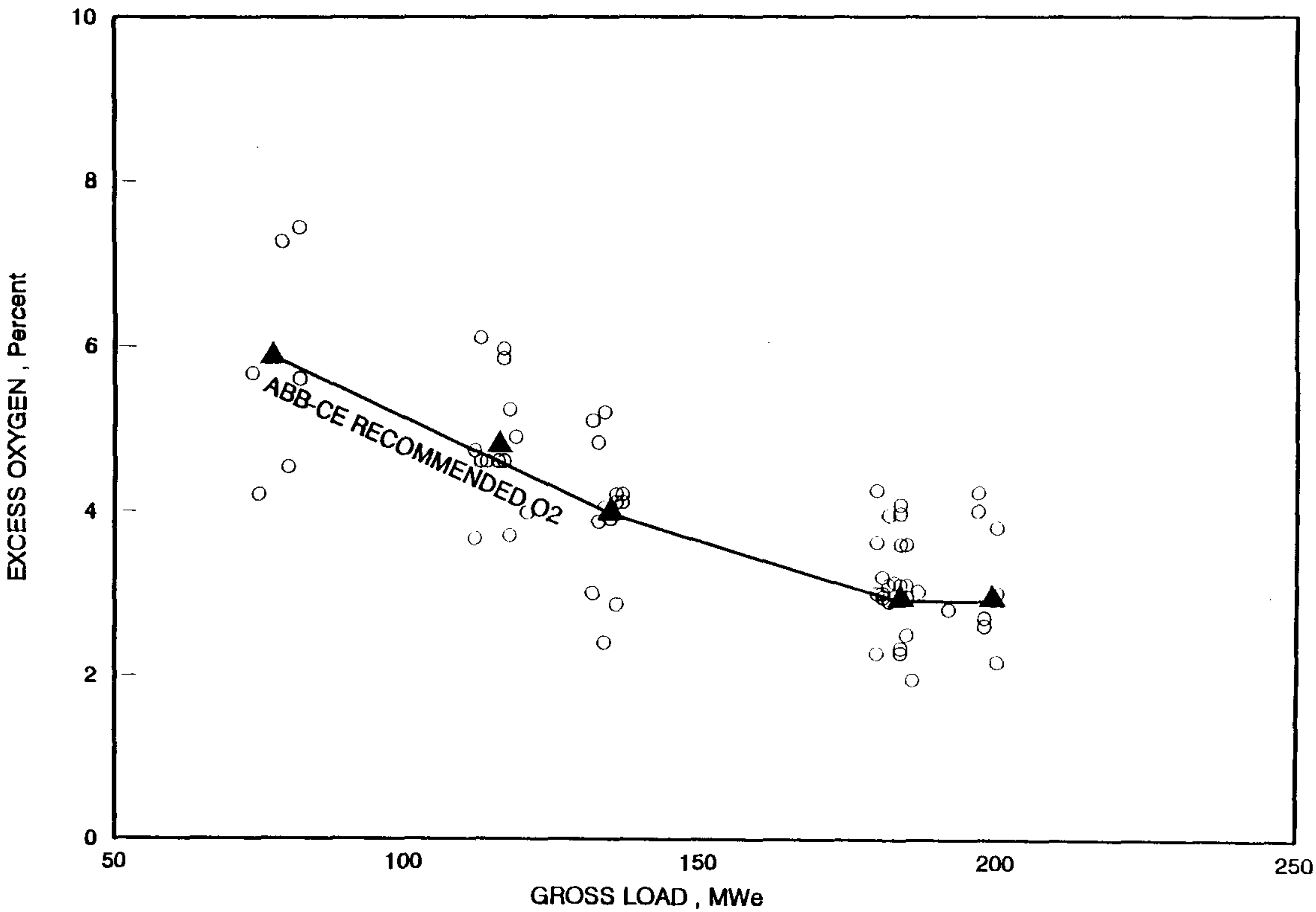


FIGURE 4 PHASE 3b 180 MWe CHARACTERIZATION

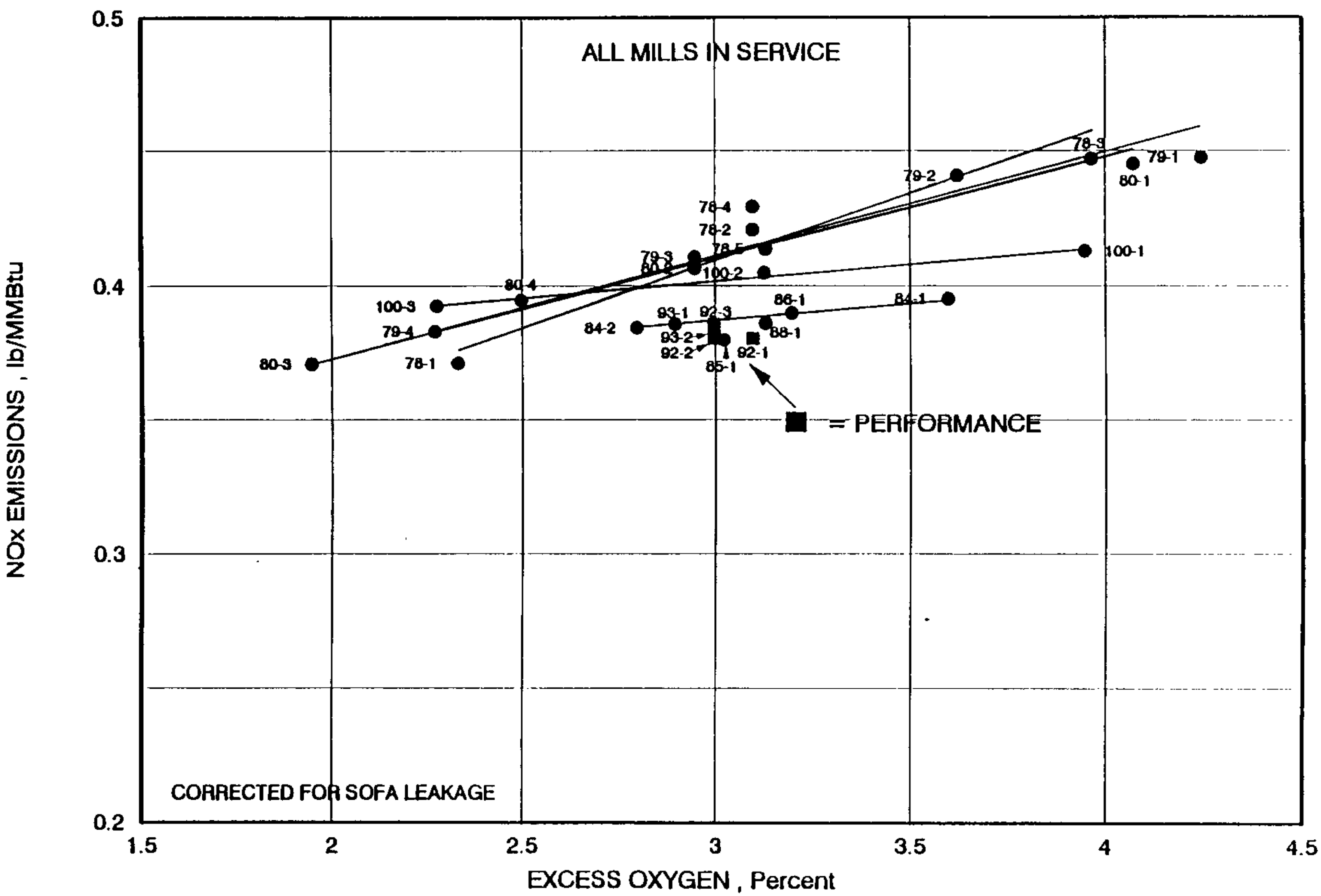


FIGURE 3 PHASE 3b 200 MWe CHARACTERIZATION

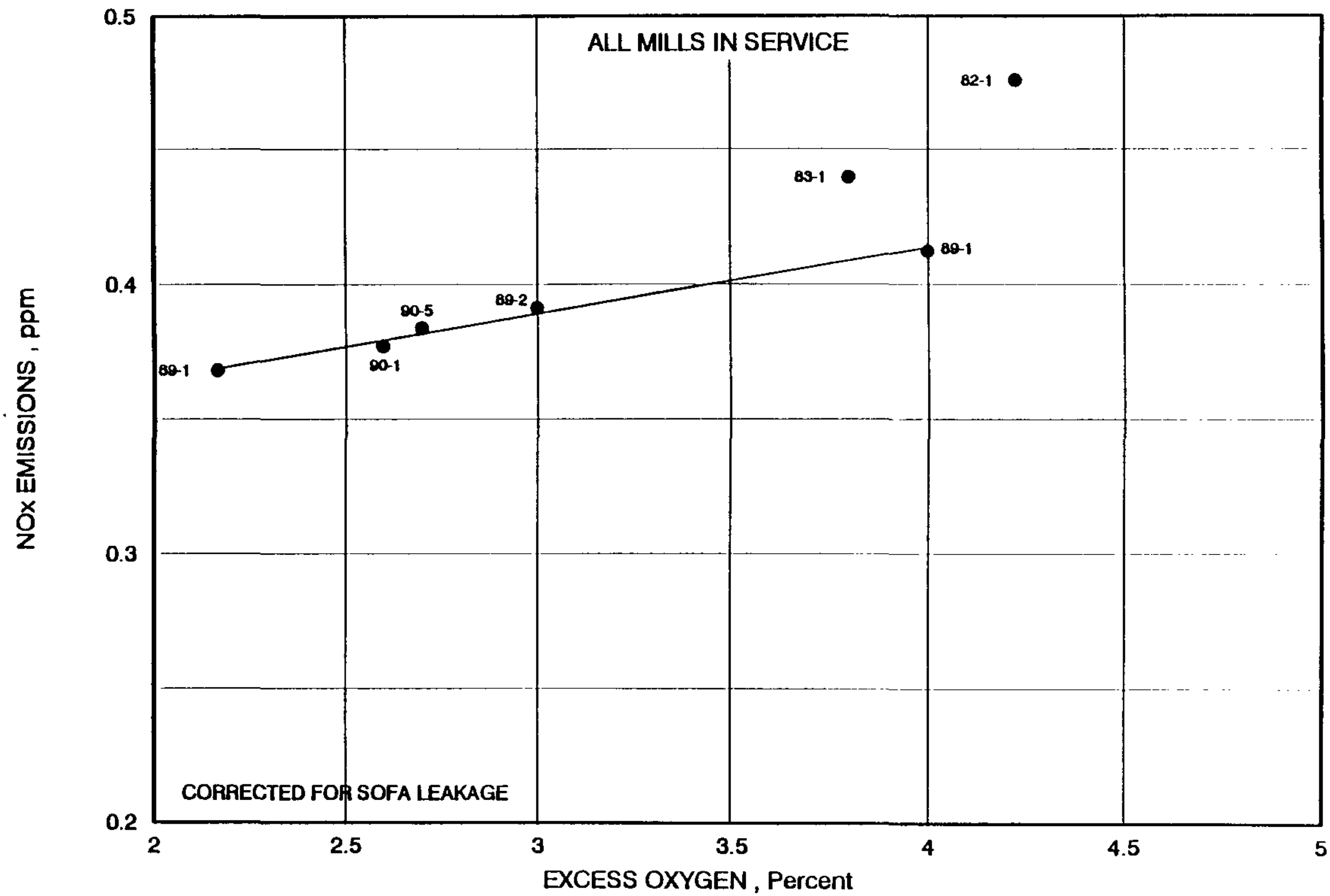


FIGURE 6 PHASE 3b 115 MWe CHARACTERIZATION

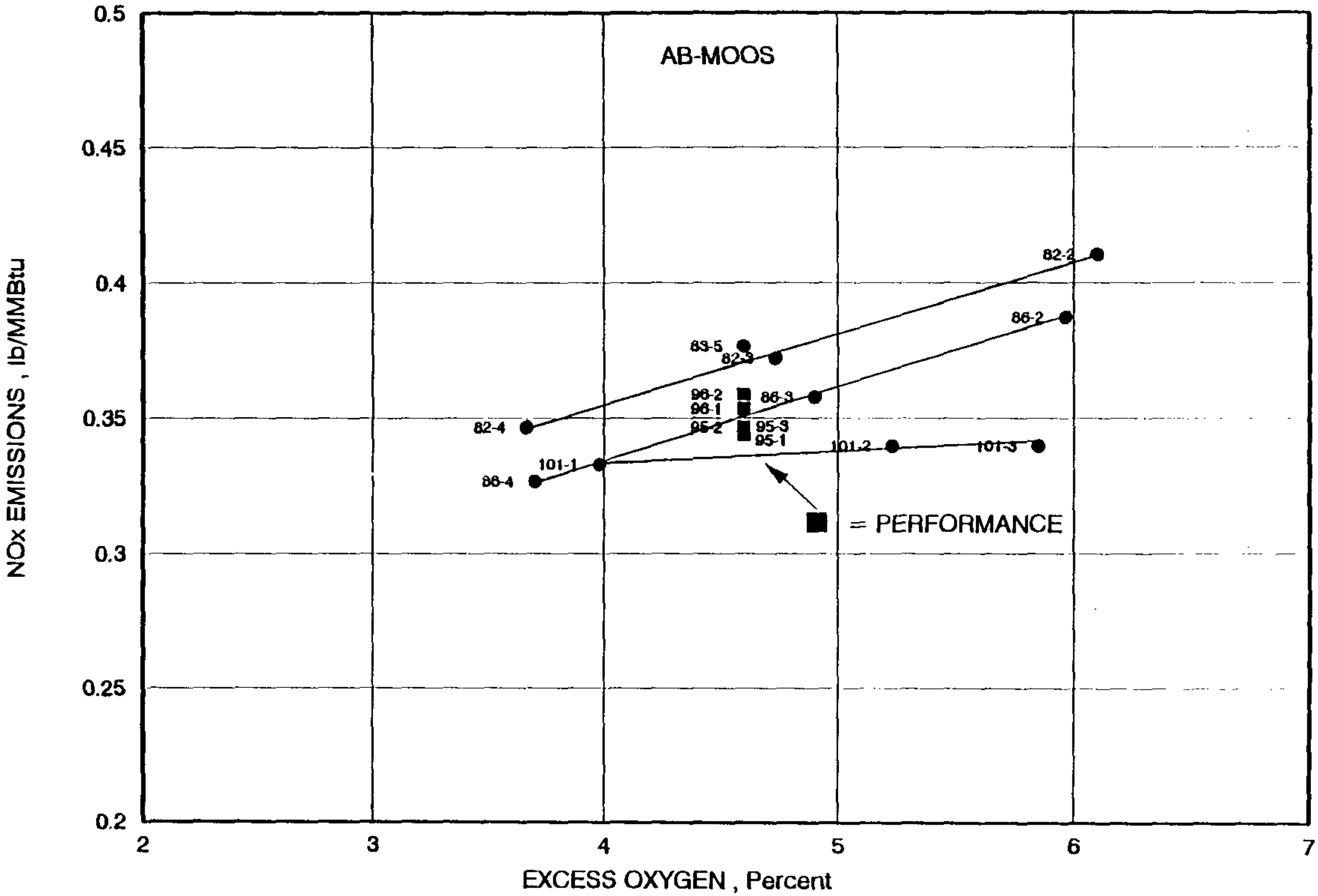


FIGURE 5 PHASE 3b 135 MWe CHARACTERIZATION

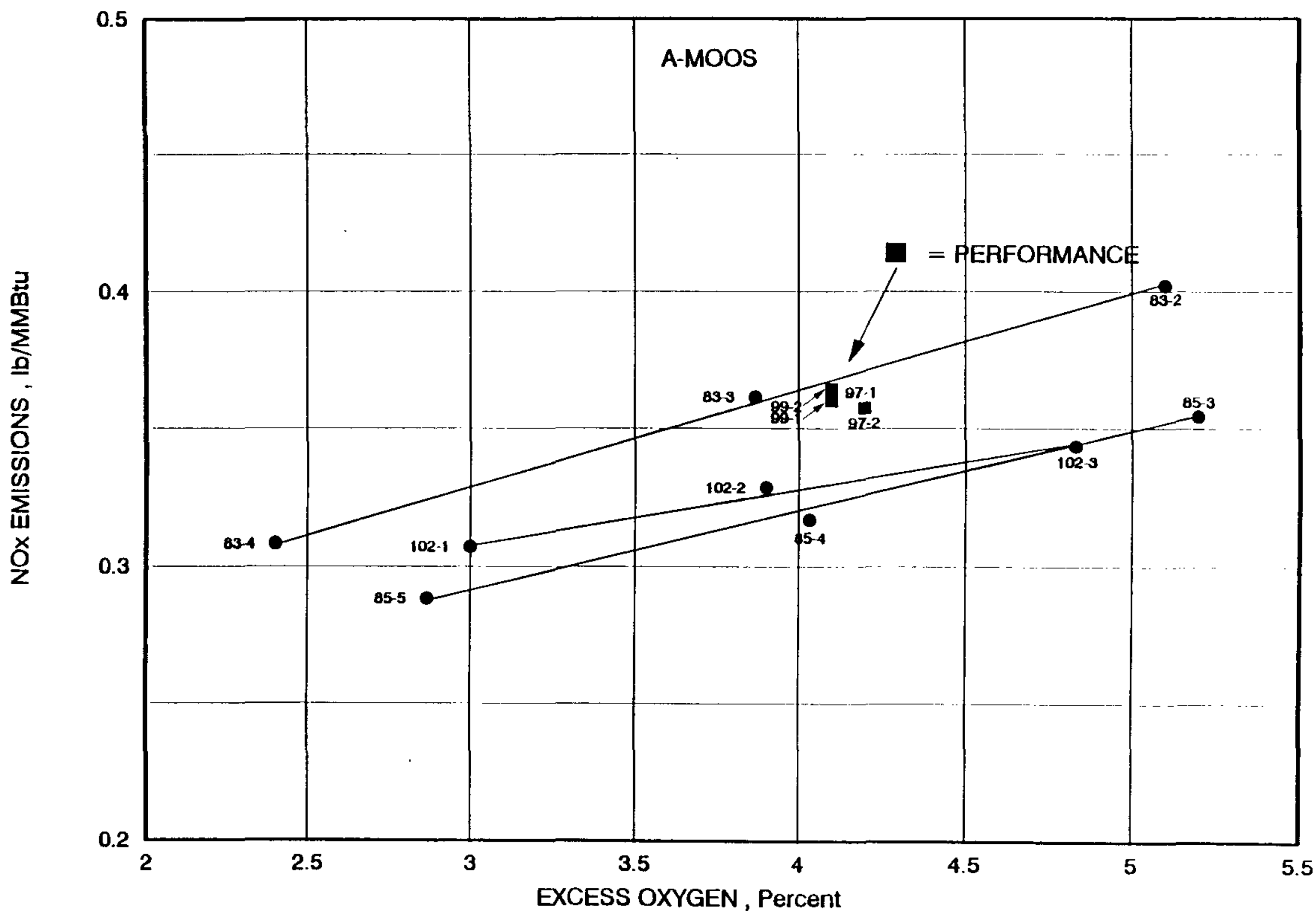


FIGURE 8   COMPARISON OF BASELINE AND LEVEL 1
180 MWe NOx EMISSIONS

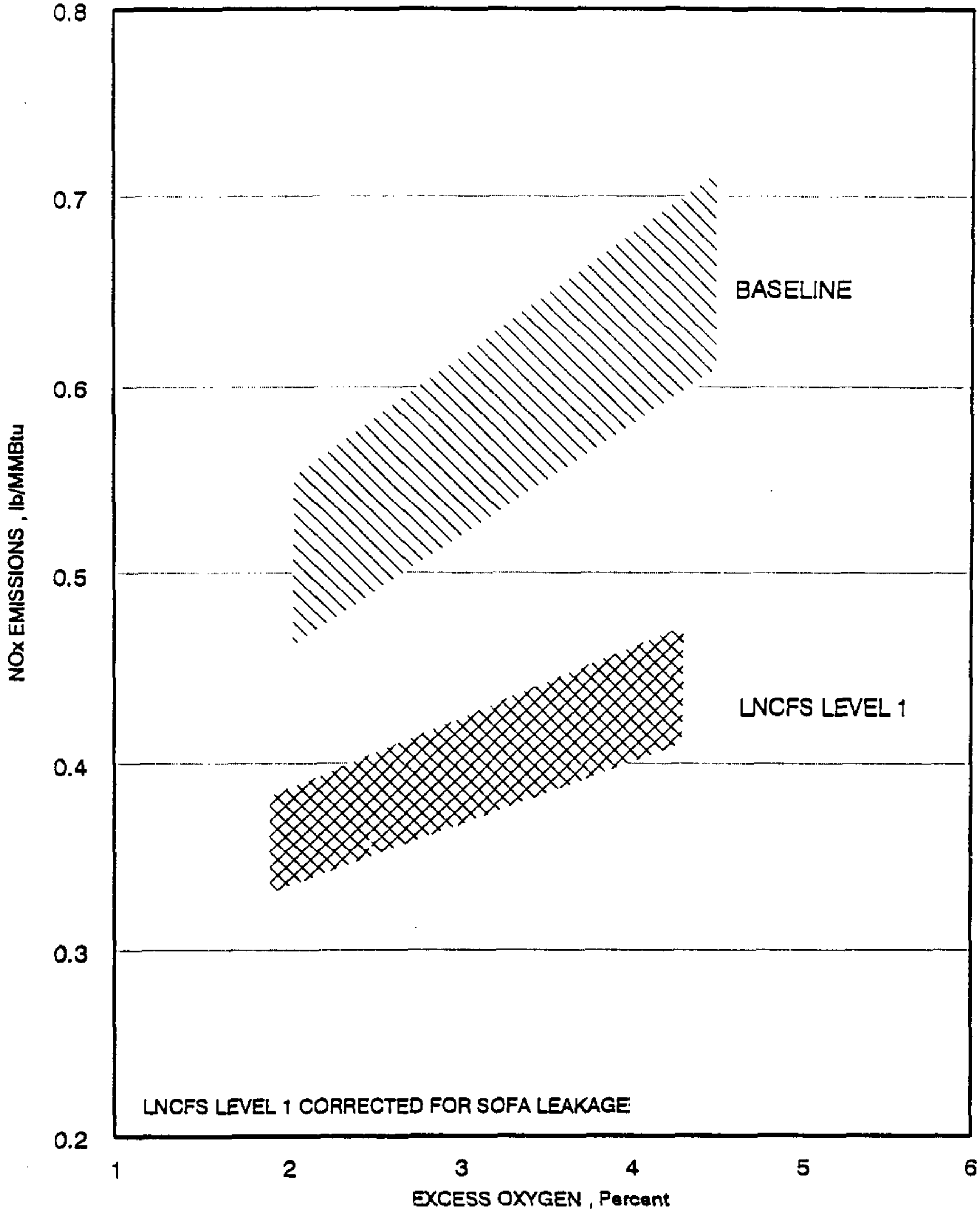


FIGURE 7 PHASE 3b 80 MWe CHARACTERIZATION

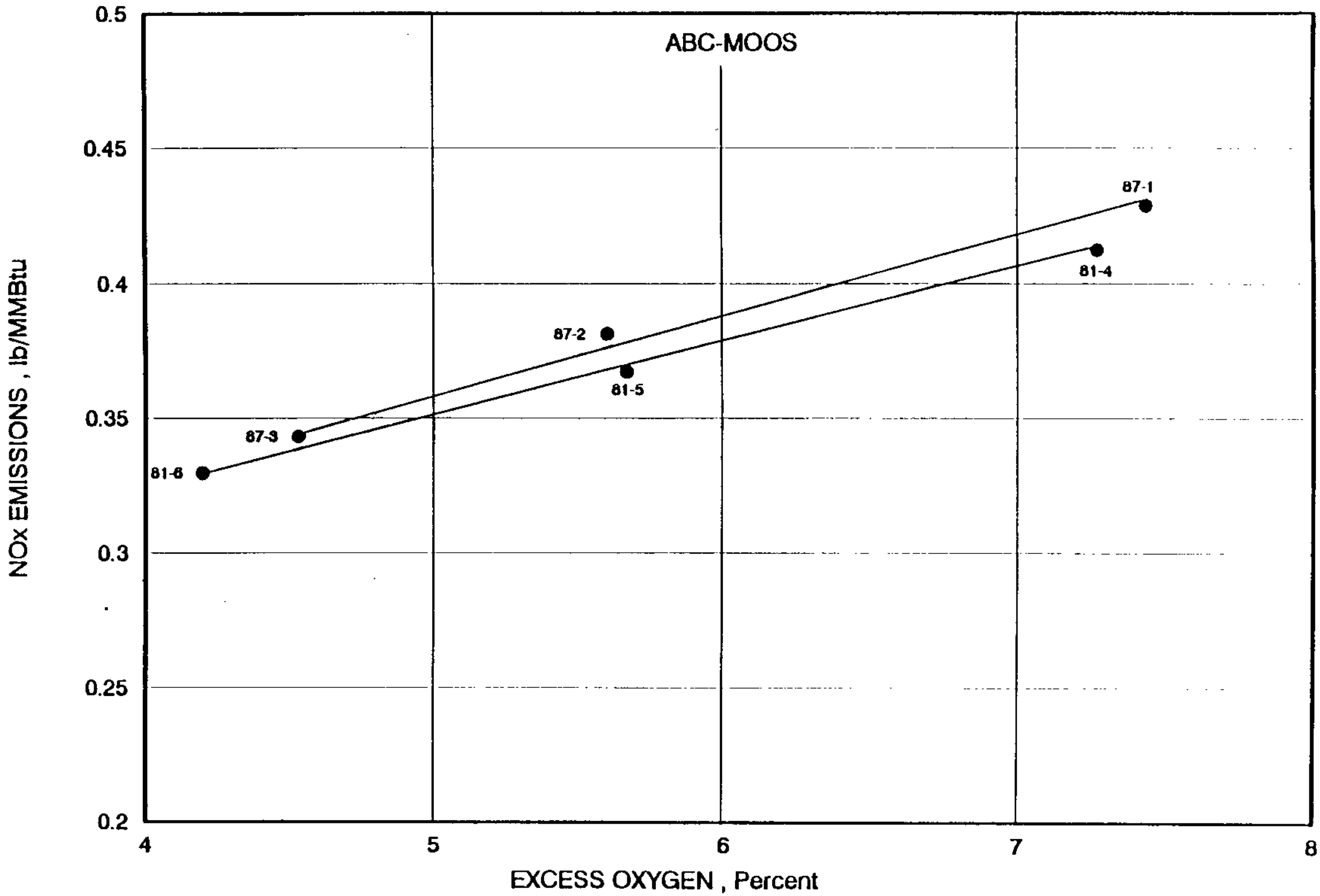


FIGURE 10 LNCFS LEVEL 1 NOx REDUCTION EFFECTIVENESS

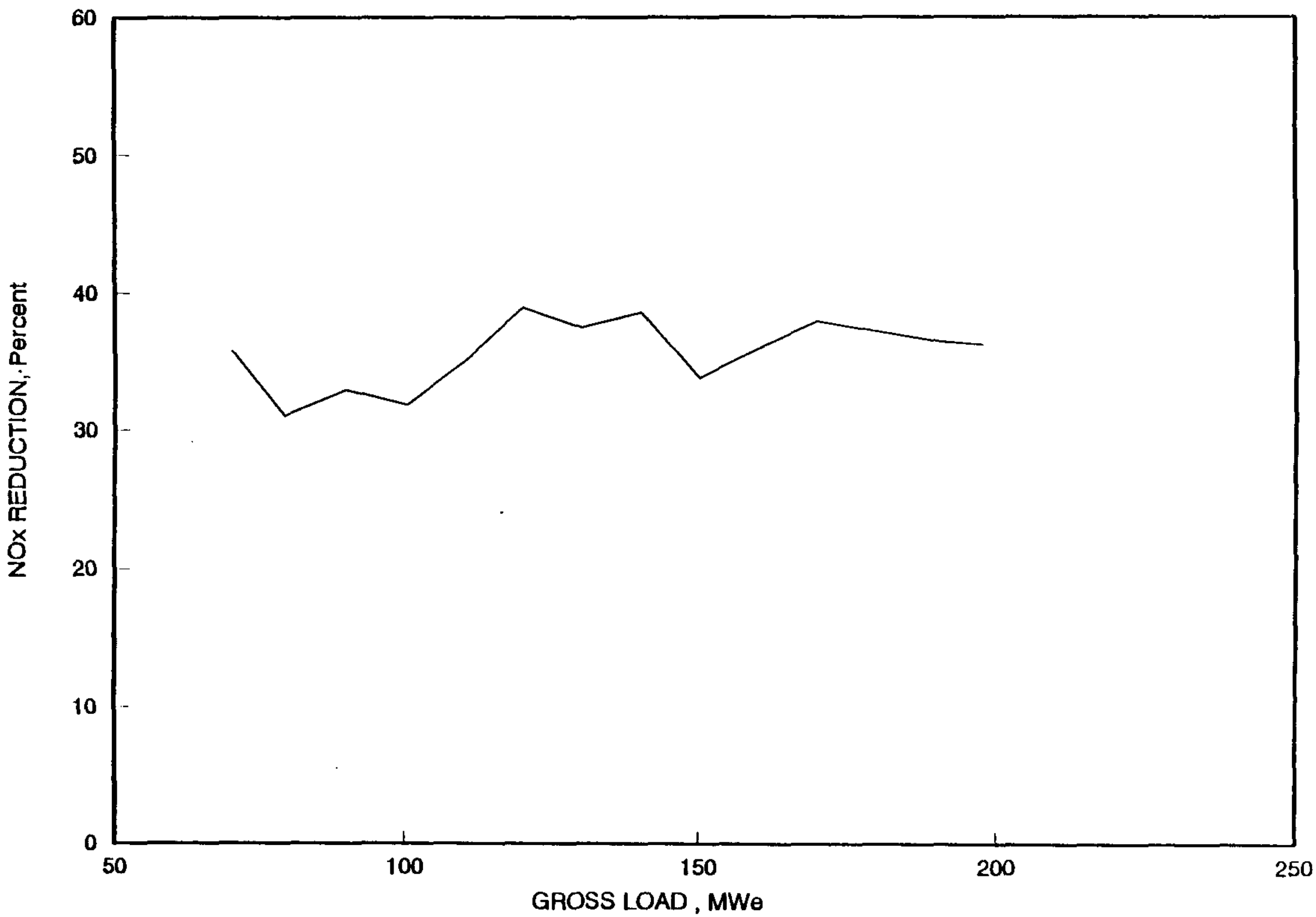


FIGURE 9 LONG-TERM NOx EMISSION CHARACTERISTIC

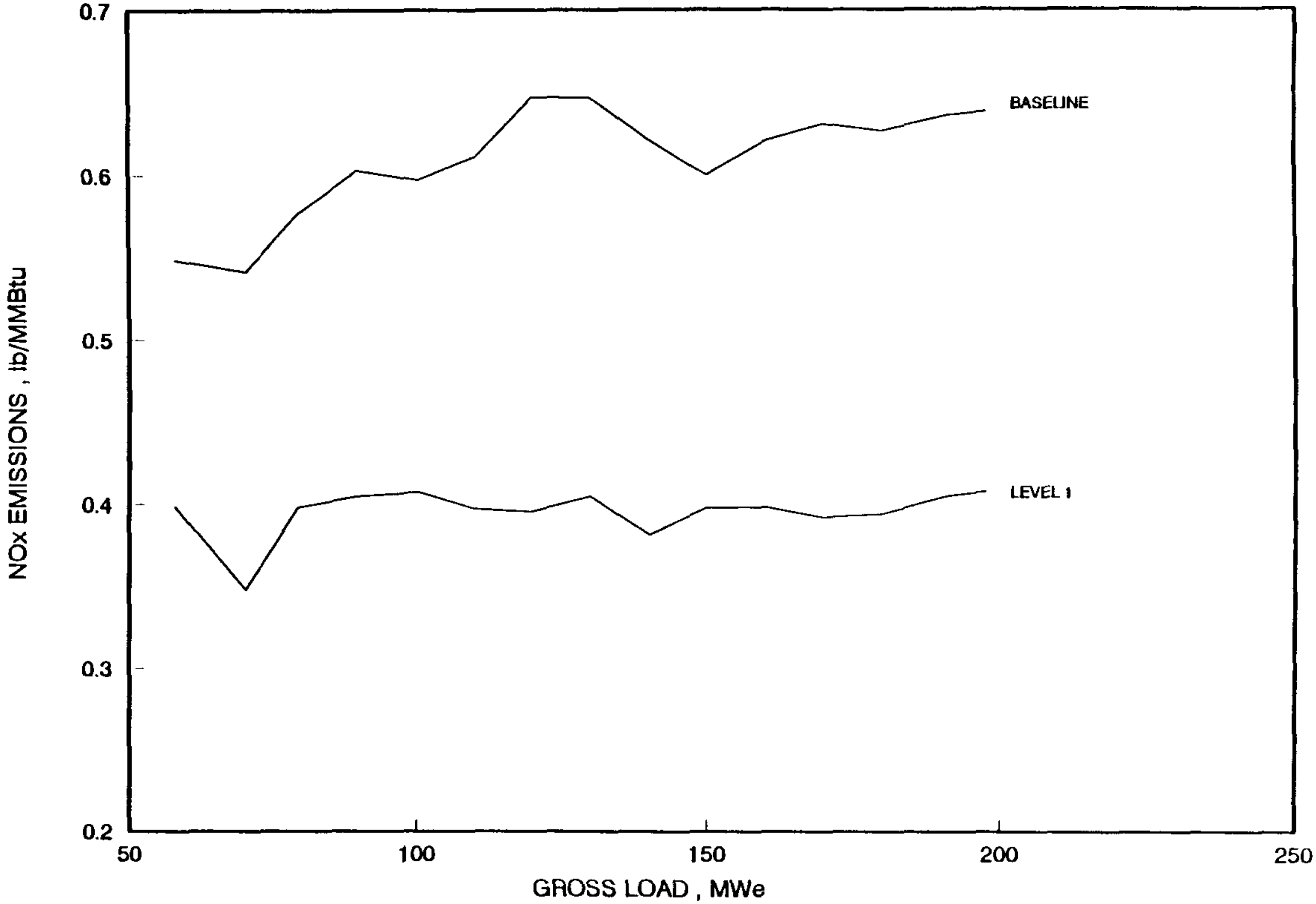


FIGURE 12 LONG-TERM CARBON MONOXIDE CHARACTERISTICS

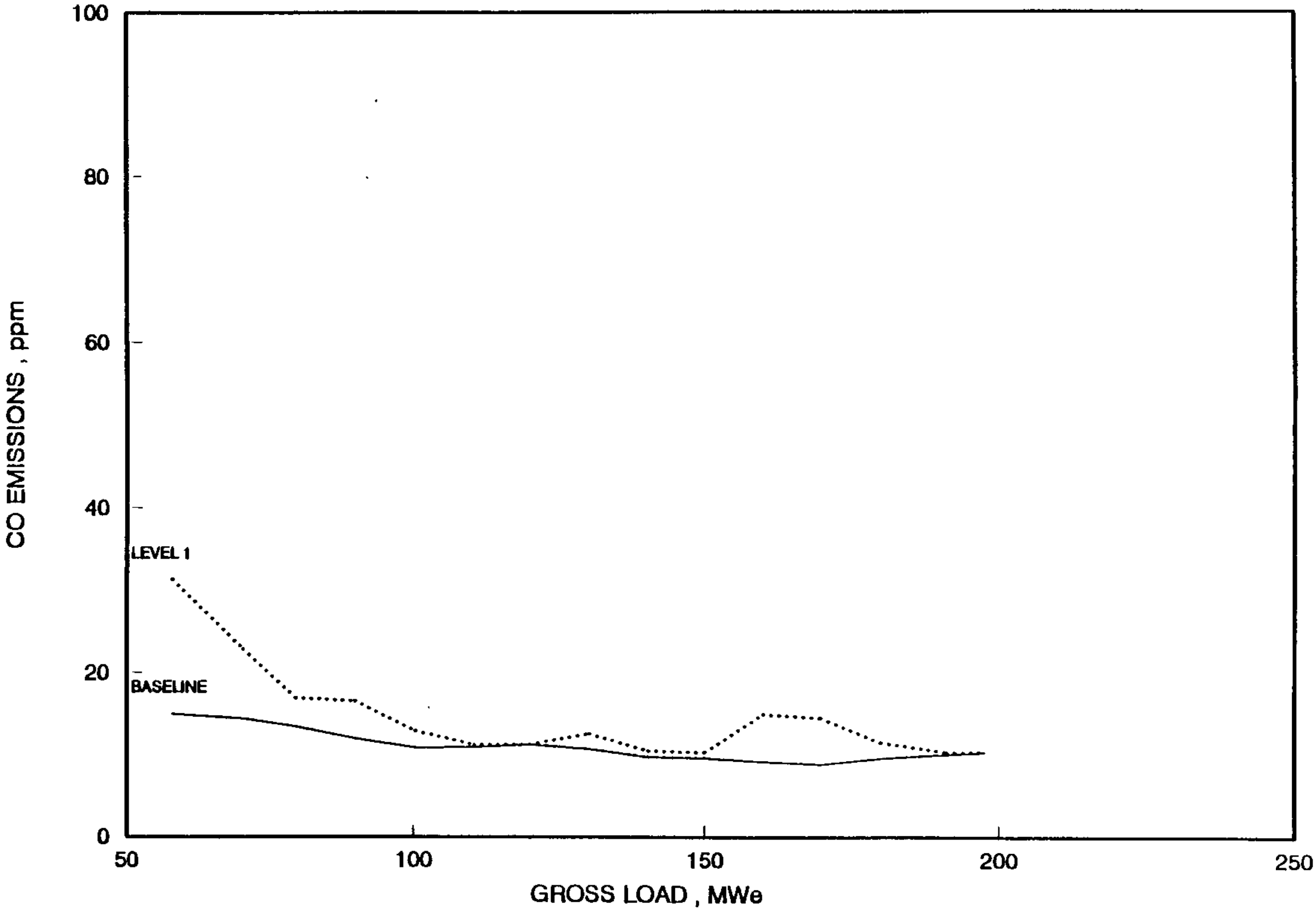


FIGURE 11 LONG-TERM EXCESS OXYGEN CHARACTERISTICS

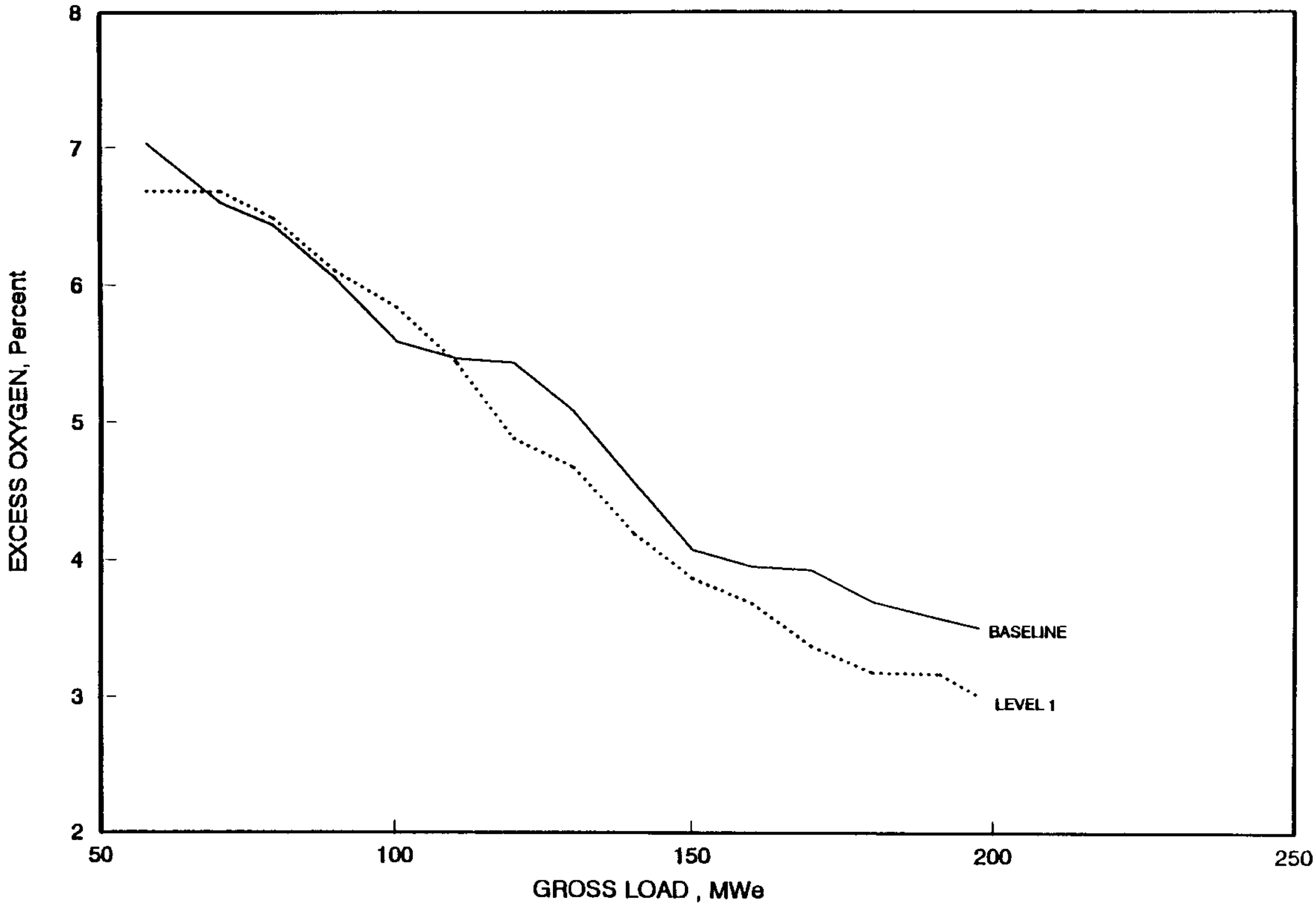


FIGURE 14 COMPARISON OF LONG-TERM BASELINE AND LNCFS LEVEL 1 SUPERHEAT TEMPERATURES

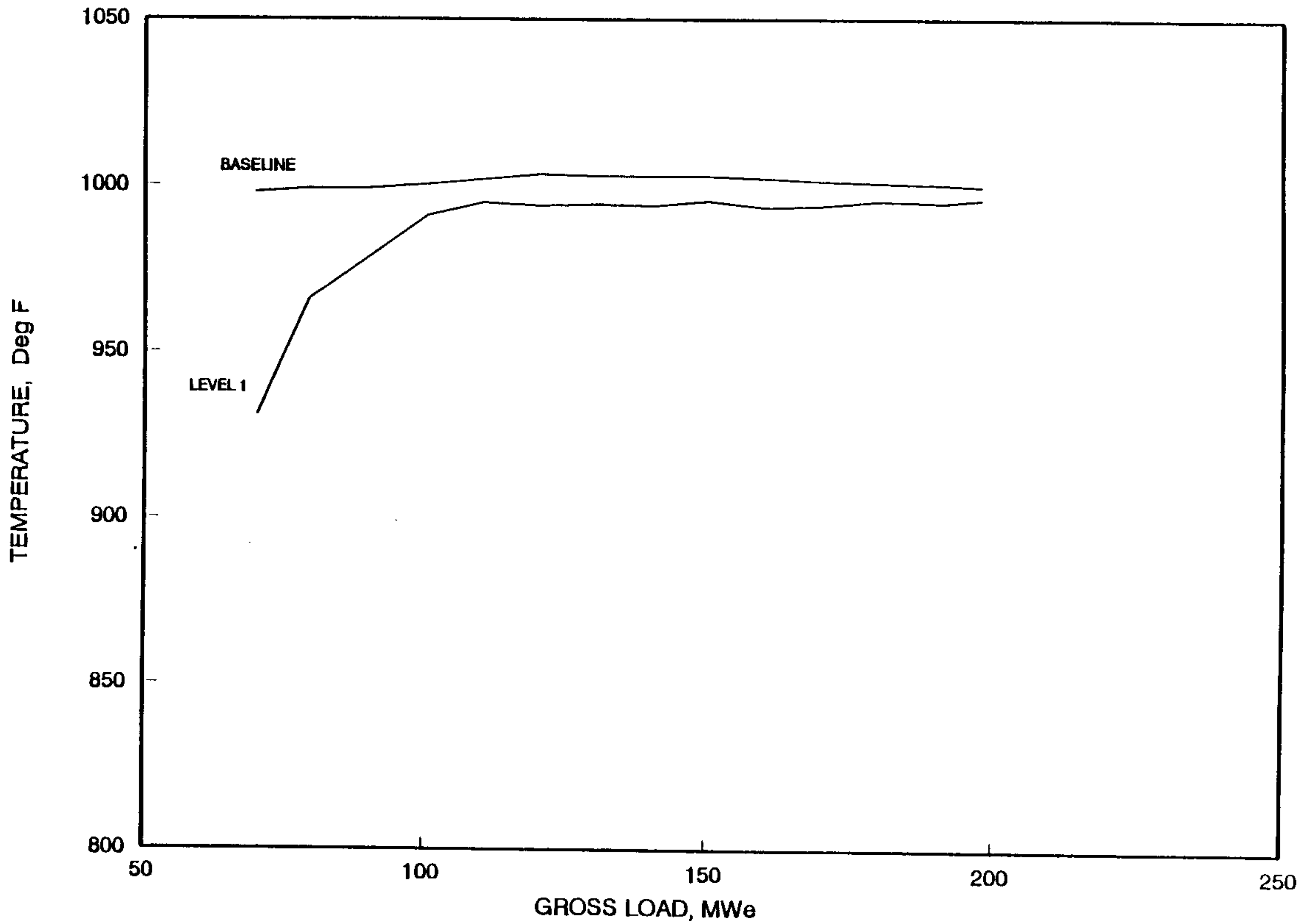


FIGURE 13 LOAD HISTORIES FOR BASELINE AND LEVEL 1 LONG-TERM TESTS

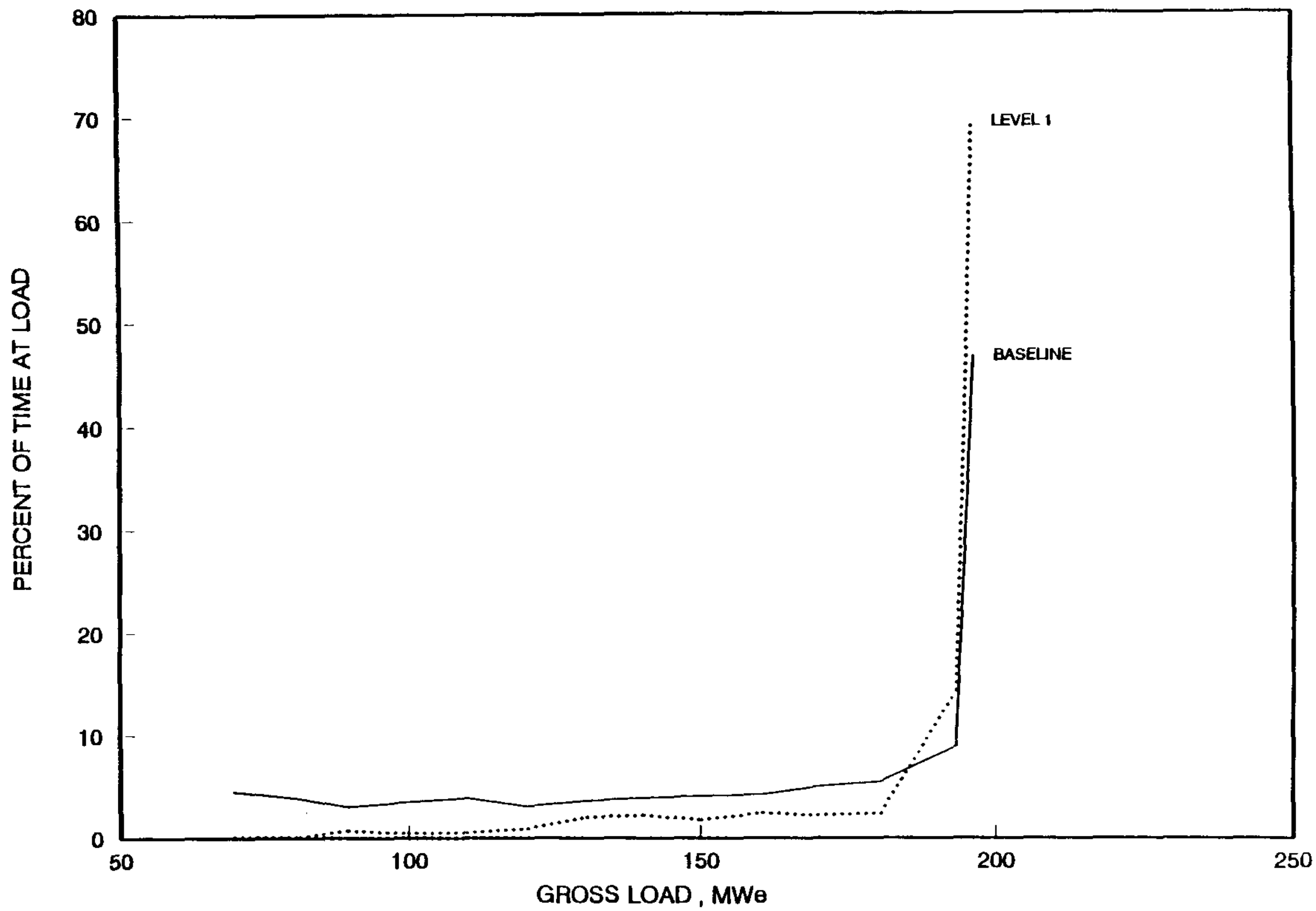
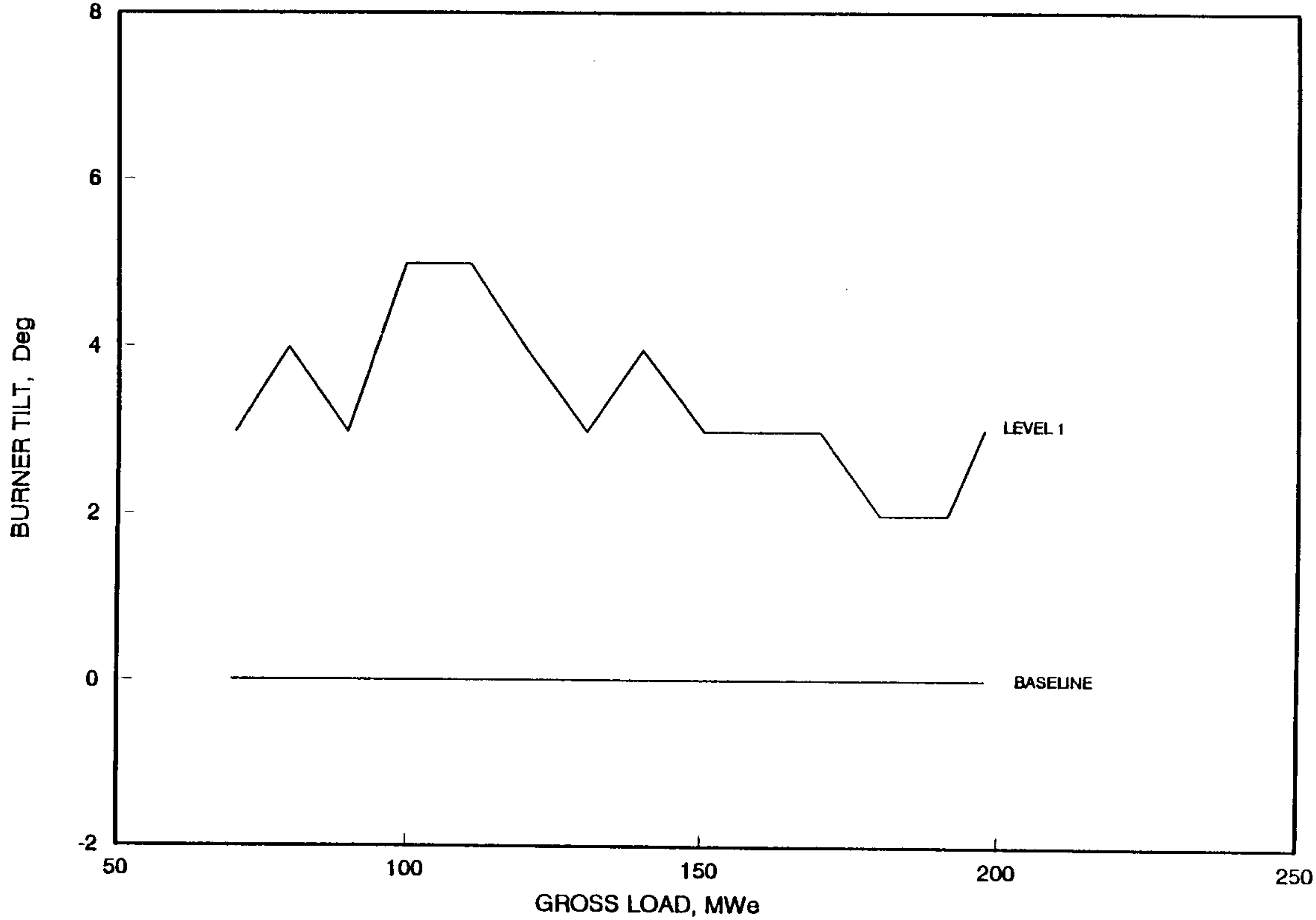
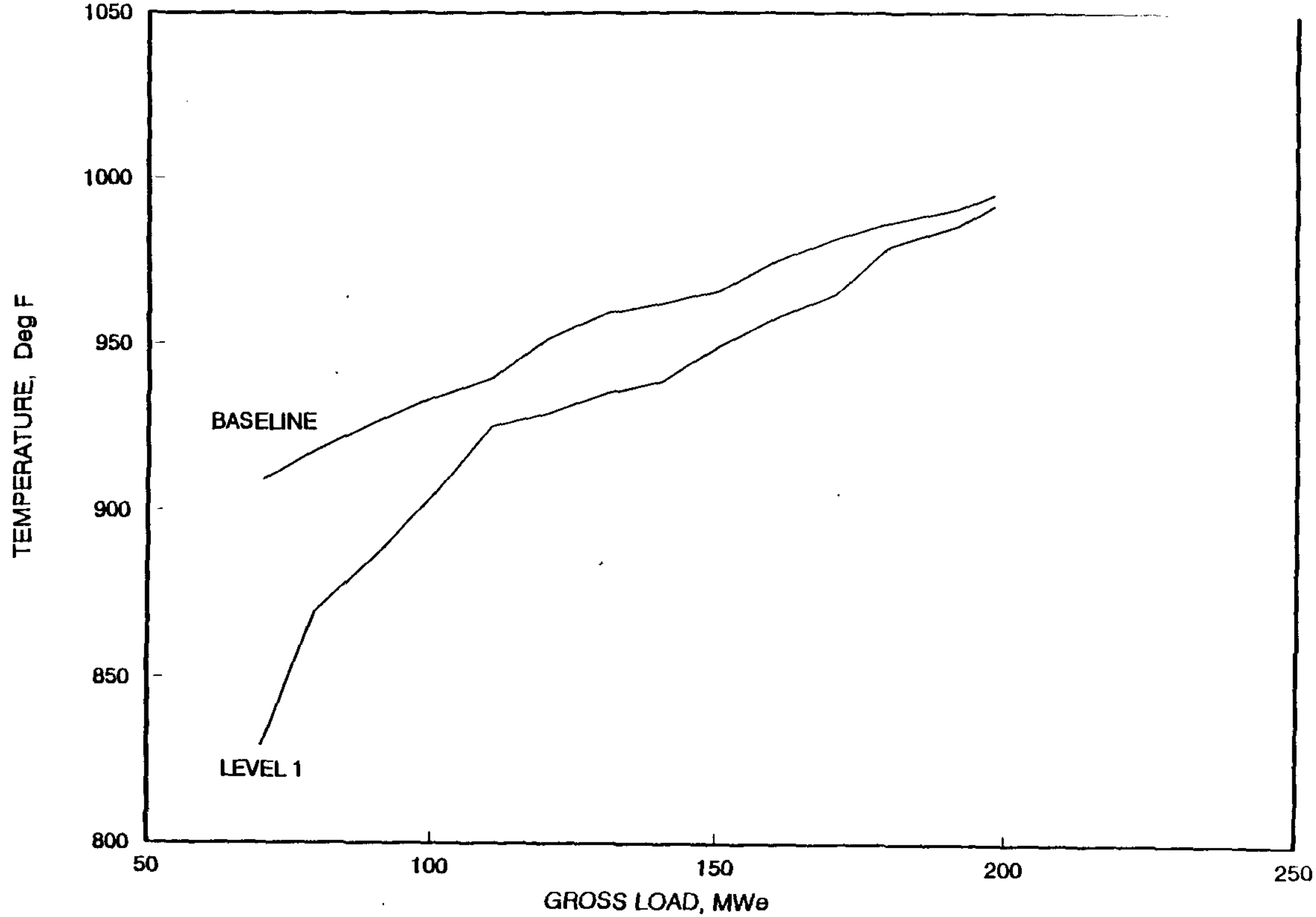


FIGURE 16 COMPARISON OF LONG-TERM BASELINE AND LNCFS LEVEL 1 BURNER TILTS





1050
1000
950
900
850
800
TEMPERATURE, Deg F
BASELINE
LEVEL 1
50
100
150
200
250
GROSS LOAD, MWe

FIGURE 18 COMPARISON OF BASELINE AND LEVEL 1 ASME PTC 4.1 EFFICIENCY