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Environmental Protection Technology Series

PROGRAM FOR REDUCTION OF NO_X FROM TANGENTIAL COAL-FIRED BOILERS PHASE IIa

NO_X CONTROL TECHNOLOGY APPLICATION STUDY

U.S. Environmental Protection Agency
Office of Research and Development
Washington, D. C. 20460

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PROGRAM FOR REDUCTION OF NO_X FROM TANGENTIAL COAL-FIRED BOILERS PHASE IIa

NO_X CONTROL TECHNOLOGY APPLICATION STUDY

by

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ABSTRACT

This report presents the results of Task IX of the Phase II - "Program for Reduction of NO_x from Tangential Coal Fired Boilers" performed under the sponsorship of the Office of Research and Development of the Environmental Protection Agency (Contract 68-02-1367).

The results presented are based on both field performance tests performed at Alabama Power Corporation, Barry #2 and current contractor experience.

The utilization of overfire air as an NO_x control technique is discussed relative to the following areas of interest:

1. Necessary equipment modifications and costs (as of March, 1975) associated with applying this technology to existing steam generators.

2. Specific limitations to the general applications of the technology developed.

3. Emission control and cost effectiveness of applying the developed technology to new steam generator designs.

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ACKNOWLEDGMENTS

The author wishes to acknowledge the constructive participation of Mr. D. G. Lachapelle, EPA Project Officer in providing the program direction necessary to its successful completion.

The cooperation and active participation of Alabama Power Company and in particular, the personnel of the Barry Steam Plant, were essential to successful completion of this program.

The results presented in this report represent the effort of many Combustion Engineering, Inc. personnel whose participation was required for its successful completion and in particular, the technical contributions made by Messrs: M. J. Hargrove and R. W. Robinson.

CONCLUSIONS

1. Prior to incorporating overfire air as an NO_x control system on existing unit designs, an exploratory test program must be performed to determine the acceptability of the unit for modification.

2. The costs of installing an overfire air system on an existing unit could range between 2 to 4 times the cost as included on a new unit design. Based on March, 1975 estimates existing unit modification costs could range from 0.2 to 1.5 $/kw, depending on unit size.

3. Approximately 40% of the existing coal fired units in the United States are of tangential design and could conceivably be modified to incorporate overfire air systems.

4. Unit size, heat rate and expected life must be considered in deciding whether modifications are justified.

5. Incorporation of an overfire air system will generally not significantly affect unit performance.

6. A large percentage of the existing tangentially coal fired units in the United States can meet current EPA standards for NO_x emission levels. The necessity of applying the overfire air technique for NO_x control should therefore be established prior to committing a unit for modification.

RECOMMENDATIONS

Existing Steam Generating Units

The applicability of the technology developed in the course of this project should be qualified by the following conditions:

1. Any unit under consideration should be subjected to an exploratory test program to determine the necessity of modification with respect to applicable NO_x compliance limits. The minimum test requirements recommended for such a study would consist of studying the effect of available process variables such as excess air level. The minimum test data would consist of NO_x, CO for combustion efficiency and sufficient board or test data to identify changes in unit operating characteristics.

2. A review should be made of the unit and turbine useful life expectancy, unit size versus modification costs, and unit heat rate.

New Steam Generating Units

All tangentially coal fired units since approximately 1970 have included OFA in the original unit design. The OFA system is therefore not considered as an additional NO_x control device.

INTRODUCTION

The effectiveness of overfire air operation in reducing NO_x emissions from existing utility steam generators was evaluated by selecting and modifying a test unit and studying the effects of this modification on unit performance and emission control. The test unit was a natural circulation, balanced draft design, firing coal through four elevations of tilting tangential fuel nozzles. Unit capacity at maximum continuous rating (MCR) is 408,000 kg/hr main steam flow with a superheat outlet temperature and pressure of 538°C and 131.8 kg/cm^2. Superheat and reheat temperatures were controlled by fuel nozzle tilt and spray desuperheating.

In order to evaluate unit performance during the study, necessary steam, water, air and gas temperature and pressure measurements were performed as well as NO_x, CO, O_2, HC, SO_2 and carbon loss determinations to assess emission performance. The specific results of the test program are included in Final Report EPA-650/2-73-005a and are therefore not presented herein. The test program was conducted in three phases consisting of baseline and biased firing portions conducted prior to modification and baseline and overfire air portions conducted after unit modification. The effect of the modification on unit performance was found to be insignificant and the test data summaries for each phase are shown on Sheets 1, 2, 3 and 4. Short term comparative corrosion tests were run over thirty day periods using corrosion coupons. During this evaluation normal operation with OFA was achieved. The unit load schedules for the baseline and biased firing and overfire air evaluations are shown on Figures 1 and 2 and the respective data summaries are shown on Sheets 5A, 5B and 5C. Corrosion coupon locations are shown on Figure 3.

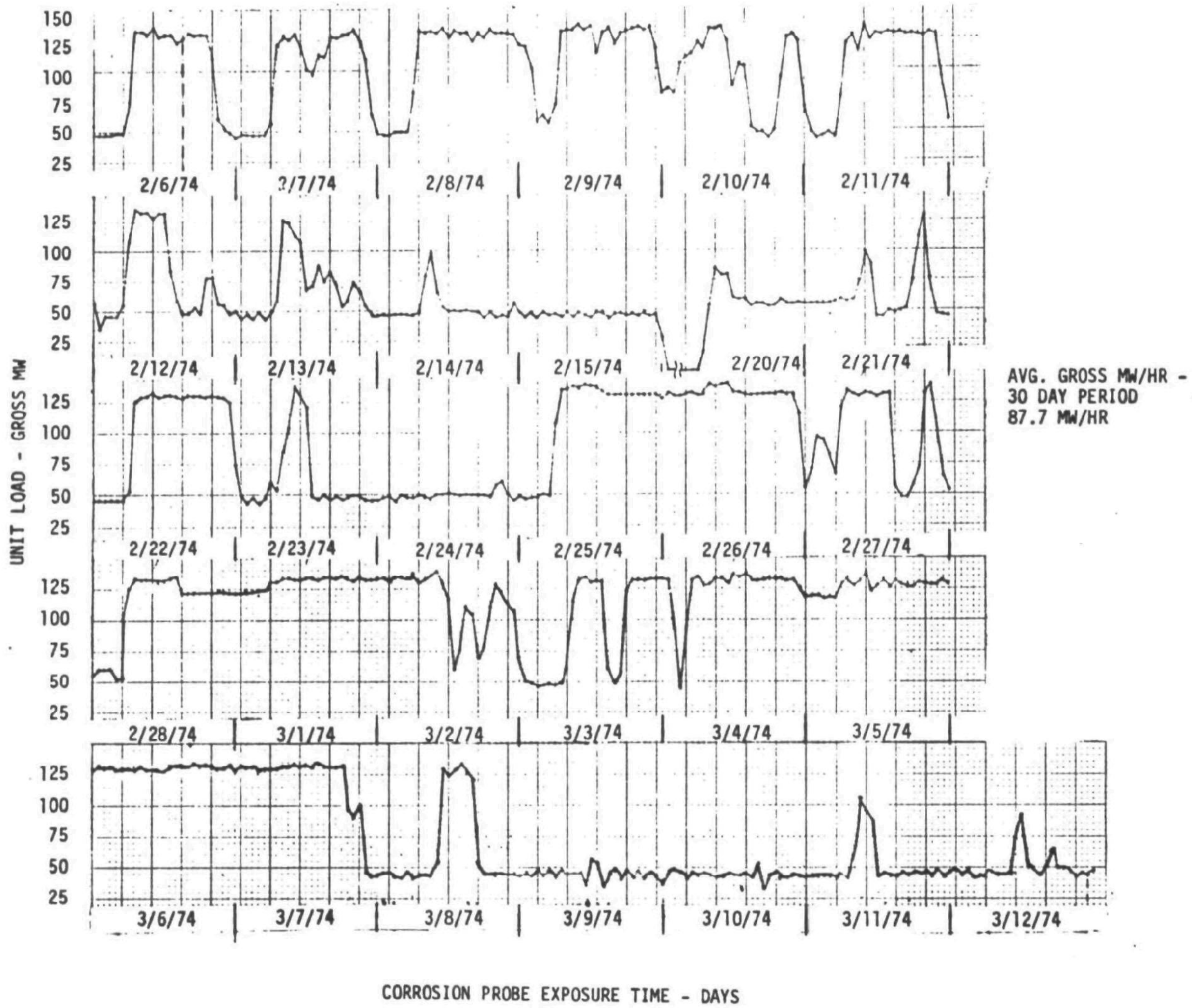

Figure 1: Gross MW Loading Vs. Time - Baseline Corrosion Probe Study

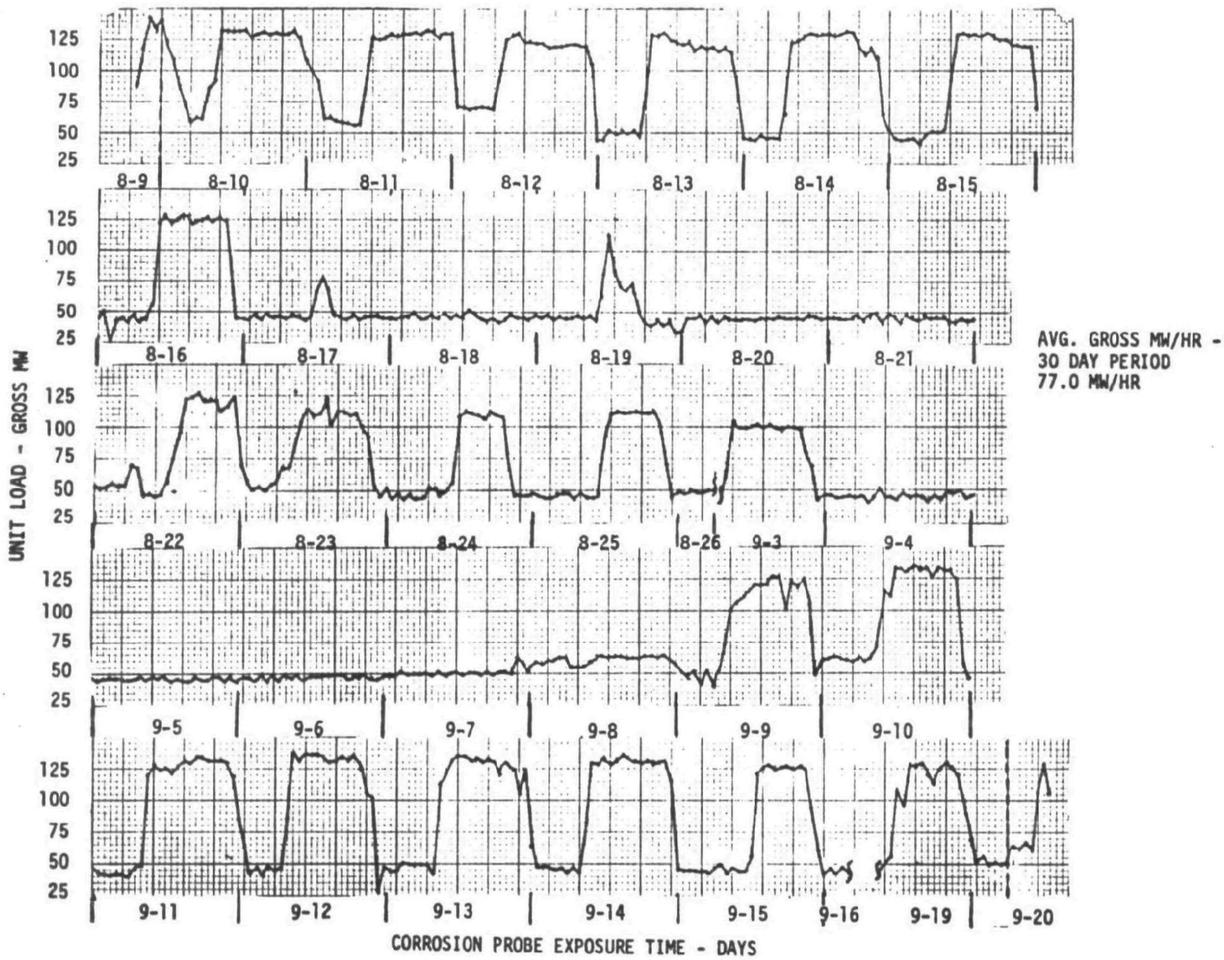

Figure 2: Gross MW Loading Vs. Time - Overfire Air Corrosion Probe Study

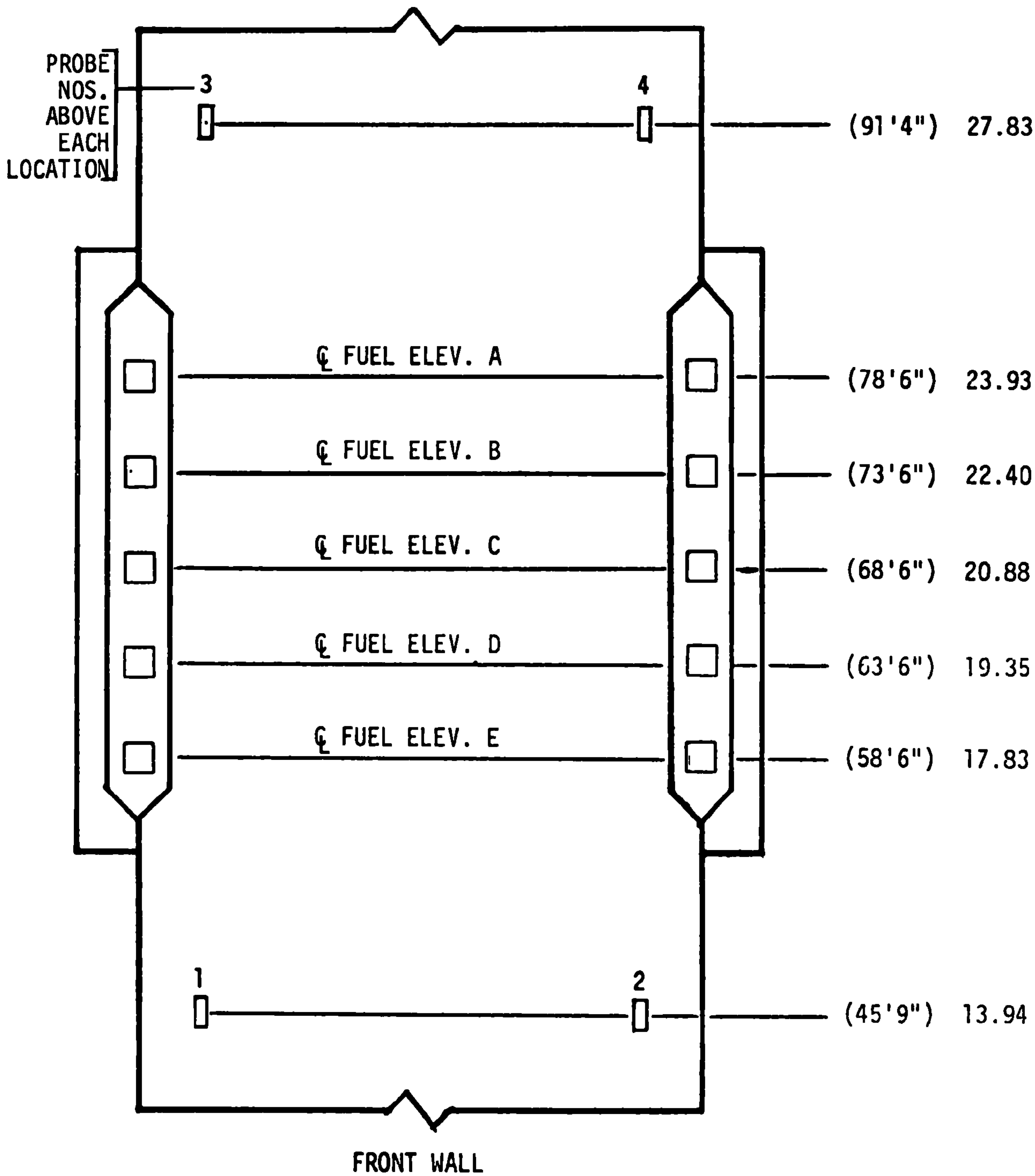

Figure 3: Waterwall Corrosion Probe Locations, Barry No. 4

Design and Description of OFA Systems

The overfire air system as incorporated in tangential coal fired furnaces consists of air compartments and nozzles, ductwork, flow control dampers and nozzle tilting mechanisms. A typical arrangement of this system is shown on Figure 4. The overfire air compartments and nozzles are designed as vertical extensions of the corner windboxes unless as in the case of some existing units, modification at that location is not possible due to structural considerations.

In the latter case, as was the situation with the test unit, the separate compartments and nozzles were installed within three meters of the top of the existing windbox. As shown on Figure 5, this arrangement requires additional ductwork for supplying air to the OFA system.

Control dampers for regulating the OFA flow rate should be coordinated with the windbox fuel and auxiliary air compartment dampers to correctly proportion air flow as required for various operating modes.

An independent OFA nozzle tilt mechanism should also be provided on retrofits of existing units to permit coordinating these nozzles with the fuel and air nozzle tilts.

The overfire air nozzles and ducts should be sized for 15% of the full load secondary* air flow using the same nozzle and duct velocities as the windbox. Each overfire air port consists of two nozzles above each windbox, usually as an extension of the windbox.

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* Secondary air does not include coal pulverizer transport air.

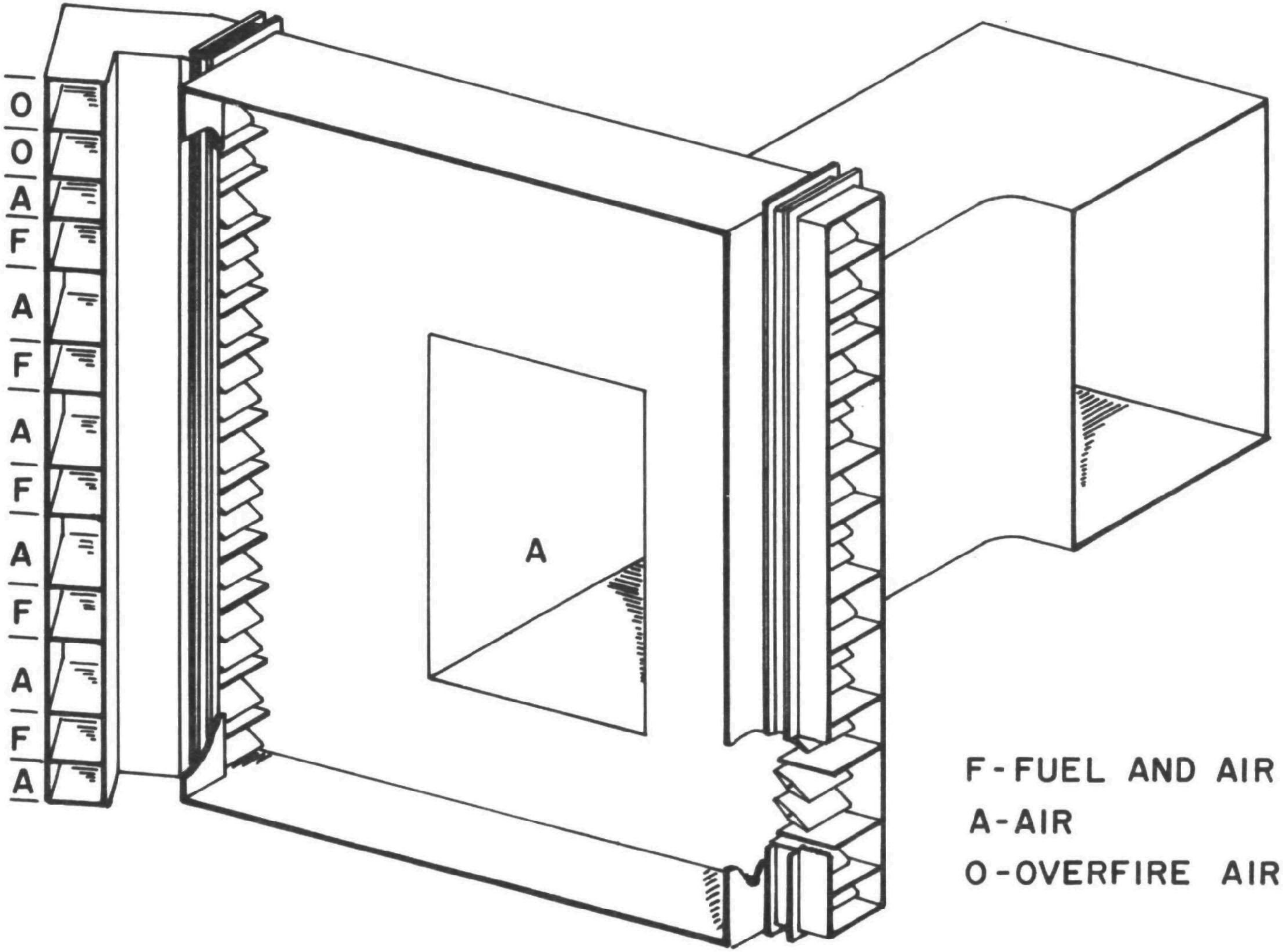

Figure 4: Typical Overfire Air Windbox Extension Coal Firing

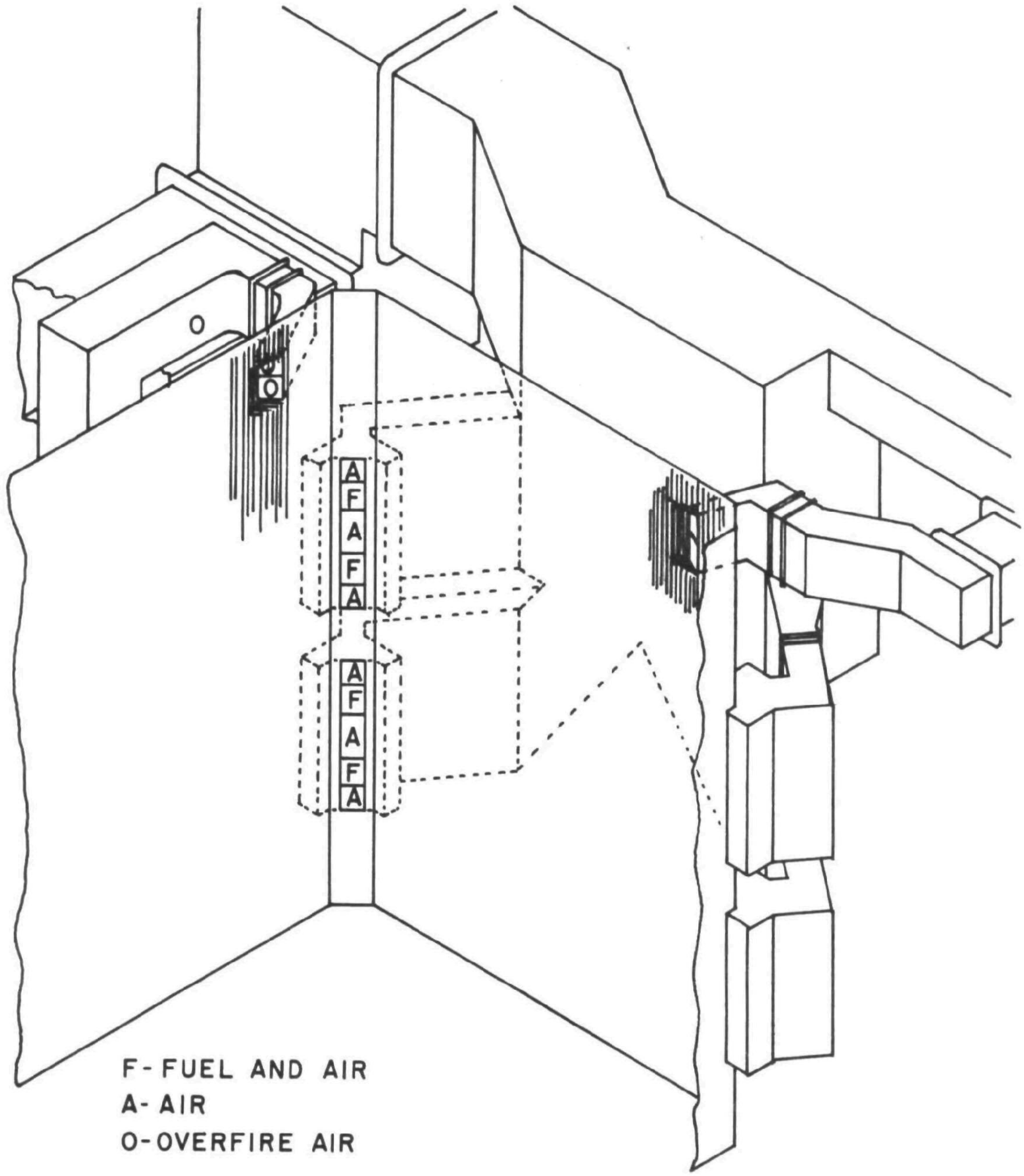

Figure 5: Schematic Overfire Air System, Barry No. 2

DISCUSSION

Field Test Program

The field performance tests conducted at Barry No. 2 firing eastern bituminous coal showed that an overfire air system on a tangential coal fired furnace can reduce NO_x emissions with no detriment to unit operation or maintenance. NO_x reductions of 20 to 30% were obtained with 15 to 20 percent overfire air when operating at a total unit excess air of approximately 15 to 20 percent as measured at the economizer outlet. This condition provided an average fuel firing zone stoichoimetry of 95 to 100 percent of theoretical air. Stoichiometries below this level did not result in large enough decreases in NO_x levels to justify their use. Biased firing (removing the top burner elevation from service), while potentially as effective, necessitated a reduction in unit loading and is therefore less desirable a method of NO_x control. In essence, this method uses the uppermost fuel and air compartment as a windbox extension.

When using overfire air as a means of decreasing the theoretical air (TA) to the fuel firing zone the percent carbon in the fly ash and CO emission levels were less affected than when operating with low excess air.* This is due to the ability to maintain acceptable total excess air levels as measured at the economizer outlet during overfire air operation while the theoretical air (TA) to the fuel firing zone is reduced.

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* A minimum of 20 percent excess air was established for the Barry No. 2 tests.

Furnace performance as indicated by waterwall slag accumulations, visual observations and absorption rates was not sifnificantly affected by overfire air operation.

On existing units where, for structural reasons, an overfire air port might not be installed as a windbox extension, test results indicate that the centerline of the overfire air port be kept within 3 meters of the centerline of the top fuel elevation. Distances greater than 3 meters did not result in decreased NO_x levels. Changes within the 3 meters limit did affect NO_x levels slightly with the NO_x levels increasing as the distance decreased.

The overfire air nozzles should tilt in unison with the fuel nozzles where possible. Tilting the overfire air and fuel nozzles towards each other directs the overfire air into the fuel admission zone thereby negating the original intent, while tilting the nozzles away from each other may result in decreased flame stability. If the overfire air nozzle tilt is fixed in a horizontal position NO_x levels would probably then vary to a limited extent with fuel nozzle position. In other words, the NO_x levels may increase or decrease as the total included angle between the fuel and OFA nozzles is decreased or increased respectively.

The results of the 30 day baseline, biased firing and overfire air corrosion coupon runs indicate that the overfire air operation for low NO_x optimization did not result in significant increases in corrosion coupon degradation. The results of this study are shown on Sheets 5A, 5B and 5C. Potential long term corrosion effects were not evaulated as part of this program.

Exploratory Field Test Program - Existing Units

To determine both the necessity and acceptability of applying the OFA technique for NO_x emissions control on existing tangentially fired units, an evaluation should be performed prior to committing the unit to modification.

This evaluation should include the study of existing process variables such as excess air as an NO_x control method. If these techniques should prove unsatisfactory, the program should then be expanded to evaluate the effect of biased firing on NO_x emissions. This technique consists of removing the top fuel elevations from service and using the upper air and fuel compartments for the introduction of overfire air. This evaluation should be conducted at the maximum possible unit loading with one pulverizer out of service and otherwise normal operation.

During biased firing operation, changes in total excess air required to maintain acceptable CO levels, the amount of carryover from the furnace outlet and furnace slagging tendencies should be observed. Carryover could be visually observed while increased slagging might be evaluated both visually and in terms of bottom ash handling system performance. Outlet steam temperatures and air heater exit gas temperatures should also be observed for comparison to normal operation.

The minimum instrumentation necessary for a comprehensive evaluation is as follows:

Unit Performance

Superheat (S.H.) Outlet Temp.	Calibrated Board Data*
Reheat (R.H.) Outlet Temp.	Calibrated Board Data*
R.H. & S.H. Spray Flows	Calibrated Board Data*
Gas Temp. Lvg. Air Heater (A.H.)	Thermocouple Grid in A.H. Outlet Duct
Excess Air Lvg. A.H.	Gas Sampling Grid in A.H. Outlet Duct
Furnace Carryover	Visual Observation
Furnace Slagging	Visual Observation and Ash System Performance, Nozzle Tilt Changes & Desuperheating sprays
Unit Gas Side Pressure Drop	Calibrated Board Readings*

Emissions Performance

NO_x, CO & O_2	Gas Sampling Grid in A.H. Inlet Duct

Effect on Unit Performance

The application of OFA as an NO_x control device spreads out the furnace fire which reduces flame intensity and temperature and the initial oxygen concentration. These effects combine to limit the formation of NO compounds with the reduced oxygen apparently affecting the fuel bound nitrogen NO formation.

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* If not available, test instrumentation should be considered.

In the case of coal firing, the NO_x emissions originate from two sources, fuel bound and atmospheric nitrogen (NO) Total = $(NO)_{Fuel\ N}$ + $(NO)_{N_2}$ in air.

The Barry 2 test results indicated that as long as the total excess oxygen (fuel compartment O_2 + OFA O_2) as measured at the economizer remains unchanged from the baseline condition, unit performance would remain unaffected. In some cases, however, a slightly increased total oxygen may be required to prevent an increase in CO and unburned carbon emission levels. This situation could be simulated with a biased firing test (top fuel elevation out of service) conducted during the exploratory program to determine the necessity of unit modification. While this approach will necessitate a reduction in unit loading, testing should be conducted at the highest possible loading obtainable for comparison to normal unit operation.

Otherwise, overall steam generator performance, including fan power, final steam temperatures, furnace wall tube temperatures and corrosion, and unit efficiency remain essentially unchanged.

The effect on furnace slagging has been found to be minimal with the coal used in this program and the coals studied in parallel programs conducted at the Barry Station.[1] However, since coal types vary widely the effect of changing firing zone stoichiometries on slagging tendencies should be evaluated during the exploratory program, again by using the biased firing technique. Where evaluating units with spare coal pulverizer capacity, this check should, if at all possible, be made at or close to full unit rating, particularly from the standpoint of evaluating unit slagging tendencies. A <u>minimum</u> evaluation period of one week is recommended for studying slagging tendencies.

On some units, the spreading out of the furnace fire might result in some combustible carryover from the unit furnace to the superheat sections. The tendency toward this condition can also be evaluated during the exploratory program by visual observation and watching for changes in unit performance.

Economic Evaluation

The cost of incorporating overfire air systems on existing and new unit designs was evaluated for steam generating units from 125 to 1000 MW capacity. The results of this study are shown on Figure 6.

The cost estimates for the revision of existing units are based on studies performed on units within this size range including the actual costs for modification of the Barry 2 unit. The cost estimates presented for including the overfire air system in new unit designs are based on current experience with these systems.

The accuracy of the March, 1975 cost estimates is plus or minus ten percent. Because the overfire air system is included as an integral part of new unit design, it is not therefore, considered as an optional or additional emissions control device. The costs for existing units could be from 0.2 to 1.5 $/kw, due to variations in existing unit design and construction which might make modifications more complicated. These costs may also vary and escalate with the prevailing economic climate.

The largest four windbox (single cell) furnaces manufactured to date have been of a 625 MW size at which point eight windbox furnaces (generally divided into two cells) have been selected. Since an eight windbox tangentially fired furnace has double the firing corners of a four windbox furnace, the costs of windboxes and ducts increase significantly.

The resulting increase in the cost of electricity generated is approxi-

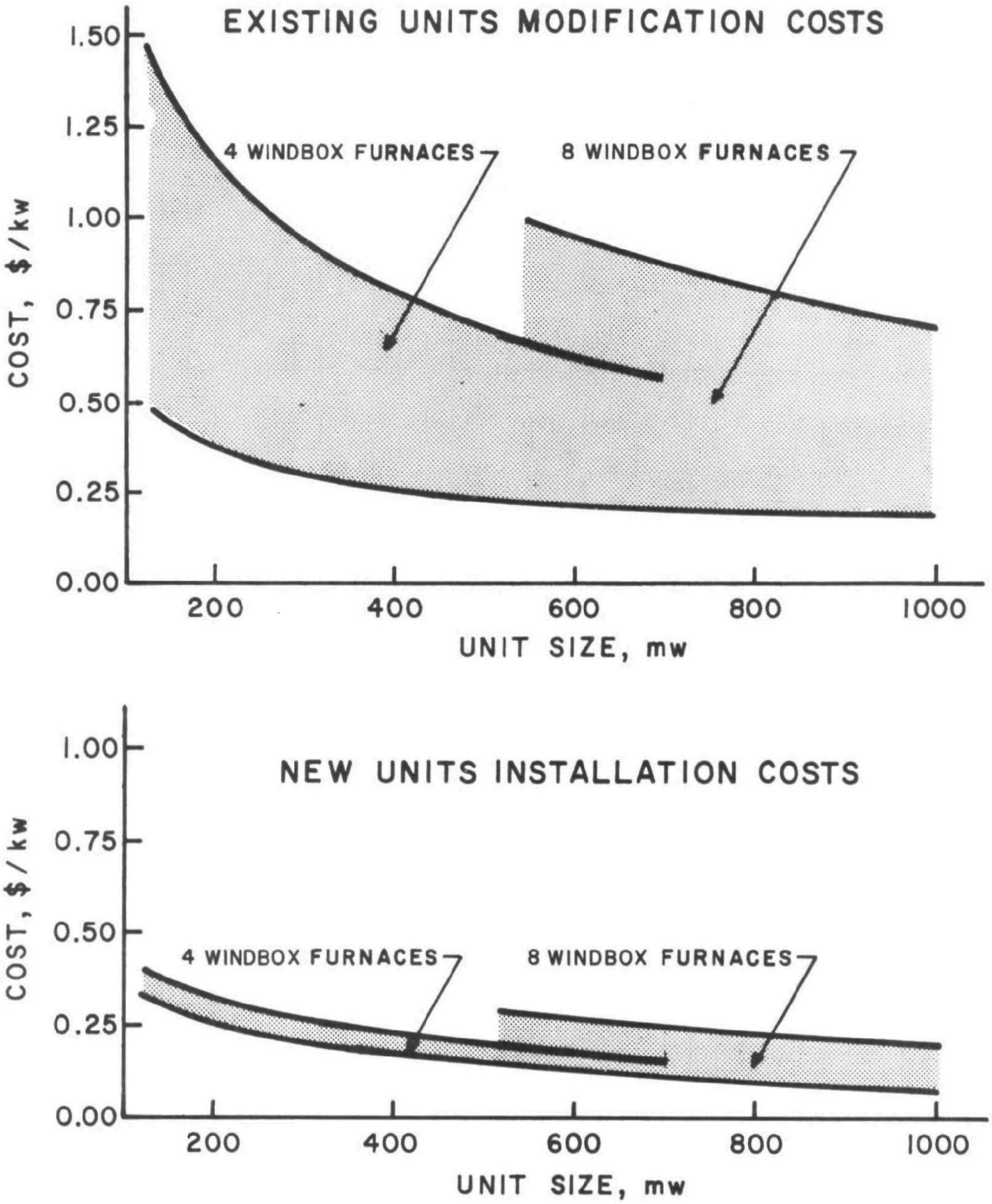

Figure 6: Overfire Air System Costs - Tangential Coal Fired Steam Generators - March, 1975 Equipment Costs

mately 0.03% for a typical new 500 MW plant* costing 500 \$/kw using coal costing 0.70 $\$/10^6$BTU, as illustrated in Table 1. The overfire air system increases capital costs by 0.2 \$/kw, and all other costs are unchanged. The mills/kwhr increase is 0.006.

An existing 500 MW plant has overfire air system costs up to 0.7 \$/kw. Generation costs for a 500 \$/kw plant increase by up to 0.10% or 0.021 mills/kwhr. An existing 500 MW plant which was installed for 250 \$/kw and receives coal costing 0.35 $\$/10^6$ BTU has much lower operating costs than the previous example. The cost increase percentage is 0.17%, but the increase in mills/kwhr remains unchanged at 0.021, as shown in the last column of Table 1.

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* March, 1975 equipment costs for 500 MW Coal Fired Power Plant with Limestone SO_2 Scrubbing System.

		\$/KW
Coal Handling, Storage, Pulverizing, Ash Handling		44
SO_2 Scrubber System		75
Boiler, Air Heaters, Fans, Stack		62
Steam Turbine-Generator, Piping, Heaters, Water Treatment, Condenser, Cooling Towers		92
Structures, Sitework Foundations, Offices, Land, Workshops, Controls, Switchgear, Transformers		63
	Subtotal	336
Engineering, Construction		44
Contingency		37
Interest During Construction		83
	Total	500

TABLE 1. COST OF ELECTRICITY GENERATED - 500 MW PLANTS

Net Heat Rate 9500 Btu/Kwhr
March, 1975 Equipment Costs

	New plant without overfire air	New plant with overfire air	Recent existing with added overfire air	Older existing without overfire air	Older existing with added overfire air
Capital Costs \$/kw	500.00	500.20	500.70	250.00	250.70
Annual Cap. Cost \$	40,000,000 (1)	40,016,000	40,056,000	20,000,000 (2)	20,056,000
Annual Fuel Cost \$	18,000,000 (3)	18,000,000	18,000,000	9,000,000 (4)	9,000,000
Labor & Maint. (5) \$	8,100,000	8,100,000	8,100,000	8,100,000	8,100,000
Total Annual Cost (6) \$	66,100,000	66,116,000	66,156,000	37,100,000	37,156,000
Electricity Cost (7) Mills/kwhr	24.481	24.487	24.502	13.741	13.762
Increase - %	---	0.024	0.086	---	0.153
Increase - Mills/kwhr	---	0.006	0.021	---	0.021

Based on:
(1) Annual Fixed Charge Rate of 16% x 500 \$/kw x 500,000 kw.
(2) 16% x 250 \$/kw x 500,000 kw.
(3) 0.70 \$/10^6 BTU coal cost x 5400 hr/yr x 500,000 kw x 9500 BTU/kwhr.
(4) 0.35 \$/10^6 BTU coal cost x 5400 hr/yr x 500,000 kw x 9500 BTU/kwhr.
(5) Labor and maintenance cost of 3.0 mills/kwhr.
(6) 5400 hr/yr at 500 MW - 2700 gwhr/yr.
(7) Cost at plant bus bar; transmission and distribution not included.

The increases in generating costs (mills/kwhr) for typical 100 MW plants are approximately double the increases for 500 MW plants. The increases for 600 MW plants with divided furnaces are 25% to 35% higher; and the increases for 1000 MW plants are the same as for 500 MW plants.

Transmission and distribution costs are not included in these comparisons. These examples are only typical; a specific plant has to be evaluated on its particular economic criteria.

Applicability

Existing Steam Generating Units

In a specific existing plant, the exploratory field test program will provide the data to determine whether an overfire air system is needed to meet NO_x limits. If so, the biased firing tests will show operating effects such as combustible loss, corrosion, or furnace slagging. Favorable results from the field tests should be followed by an evaluation as shown in Table 1 to determine whether modification costs are economically justified.

Economic considerations include plant age and efficiency. Will the plant continue to operate long enough to pay off the investment? The annual capital cost is inversely proportional to the number of years. Steam generator size also has an effect on the relative economics of overfire air system modifications. For example, the minimum modification cost is about $100,000, which is 4$/kw for a 25 MW unit. With complications, 10$/kw is possible for a 25 MW unit.

Approximately 40% of the existing coal fired units in the United States are of tangential design and could conceivably be modified to incorporate overfire air systems, if the field test and economic evaluation results are favorable. Since 1949, approximately 320 tangential units have been put into service without overfire air systems.

New Steam Generating Units

At the current levels of NO_x limits, an overfire air system should be included as a standard design feature of a new unit. The technology is proven, and the cost is minimal when included in the original design.

REFERENCES

1. Crawford, A. P., Manny, E. H. and Bartok, W., "Field Testing: Application of Combustion Modifications to Control NO_x Emissions From Utility Boilers"

BASELINE STUDY

NO_x TEST DATA SUMMARY

Test No		1	2	3	4	5	6	7
Purpose of Test		Excess Air Var - Clean Furn Cond. 1/2 Load			3/4 Load		Full Load	
Date		11-30-73	11-30-73	11-30-73	1-18-74	11-14-73	11-28-73	11-28-73
Load	MW	66	65	67	93	124	123	123
Main Steam Flow	10^3 Kg/HR	219	224	214	316	404	407	405
Excess Air Econ Outlet	%	35.5	17 5	58.9	12.6	22.7	11.7	30 8
Theo Air To Fuel Firing Zone	%	130.6	117 1	151 3	109.2	117.9	107.2	125 3
Fuel Elev In Serv.		ABC	ABC	ABC	ABC	ALL	ALL	ALL
Fuel Nozzle Tilt	Deg	+3	+7	+3	+8	+3	0	0
Nozzle Comp Damper Pos % Open: Aux		20	0	50	30	60	100	100
"A" Fuel		30	30	30	20	20	30	30
Aux		20	0	50	60	100	100	100
"B" Fuel		30	30	30	20	20	30	30
Aux /Aux		20/20	20/10	50/50	80/80	100/100	100/100	100/100
"C" Fuel		30	30	30	20	20	30	30
Aux		20	10	50	50	100	100	100
"D" Fuel		0	0	0	0	20	30	30
Aux		0	0	0	0	100	100	100
SHO Temperature	°C	529	498	548	500	539	539	538
RHO Temperature	°C	488	446	517	499	514	524	524
Unit Efficiency	%	88 3	88 2	87.6	89.3	89 0	89 1	89 5
Gas Weight Ent A H	10^3 Kg/Hr	352	360	412	386	554	578	592
NO_x	PPM - 0% O_2	631	489	718	429	494	357	664
NO_x	GR/10^6 Cal	1 337	1.030	1 519	900	1.041	761	1 403
SO_2	PPM - 0% O_2	2298	2318	1644	1635	1641	1434	1455
SO_2	GR/10^6 Cal	6 770	6 794	4.841	4 769	4.815	4 254	4 278
CO	PPM - 0% O_2	24 51	142 26	8 05	39 09	31 16	152 88	32 91
CO	GR/10^6 Cal	.0316	182	.0104	0499	0400	.198	0423
HC	PPM - 0% O_2	144	.160	0.0	0.0	509	0 0	0 0
O_2	% A H. In	5.59	3.20	7 89	2.40	3 96	2 26	5 02
O_2	% A H Out	7 28	5 61	9.09	5 14	6.24	4 63	6 87
Carbon Loss In Flyash	%	29	.97	17	.96	.48	57	20
Dust Loading	GR/SCM					4 19		

Test No		8	9	10	11	12	13	14
Purpose of Test		E.A. Var. Mod Dirty Furn. Full Load			E A Var. Dirty Furn 1/2 Load		Full Load	
Date		11-15-73	11-19-73	11-19-73	12-5-73	12-4-73	11-16-73	11-16-73
Load	MW	126	122	124	66	74	125	125
Main Steam Flow	10^3 Kg/HR	411	403	405	211	206	412	406
Excess Air Econ Outlet	%	21 5	13 0	26.0	32 7	51 2	20 7	24 3
Theo Air To Fuel Firing Zone	%	116 9	108 5	120 8	128 0	144 1	115.7	119 2
Fuel Elev In Serv		ALL	ALL	ALL	ABC	ABC	ALL	ALL
Fuel Nozzle Tilt	Deg	+8	-22	-22	0	0	-22	-22
Nozzle Comp Damper Pos % Open: Aux		60	100	100	20	50	100	100
"A" Fuel		30	30	30	30	30	30	30
Aux		100	100	100	20	50	100	100
"B" Fuel		30	30	30	30	30	30	30
Aux /Aux		100/100	100/100	100/100	20/20	50/50	100/100	100/100
"C" Fuel		30	30	30	30	30	30	30
Aux		100	100	100	20	50	100	100
"D" Fuel		30	30	30	0	0	30	30
Aux		100	100	100	0	0	100	100
SHO Temperature	°C	548	533	544	518	548	539	543
RHO Temperature	°C	533	510	531	476	508	522	529
Unit Efficiency	%	89.6	89 6	89 6	88 3	87 9	89 2	89 3
Gas Weight Ent A.H	10^3 Kg/HR	567	502	565	323	369	556	567
NO_x	PPM - 0% O_2	421	361	581	536	658	499	[illegible]
NO_x	GR/10^6 Cal	.894	748	1.198	1 118	1.370	1 037	1 22[illegible]
SO_2	PPM - 0% O_2	1171	2052	2179	2348	2164	1917	1370
SO_2	GR/10^6 Cal	3.458	5.922	6 251	6.821	6 267	5 538	3.985
CO	PPM - 0% O_2	45 75	431.8	5.48	297.59	220 56	40.85	[illegible] 61
CO	GR/10^6 Cal	.0591	.545	0069	378	.280	.052	043
HC	PPM - 0% O_2	61	128	1.54	0.0	0 0	.513	397
O_2	% A H In	3.78	2 47	4 41	5 26	7.20	3.66	4 18
O_2	% A H Out	5 31	4.60	6 64	6 99	8.63	6 01	6 42
Carbon Loss in Flyash	%	.16	.27	.05	58	20	.17	19

BIASED FIRING STUDY

NO_x TEST DATA SUMMARY

Test No.		15	16	17	18	19
Purpose of Test		Biased Firing - 1 Fuel Elev. Out of Service - Air Dampers Open 1/2 Load	3/4 Load	← Max Load		→
Date		1-19-74	1-18-74	12-3-73	12-4-73	12-5-73
Load	MW	66	96	100	103	99
Main Steam Flow	10^3Kg/HR	199	297	315	321	321
Excess Air Econ Outlet	%	50.1	26.7	21 1	22 2	21.8
Theo Air to Fuel Firing Zone	%	105.8	121.7	116.5	117.5	117 2
Fuel Elev In Serv.		ABC	ABC	ABC	ABD	ACD
Fuel Nozzle Tilt	Deg	-9	0	-15	-15	-10
Nozzle Comp Damper Pos % Open: Aux.		50	50	50	50	50
"A" Fuel		20	20	30	30	30
Aux		50	50	50	50	100
"B" Fuel		20	20	30	30	100
Aux /Aux.		50/50	50/50	50/50	50/100	50/50
"C" Fuel		20	20	30	100	30
Aux.		50	50	50	50	50
"D" Fuel		100	100	100	30	30
Aux.		100	100	100	50	50
SHO Temperature	°C	546	539	529	543	523
RHO Temperature	°C	496	506	501	520	486
Unit Efficiency	%	87.9	89.3	89.1	89 3	88 9
Gas Weight Ent A H	10^3Kg/HR	341	430	439	455	428
NO_x	PPM - % O_2	594	543	397	373	387
NO_x	GR/10^6CAL	1.206	1.142	840	792	.795
SO_2	PPM - % O_2	1721	1682	2422	2553	2292
SO_2	GR/10^6CAL	4 861	4 922	7 137	7.536	6 543
CO	PPM - % O_2	33 38	29.10	45.63	38 51	35.48
CO	GR/10^6CAL	.0412	0372	.0588	.0497	.0443
HC	PPM - % O_2	0 0	0 0	0 0	012	012
O_2	% A H. In	7.10	4.55	3 72	3.885	3.825
O_2	% A H. Out	8.54	7 19	6 08	5 80	6 30
Carbon Loss in Flyash	%	32	34	.46	.37	.42

Test No		20	21	22	23	24
Purpose of Test		Biased Firing - 1 Fuel Elev Out of Service - Air Dampers Open Max Load	3/4 Load	← 1/2 Load		→
Date		12-6-73	1-18-74	1-19-74	1-19-74	1-19-74
Load	MW	102	94	64	64	66
Main Steam Flow	10^3Kg/HR	314	308	208	211	202
Excess Air Econ Outlet	%	24 2	29.0	48 0	47.0	47.0
Theo. Air to Fuel Firing Zone	%	94 7	97 3	112.5	141 4	141 3
Fuel Elev in Service.		BCD	BCD	BCD	ACD	ABD
Fuel Nozzle Tilt	Deg.	-5	+10	0	0	-15
Nozzle Comp Damper Pos % Open: Aux.		100	100	100	50	50
"A" Fuel		100	100	100	20	20
Aux		50	50	50	100	50
"B" Fuel		30	20	20	100	20
Aux /Aux		50/50	50/50	50/50	50/50	50/100
"C" Fuel		30	20	20	20	100
Aux		50	50	50	50	50
"D" Fuel		30	20	20	20	20
Aux		50	50	50	50	50
SHO Temperature	°C	544	512	501	507	544
RHO Temperature	°C	515	469	448	454	513
Unit Efficiency	%	88 8	89 6	87.8	87.9	87 7
Gas Weight Ent A H	10^3Kg/HR	451	435	360	361	356
NO_x	PPM - % O_2	285	331	520	485	609
NO_x	GR/10^6CAL	599	696	1 124	1 043	1 282
SO_2	PPM - % O_2	2277	1566	1861	2245	1807
SO_2	GR/10^6CAL	6 661	4 578	5.593	6 710	5 288
CO	PPM - % O_2	26 61	31.28	29.10	22.41	27 54
CO	GR/10^6CAL	0341	0400	0382	0293	0353
HC	PPM - % O_2	0 0	0 0	0.0	0 0	0.0
O_2	% A H In	4 165	4 76	6.93	6 85	6 79
O_2	% A.H Out	7 31	8 37	8.40	8.58	6.87
Carbon Loss in Flyash	%	25	30	20	11	.21
Dust Loading	GR/SCM	8 65				

NO_x TEST DATA SUMMARY
BASELINE STUDY AFTER MODIFICATION

TEST NO.		1	2	3	4	5	6	7
Purpose of Test		Excess Air Var. - Clean Furnace Cond.						
		1/2 Load			3/4 Load		Maximum Load	
Date		6/25/74	6/25/74	6/25/74	6/27/74	6/19/74	6/27/74	6/27/74
Load	MW	62	62	64	92	131	127	125
Main Steam Flow	10^3KG/HR	219	213	217	315	450	441	423
Excess Air Econ Outlet	%	33.5	16 0	64.7	15.5	21 0	12 4	25.4
Theo Air to Fuel Firing Zone	%	127 1	113.4	155.4	111.0	115.3	107 1	119 5
Fuel Elev In Serv		ABC	ABC	ABC	ABC	ALL	ALL	ALL
OFA Nozzle Tilt	DEG	0	0	0	0	0	0	0
Fuel Nozzle Tilt	DEG	3	6	-14	2	-13	-3	-22
NOZZLE COMP DAMPER POS % OPEN: OFA		0	0	0	0	0	0	0
OFA		0	0	0	0	0	0	0
Aux		20	0	50	30	80	100	100
"A" Fuel		30	30	30	20	30	30	35
Aux		20	0	50	60	100	100	100
"B" Fuel		30	30	30	20	30	30	35
Aux /Aux		20/20	10/10	50/50	80/80	100/100	100/100	100/100
"C" Fuel		30	30	30	20	30	30	35
Aux		20	10	50	50	100	100	100
"D" Fuel		0	0	0	0	30	30	35
Aux		0	0	0	0	100	100	100
SHO Temperature	°C	492	468	536	504	528	524	518
RHO Temperature	°C	435	402	499	466	488	487	480
Unit Efficiency	%	88 4	88 8	87 4	89.8	88 4	89.2	89 5
Gas Weight Ent A H	10^3KG/HR	335	270	413	398	593	546	559
NO_x	PPM - 0% O_2	444	335	640	327	404	330	477
NO_2	GR/10^6CAL	929	701	1 339	684	846	692	1 000
SO_2	PPM - 0% O_2	3678	3621	2611	2634	2251	2677	2707
SO_2	GR/10^6CAL	10.718	10.551	7 606	7 674	6 559	7 800	7 889
CO	PPM - 0% O_2	27 54	375 77	34.66	109.70	26 37	127 2	21 74
CO	GR/10^6CAL	0351	4790	0442	1398	0336	1622	0277
HC	PPM - 0% O_2	0	0	0	0	0	0	0
O_2	% A H In	5 36	2 95	8 36	2 87	3 71	2 36	4 34
O_2	% A H Out.	7 35	5 52	9.70	5.5	7 36	5.75	7 02
Carbon Loss In Flyash	%	29	23	1 06	11	75	51	74

TEST NO		8	9	10	11	12	13	14
Purpose of Test		E A Var - Mod Dirty Furnace			E A Var - Dirty Furnace			
		Maximum Load			1/2 Load		Maximum Load	
Date		6/20/74	6/20/74	6/28/74	6/26/74	6/26/74	6/28/74	6/28/74
Load	MW	130	129	125	65	68	126	125
Main Steam Flow	10^3KG/HR	440	446	428	246	218	432	425
Excess Air Econ Outlet	%	17 8	12 1	26.6	30 9	63 1	22 0	25 9
Theo Air to Fuel Firing Zone	%	112 3	106 9	120 5	124 6	154 0	116 2	119 9
Fuel Elev In Serv		ALL	ALL	ALL	ABC	ABC	ALL	ALL
OFA Nozzle Tilt	DEG	0	0	0	0	0	0	0
Fuel Nozzle Tilt	DEG.	-21	-17	-6	-16	-16	-6	-6
NOZZLE COMP DAMPER POS % OPEN: OFA		0	0	0	0	0	0	0
OFA		0	0	0	0	0	0	0
Aux		80	80	100	20	50	100	100
"A" Fuel		30	30	30	30	30	30	30
Aux		100	100	100	20	50	100	100
"B" Fuel		30	30	30	30	30	30	30
Aux /Aux.		100/100	100/100	100/100	20/20	50/50	100/100	100/100
"C" Fuel		30	30	30	30	30	30	30
Aux		100	100	100	20	50	100	100
"D" Fuel		30	30	30	0	0	30	30
Aux		100	100	100	0	0	100	100
SHO Temperature	°C	526	528	524	507	531	524	529
RHO Temperature	°C	486	483	480	457	498	496	499
Unit Efficiency	%	89 0	88 9	89 5	89 3	88 0	89 0	89 4
Gas Weight Ent A.H	10^3KG/HR	565	542	584	363	419	575	583
NO_x	PPM - 0% O_2	470	334	431	373	626	391	431
NO_2	GR/10^6CAL	985	699	902	782	1.310	819	902
SO_2	PPM - 0% O_2	1941	2482	2500	2558	2461	2564	2629
SO_2	GR/10^6CAL	5 655	7 232	7 283	7 453	7 171	7 470	7 661
CO	PPM - 0% O_2	24 31	97 16	23 55	26.28	23 85	23 4	22 92
CO	GR/10^6CAL	0310	1239	0300	0335	0304	0298	0292
HC	PPM - 0% O_2	0	0	0	0	0	0	0
O_2	% A H In	3.24	2.31	4.5	5 04	8 23	3 86	4 4
O_2	% A.H Out	6 8	6 19	7 48	7 55	10 75	7 3	7 15
Carbon Loss in Flyash	%	22	42	61	17	05	36	25

NO_X TEST DATA SUMMARY

OVERFIRE AIR LOCATION, RATE & VELOCITY VARIATION

TEST NO		15	16	17	18A	19
Purpose of Test		OFA Damper Position Variation				
		← 3/4 Load →				
Date		7/10/74	7/10/74	7/10/74	7/12/74	7/11/74
Load	MW	97	98	100	100	100
Main Steam Flow	10^3KG/HR	336	340	338	344	338
Excess Air Econ Outlet	%	28.5	27 1	25 6	26 6	24.8
Theo Air to Fuel Firing Zone	%	114 5	96.7	95.8	84.8	89.3
Fuel Elev In Serv		BCD	BCD	BCD	BCD	BCD
OFA Nozzle Tilt	DEG	0	0	0	0	0
Fuel Nozzle Tilt	DEG	-5	-5	-5	-4	-4
NOZZLE COMP. DAMPER POS. % OPEN — OFA		0	100	0	100	50
OFA		0	0	100	100	50
Aux		0	0	0	0	0
"A" Fuel		0	0	0	0	0
Aux		50	50	50	50	50
"B" Fuel		30	30	30	30	30
Aux /Aux		50/50	50/50	50/50	50/50	50/50
"C" Fuel		30	30	30	30	30
Aux		50	50	50	50	50
"D" Fuel		30	30	30	30	30
Aux		50	50	50	50	50
SHO Temperature	°C	518	510	514	524	521
RHO Temperature	°C	457	452	457	476	486
Unit Efficiency	%	90 0	89 8	89 7	89 6	89 3
Gas Weight Ent A H	10^3KG/HR	458	447	442	466	468
NO_x	PPM - 0% O_2	345	254	254	229	232
NO_2	GR/10^6CAL	723	533	533	479	486
SO_2	PPM - 0% O_2	1892	1973	2092	2397	2684
SO_2	GR/10^6CAL	5 512	5 750	6.097	6 984	7 821
CO	PPM - 0% O_2	28 10	29 96	32 4	48 08	39 20
CO	GR/10^6CAL	0358	.0382	0413	.0613	0500
HC	PPM - 0% O_2	0	0	0	0	0
O_2	% A H In	4 74	4 55	4.36	4.5	4 25
O_2	% A H Out	6 51	6 49	6 08	6 32	6 05
Carbon Loss In Flyash	%	51	59	63	.54	.32

TEST NO		20	21	22	23
Purpose of Test		OFA Damper Position Variation			
		← 3/4 Load →			
Date		7/11/74	7/12/74	7/12/74	7/12/74
Load	MW	100	102	102	102
Main Steam Flow	10^3KG/HR	344	342	341	346
Excess Air Econ Outlet	%	25 4	25 4	27 9	28 1
Theo Air to Fuel Firing Zone	%	100 5	117.4	90 4	96 9
Fuel Elev In Serv		BCD	ABC	ABC	ABC
OFA Nozzle Tilt	DEG.	0	0	0	0
Fuel Nozzle Tilt	DEG	-4	-4	-4	-4
NOZZLE COMP. DAMPER POS. % OPEN — OFA		0	0	100	50
OFA		0	0	100	50
Aux		100	100	100	50
"A" Fuel		0	100	100	50
Aux		50	50	50	50
"B" Fuel		30	30	30	30
Aux /Aux		50/50	50/50	50/50	50/50
"C" Fuel		30	30	30	30
Aux		50	50	50	50
"D" Fuel		30	0	0	0
Aux		50	0	0	0
SHO Temperature	°C	524	532	524	521
RHO Temperature	°C	479	498	491	485
Unit Efficiency	%	90 2	90 1	89 0	89.1
Gas Weight Ent A H	10^3KG/HR	468	476	494	492
NO_x	PPM - 0% O_2	323	483	329	336
NO_2	GR/10^6CAL	677	1 012	689	704
SO_2	PPM - 0% O_2	1821	1814	2259	2417
SO_2	GR/10^6CAL	5 308	5 284	6 583	7.042
CO	PPM - 0% O_2	28.79	25 16	25 79	25 28
CO	GR/10^6CAL	0367	0321	0329	0322
HC	PPM - 0% O_2	0	0	0	0
O_2	% A H. In.	4 33	4 33	4 67	4 69
O_2	% A.H Out.	6 14	6.05	6.46	6 72
Carbon Loss in Flyash	%	49	46	54	60

NO_X TEST DATA SUMMARY
OFA TILT VARIATION

TEST NO		24	25	26	27	28	29
Purpose of Test		OFA & Fuel Nozzle Tilt Variation — Full Load					
Date		7/29/74	7/29/74	7/29/74	7/29/74	7/29/74	7/29/74
Load	MW	124	124	124	125	125	124
Main Steam Flow	10^3KG/HR	407	418	412	407	414	418
Excess Air Econ Outlet	%	25 9	23 7	25 1	22 3	20 2	23 7
Theo Air to Fuel Firing Zone	%	94 2	92 4	93 2	91 5	89.6	92 6
Fuel Elev In Serv		ALL	ALL	ALL	ALL	ALL	ALL
OFA Nozzle Tilt	DEG	0	0	0	-30	-30	+30
Fuel Nozzle Tilt	DEG.	-5	-23	+19	-5	+22	-21
Nozzle Comp. Damper Pos. % Open: OFA		100	100	100	100	100	100
OFA		100	100	100	100	100	100
Aux		100	100	100	100	100	100
"A" Fuel		100	100	100	100	100	100
Aux		50	50	50	50	50	50
"B" Fuel		30	30	30	30	30	30
Aux /Aux		50/50	50/50	50/50	50/50	50/50	50/50
"C" Fuel		30	30	30	30	30	30
Aux		50	50	50	50	50	50
"D" Fuel		30	30	30	30	30	30
Aux		50	50	50	50	50	50
SHO Temperature	°C	538	521	524	527	524	521
RHO Temperature	°C	532	508	527	533	535	505
Unit Efficiency	%	89 6	89 3	88 9	89.3	88 6	89 4
Gas Weight Ent A H	10^3KG/HR	548	566	585	557	586	544
NO_x	PPM - 0% O_2	339	290	368	344	404	285
NO_2	GR/10^6CAL	710	609	770	721	.846	596
SO_2	PPM - 0% O_2	2450	2920	3310	3160	3370	3240
SO_2	GR/10^6CAL	7 140	8 511	9 647	9 208	9 820	9 443
CO	PPM - 0% O_2	25 4	27 1	31.8	22.1	28 2	49 4
CO	GR/10^6CAL	0324	0346	0406	0282	0360	0630
HC	PPM - 0% O_2	0	0	0	0	0	0
O_2	% A H In	4 4	4 1	4 3	3 9	3 6	4 1
O_2	% A.H Out	5 9	6 0	6 2	6 0	5 8	6 4
Carbon Loss In Flyash	%	37	.37	40	29	29	49

LOAD VARIATION AT OPTIMUM CONDITIONS

TEST NO		30	31	32	33	34	35
Purpose of Test		Load Variation at Optimum Conditions					
		Max Load	3/4 Load	1/2 Load	Max. Load	3/4 Load	1/2 Load
Date		7/30/74	7/31/74	7/31/74	7/31/74	7/31/74	8/1/74
Load	MW	125	97	65	122	95	64
Main Steam Flow	10^3KG/HR	416	314	204	409	310	204
Excess Air Econ Outlet	%	21 6	25 2	46.9	27 4	27 4	45 9
Theo Air to Fuel Firing Zone	%	90.7	89 4	88 5	94 6	90 6	88 5
Fuel Elev In Serv		ALL	ABC	AB	ALL	ABC	AB
OFA Nozzle Tilt	DEG	0	-12	0	-22	-22	-10
Fuel Nozzle Tilt	DEG	-4	-16	-5	-22	-22	-15
Nozzle Comp. Damper Pos. % Open: OFA		100	100	100	100	100	100
OFA		100	100	100	100	100	100
Aux		100	100	100	100	100	100
"A" Fuel		100	100	100	100	100	100
Aux		50	50	50	50	50	50
"B" Fuel		30	30	30	30	30	30
Aux./Aux		50/50	50/50	50/0	50/50	50/50	50/0
"C" Fuel		30	30	0	30	30	0
Aux		50	50	0	50	50	0
"D" Fuel		30	0	0	30	0	0
Aux		50	0	0	50	0	0
SHO Temperature	°C	538	525	535	521	506	512
RHO Temperature	°C	536	514	514	521	493	493
Unit Efficiency	%	89 0	89 1	89 2	89 0	88 2	89 0
Gas Weight Ent A H	10^3KG/HR	574	456	341	584	472	329
NO_x	PPM - 0% O_2	339	338	396	333	291	313
NO_2	GR/10^6CAL	710	708	828	697	608	655
SO_2	PPM - 0% O_2	1680	1730	1740	2430	2490	2420
SO_2	GR/10^6CAL	4 896	5 043	5 070	7 083	7 256	6 960
CO	PPM - 0% O_2	26 1	26 1	24 4	24 8	26 4	25 0
CO	GR/10^6CAL	0333	0333	0311	0316	0337	0319
HC	PPM - 0% O_2	0	0	0	0	0	0
O_2	% A H In	3 8	4 3	6 8	4 6	4 6	6 7
O_2	% A H Out	5 3	5 7	8 2	6 3	6.3	8 4
Carbon Loss In Flyash	%	61	39	.32	24	33	15
Dust Loading	GR/SCM	8 64					

WATERWALL CORROSION COUPON DATA SUMMARY

WEIGHT LOSS EVALUATION

BASELINE TEST

Probe Loc.	Probe No.	Coupon No.	Initial Wt. GR.	Final Wt. GR.	Wt. Loss GR.	Wt. Loss/ Coupon MG/CM^2	Avg. Wt. Loss/ Probe MG/CM^2
1	I	1	199.2937	199.1341	.1596	3.1643	
		2	201.3871	201.2135	.1736	3.4418	2.9392
		3	198.3883	198.2384	.1499	2.9719	
		4	195.8045	195.6946	.1099	2.1789	
2	J	1	199.1977	199.0534	.1443	2.8609	
		2	199.6807	199.5009	.1798	3.5647	2.8088
		3	202.8649	202.7226	.1423	2.8213	
		4	202.3445	202.2442	.1003	1.9885	
3	E	1	199.0122	198.8632	.1490	2.9541	
		2	202.2508	202.1171	.1337	2.6507	2.13475
		3	201.9826	201.8976	.0850	1.6852	
		4	199.6584	199.5954	.0630	1.249	
4	L	1	202.5778	202.5080	.0698	1.3838	
		2	200.8579	200.7484	.1095	2.1769	1.91965
		3	202.7075	202.5924	.1151	2.282	
		4	197.7676	197.6750	.0926	1.8359	
5	K	1	199.5913	---	---	---	
		2	197.4684	197.2730	.1954	3.874	3.38826
		3	194.9513	194.7783	.1730	3.4299	
		4	202.0694	201.9251	.1443	2.8609	

Avg. Wt. Loss/Test 2.6381 MG/CM^2

WATERWALL CORROSION COUPON DATA SUMMARY

WEIGHT LOSS EVALUATION

BIASED FIRING TEST

Probe Loc.	Probe No.	Coupon No.	Initial Wt. GR.	Final Wt. GR.	Wt. Loss GR.	Wt. Loss/ Coupon MG/CM^2	Avg. Wt. Loss/ Probe MG/CM^2
1	B	1	197.9531	197.6484	.3047	6.0411	
		2	202.1660	201.8659	.3001	5.9499	5.8795
		3	198.3393	198.0383	.3010	5.9678	
		4	200.5603	200.2799	.2804	5.5593	
2	Q	1	199.3158	199.1437	.1721	3.4121	
		2	196.2751	196.0480	.2271	4.5026	4.3777
		3	202.8709	202.5541	.3168	6.2810	
		4	200.2327	200.0655	.1672	3.3150	
3	R	1	198.8940	198.7626	.1314	2.6051	
		2	199.8790	199.6842	.1948	3.8622	3.4081
		3	196.0683	195.8721	.1962	3.8899	
		4	199.3342	199.1690	.1652	3.2753	
4	M	1	199.5078	199.3628	.1450	2.8748	
		2	198.7039	198.4853	.2186	4.3341	3.8201
		3	198.3125	198.1121	.2004	3.9732	
		4	200.8838	200.6771	.2067	4.0981	
5	D	1	197.9655	197.7001	.2654	5.2619	
		2	202.9412	202.5809	.3603	7.1435	5.7289
		3	199.1306	198.7976	.3330	6.6022	
		4	198.2205	198.0234	.1971	3.9078	

Avg. Wt. Loss/Test 4.6429 MG/CM^2

WATERWALL CORROSION COUPON
DATA SUMMARY

WEIGHT LOSS EVALUATION

OVERFIRE AIR TEST

Probe Loc.	Probe No.	Coupon No.	Initial Wt. GR.	Final Wt. GR.	Wt. Loss GR.	Wt. Loss/ Coupon MG/CM^2	Avg. Wt. Loss/ Probe MG/CM^2
1	S	1	200.7678	200.5465	.2213	4.3876	
		2	196.0684	195.8121	.2563	5.0815	4.5244
		3	199.6433	199.3849	.2584	5.1235	
		4	197.8187	197.6419	.1768	3.5053	
2	T	1	200.7026	199.1437	.2802	5.5554	
		2	---	---	---	3.3540	3.9044
		3	593.7075	593.2000	.5075	3.3540	
		4	---	---	---	3.3540	
3	F	1	199.1897	198.9156	.2741	5.4344	
		2	199.4476	199.1351	.3125	6.1958	6.0401
		3	199.3119	198.9858	.3261	6.4654	
		4	199.0463	198.7404	.3059	6.0649	
4	N	1	202.8354	202.6125	.2234	4.4292	
		2	201.2249	200.9784	.2465	4.8872	3.7656
		3	---	---	---	2.8729	
		4	397.4898	397.2000	.2898	2.8729	
5	2	1	---	---	---	---	
		2	191.8528	191.6484	.2044	4.0525	3.9752
		3	192.7875	192.5909	.1966	3.8979	
		4	---	---	---	---	

Avg. Wt. Loss/Test 4.4419 MG/CM^2

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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16. ABSTRACT

The report gives results of Task IX of a program to reduce NOx from tangential coal-fired boilers. Results are based on current contractor experience, as well as on field performance tests performed at Alabama Power Corporation's Barry Unit No. 2. Use of overfire air as an NOx control technique is discussed relative to: equipment modifications and costs (as of March 1975) associated with applying this technology to existing steam generators; limitations to the general application of developed technology; and emission control and cost effectiveness of applying developed technology to new steam generator designs.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Air Pollution Control	13B
Nitrogen Oxides	Stationary Sources	07B
Boilers	Tangential Firing	13A
Coal	Overfire Air	21D
Combustion Control	Combustion Modification	21B
Cost Effectiveness		14A

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