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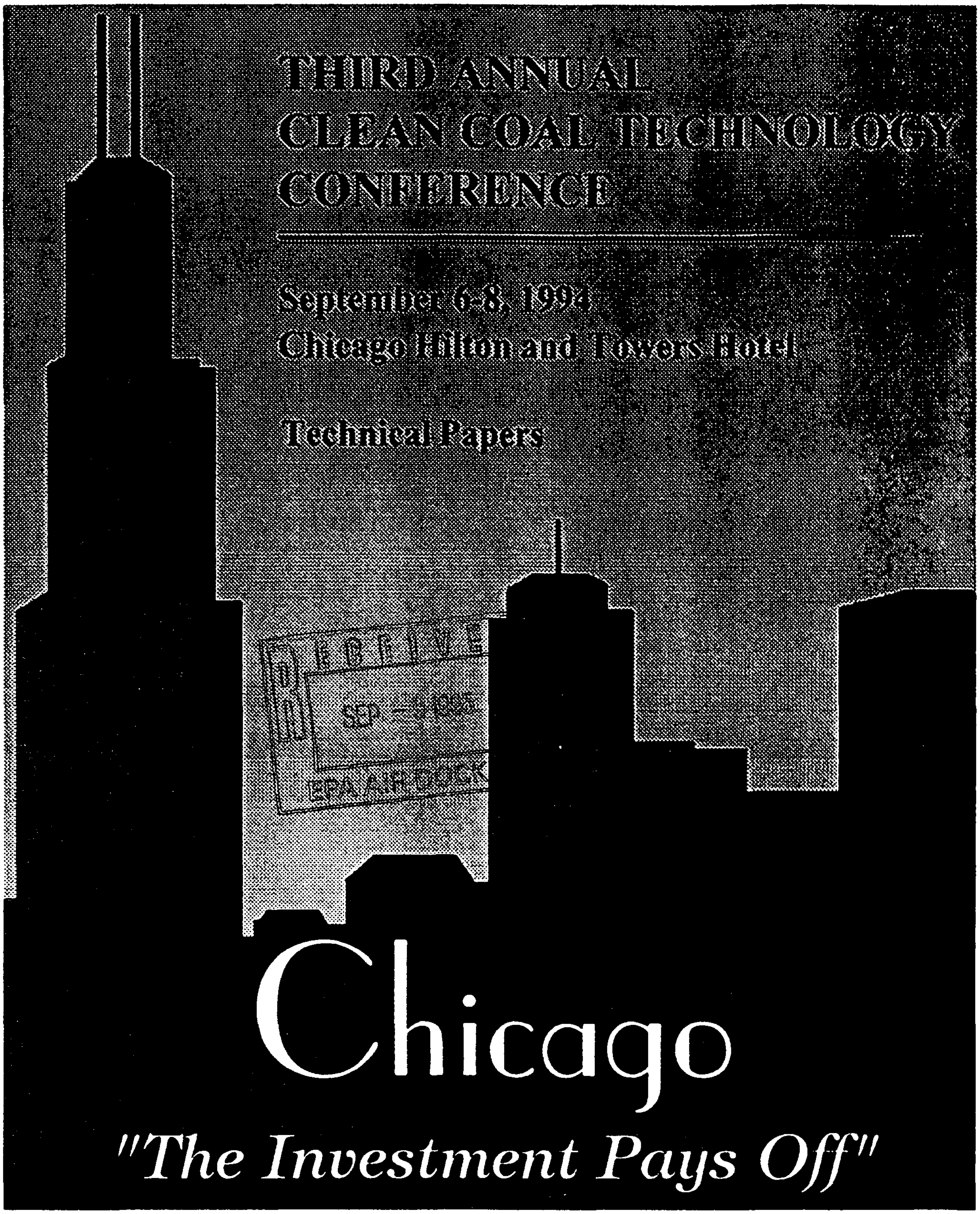

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Third Annual
Clean Coal Technology Conference

Technical Papers

OBJECTIVE

THEME: "THE INVESTMENT PAYS OFF"

The public/private investment in Clean Coal Technology pays off. The objective of this conference is to review the status and successes of the program, the role of the program in meeting domestic and global energy and environmental needs, the opportunities for commercialization in the United States and abroad, and the challenges which are being encountered. This review will be accomplished within the context of the emerging trade agreements and global energy, economic, and environmental challenges.

STATUS OF BABCOCK & WILCOX'S CLEAN COAL TECHNOLOGY COMBUSTION MODIFICATION PROJECTS: COAL REBURNING FOR CYCLONE BOILER NO_x CONTROL AND LOW NO_x CELL™ BURNER DEMONSTRATIONS

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ABSTRACT

Cyclone furnaces were developed by Babcock & Wilcox (B&W) to effectively combust low quality fuels. B&W's Cell burners were designed to maximize heat release in the boiler to improve efficiency. These objectives were readily achieved through intense combustion and resulting high temperatures; a condition generating disproportionately high levels of NO_x. Each technology represents approximately 13% of pre-New Source Performance Standards (NSPS) coal-fired generating capacity. B&W, co-sponsored by Electric Power Research Institute (EPRI), the host utilities and utility co-funding sponsors through U. S. Department of Energy (DOE) Clean Coal Technology Demonstration projects, addressed the NO_x reduction needs of utilities using cyclones and cell burners. The Ohio Coal Development Office (OCDO) also sponsored the cell burner project as part of its own Clean Coal Technology Program. Coal reburning to reduce NO_x emissions by at least 50% from cyclones was demonstrated at Wisconsin Power and Light Company's (WP&L) 110 MW_e Nelson Dewey Generating Station. The Low-NO_x Cell™ burner (LNCB™) reducing NO_x emissions by at least 50% was demonstrated at the 605 MW_e Unit No. 4 at Dayton Power & Light Company's (DP&L) J. M. Stuart Station. Both emissions and overall boiler performance test results for each Clean Coal Technology Demonstration are presented in this paper as well as present status of the technologies.

INTRODUCTION AND BACKGROUND

Coal Reburning

The "Coal Reburning for Cyclone Boiler NO_x Control Demonstration" (Project DE-FC22-90PC89659) is one of the U. S. Department of Energy (DOE) Clean Coal Technology, Round II (CCT-II) Demonstration Program Projects. The objective of the coal reburning demonstration is to evaluate the applicability of the technology to full-scale cyclone-fired boilers for reduction of NO_x emissions. The project goals are:

1. Achieve a minimum 50% reduction in NO_x emissions at full load.

2. Reduce NO_x without serious impact to cyclone operation, boiler performance or other emissions streams.

3. Demonstrate a technically and economically feasible retrofit technology.

The project participants providing funding for the work are:

- DOE - funding co-sponsor
- WP&L - host site utility and funding co-sponsors
- B&W - prime contractor, project manager and funding co-sponsor
- EPRI - testing consultant and funding co-sponsor
- State of Illinois Department of Natural Resource - funding co-sponsor
- Utility funding co-sponsors
    - Allegheny Power System
    - Atlantic Electric
    - Associated Electric
    - Baltimore Gas & Electric
    - Basin Electric Power Cooperative
    - Iowa Electric Light & Power Company
    - Iowa Public Service
    - Minnkota Power Cooperative, Inc.
    - Missouri Public Service
    - Montana-Dakota Utilities
    - Kansas City Board of Public Utilities
    - Kansas City Power & Light
    - Northern Indiana Public Service Company
    - Tampa Electric Company

Currently, 105 operating, cyclone-equipped utility boilers exist, representing approximately 13% of pre-NSPS coal-fired generating capacity (over 26,000 MW_e). However, these units contribute approximately 21% of the NO_x emitted because their inherent, turbulent, high-temperature combustion process is conducive to NO_x formation. Typically, NO_x levels associated with cyclone-fired boilers range from 1.0 to 1.8 lb/10^6 Btu input (NO_x as NO_2). Although the majority of the cyclone units are 20 to 30 years old, utilities plan to operate many of them for at least an additional 10 to 20 years. These units (located primarily in the Midwest) have been targeted for the second phase of the Clean Air Act Amendments of 1990 (CAAA) Title IV (Acid Rain Control) scheduled to go into effect in 2000. In some instances, Title I, Ozone Non-Attainment will accelerate the timetable for compliance.

No economical, commercially-demonstrated, combustion modifications have significantly reduced NO_x emissions without adversely affecting cyclone operation. Past tests with combustion air staging achieved 15 to 30% reductions. Further investigation of staging for cyclone NO_x control was halted due to corrosion concerns, as a result of reducing conditions in the cyclone during air staging. Additionally, because no mandatory federal or state NO_x emission regulation was enforced, no alternative technologies were pursued.

The use of selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR) technologies also offer the possibility of controlling NO_x emissions from these units, but at high capital and/or operating costs. Reburning is therefore a promising alternative NO_x reduction approach for cyclone-equipped units with more reasonable capital and operating costs. Reburning also complements a fuel switching SO_2 reduction strategy in that typical derates incurred in switching to a Western low sulfur subbituminous coal are offset by the reburn system's additional capacity.

The coal reburning full scale demonstration is justified via a previous EPRI-sponsored (Project RP-1402-30) engineering feasibility study and EPRI/GRI (EPRI RP-2154-11; GRI:5087-254-1471) pilot-scale evaluation of reburning for cyclone boilers performed by B&W[1,2]. These works indicated that NO_x reduction potential was significant and that the technology would apply to the majority of the cyclone boiler population.

The reburning project spanned a 50 month period, September 1989 through October 1993.

Low NO_x Cell™ Burner

The "Full-Scale Demonstration of Low-NO_x Cell Burner Retrofit" (Project DE-FC22-POP90545) is one of the U. S. Department of Energy (DOE) Clean Coal Technology (CCT-III) Demonstration Program projects and also part of OCDO CCT program. The objective of the LNCB™ demonstration is to evaluate the applicability of this technology for reducing NO_x emissions in full scale, cell burner-equipped boilers. The program goals are:

1. Achieve at least a 50% reduction in NO_x emissions.

2. Reduce NO_x with no degradation to boiler performance or life.

3. Demonstrate a technically and economically feasible retrofit technology.

The project participants providing funding for the work are:

- DOE - funding co-sponsor
- DP&L - host site utility, operations and construction management and funding co-sponsor
- B&W - prime contractor, project manager and funding co-sponsor
- EPRI - testing consultant and funding co-sponsor
- OCDO - funding co-sponsor
- Utility funding co-sponsors
    - Allegheny Power System
    - Centerior Energy
    - Duke Power Company
    - New England Power Company
    - Tennessee Valley Authority
    - Cincinnati Gas & Electric Company
    - Columbus and Southern Power Company

Economic considerations, which dominated boiler design during the 1960s, led to the development of the standard cell burner for highly efficient boiler designs. Utility boilers equipped with cell burners currently comprise 13%, or approximately 26,000 MW_e of pre-NSPS coal-fired generating capacity. Cell burners are designed for rapid mixing of the fuel and oxidant. The tight burner spacing and rapid mixing minimize the flame size while maximizing the heat release rate and unit efficiency. Consequently, the combustion efficiency is good, but the rapid heat release produces relatively large quantities of NO_x. Typically NO_x levels associated with cell burners will range from 1.0 to 1.8 $lb/10^6$ Btu input (NO_x as NO_2).

To reduce NO_x emissions, the LNCB™ has been designed to stage the mixing of the fuel and combustion air. A key design criterion for the burner was accomplishing delayed fuel-air mixing with no pressure part modifications, i.e. a plug-in design. The plug-in design reduces material costs and outage time required to complete the retrofit, compared to installing conventional, internally staged low NO_x burners, thus providing a lower cost alternative to address cell burner NO_x reduction requirements.

Justification for the LNCB™ full scale demonstration was based on a laboratory test program which was designed to fully characterize the LNCB™ at several scales: 1.7S MW_e, 30 MW_e, and utility scale[3]. This development work was done in association with EPRI. Several aspects of the LNCB™ performance including NO_x reduction, unburned carbon (UBC), carbon monoxide (CO), corrosion and impact to furnace exit gas temperature (FEGT) were investigated. Results of the pilot scale studies showed that the LNCB™ burner arrangement was stable over the burner operating range and that greater than 50% NO_x reduction was possible with acceptable impact to CO, UBC, and FEGT levels[4].

In 1985, one two-nozzle cell burner was replaced with an LNCB™ at DP&L's Stuart Station Unit No. 3 to test the mechanical reliability. After three years of normal burner operation, with no signs of material degradation, the test was deemed successful.

The LNCB™ project commenced in April 1990 with long term emission testing completed in April of 1993. The completion of corrosion testing scheduled for December 1994 will mark the end of the project.

COAL REBURNING

Description of Technology

The Coal Reburning technology combines pulverized coal combustion with existing cyclone-fired technology. Instead of all of the combustion taking place within the cyclones, 20 to 35% of the fuel is diverted to a pulverized coal system and fed to the reburn burners downstream of the cyclones. These additional burners are used to create a reducing zone within the main furnace area. Within this zone, stoichiometries of less than 1.0 are maintained for as long as possible to allow mixing and chemical reduction of NO_x to occur. Overfire air is added higher in the furnace to provide enough air to complete the combustion process. At the furnace exit, the stoichiometry matches the original, unmodified condition.

In the reburn zone, up to 35% (at lower loads) of the total heat input required by the boiler is introduced substoichiometrically. This creates large quantities of unburned (unoxidized) hydrocarbon gases which actively seek oxygen to complete the combustion process. Chemically, this oxygen comes from the NO_x molecules created in the cyclones. The reaction reduces the NO_x to elemental nitrogen (N_2). The combustion process is completed as the flue gas enters the overfire air zone where excess oxygen is available, but at a significantly lower temperature than found within the cyclone (2500 versus 3300F). This lower temperature limits NO_x reformation. Figure 1 presents the various combustion zones of the furnace: the main combustion zone, the reburn zone and the burnout zone.

Reburn System at Nelson Dewey Unit No. 2

The demonstration boiler host site at WP&L's Nelson Dewey Unit No. 2 is shown in Figure 2. The unit is a Babcock & Wilcox manufactured 100 MW_e cyclone fired RB boiler capable of firing bituminous and subbituminous coals. It is fired by three 9 ft. diameter cyclones equipped with vortex burners. Initial operation was in October of 1962.

The reburning system design activities included pilot-scale testing, physical and three-dimensional numerical modeling and engineering which incorporated B&W low NO_x burner/overfire air port design experience. With the objective of maximizing mixing in the reburn and overfire air zones, the size, number, and location of reburn burners and overfire air ports were determined. Application of Small Boiler Simulator (SBS)-Pilot Scale testing results as well as physical flow and numerical models to design of the reburn system are described elsewhere[5,6].

The isometric view of the system shown in Figure 3 gives the spacial relationships of the four reburn burners and four overfire air ports, the MPS-67 pulverizer and hot primary air fan as well as the coal pipes, secondary air ducts, and gas recirculation flues.

Coal Reburning Test Results

The primary test coal for the coal reburning demonstration was an Illinois Basin bituminous coal (Lamar). The majority of the testing was performed while firing this fuel to reflect the higher sulfur bituminous coal fired by many of the utilities operating cyclones. Following the bituminous coal testing, subbituminous Powder River Basin (PRB) coal tests were performed to evaluate the effect of coal switching on reburn operation. In addition, WP&L's strategy to meet sulfur emission limitations as of January 1, 1993 is to fire the low sulfur coal. Reburning test parameters are described elsewhere[6].

NO_x and CO Emissions

Baseline (no reburning) data for NO_x emissions under various load conditions for both coals are summarized in Figure 4 and in Table 1.

TABLE 1 - Baseline NO_x Levels for Lamar and PRB Coals

Load (MW_e)	**Baseline NO_x Emissions - ppm (lb/10^6 Btu) Corrected to 3% Oxygen**	
	Lamar Coal	**Powder River Basin Coal**
118	635 (0.86)	-
110	609 (0.83)	560 (0.75)
82	531 (0.72)	480 (0.64)
60	506 (0.69)	464 (0.62)
38	600 (0.82)	-

NO_x levels increase at 38 MW_e during Lamar firing because the boiler goes to single cyclone operation, approaching the heat release conditions and corresponding NO_x emissions achieved at full load.

CO emission levels during baseline operation were low while firing either of the two coal types. Generally speaking, the CO levels were slightly lower during the PRB coal firing tests (approximately 30 to 45 ppm versus 60 to 70 ppm over the load range).

Reburn testing on both the Lamar and PRB coals indicates that varying reburn zone stoichiometry is the most critical factor in changing NO_x emission levels during coal reburning operation. The reburn zone stoichiometry can be varied by altering the air flow quantities (oxygen availability) to the reburn burners, the percent reburn heat input, the gas recirculation flow rate or the cyclone stoichiometry.

Figure 5 represents B&W economizer outlet NO_x and CO emission levels in ppm corrected to 3% O_2 versus reburn zone stoichiometry at full load conditions (110 MW_e) while firing Lamar coal. This figure consists of parametric optimization and performance testing data. Figure 6 presents NO_x and CO emissions while firing PRB coal.

Load versus NO_x emissions for both coals are shown in Figure 7 and summarized in Table 2.

TABLE 2 - Reburn NO_x Emissions Versus Load for Lamar and PRB Coals		
Load (MW_e)	**Reburn NO_x Emissions/% Reduction from Baseline (ppm/%)**	
	Lamar Coal	**PRB Coal**
118	-	275/-
110	290/52	208/62
82	285/47	215/55
60	325/36	220/53
41	-	220/-

Reburn operation burning PRB produced lower overall NO_x emission levels. Baseline NO_x levels with PRB were approximately 10% lower, and better NO_x reduction is probably due to the higher Western fuel volatile content. Higher volatile content generates higher concentrations of hydrocarbon radicals in the substoichiometric region of the furnace. Figure 7 also shows that PRB NO_x emissions could be maintained at a constant level - over the 110 to 41 MW_e load range.

With PRB coal, at loads higher than 110 MW_e NO_x emissions increased. At 118 MW_e, the NO_x level was 275 ppm (0.37 lb/10^6 Btu). Higher NO_x was due to less percent reburn heat input because of reburn feeder limitations. No baseline NO_x level were obtained at this higher load because the boiler could not reach it on PRB coal without reburn burners in service.

<u>Other Operating Parameters</u>

Impact of the reburn process with both Lamar and PRB coals on electrostatic precipitation performance, unburned carbon efficiency loss, furnace exit gas temperature, slagging and fouling, furnace corrosion and hazardous air pollutant emissions are described in detail elsewhere[6].

Table 3 presents a summary comparison of anticipated and actual results of reburn operation for these parameters.

TABLE 3
Effect of Reburn System on Unit Performance

Parameter	Anticipated Results	Actual Results
NO_x Emissions (full load) Illinois Basin Coal	Reduced 50% or more	Nominal 55% reduction
NO_x Emissions (full load) Powder River Basin Coal	Reduced 50% or more	Nominal 61% reduction
Precipitator capacity	Up 5 to 10%	No increase from base
Slagging/Fouling	No change	Cleaner than normal
Furnace corrosion	No change	No change
Header/tube temps.	Higher 25 to 50F	No increase from base
FEGT (Illinois Basin - Lamar coal)	Higher by 50 to 75F	Reduced by 100 to 150F
FEGT (PRB)	Higher by 50 to 75F	Reduced by 25 to 50F
SH & RH sprays (Illinois Basin - Lamar coal)	Higher by 30%	50% of base
Unburned carbon efficiency loss (Full load) Illinois Basin Coal	Higher	Higher by 0.1%
Unburned carbon efficiency loss (Full load) Powder River Basin Coal	Higher	No change
Hazardous air pollutants (Illinois Basin - Lamar coal)	No change	No change

Fuel Switching Advantage

A significant advantage of coal reburning is that it minimizes and possibly eliminates a 10 to 25% derate normally associated with switching to a PRB coal in a cyclone unit. The derate is a result of using of lower Btu content fuel in the volume limited cyclone. The reburn system transfers about 30% of the heat input out of the cyclones to the reburn burners, bringing the cyclone feed rate down to a manageable level, while maintaining full load heat input to the unit. At Nelson Dewey, maximum pre-reburn retrofit full load on PRB coal was 108 to 110 MW_e, while on the higher Btu Lamar coal, 118 MW_e could be achieved. With reburn in operation, the unit was able to achieve 118 MW_e on PRB coal. Accordingly, there is a possibility to economically justify a reburn system based on fuel cost savings and regained unit capacity when switching to a PRB coal. This is a site specific issue based on ability of the unit to fire PRB coal and deal with the other impacts such as slagging and fouling.

Reburn Technology Status

The reburn system has performed very well as evidenced by WP&L's decision to take title of the system and operate it beyond the term of the DOE project. Current operation is less frequent than anticipated, on the order of once a week for a period of a day. The reason for reduced operation is a problem with the hot primary air fan variable frequency AC drive which controls fan speed. The fan provides hot air to dry and convey the pulverized coal to the burners. Once the PA fan drive problem is resolved, WP&L will resume regular reburn system operation. Also, when burning 100% PRB coal, problems with convection pass fouling have occurred due to the nature of the fuel. From a commercialization point of view, a number of utilities have asked B&W to perform engineering studies on their respective units to determine expected performance and cost.

LOW NO_x CELL BURNERS (LNCB™)

Description of Technology

The original cell burner design consisted of two or three circular burners mounted in the lower furnace. Figure 8 shows a two-nozzle cell burner. The two-nozzle LNCB™ shown in Figure 9 was developed by B&W in association with the EPRI. The features of the LNCB™ were designed to minimize the formation of thermal and fuel NO_x. The two original circular burners in each cell are replaced with a single S-type circular burner and a close coupled secondary air injection port. The flame shape is controlled using an impeller at the exit of the burner and adjustable spin vanes in the secondary air zone. The air port louver dampers provide additional control over the mixing between the fuel and air streams. The S-burner operates at a low air-fuel stoichiometry, typically 0.6, with the balance of air entering through the adjacent air port. The delayed mixing of the fuel and air during the initial stage of combustion limits the formation of NO_x.

Low NO_x Cell Burners at J.M. Stuart Station Unit No. 4

The host site for the full scale demonstration of the LNCB™ was DP&L's J.M. Stuart Station Unit No. 4 (JMSS4). JMSS4 is a B&W 605 MW_e Universal Pressure (UP) boiler, a once-through design, originally equipped with 24, two-nozzle cell burners arranged in an opposed wall configuration as shown in Figure 10.

Each of the original two-nozzle cell burners were replaced with a single S-type circular burner in place of the lower cell burner and a close coupled secondary air injection port at the upper cell location, shown in Figure 9. To avoid replacing coal pipes and pulverizer top housings, the two coal pipes, one to each burner of the original cell, were combined at the burner front to supply the new single S-type circular burner by using a special Y-pipe assembly. As a special feature of the LNCB™ technology, no pressure part modifications were necessary and the existing control system was utilized. The retrofit of the LNCB™ equipment was completed during a six week scheduled turbine outage during October/November 1991.

Initial test results with this original arrangement (Figure 11) indicated high levels of CO and hydrogen sulfide (H_2S) in the lower hopper region of the furnace, an unacceptable operating condition in this pressurized furnace. As a demonstration project, resources were allocated to perform in depth background work to develop the numerical model to help understand flow behavior in the unit. When problems with the LNCB™ operation arose, B&W used its three dimensional numerical modeling capabilities to simulate the existing operating condition, as well as evaluate alternative burner/secondary air port arrangements that could mitigate this problem. The best computer generated analysis identified for maximum mitigation of CO and H_2S levels was to invert the air port and burner of every other LNCB™ on the lowest level of burners (Figure 12)[7]. This is the final configuration of the LNCB™ system tested during the project.

A second result of initial testing showed that NO_x reduction of only 35% from baseline levels was being achieved with the 50 degree coal impellers. By retracting the impellers within the coal nozzles, NO_x reduction increased to 45%. This indicated a need for an impeller design change in order to achieve the NO_x reduction goals of the project. A coal impeller with a 25 degree included angle was designed, fabricated and installed during the same one week outage in April 1992 in which the alternating inverted LNCB™ arrangement was accomplished.

Low NO_x Cell Burner (LNCB™) Test Results

The LNCB™ demonstration emphasized evaluation of boiler performance, boiler life and environmental impact. Key boiler performance parameters that were measured included boiler output (steam temperatures); flue gas temperatures at the furnace, economizer and air heater exits; the slagging tendencies of the unit; and UBC losses. Evaluation of H_2S levels, ultrasonic testing of lower furnace tube wall thicknesses and destructive examination of a corrosion test panel were the mechanisms used to predict impact on remaining boiler life. Environmentally, NO_x, CO, carbon dioxide (CO_2), total hydrocarbons (THC) and particulate matter, dust loadings and precipitator collection efficiency were measured at varying test conditions. —

Performance results during parametric testing for NO_x, CO emissions and unburned carbon losses are described in detail elsewhere [6,8]. In general, full load (604 MW_e) NO_x emissions with all mills in service averaged .53 lb/10^6 Btu, representing a 54.4% reduction. At full load with five mills in service, NO_x emissions ranged from 0.48 to 0.56 lb/10^6 Btu depending on which mill was out of service. When mills fueling the upper burners were out of service, the best NO_x reductions were obtained. This is possibly due to deeper staging of lower burners, which are fired harder with one mill out of service, followed by higher secondary air availability at the burner out-of-service level. CO levels did not exceed 55 ppm and efficiency losses due to unburned carbon were significantly improved, with all mills in-service and only slightly improved for one mill out of service.

At intermediate load (460 MW_e) NO_x emissions were 0.42 lbs/10^6 Btu, a 54% reduction. CO levels were in the 28 to 45 ppm range and unburned carbon efficiency improved significantly. At low load (350 MW_e) NO_x emissions were 0.37 lbs/10^6 Btu, a 48% reduction. CO ranged from 5 to 27 ppm and efficiency loss due to unburned carbon increased slightly.

<u>Long Term Averages</u>

An important aspect of the project was to record NO_x emission levels from JMSS4 during normal load dispatch operations over a long period. Table 4 and Table 5 show the average NO_x emissions for JMSS4 with all mills in service and one mill out of service, respectively. This data was recorded by the Acurex CEM equipment through a total of two probes located one in each of the east and west economizer outlet ducts. This data was acquired between August 1992 and March 1993 during periods when the boiler was operating above 590 MW_e.

TABLE 4 - LONG TERM FULL LOAD ALL MILLS IN SERVICE DATA

All Mills in Service Averages at JMSS4
Acurex CEM Test Results for Loads Above 590 MW_e

Month	Days * @ Full Load All Mills	All Mills in Service			
		Load MW_e	Dry O_2 Econ Out	Dry NO_x ppm Corr to 3% O_2	NO_x lb/10^6Btu
August	8.54	604	3.7	367	0.50
September	7.29	604	3.2	333	0.45
October	14.51	605	3.3	367	0.50
November	12.03	605	3.2	345	0.47
December	4.94	605	3.1	360	0.49
January	6.83	605	3.2	410	0.56
February	7.22	606	3.2	364	0.50
March	17.66	602	2.9	353	0.48

TABLE 4 - LONG TERM FULL LOAD ALL MILLS IN SERVICE DATA					
All Mills in Service Averages at JMSS4 Acurex CEM Test Results for Loads Above 590 MW_e					
Month	Days * @ Full Load All Mills	All Mills in Service			
		Load MW_e	Dry O_2 Econ Out	Dry NO_x ppm Corr to 3% O_2	NO_x $lb/10^6 Btu$
Weighted 8-mo Avg.		604	3.2	360	0.49
Total Days 79.02 * Remaining days at lower load or mill out of service.					

TABLE 5 - LONG TERM FULL LOAD MILL OUT OF SERVICE DATA					
Mill Out of Service Averages at JMSS4 Acurex CEM Test Results for Loads Above 590 MW_e					
Mill Out of Service	Days * @ Full Load 1 Mill Out	August '92 - March '93			
		Load MW_e	Dry O_2 Econ Out	Dry NO_x ppm Corr to 3% O_2	NO_x $lb/10^6 Btu$
A	1.04	603	3.4	314	0.43
B	1.81	608	3.6	361	0.49
C	1.41	602	3.5	388	0.53
D	2.29	602	3.6	404	0.55
E	3.02	606	3.3	357	0.49
F	8.48	604	3.9	314	0.43
Weighted 8-mo Avg.		604	3.7	343	0.47
Total Days 18.05 * Remaining days at lower load or all mills in service.					

With all mills in service, the average NO_x level achieved for the eight month period was 0.49 $lb/10_6$ Btu or a 58% reduction from baseline. The highest monthly average NO_x level observed was in January at 0.56 $lb/10^6$ Btu. Wet coal and accompanying problems were suspected to have caused the higher level which still represented a 52% reduction. The excess O_2 levels averaged 3.2%.

For full load, mill out service NO_x emission levels (Table 5) averaged 0.47 $lb/10^6$ Btu. The lower NO_x levels recorded with either A or F mill out of service, as observed previously, can be attributed to the fact that these mills feed the burners on the upper elevation only.

Long-Term Operational Performance

The operational performance of the Low-NO_x Cell™ Burner (LNCB™) equipment has been good since the final arrangement and impeller modifications were made in April 1992. The LNCB™s have been providing stable combustion conditions with good carbon burnout.

The amount of flyash produced appears to have increased while the amount of bottom ash has decreased. The flyash appears to be finer as compared to that produced with the original cell burners. Even though the overall dust loading has increased, the performance of the precipitators has improved.

The cell burners formerly produced a buildup of agglomerated "popcorn" ash on the horizontal convection pass sections of the boiler, particularly on the economizer. This ash buildup and associated tube erosion has been greatly reduced since the installation of the LNCB™s. The required maintenance associated with the airheaters, the flyash handling equipment, and the bottom ash handling equipment has been reduced due to the condition of the ash produced by the LNCB™s in this boiler.

Corrosion Studies

During burner installation in October/November 1991, a corrosion test panel was installed on the boiler side wall between the upper and lower burner rows to evaluate corrosion potential. The panel consists of SA-213T2 bare tube material, aluminized spray coated T2 tube material and a chromized T2 tube material. In addition, UT measurements were conducted in the furnace.

Destructive examination of the furnace wall samples taken from the corrosion test panel was performed. In addition, predictive equations were developed based on laboratory investigations.

The long-term corrosion panel test in J.M. Stuart Station Unit #4 (JMSS 4) indicates that the maximum metal wastage of SA213-T2 is approximately 21 mils after the 15-month operating period.

This wastage rate is equivalent to a corrosion rate of 17 mpy. Based on predictive equations developed during the long-term test task, maximum metal wastage of T2 was calculated to be 15 mpy. These equations based their predictions upon: 1) the metal temperature, 2) H_2S concentration in the flue gas, and 3) Cr concentration in the alloys under the test conditions employed.

All of the commercial high-alloy steels investigated in this task, including a popular and economical steel -- SA213-TP304, appear to possess suitable corrosion resistance to the laboratory mixed gases. Their good performance was also confirmed by the field test. Therefore, the selective use of chromia-forming alloys in areas of the boiler where chemically reducing flue gases have wall contact should alleviate the corrosion concern of many low-NO_x technologies.

By contrast, the corrosion performance of carbon and low-alloy steels commonly used in the lower furnace of utility boilers may suffer due to sulfidation attack under reducing combustion gases. Therefore, these materials require surface protection locally in the lower furnace where reducing gases are present. However, high tube wastage was reported prior to the retrofit in JMSS4 where reducing combustion gases were suspected.

Results of the field test suggest that a chromia-forming coating relatively free of structural defects may be locally applied to the surfaces of waterwalls to combat the above noted sulfidation attack. However, these corrosion resistant materials can be significantly affected by their microstructure integrity. When pre-existing structural defects, such as cracks, pores, and oxide stringers are present, the corrosion attack can proceed preferentially along these sites. As a result, the metal wastage can be much greater than anticipated when the surface coatings are not applied properly.

UT testing of the furnace will continue over the next five years to evaluate corrosion potential.

<u>Commercial Status of LNCB™ Technology</u>

Since the completion of the test program, B&W has pursued commercialization of LNCB™ technology. To date, commercial sales have resulted for 5 units, totalling 3300 MW_e. These include three units at Allegheny Power System (APS) and two units at Detroit Edison. As of this time, Hatfield's Ferry Unit No. 2 of Allegheny Power has been installed and started up. All others are in stages of engineering and fabrication . These represent the first commercial sales of a DOE Clean Coal Technology developed in the Clean Coal Program.

The LNCB™ system at Hatfield's Ferry Unit No. 2 was installed during an eight week outage, September 24 through November 23, 1993, concurrently with major turbine work. This system included an upgraded design of the commercial B&W NO_x port (overfire air port) which reduced resistance to air flow. This was made possible through a downsizing of the air distribution bluff body within the port. The stoichiometries used at Stuart Station can be achieved at Hatfield's Ferry with a windbox to furnace differential pressure in the range of 1.7 in WC lower (Stuart 4.5 in WC and Hatfield's Ferry 2.8 in WC).

Preliminary results at Hatfield's Ferry reveal NO_x reductions at the 50% level have been achieved with no significant impact on unburned carbon efficiency loss.

For cell burner units in general, application specific burner zone heat release rates, furnace configuration, and coal type (ex. volatility, fixed carbon level, bituminous versus subbituminous, nitrogen content, and oxygen content etc.) will impact expected NO_x results. Boilers firing fuels similar to DP&L's J.M. Stuart Station are expected to experience at least a 50 percent NO_x reduction when retrofitted with LNCB™ technology.

Units with higher burner zone heat release rates than J.M.Stuart Station will generally have higher baseline NO_x levels. For these units, LNCB™ technology has the potential to reduce NO_x emissions by 50 percent from baseline levels, but not necessarily to absolute levels as low as those attained at DP&L Stuart Station.

The pre-retrofit burner equipment at DP&L had not been upgraded from its original configuration. The air registers on most of the pre-retrofit burners had been welded in an open position, and no work had been performed recently to balance air and fuel flows. Therefore some combustion relation items such as furnace exit gas temperature (FEGT), surface cleanliness, and unburned carbon results were improved by the mechanical improvements and air balancing capability of the LNCB™ equipment.

If a unit is similar to Stuart Station where there has been no major burner equipment or combustion upgrades, then similar results can be expected. However, if mechanical improvements have already been made to the burners such that "per burner air control" and/or per burner fuel/air balancing has been improved, then:

a. FEGT may be slightly higher than baseline. Numerical modeling results indicated that in a balanced configuration, a 10°F increase in FEGT may result.

b. Surface cleanliness will not show as dramatic an improvement because combustion efficiency will have already been improved.

c. Unburned carbon losses may be slightly higher. The impact was minimized during the DOE demonstration program because the Stuart Station unit fuel/air flow was not balanced.

All other performance related parameters should have the same pre- to post-retrofit results as DP&L Stuart Station demonstration.

As far as corrosion potential is concerned, laboratory results suggest that there is a significant potential for localized furnace tube wall corrosion to occur. However, this risk is no greater than the risk associated with any other two-stage combustion process (i.e. overfire air system). There is evidence to suggest that the risk is no greater than the potential for corrosion with the current cell burner equipment. It is strongly suggested that steps be taken at the time of installation of this or any other staged combustion process, to also add commercially available products such as wall coatings that retard furnace wall corrosion.

CONCLUSIONS

Both the Coal Reburning and LNCB™ projects have achieved the respective Clean Coal Program objectives. Both technologies have demonstrated NO_x reductions in excess of 50% without significant adverse impact to other boiler emissions streams. The host site units have each continued to reach pre-retrofit full load output without significant impact to boiler operation. Results of long term emissions testing indicate performance has continued to exceed the project goals for each technology and both DP&L and WP&L[8] have decided to operate the respective Clean Coal Technologies beyond the project end dates.

The low cost and short outage time for a LNCB™ retrofit make the design financially attractive. In a typical retrofit installation, the capital cost will include the LNCB™ hardware, coal pipe modifications, hangers, support steel, sliding air damper drives and associated electrical, with a capital cost of about $5.5 to $8.0 per kW in 1993 dollars, based upon the DOE 500 MW_e reference unit for material and erection. The outage time can be as short as five weeks because the LNCB™ is a plug-in design.

For cyclones, coal reburning offers a NO_x reduction alternative at a higher price. Costs are expected to be in the $65/kW range for a 100 MW_e unit and in the $40/kW range for a larger 600 MW_e unit. Unlike a burner retrofit which already has coal handling and pulverizers/coal piping in place, this equipment must be included in the cost of a reburn system. Site specific factors related to pulverizer location and coal supply can greatly influence overall reburn system cost. However, coal reburning brings with it benefits allowing increased flexibility in coal selection which can yield significant fuel savings.

Corrosion potential will continue to be investigated over the next five years for both technologies.

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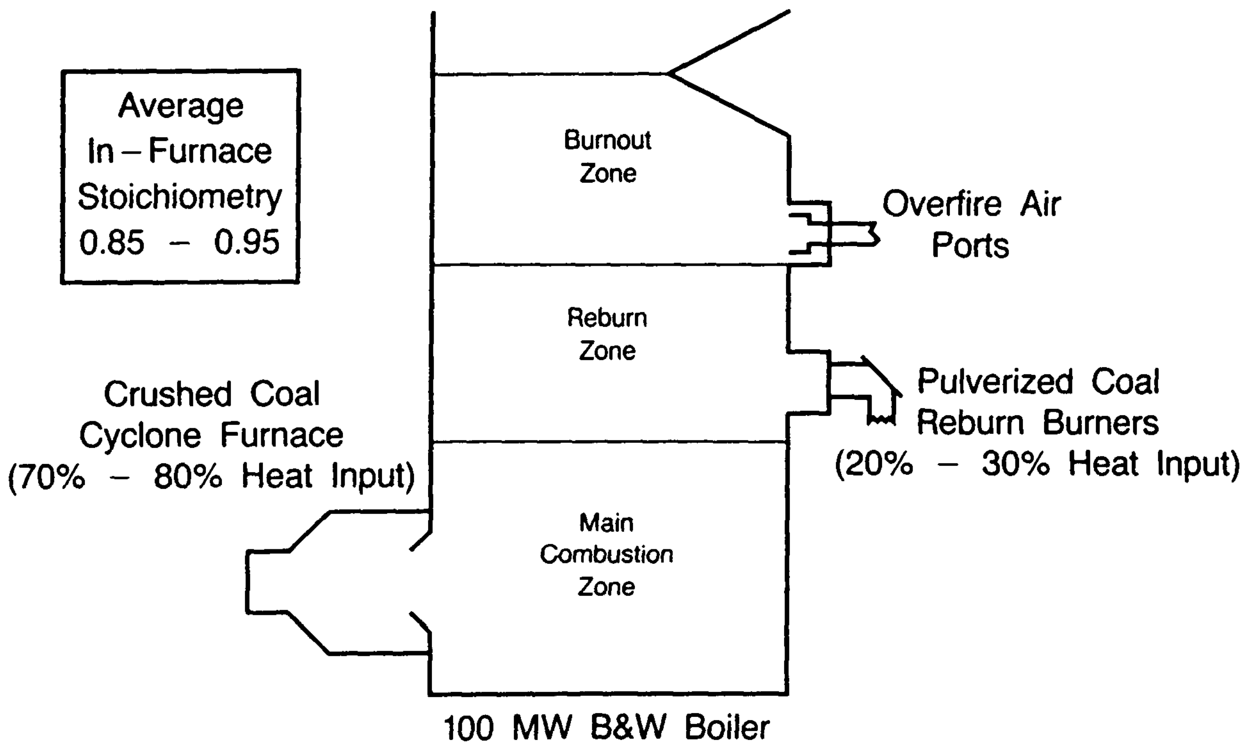

Fig. 1 Cyclone reburn combustion zones.

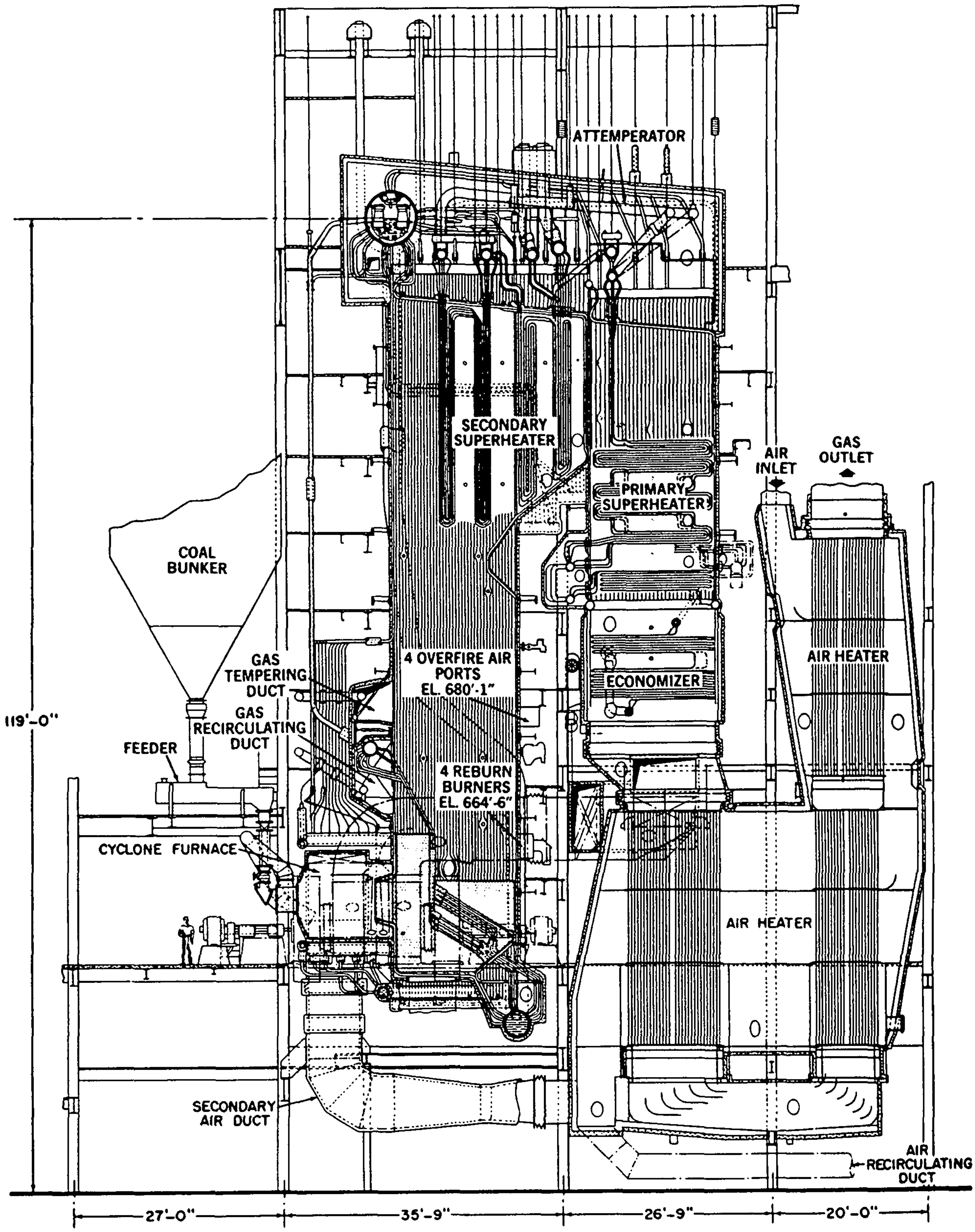

Fig. 2 WP&L Nelson Dewey Unit No. 2.

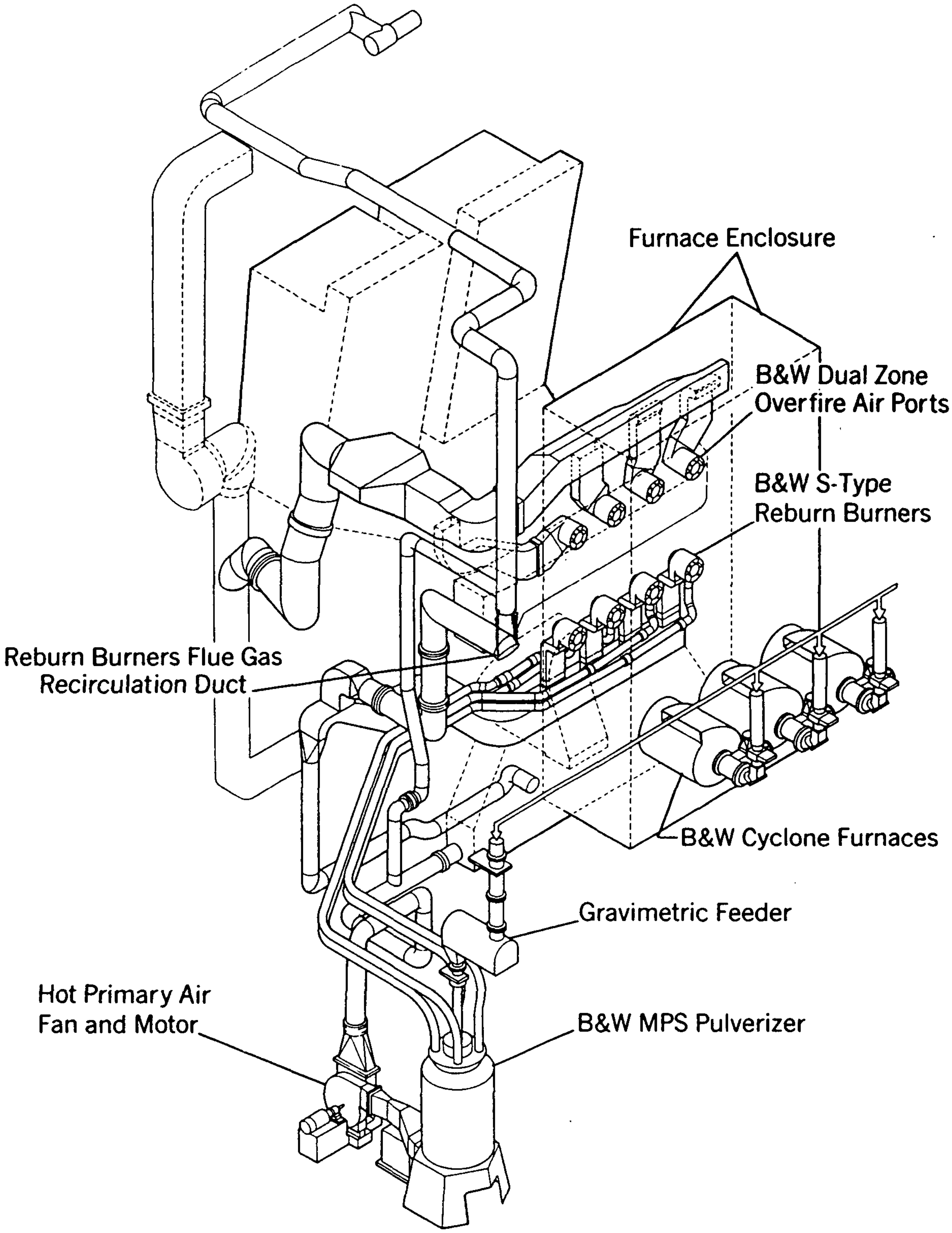

Fig. 3 Isometric view of Coal Reburning for Cyclone Boiler NO_x Control.

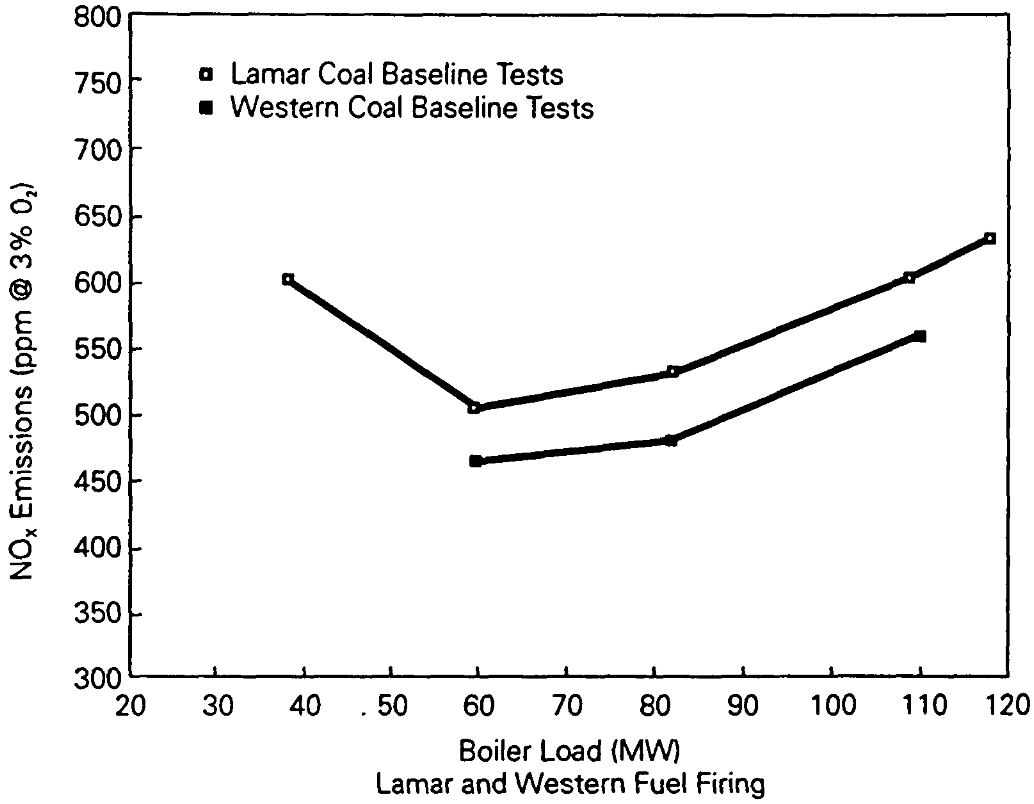

Fig. 4 Baseline NO_x emissions versus load, Nelson Dewey Unit 2.

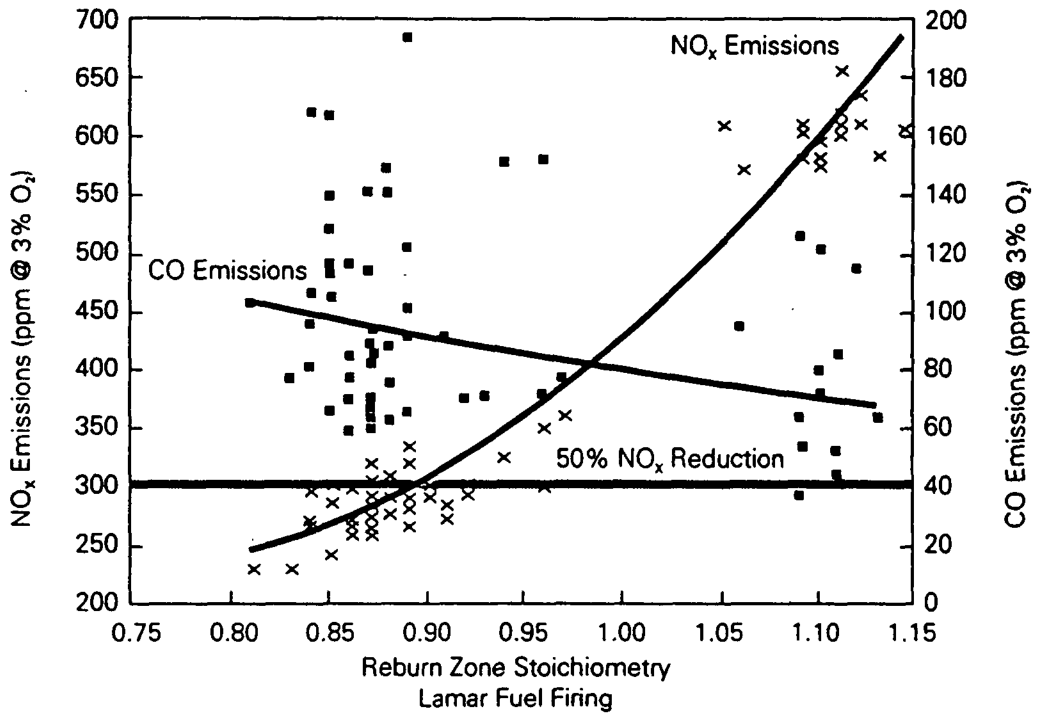

Fig. 5 NO_x and CO emissions versus reburn zone stoichiometry at full load firing Lamar coal.

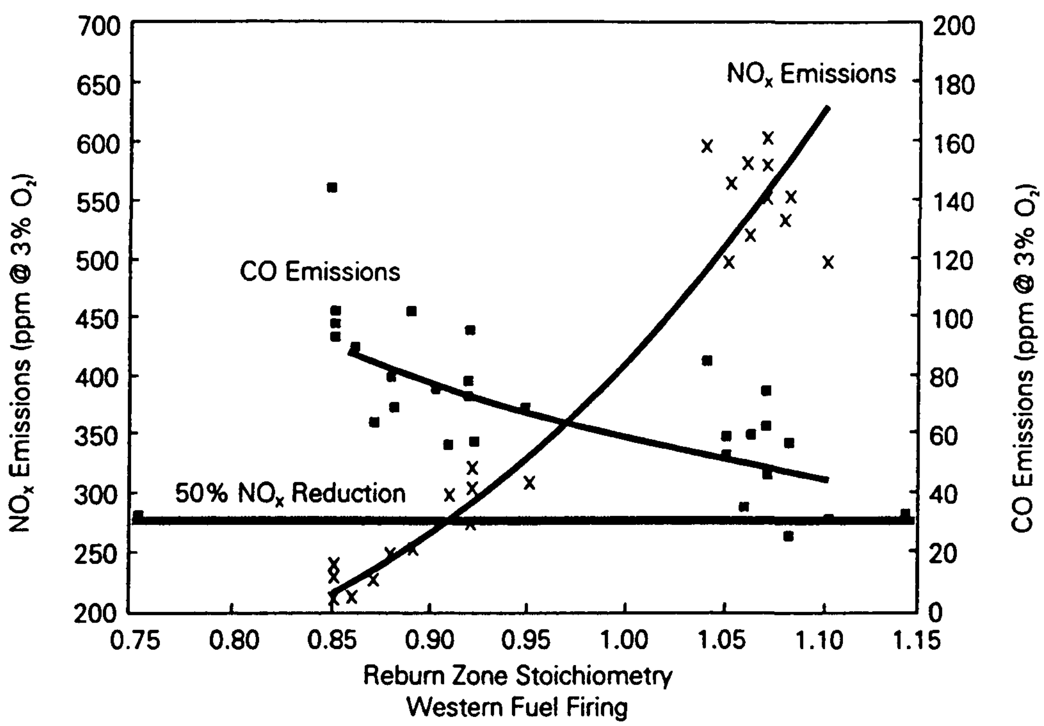

Fig. 6 NO$_x$ and CO emissions versus reburn zone stoichiometry at full load firing Western coal.

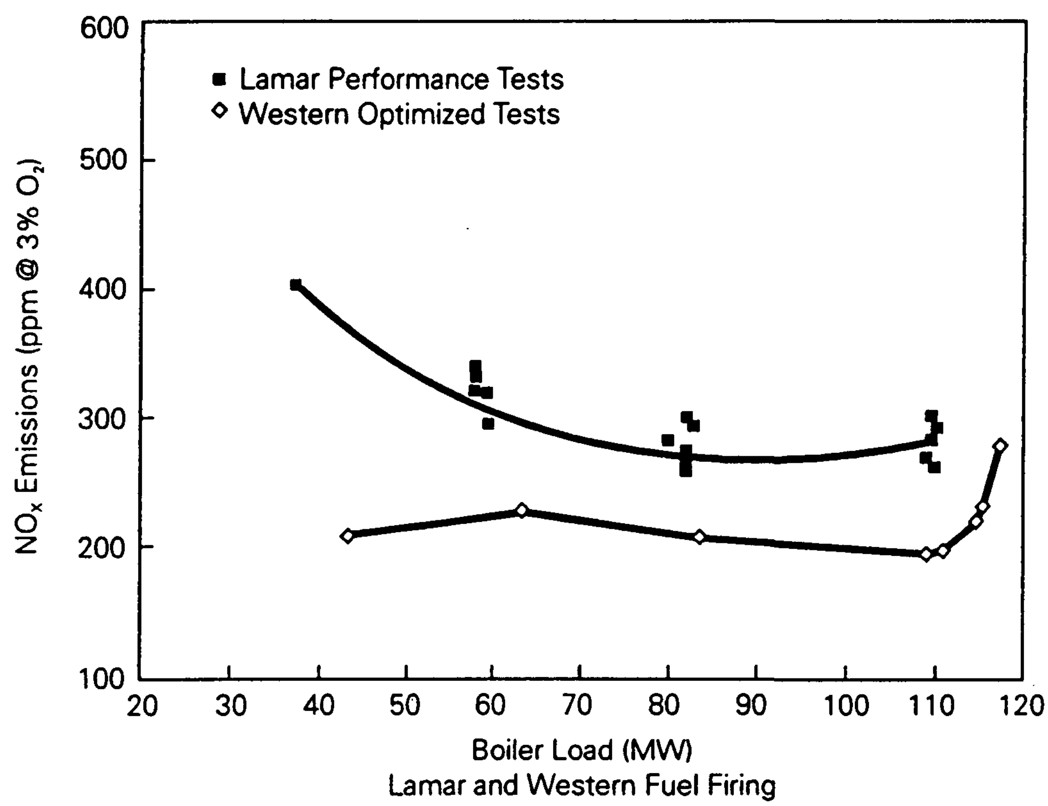

Fig. 7 NO$_x$ emissions versus load firing Lamar and Western coals with reburn system in operation.

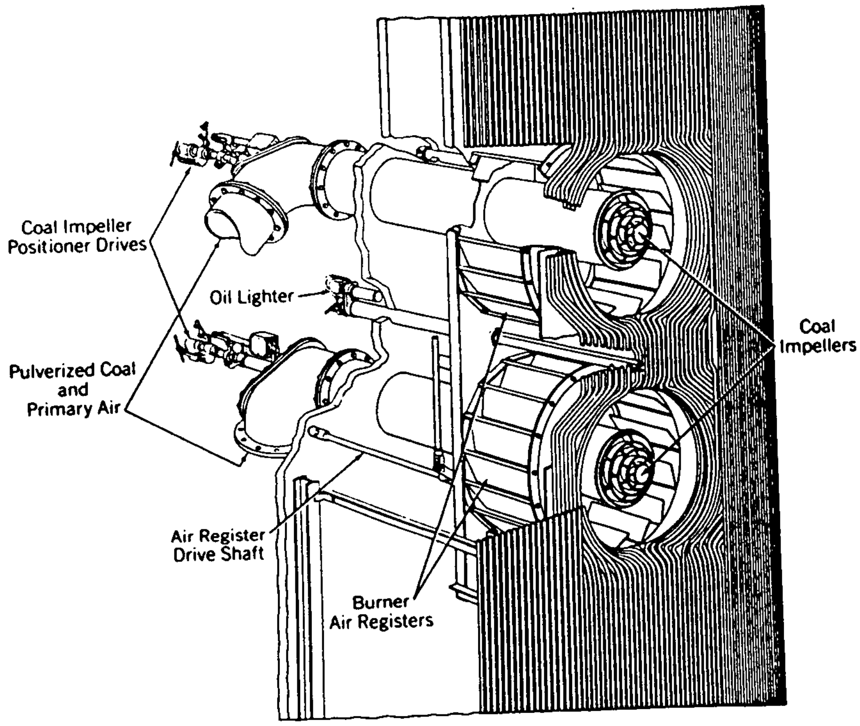

Fig. 8 Standard two-nozzle cell burner.

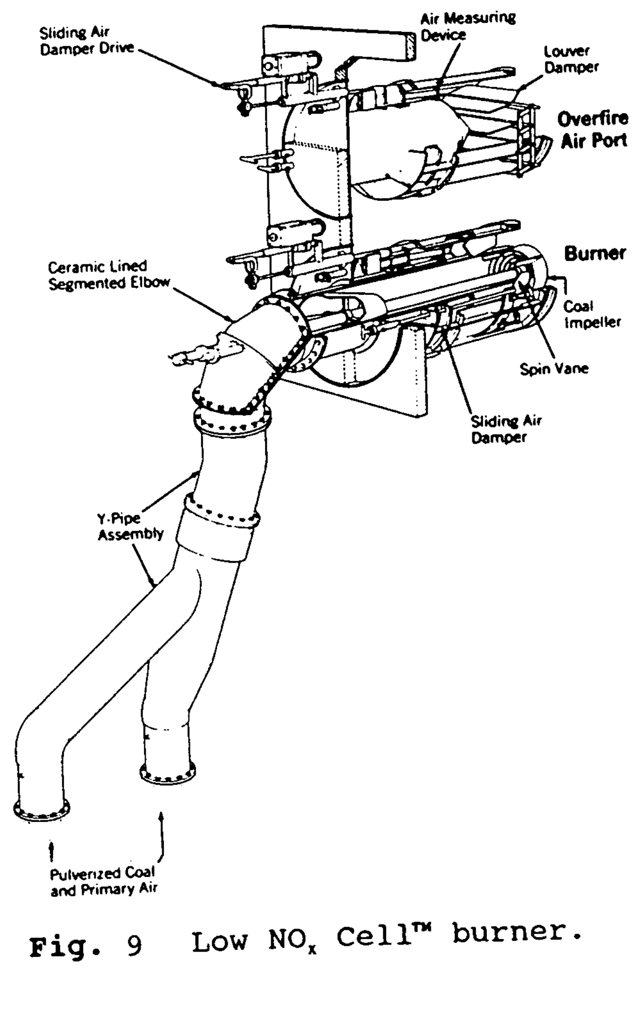

Fig. 9 Low NO_x Cell™ burner.

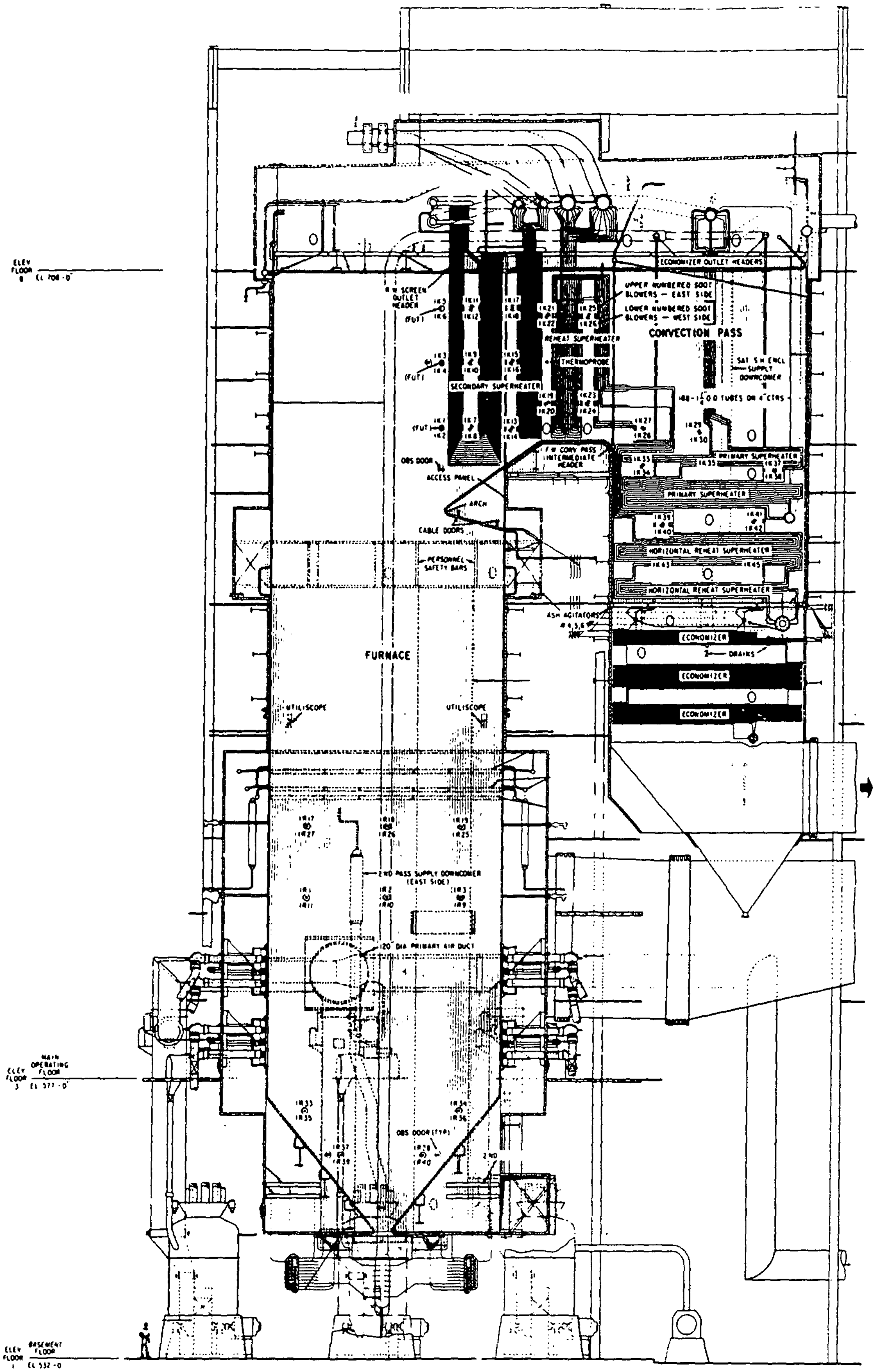

Fig. 10 DP&L J.M. Stuart Station Unit No. 4.

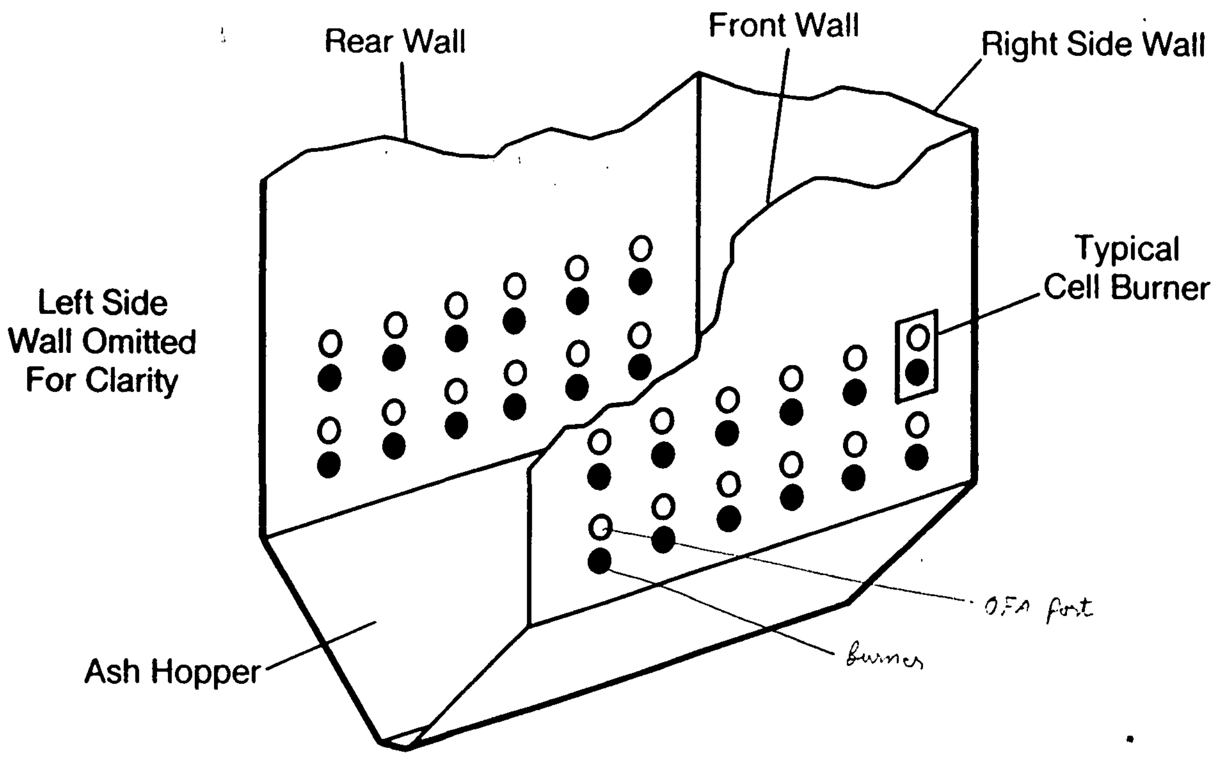

Fig. 11 Original LNCB™ arrangement.

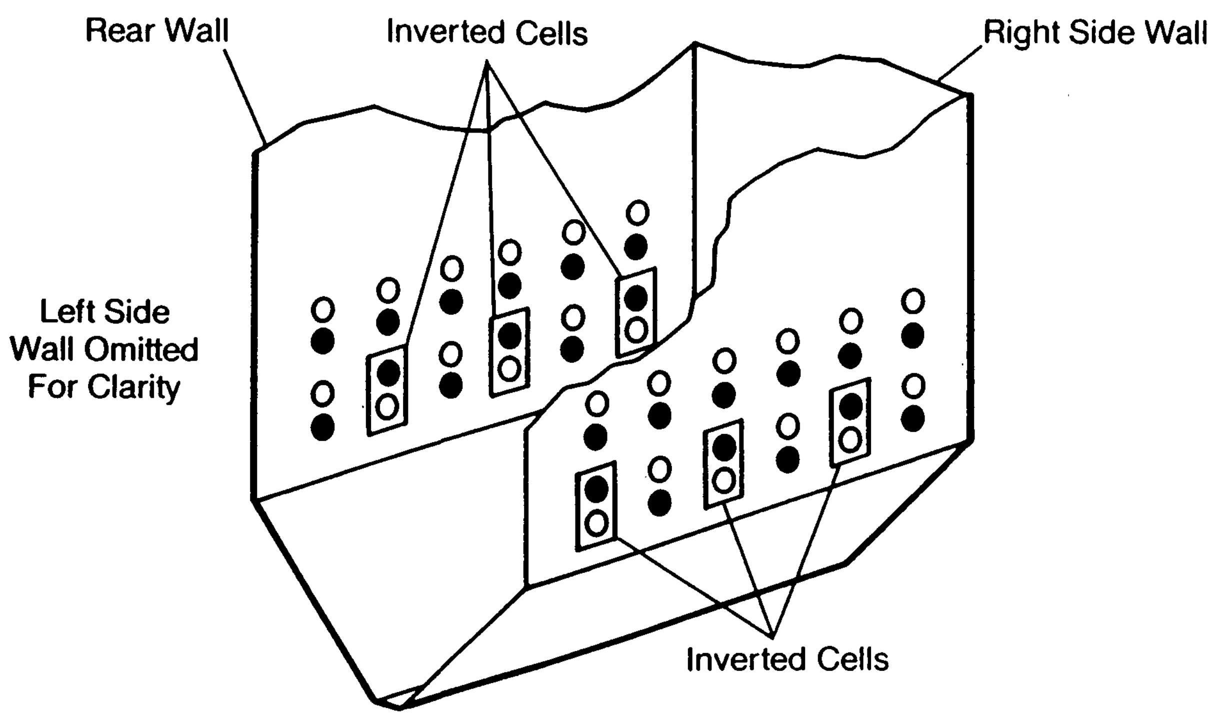

Fig. 12 Partially inverted LNCB™ arrangement.