Coal Reburning for Cyclone
Boiler NOx Control Demonstration

Quarterly Report No. 12
January, February, and March 1993

DOE Agreement No.: DE-FC22-90PC89659
B&W CRD Agreement No.: CRD-1229

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Prepared by:
Babcock & Wilcox
a McDermott Company
DISCLAIMER

This report was prepared by Babcock & Wilcox pursuant to a cooperative agreement partially funded by the U.S. Department of Energy and neither Babcock & Wilcox nor any of its subcontractors nor the U.S. Department of Energy, nor any person acting on behalf of either:

(a) Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately-owned rights; or

(b) Assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Department of Energy. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Department of Energy.
Table of Contents

I. Executive Summary

II. Introduction

III. Project Description

IV. Project Status

V. Planned Activities (for next quarter)

VI. Summary

VII. Report Distribution List
1.0 EXECUTIVE SUMMARY

The Coal Reburning for Cyclone Boiler NOx Control Demonstration project (DOE Agreement No. DE-FC22-90PC89659) progress for January, February, and March 1993 is identified in this twelfth quarterly report and pertains to the on-going activities of Phase III - Operation and Disposition. The project involves retrofitting/testing the reburning technology at Wisconsin Power & Light's 100 MWe Nelson Dewey Unit #2 in Cassville, Wisconsin to determine the commercial applicability of this technology to reduce NOx emission levels.

Phase III - Operation and Disposition activities emphasized preparation of the final report. A draft has been completed and it will be provided to DOE/PETC in April for review and comment. The Phase III review for a project was held on March 16, 1993 in Cleveland, Ohio.

Based upon the data collected and evaluated for reburn NOx reduction performance with the Lamar Indiana bituminous coal for boiler loads of 110 MW, 82 MW, and 60 MW, average NOx reductions of 52.4%, 50.1% and 35.8%, respectively were achieved. Average emissions of NOx with reburn in operation were 290 ppm (.39 lb/million Btu), 265 ppm (.36 lb/million Btu) and 325 ppm (.44 lb/million Btu) respectively, all corrected to 3% O2 content. Boiler efficiency losses due to increased unburned carbon in the ash were 0.1% at 110 MW, .25% at 83 MW and 1.5% at 60 MW.

Reburn performance results with western sub-bituminous coal at 110 MW, 82 MW and 60 MW boiler loads indicated NOx reductions of 55.4%, 52.1% and 52.6% respectively. Under optimal conditions, NOx reductions approaching 63% were achieved with the more reactive western sub-bituminous coal. Boiler efficiency losses due to increased unburned carbon in the ash were unchanged at full load, a loss of 0.2% at 83 MW and a loss of .3% at low load, much improved over results with the Lamar coal.

Results of the ultrasonic thickness testing in the furnace do not indicate a corrosion problem exists at this point. B&W and WP&L will continue to monitor results for the next five years to assure a problem is not developing.

Preliminary results of the hazardous air pollutant (HAP) testing indicate no major impact of reburn on volatile organics emissions. HAP results will be completed and reported by Acurex in April, 1993.
2.0 INTRODUCTION

As per the Cooperative Agreement No. DE-FC22-90PC89659 dated April 2, 1990, the following quarterly report has been prepared for the Coal Reburning for Cyclone Boiler NOx Control Demonstration Project. The period covered by this quarterly report is January through March 1993. This report represents the twelfth three-month period of the project.

The subject of this report identifies progress during the quarter for Phase III - Operation and Disposition.

Under Phase III - Operation and Disposition, preparation of the final report continues. The final emissions and boiler performance results which will be part of the final report are discussed in this quarterly report.
3.0 PROJECT DESCRIPTION

3.1 PROJECT OVERVIEW

The current energy policy of the United States includes the expanded use of coal in utility and industrial applications. However, the increased use of coal must not conflict with environmental goals and thus requires development of cost-effective technology to control the pollutants resulting from coal combustion. Of major concern is the problem of oxides of nitrogen in the Northeastern United States and portions of Canada.

The reduction of NO\textsubscript{x} and SO\textsubscript{2} emissions from fossil fired boilers has been a major objective of the DOE, the EPA, and all of the major boiler and burner manufacturers for many years. This is demonstrated by a number of concurrent efforts that have been and are being conducted to develop lower NO\textsubscript{x} burners for pulverized coal applications. Reduction of NO\textsubscript{x} emissions via combustion modifications presents many options for most coal-fired utility boilers, but not for the 26,000 MWe of cyclone boiler generating capacity. The operating characteristics of a cyclone boiler do not lend themselves to delayed mixing or staged combustion which are the two major low-NO\textsubscript{x} alternatives for coal-fired boilers. The reburning process is the best known technically and economically feasible low-NO\textsubscript{x} alternative via combustion modification for cyclone boilers. Back-end NO\textsubscript{x} removal systems, such as Selective Catalytic Reduction (SCR) technology offers promise of NO\textsubscript{x} control for cyclones but at high capital and operating costs.

B&W engineering studies followed by pilot-scale testing has developed/confirmed the potential of utilizing gas, oil or coal reburning as a viable NO\textsubscript{x} reduction technology. To date, two U.S. sponsored programs promote natural gas/oil as a reburning fuel because it was believed that gas/oil will provide significantly higher combustion efficiency than using coal at the reburn zone. Although B&W has shown that gas/oil reburning will play a role in reducing NO\textsubscript{x} emissions from cyclone boilers, B&W coal reburning research has also shown that coal as a reburning fuel performs nearly as well as gas/oil without deleterious effects on combustion efficiency. This means that boilers using reburning for NO\textsubscript{x} control can maintain 100% coal usage instead of switching to 20% gas/oil for reburning. As a result of the B&W performed coal reburning research, the technology has advanced to the point which it is now ready for demonstration on a commercial scale.

The coal reburning equipment is to be installed in the furnace of the boiler, downstream of the cyclone burners. The equipment consists of coal reburning burners and overfire air ports and associated control systems. Outside of the boiler, a coal pulverizer will be installed as well as coal piping to the reburn burners. The reburn system will inject 20% to 30% of the coal feed.
directly into the boiler, bypassing the cyclones and reducing cyclone load to 80% to 70% of normal. An increase in ash particulate, which is substantially removed in the cyclones will occur within the boiler, increasing ash collection requirements at the precipitator. The majority of plant's precipitators should be capable of handling the increased ash loading.

The coal reburning for cyclone boiler NO\textsubscript{x} control system consists of commercially available equipment, such as a pulverizer, burners, a pneumatic coal transfer system, overfire air ports and a control system, all of which are well proven, reliable equipment that can be readily installed. Extensive power plant modification is not required to implement the reburn technology which will increase the potential for commercialization.

The coal reburning technology will be a desirable alternative for cyclone boiler NO\textsubscript{x} control by offering:

- A technically and economically feasible low-NO\textsubscript{x} alternative for cyclone boilers to achieve a 50% to 60% NO\textsubscript{x} reduction where one currently does not exist.
- Significant reductions in emission-levels of oxides of nitrogen achieved at a low capital cost and very low operating costs (compared to the SCR technology).
- No need for a supplemental fuel. Reburn will be carried out using the present boiler fuel which is coal.
- A system that will maintain boiler reliability, operability, and steam production performance after retrofit.

The coal reburning for cyclone boiler NO\textsubscript{x} control demonstration project will be carried out at the Nelson Dewey Station Unit No. 2 of Wisconsin Power and Light in Cassville, Wisconsin. Unit No. 2 is small enough (100 MWe) to limit project costs, but large enough to assure that the reburning technology can be successfully applied to the cyclone-fired utility boiler population. As part of the project, B&W's 6 million Btu/hr SBS pilot facility will be utilized to duplicate the operating practices of WP&L's Nelson Dewey Unit #2. The coal which is fired at Nelson Dewey will be fired in the SBS cyclone and will also be utilized as the reburn fuel. During the field test phase at Nelson Dewey Station, emission and performance data will be acquired and analyzed before and after the coal reburn conversion to determine the NO\textsubscript{x} reduction and impact on boiler performance. Combining these combustion test results with physical and numerical flow modeling of the technology as applied to Dewey Unit #2, will provide a comprehensive test program not only for successful application of WP&L's Unit, but for the cyclone population as a whole.
3.2 OBJECTIVES

It is the objective of the Coal Reburning for Cyclone Boiler NO\textsubscript{x} Control Project to fully establish that the coal reburning clean coal technology offers cost-effective alternatives to cyclone operating electric utilities for overall oxides of nitrogen control. The project will evaluate the applicability of the reburning technology for reducing NO\textsubscript{x} emissions in full scale cyclone-fired boilers which use coal as a primary fuel. The performance goals while burning coal are:

- Greater than 50 percent reduction in NO\textsubscript{x} emissions, as referenced to the uncontrolled (baseline) conditions at full load.

- No serious impact on cyclone combustor operation, boiler efficiency or boiler fireside performance (corrosion and deposition), or boiler ash removal system performance.

3.3 BACKGROUND

Boilers equipped with cyclone furnaces have many important advantages over conventional pulverized-coal-fired boilers, such as the capability to burn a range of low-grade fuels and simpler, more economical coal preparation and feeding system. However, cyclone units utilize extremely fast mixing between the coal and combustion air and, therefore, inherently promote well mixed combustion and elevated NO\textsubscript{x} emissions. It is estimated that 21% of the total NO\textsubscript{x} emissions from coal fired power stations in the U.S. come from cyclone fired boilers. The majority of the existing 26,000 MW of cyclone boiler generating capacity will probably continue to operate for the next 20 years. Thus, cyclone boilers are prime candidates for mandated reduction in the emissions of oxides of nitrogen. Currently there is no proven retrofit low NO\textsubscript{x} combustion control technology for cyclone boilers. The previous attempts to apply staged combustion have not been successful due to operational problems (cyclone corrosion).

The use of Selected Catalytic Reduction (SCR) technology offers promise of controlling NO\textsubscript{x} from these units, but at high capital and operating cost. Reburning is therefore a promising alternative NO\textsubscript{x} reduction approach for cyclone equipped units at a more reasonable operating cost.

Reburning is a process by which NO\textsubscript{x} produced in the cyclone is reduced (decomposed to molecular nitrogen) in the main furnace by injection of a secondary fuel. The secondary (or reburning) fuel creates an oxygen deficient (reducing) region which accomplishes decomposition of the NO\textsubscript{x}. Since reburning can be applied while the cyclone operates under its normal oxidizing condition, it effects
on cyclone performance can be minimized. Sometime ago, B&W performed a feasibility analysis for applying reburn technology to utility cyclone-fired boilers, and the results were very encouraging. Based on the results of the feasibility analysis, pilot scale evaluation of cyclone reburn was undertaken. B&W's 6 million Btu/hr Small Boiler Simulator (SBS) was utilized to perform the pilot-scale cyclone reburning tests. Three different reburning fuels, natural gas, #6 oil, and pulverized coal were utilized. The results indicate that 50 to 80% NOx reduction from baseline conditions can be achieved while utilizing 15 to 25% reburning fuel. Additionally, the tests revealed that the potential side effects of the technology (e.g., changes in combustion efficiency, deposition, and corrosion) would not adversely affect boiler performance.

3.4 HOST SITE BOILER

The host site is Wisconsin Power and Light's Nelson Dewey Unit No. 2. The following is a summary of pertinent information.

• UTILITY: Wisconsin Power & Light
• UNIT ID: Nelson Dewey Unit No. 2
• LOCATION: County Trunk VV, Cassville, Grant County, Wisconsin 53806
• NAME PLATE RATE: 100 MWe
• TYPE: Steam Turbine
• PRIMARY FUEL: Bituminous Coal
• OPERATION DATE: October 1962 - Unit No. 2
• BOILER ID: B&W RB-369
• BOILER CAPACITY: Nominal 110 MWe
• BOILER GENERAL CONDITION: Good
• BOILER MANUFACTURER: Babcock & Wilcox
• BOILER TYPE: Cyclone Fired RB Boiler
• REBURNING DEMONSTRATION FUEL: Indiana (Lamar) Bituminous Coal, Medium Sulfur (1.87%)
• BURNERS: Three B&W Vortex-Type Burners, Single-wall fired
• PARTICULATE CONTROL: Research Cottrell ESP
• BOILER AVAILABILITY: 90% Availability
3.5 PROJECT TEAM


Major subcontractors are Acurex and Sargent & Lundy. Acurex has been designated to perform continuous emissions monitoring activities as well as various analytical requirements during the testing program. Sargent & Lundy will perform those activities pertaining to the coal handling system supplying coal to the coal pulverizer in addition to various structural steel and electrical design specification activities.

A summary of the overall project organization is as follows:

Project Organization
- Department of Energy - 50% funding co-sponsor
- Babcock & Wilcox - Prime contractor and project manager
- Wisconsin Power & Light - Host site utility and funding co-sponsor
- EPRI - Technical advisor and funding co-sponsor
- State of Illinois - funding co-sponsor
- Utility funding co-sponsors
- Acurex Corporation - testing subcontractor
- Sargent & Lundy - architect engineer subcontractor

3.6 PROJECT PHASES

The coal reburn project, which is a $10.65 million project, consists of four separate phases which are planned to occur over a 43 month period. These are:

- Phase I - Design and Permitting

During this phase, collection of baseline emissions and performance data, along with performance of general boiler system assessment, will be completed at WP&L's Nelson Dewey Unit #2 prior to the coal reburning retrofit. The coal reburn
system will be designed based upon B&W's pilot-scale combustion tests, physical and numerical flow modeling tests, and experience/knowledge of full-scale burner/OFA port/control system retrofits.

- Phase IIA - Long Lead-Time Item Procurement

In order to meet the construction schedule, long lead-time equipment will be ordered during the design and permitting phase. To facilitate the funding of this procurement activity, Phase II is divided into two parts, Phase IIA and Phase IIB.

- Phase IIB - Construction and Start-up

The coal reburn system will be fabricated and installed at Nelson Dewey No. 2 and started up to provide a fully operational system prior to testing.

- Phase III - Operation and Disposition

Parametric/optimization and performance tests will assess the potential of the technology from both the resulting emission reductions and boiler performance capability aspects. Both full load and reduced load operations will be evaluated for the cyclone reburn technology. Finally, readiness for commercialization will be determined from both a technical and economic viewpoint.
4.0 PROJECT STATUS

The time period covered by this Quarterly Report No. 12 is January, February, and March 1993. Progress will be discussed on a task basis for Phase III activities.

4.1 PHASE I - DESIGN AND PERMITTING

All major activities in Phase I are complete.

4.2 PHASE IIA - LONG LEAD-TIME ITEM PROCUREMENT

The long lead-time item procurement process is complete.

4.3 PHASE IIB - FABRICATION, INSTALLATION, START-UP AND SHAKEDOWN

All major activities of Phase IIB are complete.

4.4 PHASE III: OPERATION AND DISPOSITION

Activities in Phase III include Management and Reporting Parametric Optimization Testing, Long-Term Performance Testing, Performance, Economic and Application Studies, the Final Report and Disposition. A description of activities expected in each task is provided followed by reported activity.

4.4.1 Task 1 - Project Management and Report

The purpose of this task is to account for the management and reporting activities and cost monitoring that apply to all tasks collectively in Phase III.

This task provides for overall project coordination, reporting, and supervision for Phase III of the Coal Reburning project. Additionally, this task includes a single point contact within B&W for DOE on the Coal Reburning project for reporting and resolution of technical and cost issues.

Monthly reports for the period of January, February, and March 1993 were completed and issued to DOE/PETC.

The Phase III review for the project was held at the Sheraton Hopkins Airport Hotel in Cleveland, Ohio on March 16, 1993.

4.4.2 Task 2 - Parametric Optimization Tests of the Reburn System

Parametric optimization testing is complete.
4.4.3 Task 3 - Long Term Performance Testing

Long-term testing is complete. The following is a summary of emissions and boiler performance testing results for both Lamar bituminous coal and western sub-bituminous coal.

4.4.3.1 Coal Reburning Technical Impacts

The focus of this demonstration project's testing program is to determine the maximum NOx reduction capabilities without adversely impacting boiler performance, operation or maintenance between full load (110 MW) and 50% load (55 MW). Incorporating the optimized test results obtained during the parametric/performance testing into the Nelson Dewey Unit #2 boiler controls then provided WP&L a reburn system that could operate in a fully automated condition. The testing phases are designed to not only evaluate the most efficient conditions to operate the reburn system at Nelson Dewey, but to also provide sufficient data to confirm and expand upon the previously performed B&W SBS pilot scale testing and engineering study results. Utilizing this information will enhance the design considerations for future applications.

The parametric/performance testing program is divided into a series of six (6) separate series while firing a total of two (2) different coal types. The primary demonstration coal was an Indiana bituminous coal (Lamar) and the majority of the testing is performed while firing this fuel. Following the bituminous coal testing, sub-bituminous western coal tests were performed to evaluate the effect of coal switching on reburn operation. In addition, WP&L's future strategy to meet sulfur emission limitations is to fire low sulfur coal, thus the reburn system had to be re-optimized to handle this fuel switching alternative. The following sections summarize all the testing results obtained throughout the post-reburning retrofit phases. The six (6) test series are:

1. Initial Reburn Tuning Tests (B&W emission testing) - "T" Series
2. Reburn Parametric Tests (B&W/ACUREX emission testing - "A" Series)
3. Initial Performance Tests (B&W/ACUREX emission testing - "P" Series)
4. Final Performance Tests (B&W/ACUREX emission testing - "F" Series)
5. Western Fuel Tests (B&W emission testing - "W" Series)
6. Hazardous Air Pollutant Tests (ACUREX emission tests - "HAP" Series)

The majority of the above stated tests are performed utilizing the Indiana bituminous coal. The bituminous coal was chosen as the demonstration fuel to reflect the operation of the majority of
cyclone utilities which fire the higher BTU/sulfur coal. The western coal was then tested to obtain additional data with respect to reburning and fuel switching. Since WP&L was firing the western coal to meet state legislation, the perfect opportunity was presented to evaluate a direct reburning effectiveness versus coal type correlation. In addition, based upon optimized western fuel reburn results, the control system was tuned to accommodate automatic boiler operation.

4.4.3.2 Test Parameters

Numerous variables are associated with the reburn system and a test matrix had to be established in order to proceed from one parameter to another during the optimization testing. Based upon WP&L's day-to-day boiler requirements, the specific test matrices were modified on-site to accommodate WP&L's energy demands while maintaining the reburn program's initiatives. The test variables included in the matrix along with the approximate ranges tested are:

- Boiler load (37 - 118 MW)
- Reburn system percent of total boiler heat input (-25 - 40%)
- Reburn zone stoichiometry (-0.83 - 0.96)
- Reburn burner stoichiometry (-0.35 - 0.70)
- Reburn burner pulverized coal fineness (80 - 98% thru 200 mesh)
- Gas recirculation rates to reburn burners (0 - 5% of boiler)
- Reburn burner spin vane and impeller/swirler adjustments
- Overfire air (OFA) port spin vane/sliding disk adjustments
- Economizer outlet O₂% (2 - 4%)

In order to achieve the stated goals of the project, the above parameters were investigated for both the Indiana bituminous and the western sub-bituminous coals. Babcock & Wilcox and the Acurex Corporation installed separate boiler performance/emission systems to evaluate the tested variables. The subsequent sections discuss the information collected throughout these parametric evaluations.

4.4.3.3 NOₓ and CO Emission Levels - Lamar Coal Firing

Numerous test data points are available to evaluate the coal reburning impact on NOₓ and CO emission levels. All the test series addressed earlier involve changing specific reburning variables and identifying the resultant NOₓ and CO emission levels. The first section herein reports the results during utilization of the demonstration Lamar bituminous coal.
Reburn Zone Stoichiometry Impact

Varying reburn zone stoichiometry is the most critical factor in changing NO\textsubscript{x} emission levels during coal reburning operation. The reburn zone stoichiometry can be varied via altering the air flow quantities (oxygen availability) to the reburn burners, the reburn heat input, the gas recirculation flow rate, or the cyclone stoichiometry. The following series of figures reveal NO\textsubscript{x} and CO emission levels versus reburn zone stoichiometry at various load conditions.

Figure 1 represents B&W economizer outlet NO\textsubscript{x} and CO emission levels in ppm corrected to 3% O\textsubscript{2} versus reburn zone stoichiometry at full load conditions (110 MW). The data base used in this figure is comprised of series "T", "A", "P", and "F" and show a range of reburn zone stoichiometries from 1.14 (baseline - no reburning) to 0.81 (lowest stoichiometry tested with reburning). The average B&W baseline NO\textsubscript{x} level identified during the 1990 Baseline Tests is 609 ppm (0.826#/million Btu) and Figure 1 shows that the post-retrofit baseline NO\textsubscript{x} is approximately the same. In order to obtain the required goal of 50% NO\textsubscript{x} reduction (305 ppm or 0.413#/million Btu), Figure 1 reveals that the reburn zone stoichiometry must be at about 0.895. In addition, the data shows that the lowest reburn stoichiometry tested at 0.81 would yield a corresponding NO\textsubscript{x} level of 233 ppm (0.32#/million Btu) or a 61.8% NO\textsubscript{x} reduction.

The CO emission levels (ppm @ 3% O\textsubscript{2}) versus reburn zone stoichiometry at the 110 MW load condition during test series "T", "A", "P", and "F" are also shown in Figure 1. Although CO emission data scatter exists, the average baseline and reburn operation CO emission levels increased from about 70 ppm to 100 ppm. Assuming the reburn system is maintaining a 50% reduction at about a 0.895 reburn zone stoichiometry, the average CO emission level during reburning operation is 92 ppm.

Reburning's Effect on Unit Load

Post-retrofit baseline and reburning tests were performed over the boiler load range of 37 - 110 MW. WP&L's typical pre-retrofit low load was about 30 MW and without reburn in operation this level was not affected after the retrofit. Due to reburn flame stability issues and the fact that the cyclones have to maintain a minimum firing rate, this 30 MW low load condition had to be increased to 37 MW. Although not ideal, the resultant boiler turndown was 66% with reburn in operation, exceeding the project's goal of 50% turndown. The following discussion describes the results in terms of load versus NO\textsubscript{x} emissions and % NO\textsubscript{x} reductions.

Figure 2 shows the data from all the Lamar bituminous test series for load versus NO\textsubscript{x} emissions under baseline and reburning conditions. The baseline data is from all the post-retrofit
testing and as stated earlier, the results compare favorably with those obtained during the 1990 Baseline Test Phase. The 1990 B&W economizer outlet data for the 3 loads tested are as follows:

- 110 MW baseline NO\textsubscript{x} = 609 ppm @ 3\% O\textsubscript{2} (0.826 #/million Btu)
- 82 MW baseline NO\textsubscript{x} = 531 ppm @ 3\% O\textsubscript{2} (0.72 #/million Btu)
- 60 MW baseline NO\textsubscript{x} = 506 ppm @ 3\% O\textsubscript{2} (0.69 #/million Btu)

As seen per Figure 2, the average post-retrofit baseline NO\textsubscript{x} emission levels are within about 5-10 ppm of the above stated values. Although the average post-retrofit baseline NO\textsubscript{x} emissions reveal a good correlation with the pre-retrofit valves, day to day variations are observed. The large variations are seen at 110 MW's where the baseline levels range between 573 to 657 ppm. This variation is typical and is explained via changes in boiler conditions (boiler cleanliness, temperatures, air flows, etc.) and coal analyses (% nitrogen contents).

Additional baseline tests were performed at 37-38 MW during the post-retrofit tests and Figure 2 shows that the NO\textsubscript{x} levels increase up to 600 ppm at these load conditions. The NO\textsubscript{x} level increase is due to the fact that the boiler goes to single cyclone operation. Operating in this mode results in an increased heat input for the operating cyclone which represents close to full load cyclone capacity. In addition to the higher cyclone capacity (thus higher localized temperatures and higher resultant NO\textsubscript{x} levels), the cooling air flow to the idle cyclones also increases the overall boiler oxygen content which is conducive to higher NO\textsubscript{x} emission levels.

Operating the coal reburn system over the load range resulted in various NO\textsubscript{x} reduction levels. As shown in Figure 2, the average NO\textsubscript{x} emission levels varied as follows:

- 110 MW reburn NO\textsubscript{x} level = 290 ppm @ 3\% O\textsubscript{2} (0.39 #/million Btu)
- 82 MW reburn NO\textsubscript{x} level = 265 ppm @ 3\% O\textsubscript{2} (0.36 #/million Btu)
- 60 MW reburn NO\textsubscript{x} level = 325 ppm @ 3\% O\textsubscript{2} (0.44 #/million Btu)

Based upon the above data, the approximate NO\textsubscript{x} reductions for the 110 MW, 82 MW, and 60 MW boiler load cases are 52.4\%, 50.1\%, and 35.8\% respectively. Finally, at 37-38 MW an approximate 33.3\% reduction is achieved based upon the resulting reburn operation NO\textsubscript{x} level of 400 ppm (0.54 #/million Btu).
4.4.3.4 NO\textsubscript{X} and CO Emission Levels - Western Fuel Firing

The western sub-bituminous coal firing tests were completed to obtain a direct comparison of reburn performance for two different coal types. In addition, sufficient data were collected in order to allow optimized reburning performance curves to be generated and incorporated into the boiler control system at Nelson Dewey Unit #2. Similar tests to those performed earlier in series "T", "A", "P", and "F" were carried out within series "W".

Reburn Zone Stoichiometry Impact

Figure 3 represents B&W economizer outlet NO\textsubscript{X} and CO emission levels in ppm corrected to 3% O\textsubscript{2} versus reburn zone stoichiometry at full load conditions (110 MW). The figure shows a range of reburn zone stoichiometries from about 1.07 (baseline - no reburning) to 0.85 (lowest stoichiometry tested w/reburning on western fuel). The average baseline NO\textsubscript{X} level identified is 560 ppm (0.75 #/million Btu). In order to obtain the required goal of 50% NO\textsubscript{X} reduction (280 ppm or 0.375 #/million Btu), the reburn zone stoichiometry must be at about 0.91 as shown in Figure 3. In addition, the data shows that the lowest reburn stoichiometry tested at 0.85 would yield a corresponding NO\textsubscript{X} level of 208 ppm (0.28 #/million Btu) or a 62.9% NO\textsubscript{X} reduction.

The average baseline versus reburn operation CO emission levels increased from about 44 ppm to 92 ppm. Assuming the reburn system is maintaining a 50% reduction at about a 0.91 reburn zone stoichiometry, the average CO emission level during reburning operation was 78 ppm. As expected, reducing NO\textsubscript{X} emissions via lowering the reburn zone stoichiometry results in increasing the CO emission levels. Less CO emission data scatter is apparent during the western fuel firing tests as compared to that observed during the Lamar tests.

Reburning's Effect on Unit Load

Post-retrofit baseline and reburning tests were performed over the boiler load range of 41 - 118 MW during the western fuel firing tests.

Figure 4 shows the data results from all the western sub-bituminous tests for load versus NO\textsubscript{X} emissions under baseline and reburning conditions. As observed with the Lamar testing results, operating the coal reburn system over the load range resulted in obtaining different NO\textsubscript{X} reduction levels at various load conditions. As shown in Figure 4, the average NO\textsubscript{X} emission levels during baseline and reburn operation varied as follows:
Based upon the above data, the approximate % NO\textsubscript{x} reductions for the 110 MW, 82 MW, and 60 MW boiler load cases are 55.4%, 52.1%, and 52.6% respectively.

The 41-42 MW results revealed a NO\textsubscript{x} level with reburning of 210 ppm (0.28 #/million Btu). No baseline data was obtained at these loads during the "W" series. Finally, higher loads than tested during the Lamar coal firing phase were also evaluated. The maximum load tested was 118 MW and the limiting factor at that point was the fact that the feedwater pumps were at maximum capacity. The associated NO\textsubscript{x} emission level at 118 MW’s was 275 ppm (0.37 #/million Btu).

### 4.4.3.5 Lamar versus Western Coal Reburning

Comparisons between the western sub-bituminous ("W" series) and the Lamar bituminous ("P"/",F" series) coal tests for load versus NO\textsubscript{x} emissions are shown in Figure 5. The western fuel firing reburn operation achieved lower overall NO\textsubscript{x} emission levels. Two (2) factors contribute to the lower NO\textsubscript{x} emissions. First, the primary baseline NO\textsubscript{x} levels are approximately 10% less during the western fuel firing due to the inherent fuel characteristics. Secondly, a higher % reduction is realized during reburn operation. This is probably due to the higher western fuel volatile content and thus higher concentrations of hydrocarbon radicals being developed in the substoichiometric region of the furnace. In addition, a change in overall mixing is a possible explanation. The other interesting observation from Figure 5 is that the NO\textsubscript{x} emissions could be maintained at a constant level over the 110 to 41 MW load range.

The direct comparison between the western and Lamar coal ("F" series) tests showed that the resultant NO\textsubscript{x} emissions were about 301 ppm versus 234 ppm at 110 MW, 285 ppm versus 234 ppm at 82 MW, and 328 ppm versus 232 ppm at 60 MW for Lamar and western fuel, respectively. This direct comparison is based upon operating the reburn system under similar conditions such as the same reburn % heat input and reburn zone stoichiometries. Optimizing the western
fuel firing resulted in a further improvement in the overall NO\textsubscript{x} emission levels. The NO\textsubscript{x} emission levels ranged from about 208 ppm to 220 ppm over the 110 to 41 MW load conditions.

Increasing load above 110 MW resulted in higher NO\textsubscript{x} emissions. At 118 MW, the resultant NO\textsubscript{x} level was 275 ppm. This increase in NO\textsubscript{x} level was due to the fact that less % reburn heat input could be supplied as a result of reburn feeder limitations. Also, the baseline NO\textsubscript{x} emission levels increased at this higher load.

Finally, since the reburn system removes approximately 30% of the heat input (coal flow) from the cyclones, higher boiler loads were maintained during 100% western fuel firing as compared to normal cyclone only (no reburning) operation. Typically, an approximate 10-25% derate is experienced when cyclone boilers fire 100% western fuel as compared to their normal design fuel. A major reason for this derate condition is that cyclone heat input and coal feed has to be increased with western fuel to maintain the same load carrying capability. This is due to the inherent higher moisture content and lower heating value of the western fuel. Maximum design heat input and coal flow loadings to the cyclones will limit boiler load. Thus, reburn operation minimizes or eliminates this derate impact when switching fuels by diverting a portion of the cyclone heat input and coal flow to the reburn system.

4.4.3.6 Discussion of Boiler Performance Results (LAMAR COAL)

The critical parameters in evaluating the impact of the reburn system on unit performance are superheat and reheat final steam temperatures, superheat and reheat spray flow quantities, furnace exit gas temperature (FEGT), surface cleanliness factors (K_i's), efficiency, unburned carbon (UBC), flyash splits, Nox emissions, and CO emissions. The following discussion will summarize the % flyash splits, % efficiency loss due to UBC, overall boiler efficiency and FEGT results.

Percent of Ash as Flyash (Flyash Split)

Figure 6 shows the percent flyash as a function of load. At 100 % load (110 MW), percent of ash as flyash increases from 23 % to 37 % with reburn in service. With 30 percent of the fuel input to the reburn burners, the percent flyash could have been as high as 46 % if all of the ash to the reburn system were to leave the unit as flyash. This would indicate that approximately 60 % of the reburn ash is leaving the unit as flyash, or some higher percentage of the reburn ash is leaving the unit and the reburn combustion process is capturing some of the flyash generated by the cyclones. At 75 % load (82 MW), the percent of ash as flyash increases from 26 % to 36 % with reburn in service. And at 50 % load (55 MW), the percent of ash as flyash increases from 47 % to 57 % with reburn in
service. The increase in flyash percent is fairly constant over the load range.

Unburned Carbon (UBC)

Figure 7 is a plot of the efficiency loss due to unburned carbon (UBCL) versus steam flow. At full load the UBCL with reburn is 0.1% higher than the UBCL with reburn out of service. The increase in UBCL at 75 percent load is 0.25% efficiency loss, and at 50 percent load the UBCL increase is 1.5% efficiency loss.

Unit Efficiency

Figure 8 contains the efficiency versus steam flow for the P and F series performance tests. At full load the efficiency of the unit actually increases by 0.2% with reburn in service. This is caused by a decrease in the dry gas loss of 0.3% which compensates for the increase in the unburned carbon loss of 0.1%. At 75 percent load, unit efficiency decreases by 0.1% with reburn in service. Once again, the dry gas loss decreased by 0.15% to partially offset the 0.25% increase in unburned carbon loss. At 50 percent load the unit efficiency decreases by 1.5%. There is no change in dry gas loss.

The decrease in dry gas loss at full load and 75 percent load with reburn in service is caused by a lower air heater gas outlet temperature. The decrease in air heater gas outlet temperature is a result of the decreased air heater gas inlet temperature. The lower air heater gas inlet temperature is caused by differences in operating conditions. These include the operation of the gas recirculation fan, which changes the gas split between the primary superheater and the re heater, and a higher economizer cleanliness factor for the tests conducted with reburn in service. This benefit cannot be attributed to the reburn system as a credit due to the variations observed in these controllable factors throughout the various tests. Therefore, the impact of the reburn system on unit efficiency is the increase in unburned carbon loss.

Furnace Exit Gas Temperature (FEGT)

Figure 9 shows the FEGT with and without reburn in service for the P and F series tests. At full load, the FEGT decreased by approximately 100°F with reburn in service. The gas recirculation flow with reburn in service would be expected to decrease the FEGT by approximately 25°F of this change. There was no change in FEGT at 75% load with reburn in service, and an increase of 50 to 75°F at 50% load with reburn in service.

4.4.3.7 Discussion of Boiler Performance Results (WESTERN COAL)
Percent of Ash as Flyash (Flyash Split)

There is a large scatter in the ash split data with reburn out of service. However, since the ash splits for the reburn in service tests are extremely close to the Lamar coal test results, it is a reasonable assumption that the ash splits without reburn in service are also similar to the Lamar coal test results. The unburned carbon in the ash was so low for these tests, that the flyash split has very little impact on the unburned carbon loss. For this reason, the flyash split was not considered as a critical parameter in this evaluation.

Unburned Carbon (UBC)

Figure 10 is a plot of the efficiency loss due to unburned carbon (UBCL) versus steam flow. At full load the UBCL with reburn is the same as the UBCL with reburn out of service. The increase in UBCL at 75 percent load is 0.2 % efficiency loss, and at 50 percent load the UBCL increase is 0.3 % efficiency loss.

Unit Efficiency

Figure 11 shows efficiency versus steam flow for all of the W series tests. At full load, the efficiency of the unit is 0.2 % lower with reburn in service. This is caused by an increase in the dry gas loss of 0.2 %. At 75 percent load, unit efficiency decreases by 0.3 % with reburn in service. Once again, the dry gas loss increased by 0.1 % in addition to the 0.2 % loss from unburned carbon. At 50 percent load, the unit efficiency decreases by 0.35 %. There is a slight increase in dry gas loss.

The increase in dry gas loss with reburn in service is caused by a higher air heater gas outlet temperature. The increase in gas temperature with reburn in service is caused by a lower Kf for the economizer. The lower economizer Kf should not be attributed to the reburn system being in service, since the majority of the reburn tests were normally run after a lengthy period of non-sootblowing operation (which attributed to the lower Kf’s). Individual test results show that if sootblowing in the economizer region was performed, higher gas temperatures would not be observed and thus, no change in Kf valves. Therefore, the impact of the reburn system on unit efficiency is the increase in unburned carbon loss.

Furnace Exit Gas Temperature (FEGT)

Figure 12 is a plot of FEGT versus steam flow for the W series tests. At full load, the FEGT decreased by approximately 50 °F with reburn in service. Once again, the gas recirculation flow with reburn in service would account for approximately 25 °F of this change. There was no change in FEGT at 75 % load with reburn in service.
service, and an increase of 75 °F at 50 % load with reburn in service. out reburn in service.

4.4.3.8 Hazardous Air Pollutant (HAP) Testing

Results of the HAP testing indicated very low organics loadings in both the baseline and reburn operation modes for the cyclone fired boiler. No significant emission of semi-volatile target compounds were observed during baseline or reburn operation. Table 1 summarizes both volatile and semi-volatile organics results. The primary volatile target compounds detected were toluene and benzene. Traces of xylene appeared in several of the chromatograms. The detection limit for toluene and benzene was in the 0.2 ppb range, indicating the emission levels experienced were not greatly above the detection limit. Regarding aldehydes, none of the samples taken indicated any levels of aldehydes (formaldehyde and acetaldehyde) down to a detection limit of 5 ppb. The general observation from these data is that the cyclone appears to be an efficient combustor for volatile and semi-volatile organics and the reburn technology does not compromise this capability.

<table>
<thead>
<tr>
<th>Organics Results at ESP Outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Baseline A</td>
</tr>
<tr>
<td>Baseline B</td>
</tr>
<tr>
<td>Baseline C</td>
</tr>
<tr>
<td>Reburn A</td>
</tr>
<tr>
<td>Reburn B</td>
</tr>
<tr>
<td>Reburn C</td>
</tr>
</tbody>
</table>

4.4.3.9 Corrosion Evaluation

At the inception of the coal reburning project, there was concern regarding the possibility of tube corrosion in the furnace area where sub-stoichiometric reburn conditions occur. Accordingly, ultrasonic thickness testing as a baseline was carried out in October of 1991 during the outage for reburn installation. Five (5) separate bands around the furnace were tested. These are at
elevations 663'-0", 670'-6", 678'-1", 688-0", and 696'-0". The bands were sandblasted clean prior to UT testing.

Based on the testing results, the furnace walls had not experienced wall thinning. Less than 1% of the inspected tubes fell below the specified original wall thickness. None of the tubes were below the Babcock & Wilcox wall thickness guidelines for required repair (70% of original specified thickness for water cooled tubes).

In October of 1992, one year after reburn installation at Nelson Dewey Unit No. 2, a similar series of UT testing was performed. Bands were sandblasted at the original locations and measurements were taken. Comparisons of the original 1991 data with 1992 data showed inconsistencies, implying areas of both severe tube wall loss as well as wall thickening. The inconsistencies mandated another UT testing excursion to the plant which fortunately had a short outage in February, 1993. This outage window allowed only enough time to retest the areas of the most questionable readings, the upper elevations on the left and right side walls.

Table 2 summarizes both the 1992 data, which is considered questionable and the February 1993 data for the upper three side wall elevations. As can be seen from the table, the 1992 data indicates an average loss of from 14 to 19 mills, which would be significant if the values are valid. However, the range of differences between baseline 1991 and 1992 data for these three side wall elevations is anywhere from a loss of 40 mills to a gain of 120 mills. These same data indicate a total of 49 tubes below specification thickness of 0.200 inches.

The 1993 verification data is also shown in Table 2 for the top three elevations of the side walls. The average differences were from a gain of three mills to a loss of five mills; within the error range of the UT instruments, indicating no significant corrosion has taken place. This data also showed that no tube thicknesses were below the specification thickness of .200 inches.

Additional rationale for questioning the validity of the 1992 data is:

1. The most severe problems highlighted by the 1992 data were in the upper regions of the furnace side walls, well above the overfire air port injection elevation of 681'2" in an oxidizing atmosphere. It would be expected that a corrosion problem with reburn would be manifested in the reburn region between the burners and overfire airports (from elevation 664'6" to 681'2") and particularly at the rear wall which is closest to the reburn burner flames. There was no indication of problems in the rear wall at any elevation.

2. In order to simulate supercritical boiler operation with higher tube wall temperatures, a panel consisting of two
thicker walled (0.420 in. minimum wall) tubes, each three feet in length was installed in the rear wall between the burner and overfire air elevations. One tube consisted of the normal steel tube material while the other was clad with approximately .060 inches of 304 stainless steel for corrosion protection. The 1992 UT test data indicated .075 inches wall loss for both tubes. To verify the measurements, the tube panel was removed during the February 1993 outage and submitted to B&W Alliance Research Center for Analysis. Wall thicknesses for both tubes were analyzed to be well above the 0.420 inches minimum wall thickness, indicating no corrosion wall thinning was apparent.

It is both WP&L's and B&W's intent to investigate furnace tube condition over the next five years to assure that any corrosion problems are not left undetected. These UT investigations will be carried out on a yearly basis during a boiler outage of WP&L's choice.

<table>
<thead>
<tr>
<th>Wall</th>
<th>Elevation</th>
<th>1992 (Questionable)</th>
<th>1993 (Verification)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average Loss (mills)</td>
<td>Average Loss (mills)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range (mills)</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>679'-1&quot;</td>
<td>17 +95 to -30</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>688'-0&quot;</td>
<td>15 +40 to -30</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>696'-0&quot;</td>
<td>17 +10 to -35</td>
<td>5</td>
</tr>
<tr>
<td>Right</td>
<td>678'-1&quot;</td>
<td>14 0 to -30</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>688'-0&quot;</td>
<td>14 +5 to -30</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>696'-0&quot;</td>
<td>19 +120 to -40</td>
<td>4</td>
</tr>
</tbody>
</table>

* Tube Spec. (OD x thickness) = 2.969" x 0.200"

4.4.4 Task 4 - Performance, Economic, and Application Studies

As part of the economic analysis, EPRI has provided an updated version of its Technical Assessment Guide for use in evaluation of the reburn technology. Capital costs (dollars/installed KW) and levelized cost for NOx removal (dollars/ton of NOx removed) are being developed for the 110 MW size as well as a hypothetical 600 MW size. This information will be summarized in the project final report. Preliminary results are provided in Table 3.
4.4.5 Task 5 - Final Report

Data analysis and reduction continues as information for the report is assembled.

<table>
<thead>
<tr>
<th>TABLE 3</th>
<th>Economic Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Size:</td>
<td>110 MW</td>
</tr>
<tr>
<td>Capital Requirement:</td>
<td>$66.46/kw</td>
</tr>
<tr>
<td>Levelized Bus Bar Cost:</td>
<td></td>
</tr>
<tr>
<td>10 year</td>
<td>2.39 mills/kw</td>
</tr>
<tr>
<td>30 year</td>
<td>2.27 mills/kw</td>
</tr>
</tbody>
</table>

4.4.6 Task 6 - Disposition

The title to the reburn system now resides with WP&L as one of the conditions of their involvement. The reburn system continues to be operated on Unit No. 2 in a load following manner. This task is complete.
5.0 PLANNED ACTIVITIES

Planned activities for the next quarter, April, May, and June 1993 will focus on completion of the final report. This final task of the project will be complete in June 1993. Also, Environmental Monitoring Quarterly Reports being completed by Acurex will be issued to DOE.
6.0 SUMMARY

The coal reburning for cyclone boiler NO\textsubscript{x} control demonstration project's twelfth Quarterly Report covering the time period of January, February, and March 1993 involves the work performed in Phase III - Operation and Disposition.

Phase III activities consisted of evaluation of performance data and preparation of the final report. The Phase III review for the project was held on March 16, 1993 in Cleveland, Ohio.

Results of data evaluation indicate that the performance of the reburn system has achieved the objectives of the project. Reductions of NO\textsubscript{x} in excess of 50% were obtained at full load and 75% load with Lamar bituminous coal. At 50% load, NO\textsubscript{x} reduction falls off to 35.8%. With western sub-bituminous coal, reductions in excess of 50% were achieved at all loads with a reduction approaching 63% under optional full load conditions.

Ultrasonic thickness testing in the furnace does not indicate that a corrosion problem exists. B&W and WP&L will continue to monitor the furnace over the next five years to assure possible problems are detected.

Hazardous air pollutant testing shows that the cyclone appears to be an efficient combustor for volatile and semi-volatile organics and the reburn technology does not compromise this capability.
7.0 REPORT DISTRIBUTION LIST

(1) Mr. Ronald W. Corbett  
PETC Technical Project Manager  
Mail Stop 920-L  
U.S. Department of Energy/PETC  
P.O. Box 10940  
Pittsburgh, PA 15236

(2) Mr. David L. Hunter  
Contracting Specialist  
AD-21, Mail Stop 921-165  
U.S. Department of Energy/PETC  
P.O. Box 10940  
Pittsburgh, PA 15236

(3) Dr. C. Lowell Miller  
Associate Deputy Assistant Secretary for Clean Coal Technology  
FE-22, 3E-042, Forrestal  
U.S. Department of Energy  
Washington, DC 20585

(4) Office of Patent Counsel  
U.S. Department of Energy  
9800 South Cass Avenue  
Argonne, IL 60439

(5) Department of Energy (1)  
Office of Technology Transfer  
Mail Stop 58-MEZZ  
Pittsburgh Energy Technology Center  
P.O. Box 10940  
Pittsburgh, PA 15236

(6) Dr. S. N. Roger Rao  
Burns and Roe Technical Group Manager  
P.O.Box 18288  
Pittsburgh, PA 15236

(7) Mr. George Lynch  
HQ DOE Program Manager  
SE-221, 3E-042, Forrestal  
U.S. Department of Energy  
Washington, DC 20585
BABCOCK & WILCOX ECONOMIZER OUTLET EMISSION DATA
110 MW - NOX/CO EMISSIONS VS REBURN ZONE STOICH

FIGURE 1
BABCOCK & WILCOX ECONOMIZER OUTLET EMISSION DATA
NOX EMISSIONS VS LOAD (MW)

T/A/P/F TEST SERIES - LAMAR FUEL FIRING

FIGURE 2
BABCOCK & WILCOX ECONOMIZER OUTLET EMISSION DATA
110 MW - NOX/CO EMISSIONS VS REBURN ZONE STOICH

NOX EMISSIONS (ppm @ 3% O2)

CO EMISSIONS (ppm @ 3% O2)

50% NOX REDUCTION

W TEST SERIES - WESTERN FUEL FIRING

FIGURE 3
BABCOCK & WILCOX ECONOMIZER OUTLET EMISSION DATA
NOX EMISSIONS VS LOAD (MW)

W TEST SERIES - WESTERN FUEL FIRING

FIGURE 4
BABCOCK & WILCOX ECONOMIZER OUTLET EMISSION DATA

NOX EMISSIONS VS LOAD (MW)

NOX EMISSIONS [ppm @ 3% O2]

BOILER LOAD (MW)

P/F VS W TEST SERIES - LAMAR VS WESTERN FUEL

FIGURE 5
ADJUSTED FLYASH SPLITS vs. STEAM FLOW
PERFORMANCE TESTS: P AND F SERIES

FIGURE 6
UNBURNED CARBON LOSS, % vs. STEAM FLOW
PERFORMANCE TESTS: P AND F SERIES

FIGURE 7
CORRECTED EFFICIENCY vs. STEAM FLOW
PERFORMANCE TESTS: P AND F SERIES

FIGURE 8
FURNACE EXIT GAS TEMPERATURE VS. STEAM FLOW PERFORMANCE TESTS: P AND F SERIES

FIGURE 9
CORRECTED EFFICIENCY vs. STEAM FLOW
WESTERN FUEL

FIGURE 11