HEALY CLEAN COAL PROJECT (HCCP) DEMONSTRATION TEST PROGRAM

TOPICAL REPORT: COMBUSTION SYSTEM OPERATION FINAL REPORT

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ABSTRACT

The Healy Clean Coal Project (HCCP) was selected by the U.S. Department of Energy under Round III of the Clean Coal Technology Program. The Alaska Industrial Development and Export Authority (AIDEA) is the project participant and team members include Golden Valley Electrical Association (GVEA), Stone & Webster Engineering Corporation (SWEC), TRW, Inc., Babcock & Wilcox, and Usibelli Coal Mine. After more than five years of planning, design engineering, and permitting activities, the project celebrated its ground-breaking ceremony at Healy, Alaska on May 30, 1995. Most of the major plant equipment was delivered to the Healy site 250 miles north of Anchorage, Alaska (near Denali National Park and Preserve) in 1996. This equipment included two 350 million Btu/hr coal combustors and the associated coal and limestone feed systems that were fabricated by TRW and their subcontractors. Construction of the plant was completed in November 1997, with coal-fired operations starting in January 1998. Demonstration operations were completed in December 1999.

The HCCP is the first utility-scale (50 MW_e net) demonstration of the TRW Clean Coal Combustion System. The TRW Combustion System is designed to minimize emissions of nitrogen oxides (NO_x), achieve very high carbon burnout, and remove the majority of flyash from the flue gas prior to the boiler. The TRW system also provides the first step of a three-step process for controlling sulfur dioxide (SO_2) by converting limestone to flash calcined lime that subsequently absorbs SO_2 within the boiler. The majority of SO_2 is removed downstream of the boiler, using Babcock & Wilcox's (B&W's) activated spray dryer absorber (SDA) system, which utilizes the flash calcined material (flash calcined lime + flyash) produced by the TRW system. Since most of the coal ash is removed by the combustors, the flash calcined material is rich enough in calcium content such that the SDA can be operated solely on recycled lime, eliminating the need to purchase or manufacture lime for the backend scrubbing system.

This report presents a summary of the tests performed during 1998 and 1999 as part of the TRW Combustion System Characterization Test Activities. The Combustion System Characterization Test Series was conducted over a cumulative 6-month time period during 1998 and 1999. The focus of the Combustion System Characterization Testing was to (1) establish the baseline performance of the combustion system while burning Run-of-Mine (ROM) Coal and ROM / Waste Coal blends, (2) map the combustor performance characteristics over a broad range of operating conditions and hardware configurations, and (3) determine the best configuration and operating conditions for long-term operation. Key combustor operating parameters investigated included precombustor and slagging combustor stoichiometry, precombustor coal split, precombustor exit temperature and velocity, and furnace calcium-to-sulfur (Ca/S) ratio. Shutdowns were incorporated into the test planning activities in order to inspect the combustor internal slagging characteristics as a function of the various hardware configurations and test conditions evaluated.

During January 1998 through June 1999, approximately 7200 hours of plant thermal operation were accumulated, with approximately 6500 hours of coal-fired operating time. Both ROM and ROM / Waste Coal blends were tested in the combustion system. Typically, the ROM / Waste Coal blends had caloric heating values ranging from 6196 to 8271 Btu/lb, ash contents ranging from 5.7 to 24.0 %, and ash fluid temperatures ranging from 2270 to 2900 ^{o}F. An additional 2200 hours of coal-fired operating time were accumulated during July through November 1999, including the 90-day Test conducted during the months of August through November 1999, which brought the total coal-fired operating time up to approximately 8700 hours, or the equivalent of approximately 1-year continuous operation.

The NO_x, SO_2, and carbon monoxide (CO) emission goals were met while burning both ROM and ROM / Waste Coal blends during operation at nominal 50 MWe net. The testing consistently demonstrated the ability to achieve low NO_x emissions (0.20 to 0.30 lb/million Btu (MMBtu) for furnace oxygen (O_2) levels between 3 and 5% at near full load of 290 to 315 MMBtu/hr per combustor) simultaneously with extremely low CO emissions in the furnace (10 to 90 ppm) and high carbon burnout (>99%), removal of the majority of the slag ash prior to the furnace (typically 78 to 85%), and good limestone calcination efficiency with consistent achievement of SO_2 emissions less than 0.10 lb/MMBtu.

Throughout the Combustor Performance Characterization Test Program, the slagging stage of the combustor performed extremely well and continuously demonstrated the capability to reliably burn ROM and ROM / Waste Coal blends over a broad range of operating conditions, while maintaining a thin molten slag layer over the entire tubewall surface. The precombustor performed very well with ROM coal but exhibited more variable performance, in terms of slagging behavior, during the initial tests with ROM / Waste Coal blends. During 1998 and early 1999, a combination of hardware configuration and operational changes were made which successfully resolved this problem. The key changes made were as follows: (1) relocating the secondary air from precombustor mix annulus to the headend of the slagging stage, (2) completely transferring the precombustor mill air to the boiler NO_x ports following the boiler warm up and 3) modifying the precombustor burner air injection configuration in order to improve air/coal mixing characteristics.

The operation of the TRW coal feed system was very steady and reliable during the Demonstration Test Program (DTP), which is the first utility-scale demonstration of this novel pulverized coal feed splitter system. The system operated within its established pressure budget (<60 i.w.g.), and demonstrated the capability to deliver various splits of coal and transport air to the precombustor, slagging combustor, and the furnace NO_x ports.

Data was also gathered during the 1998 and 1999 Combustor Performance Characterization Test Series to assess combustor availability. Over the time period considered, the overall combustor availability during 1998 was approximately 75 to 77%, and during 1999 was 92%. Initial long duration operation availability data was acquired during the 90-day test performed during August through November 1999, and resulted in a calculated plant availability greater than 97% and a capacity factor of approximately 95%. Additional 90-day Test results will be released in a separate topical report prepared by AIDEA.

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ACRONYMS AND ABBREVIATIONS

AIDEA	Alaska Industrial Development and Export Authority
B&W	Babcock & Wilcox
Ca/S	Calcium to Sulfur Molar Ratio
CEMS	Continuous Emissions Monitoring System
CFS	Coal Feed System
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CTS	TRW's Capistrano Test Site
DTP	Demonstration Test Program
FCM	Flash Calcined Material
FD Fan	Forced Draft Fan
FWEC	Foster Wheeler Energy Corporation
GVEA	Golden Valley Electric Association
HCCP	Healy Clean Coal Project
HHV	Higher Heating Value
ID Fan	Induction Fan
IWG	Inches Water Gauge
KPPH	Thousands of Pounds per Hour
LFS	Limestone Feed System
LS	Limestone
Load	Combustor Thermal Input
MCR	Maximum Continuous Rating (Boiler)
MMBtu	Million (10^6) Btu
MW_e	Mega (10^6) Watts Electric
MWhr	Mega (10^6) Watt Hours
NO_x	Nitrogen Oxides
NSPS	New Source Performance Standards
O_2	Oxygen (Boiler)
ODMS	On-line Data Management System
O&M	Operation and Maintenance
PC	Precombustor
PC Coal Split	Fraction of Coal to the Precombustor versus the Slagging Combustor
PCS	Plant Control System
Phi	Air-to-Fuel Stoichiometric Ratio
PPM	Parts per Million
ROM	Run of Mine Coal
SC	Slagging Combustor
SDA	Spray Dryer Absorber
SO_2	Sulfur Dioxide
SRS	Slag Recovery Section
SS	Slagging Stage
SWEC	Stone and Webster Engineering Corporation
T_{250}	Ash Fusion Temperature
UCM	Usibelli Coal Mine

EXECUTIVE SUMMARY

Background

The Healy Clean Coal Project (HCCP) was selected by the U.S. Department of Energy under Round III of the Clean Coal Technology Program. An overview of the project participants, team members, and key project milestones is provided in Figure 1. The project is owned and financed by the Alaska Industrial Development and Export Authority (AIDEA), and is cofunded by the U.S. Department of Energy. Golden Valley Electric Association, Inc. of Fairbanks, Alaska provided the plant operators. The plant engineer was Stone and Webster Engineering Corporation. The coal supplier is Usibelli Coal Mine, Inc., located adjacent to the Healy plant.

After more than five years of planning, design engineering, and permitting activities, the project celebrated its ground-breaking ceremony at Healy, Alaska on May 30, 1995. Most of the major plant equipment was delivered to the Healy site 250 miles north of Anchorage, Alaska (near Denali National Park and Preserve) in 1996. This equipment included two 350 million Btu/hr coal combustors and the associated coal and limestone feed systems that were fabricated by TRW and their subcontractors. Construction of the plant was completed in November 1997, with coal-fired operations starting in January 1998. Demonstration operations were completed in December 1999.

A schematic of the HCCP power generation system (50 MW_e net) is provided in Figure 2. The HCCP is the first utility-scale demonstration of the TRW Clean Coal Combustion System. The TRW Combustion System is designed to minimize emissions of nitrogen oxides (NO_x), achieve very high carbon burnout, and remove the majority of flyash from the flue gas prior to the boiler. The TRW system also provides the first step of a three-step process for controlling sulfur dioxide (SO_2) by converting limestone to flash calcined lime that subsequently absorbs SO_2 within the boiler. The majority of SO_2 is removed downstream of the boiler, using Babcock & Wilcox's (B&W's) activated spray dryer absorber (SDA) system, which utilizes the flash calcined material (flash calcined lime + flyash) produced by the TRW system. Since most of the coal ash is removed by the combustors, the flash calcined material is rich enough in calcium content such that the SDA can be operated solely on recycled lime, eliminating the need to purchase or manufacture lime for the backend scrubbing system.

HCCP Demonstration Test Program

The HCCP Demonstration Test Program (DTP) was initiated in early 1998. The test program was comprised of several test activities including Coal-firing Trials (Task 1), Compliance Testing (Task 2), TRW Combustion System Characterization Testing (Task 3), B&W SDA Technology Characterization Testing (Task 4), Boiler Characterization Testing (Task 5), Coal Blend Testing (Task 6), Performance Guarantee Testing (Task 7), 90 Day-Commercial Operation Test (Task 8), and Long-Term Commercial Operation Demonstration (Task 9).

The first 4 months of the HCCP Demonstration Test Program were dedicated to coal-firing start-up operations and focused on slowly bringing all plant systems on line while burning run-of-mine (ROM) coal at part-load operation. The plant reached full load for the first time in March 1998. Combustion System Characterization Testing was initiated in May 1998, concurrent with the initial firing of ROM / Waste Coal blends. Approximately four months of characterization testing were performed during 1998. By the end of 1998, the majority of the Combustion System Characterization Test Program had been completed. During early 1999, test operations were limited due to a variety of facility and instrumentation problems, including a limited supply of limestone. Combustion System Characterization Testing resumed in March 1999 and was completed by early May 1999. By the end of 1999, all of the planned Technology Characterization and Performance Guarantee testing (Tasks 4, 5, and 7) had been completed. The 90-day Commercial Operation Test (Task 8) was initiated in August 1999 and successfully completed in November 1999. The Long-term Commercial Operation Demonstration (Task 9) was not completed prior to the DOE reporting deadline.

This report presents a summary of the tests performed during 1998 and 1999 as part of the TRW Combustion System Characterization Test Activities (Task 3). The TRW Combustion System Characterization Test Activities consisted of three test series:

Test Series 1: Initial Performance Characterization Tests
Test Series 2: Operating Envelope Characterization Tests
Test Series 3: Steady-State Operation Characterization Tests

The focus of the Combustion System Characterization Testing was to (1) establish the baseline performance of the combustion system while burning ROM and ROM / Waste Coal blends, (2) map the combustor performance characteristics over a broad range of operating conditions and hardware configurations, and (3) determine the best configuration and operating conditions for long-term operation. Key combustor operating parameters investigated included precombustor and slagging combustor stoichiometry, precombustor coal split, precombustor exit temperature and velocity, and furnace calcium-to-sulfur (Ca/S) ratio. Shutdowns were incorporated into the test planning activities in order to inspect the combustor internal slagging characteristics as a function of the various hardware configurations and test conditions evaluated.

Operation and Performance Summary

Overall Summary

During January 1998 through June 1999, approximately 7200 hours of plant thermal operation were accumulated, with approximately 6500 hours of coal-fired operating time. Both ROM and ROM / Waste Coal blends were tested in the combustion system. Typically, the ROM / Waste Coal blends had caloric heating values ranging from 6196 to 8271 Btu/lb, ash contents ranging from 5.7 to 24.0 %, and ash fluid temperatures ranging from 2270 to 2900 ^{o}F. An additional 2200 hours of coal-fired operating time were accumulated during July through November 1999, including the 90-day Test conducted during the months of August through November 1999, which brought the total coal-fired operating time up to approximately 8700 hours, or the equivalent of approximately 1-year continuous operation.

The $NO_{x,}$ $SO_{2,}$ and carbon monoxide (CO) emission goals were met while burning both ROM and ROM / Waste Coal blends during operation at nominal 50 MWe net. The testing consistently demonstrated the ability to achieve low NO_x emissions (0.20 to 0.30 lb/MMBtu for furnace oxygen (O_2) levels between 3 and 5% at near full load of 290 to 315 MMBtu/hr per combustor) simultaneously with extremely low CO emissions in the furnace (10 to 90 ppm) and high carbon burnout (>99%) , removal of the majority of the slag ash prior to the furnace (typically 78 to 85%), and good limestone calcination efficiency with consistent achievement of SO_2 emissions less than 0.10 lb/MMBtu.

Throughout the Combustor Performance Characterization Test Program, the slagging stage of the combustor performed extremely well and continuously demonstrated the capability to reliably burn ROM and ROM / Waste Coal blends over a broad range of operating conditions, while maintaining a thin molten slag layer over the entire tubewall surface. The precombustor performed very well with ROM coal but exhibited more variable performance, in terms of slagging behavior, during the initial tests with ROM / Waste Coal blends. During 1998 and early 1999, a combination of hardware configuration and operational changes were made which successfully resolved this problem. The key changes made were as follows: (1) relocating the secondary air from precombustor mix annulus to the headend of the slagging stage, (2) completely transferring the precombustor mill air to the boiler NO_x ports following the boiler warm up and 3) modifying the precombustor burner air injection configuration in order to improve air/coal mixing characteristics.

The operation of the TRW coal feed system was very steady and reliable during the DTP, which is the first utility-scale demonstration of this novel pulverized coal feed splitter system. The system operated within its established pressure budget (<60 i.w.g.), and demonstrated the capability to deliver various splits of coal and transport air to the precombustor, slagging combustor, and the furnace NO_x ports.

Data was also gathered during the 1998 and 1999 Combustor Performance Characterization Test Series to assess combustor availability. Over the time period considered, the overall combustor availability during 1998 was approximately 75 to 77%, and during 1999 was 92%. Preliminary long duration operation availability data was acquired during the 90-day test performed during August through November 1999, with a resulting calculated availability greater than 97% and a capacity factor of approximately 95%. The 90-day Test results will be released in a separate topical report prepared by AIDEA.

The following sections provide a summary of the specific test results for the 1998 and 1999 Combustor Performance Characterization Test activities.

1998 Summary

During 1998, approximately 5,000 hours of plant thermal operation were accumulated, with approximately 4,500 hours of coal-fired operating time. Both ROM and ROM / Waste Coal blends were tested in the combustion system. Typically, the ROM / Waste Coal blends had caloric heating values ranging from 6,200 to 7,500 Btu/lb, ash contents ranging from 10 to 24%, and ash fluid temperatures ranging from 2300 to 2900 ^oF.

A key performance goal of the 1998 test program, demonstrating the capability to meet the emission limit goals while burning both ROM and ROM / Waste Coal blends, was met. The NO_x and SO_2 emission goals were met while burning all coal blends. In particular, the NOx emissions appeared to be independent of the coal type, with low NO_x emissions demonstrated for all coal blends tested. Table 1 provides a summary of these preliminary performance results, including a comparison to the New Source Performance Standards (NSPS), HCCP Air Quality Permit emission limits, and HCCP performance specifications. The emission levels of $NO_{x,}$ $SO_{2,}$ and particulate matter from this 50 MW_e (net) power plant were significantly lower than permitted emission limits.

During 1998, all combustor performance parameters met or exceeded expectations. NO_x emissions were typically in the 0.20 to 0.30 lb/MMBtu range, for furnace O_2 levels between 3.0 and 4.5% at near full load (300 to 315 MMBtu/hr per combustor). Based on preliminary analysis of the carbon in the slag and the flyash, carbon burnout is very high (>99%), indicating excellent combustion. Carbon monoxide (CO) emissions were also very low, typically in the 10-50 ppm range, compared to the permit value of 0.20 lb/MMBtu (200 ppm @ 3.5%O_2). Slag recovery was determined to be approximately 80-85% over 45 cumulative days of operation (combination of 4 consecutive test runs, including 4 start-up and shutdown periods).

The slagging stage of the combustor performed extremely well and continuously demonstrated the capability to reliably burn ROM and ROM / Waste Coal blends over a broad range of operating conditions, while maintaining a thin molten slag layer over the entire tubewall surface. The precombustor performed very well with ROM coal but exhibited more variable performance, in terms of slagging behavior, during the initial tests with ROM / Waste Coal blends. Localized slag freezing was observed in the precombustor during the 1998 test program. A combination of hardware configuration and operational changes were made which were demonstrated to minimize precombustor slag freezing. The key changes made during 1998 were as follows: (1) relocating the secondary air from precombustor mix annulus to the headend of the slagging stage and (2) completely transferring the precombustor mill air to the boiler NO_x ports following the boiler warm up. These changes eliminated the mixing of excess air downstream of the precombustor combustion chamber to minimize local slag freezing, and increased the precombustor operating temperature in order to provide additional temperature margin. The mill air change had the added benefit of simplifying combustor operation by eliminating the need to monitor and control the coal-laden mill air flow to the precombustor mill air ports during steady-state operation.

The operation of the TRW coal feed system was very steady and reliable during the 1998 DTP, which is the first utility-scale demonstration of this novel pulverized coal feed splitter system. The system operated within its established pressure budget (<60 i.w.g.), and demonstrated the capability to deliver various splits of the coal to the precombustor and the slagging combustor. The blowdown cyclone control approach also worked well, demonstrating that the system is capable of maintaining sufficient transport velocities in each transport line under different coal splits, coal types, boiler load, and back pressure conditions.

The limestone feed system also performed very well, once some initial problems with accurately controlling the low end feed rate were diagnosed and resolved. The system demonstrated that it could continuously feed limestone over the required range to ensure overall plant SO_2 compliance.

Preliminary data was also gathered in 1998 to assess combustor availability. The test period from April 23, 1998 through December 31, 1998 was reviewed in order to identify the cause(s) of each plant shut-down, as well as to estimate the amount of time the combustors were unavailable during a plant shut-down. During this period, no plant trips were attributed to the TRW coal feed and coal combustor systems. As noted previously, a number of these plant shut-downs were incorporated into the test planning activities in order to inspect the combustor internal slagging characteristics and/or implement any configuration changes. Over the time period considered, it was estimated that Combustor A was not available for approximately 1392 hours and Combustor B was not available for 1546 hours out of the 6060 total elapsed hours, corresponding to overall combustor availabilities of approximately 77.0% and 74.5%, respectively. However, it should be noted that the majority of unscheduled combustor downtime during this period was related to the previously mentioned problem of slag freezing within the precombustor subsystem. Significant progress was made during 1998 in controlling the precombustor slagging behavior. When combustor downtimes attributed to the precombustor slag freezing program are excluded, the corresponding availability for the remaining combustor subsystems was estimated to be approximately 94% for both combustors.

Another on-going goal of the test program had been to increase the reliability of the combustor instrumentation and control equipment, as well as simplify the operation as much as possible. In May 1998, most of the combustor start-up and shut-down operations were automated. During steady-state operation, slagging combustor stoichiometry can also be programmed to adjust automatically to changes in coal load and coal type. In addition, all of the key combustor operating parameters have alarm levels to alert the operator of upset conditions, and additional diagnostic pages have been included on the Plant Control System (PCS) to assist with process monitoring and troubleshooting. Additional flame scanners were also added to the combustion flame monitor system to provide additional system redundancy and enhance system safety. At the end of 1998, efforts were also underway to provide redundant and/or independent measurements for various flow parameters in order to increase operational reliability.

Overall, the combustor operation and performance demonstrated during the 1998 Combustor System Characterization Test Series was quite encouraging given it is the first utility-scale demonstration of this promising new technology. The overall system met or exceeded all goals for achieving low NO_x and SO_2 emissions at the stack, with extremely low CO levels in the furnace, very high carbon burnout, and removal of the majority of ash prior to entering the furnace, while burning both ROM and ROM / Waste Coal blends. Major strides were made in controlling precombustor slagging behavior while burning ROM / Waste Coal blends, through both changes in operating conditions and hardware configuration.

1999 Summary

Efforts during 1999 focused on completing the Combustion System Characterization Test Matrix, optimizing the Precombustor Burner configuration and operating conditions, and evaluating integrated system performance during longer duration steady-state tests.

During January through June 1999, approximately 2200 hours of plant thermal operation were accumulated, with approximately 2000 hours of coal-fired operating time. Almost all testing was performed with ROM / Waste Coal blends. During 1999, the ROM / Waste Coal blends had caloric heating values ranging from 6766 to 7826 Btu/lb, ash contents ranging from 8.02 to 19.08, and ash fluid temperatures ranging from 2275 to 2852 ^{o}F.

Consistent with 1998 test results, emission levels of NO_x, SO_2 and particulate matter during the first six months of 1999 test operations were significantly lower than permitted emission limits. The ability to achieve low NO_x emissions simultaneously with low CO emissions, good carbon burnout, and high levels of ash removal prior to the furnace, was consistently demonstrated. During 1999 test operation from January through June, NO_x emissions were typically in the 0.228 to 0.271 lb/MMBtu range, for furnace O_2 levels between 3.9 and 4.9 % at 286 to 311 MMBtu/hr per combustor, with greater than 99% carbon burnout (based on slag and flyash analysis), 8 to 89 ppm CO, and nominally 75 % ash removal prior to the furnace. Limestone calcination efficiency remained at high levels resulting in consistent achievement of SO_2 levels less than 0.10 lb/MMBtu.

During the first six months of 1999 test operations, the slagging stage of the combustor continued to perform extremely well and continuously demonstrated the capability to reliably burn ROM / Waste Coal blends over a broad range of operating conditions, while maintaining a thin molten slag layer over the entire tubewall surface. The precombustor performance while burning ROM/Waste Coal blends continued to improve during the first six months of 1999 test operations. In particular, following optimization of the Precombustor Burner configuration and operating conditions in early May 1999, the Precombustor slagging behavior was consistent from test to test and there was no further evidence of localized slag freezing. The key changes made were as follows: (1) installation of an inner air register swirler and flow trip devices to improve flame anchoring and (2) increasing the temperature and flowrate of the burner tertiary air to improve coal fines combustion.

The operation of the TRW coal feed system and limestone feed system continued to be very steady and reliable during the 1999 DTP.

During 1999 test operations, additional data was also gathered to assess combustor availability. The test period from January through June was reviewed in order to identify the cause(s) of each plant shut-down, as well as to estimate the amount of time the combustors were unavailable during a plant shut-down. The majority of the test trips during this test period were due to a common cause: high furnace pressure spike that resulted from an abrupt fall of accumulated flyash/slag from the Furnace Hopper Slope. This problem was resolved in July 1999 by the installation of a water lance on the Furnace Hopper Slope to mitigate ash accumulation in this region. The remaining test trips that occurred during 1999 were due to instrumentation problems (two of which were related to the combustion system) or operator error. Over the time period considered, it was estimated that both Combustors A and B were not available for approximately 353 hours out of the 4344 total elapsed hours, corresponding to overall combustor availability of approximately 92%. A more accurate determination of combustor availability was made during the long-duration 90-day Test performed during August through November 1999, and resulted in a calculated plant availability greater than 97% and a capacity factor of approximately 95%. The 90-day test results will be released in a separate topical report prepared by AIDEA.

Overall, the combustor operation and performance demonstrated during the 1999 Combustor System Characterization Test Series continued to be quite encouraging. The overall system continued to meet or exceed all goals for achieving low NO_x and SO_2 emissions at the stack, with extremely low CO levels in the furnace, very high carbon burnout, and removal of the majority of ash prior to entering the furnace, while burning ROM / Waste Coal blends. The ability to control precombustor slagging behavior while burning ROM / Waste Coal blends was demonstrated, through improvements in Precombustor Burner configuration and operating conditions.

Participant:
Alaska Industrial Development and Export Authority

Sponsor:
U.S. Department of Energy

Team Members:
Golden Valley Electrical Association - Host Utility
Stone and Webster Engineering Corp. - Engineer
TRW Inc. - Technology Supplier
Babcock & Wilcox - Technology Supplier

Location:
Healy, Alaska

New Technology:
TRW's Slagging, Multi-Staged Combustor
Babcock & Wilcox Spray Dryer Absorber with Sorbent Recycle

Plant Capacity/Production:
50 MWe (Nominal Electric Output)

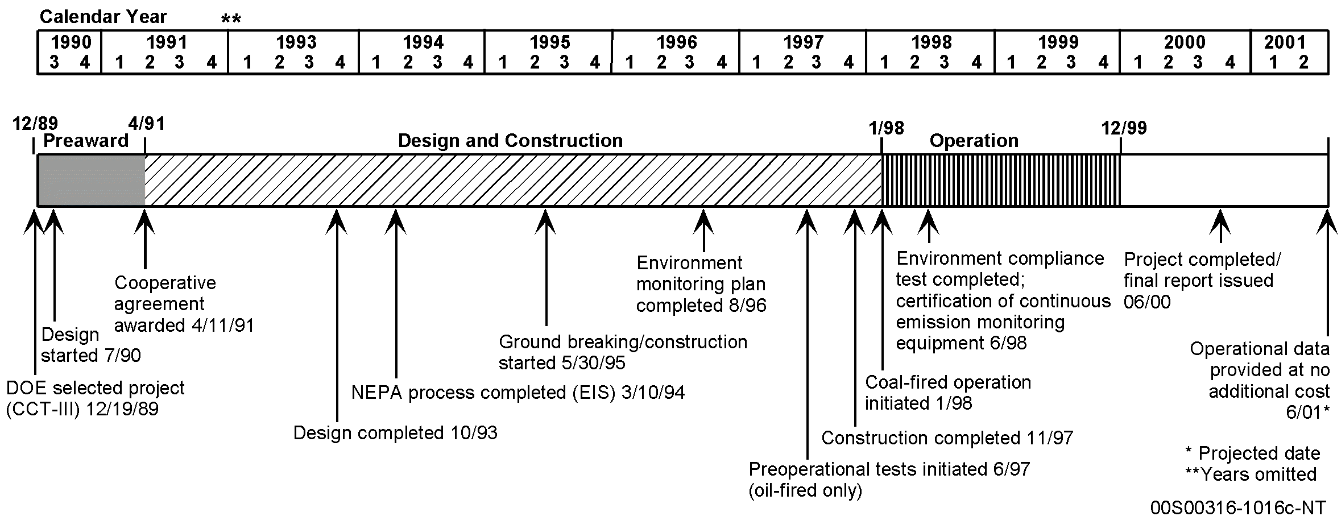


FIGURE 1 – OVERVIEW OF HEALY CLEAN COAL PROJECT

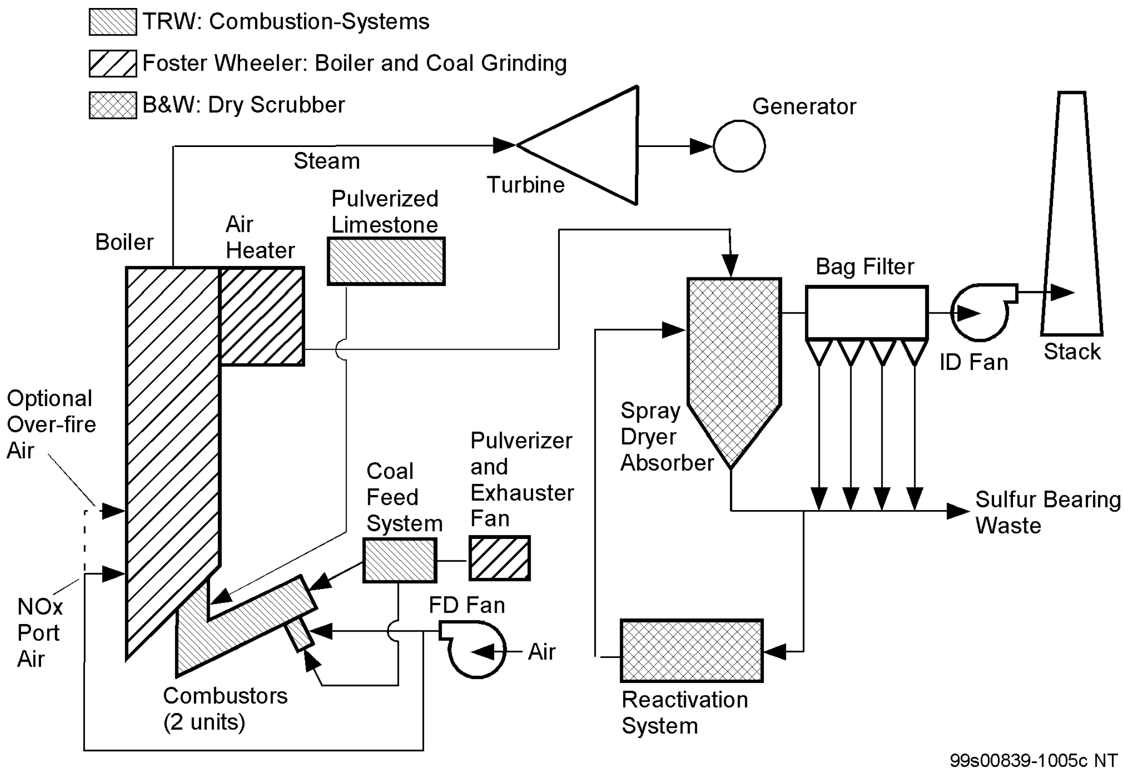


FIGURE 2 – HCCP INTEGRATED SYSTEM

TABLE 1 – HCCP PERFORMANCE GOALS AND RESULTS

PARAMETER	New Source Performance Standards (NSPS) [1]	HCCP AIR QUALITY PERMIT	CONTRACT GOALS	DEMONSTRATED IN 1998 (June - December, 1998)	
				RANGE	TYPICAL
NOX	0.5 lb/MMBtu (prior to 7/97) 0.15 lb/MMBtu (modified after 7/97) 1.6 lb/MWhr (new plant after 7/97)	0.350 lb/MMBtu (30 day rolling average)	< 0.35 lb/MMBtu	0.208-0.278 lb/MMBtu 30-day rolling ave. [9], [10]	0.245 lb/MMBtu 30-day rolling ave. [9], [11]
CO	Dependent on ambient CO levels in local region (Title V of 1990 CAAA)	0.20 lb/MMBtu, (hourly average) (202 ppm CO @ 3.0% O2)	< 200 ppm (dry basis) at 3.5% O2 (dry basis) [2] (<206 ppm CO @ 3.0% O2)	<130 ppm at 3.0% O2 [6], [8]	30-40 ppm at 3.0% O2 0.036 lb/MMBtu [5], [8]
SO2	90 % removal and less than 1.2 lb/MMBtu 70% removal when emissions are less than 0.60 lb/MMBtu	0.086 lb/MMBtu, (annual average) 0.10 lb/MMBtu, (3-hour average) 65.8 lb/hr max, (3-hour average)	70 % Removal (minimum) 79.6 lb/hr SO2 (maximum)	< 0.09 lb/MMBtu (<35 ppm @ 3% O2) [6], [8]	0.038 lb/MMBtu (15 ppm @ 3% O2) (25 lb/hr) [5], [8]
OPACITY	20% Opacity (6 min. average)	20% Opacity, (3 min average) 27% Opacity (one 6 min period per hour)	20% Opacity, 3 min average	<10 % Opacity [6]	5.6% Opacity (Jun - Dec 1998) [5],[15] 2.3% Opacity (1999) [15]
PARTICULATE MATTER	0.03 lb/MMBtu	0.02 lb/MMBtu, (hourly average)	0.015 lb/MMBtu		0.0047 lb/MMBtu (1999) [14], [15]
CARBON BURNOUT	NA	NA	> 99% at 100% MCR for Perf., ROM, and 55/45 Blend [3] >98% at 100% MCR for Waste Coal	NA	99.7% [4]
SLAG RECOVERY	NA	NA	> 70% at 100% MCR for all coals [3]	78-87% [7]	83% [7]
NET POWER PRODUCTION	NA	NA	50 MWe for all coals	NA	50-55 MWe [12],[13]

NOTES
[1] From 40CFR60.40a - 40CFR60.49a; New NOx Standards based on 62 FR 36948
[2] From minimum to 100% MCR (Maximum Continuous Firing Rate)
[3] 100% MCR for Performance Coal is 315 MMBtu/Hr, ROM Coal is 306 MMBtu/Hr, Waste Coal is 322 MMBtu/Hr, 55/45 Waste/ROM Coal is 316 MMBtu/Hr
[4] Measured for one test based upon slag and flyash carbon contents
[5] Average of available 30 min. (average) test data, June 12,1998 to December 21, 1998 (total of 3100 hours of run time)
[6] 95% of CO, SO2, and opacity data are observed to be less than these reported value (using available 30 min average test data)
[7] Slag weight corrected for 6% moisture content.
[8] Data corrected to 3% O2
[9] 30-day rolling average determined from available 30 min (average) test data, June 12, 1998 to December 21, 1998, total of 3100 hours (5480 data points).
30-day rolling average only includes days in which power was generated.
[10] Represents minimum and maximum of 30-day rolling average data described in Note [9]
[11] Represents the average of 30-day rolling average data described in Note [9]
[12] Nominal power set point from April through September, 1998 was 60-62 MWe (gross), 53-55 MWe (net);
[13] Nominal power set point in November and December, 1998 was 57 MWe (gross), 50 MWe (net)
[14] Based on independent particulate matter testing performed on March 10-11, 1999 by Haas, Morgan & Hudson
[15] Opacity and particulate matter emissions during 1998 were higher than expected due to a problem with premature baghouse filter bag failure, which was corrected in 1999

1.0 INTRODUCTION

The Healy Clean Coal Project (HCCP) was selected by the U.S. Department of Energy under Round III of the Clean Coal Technology Program. After more than five years of planning, design, and permitting activities, the project celebrated its ground-breaking ceremony at Healy, Alaska on May 30, 1995. Two 350 million Btu/hr coal combustors and the associated coal and limestone feed systems were fabricated by TRW and their subcontractors, and delivered to the Healy site 250 miles north of Anchorage, Alaska (near Denali National Park and Preserve) in 1996, for installation in a new nominal 50 megawatt (MW_e) net coal-fired power generating facility. The location of the facility is on land adjacent to the existing Golden Valley Electric Association, Inc. (GVEA) Healy Unit No. 1 power plant. Construction was completed in November 1997, with coal-fired operations starting in January 1998. Demonstration operations were completed in December 1999. Long-term commercial operation demonstration was not completed prior to the DOE reporting deadline.

The project is owned and financed by the Alaska Industrial Development and Export Authority (AIDEA), and is cofunded by the U.S. Department of Energy. Golden Valley Electric Association, Inc. (GVEA) of Fairbanks, Alaska provided the plant operators. The plant engineer was Stone and Webster Engineering Corporation. The coal supplier is Usibelli Coal Mine, Inc., located adjacent to the Healy plant.

The technology currently being demonstrated in the HCCP combines the TRW Clean Coal Combustion System and the Babcock and Wilcox (B&W)/Joy/NIRO Activated Recycle Spray Dryer Absorber (SDA) System into a single, integrated, combustion / emission control process. These technologies have been designed to achieve reductions in emission of sulfur dioxide (SO_2), oxides of nitrogen (NO_x), and particulate matter, thereby meeting future energy needs from coal-fired generation in an environmentally acceptable manner while burning a variety of coals.

The TRW Combustion System achieves low NO_x emissions through a combination of well-controlled fuel and air staging. Limestone injection at the exit of the combustor results in the production of a flash calcined lime material (FCM) that provides the first stage in SO_2 removal via furnace absorption of some of the SO_2 in the combustion flue gas. The combustor also removes approximately 80 to 90 percent of the coal ash as a slag by-product. This approach results in lower concentrations of NO_x, SO_2 and particulates than typically found in flue gas from more conventional combustion methods. The FCM is subsequently used downstream in the SDA system, the post-combustion cleanup technology that is also currently being demonstrated, for the second-stage of SO_2 removal. Third-stage SO_2 removal and particulate collection takes place in the B&W/Joy pulse jet baghouse.

2.0 HCCP DEMONSTRATION TEST PROGRAM

2.1 DEMONSTRATION TEST PROGRAM GOALS

The HCCP Demonstration Test Program (DTP) goals include demonstration of the following features of the integrated HCCP combustion and air pollution control systems:

- Demonstration of the capability to control NO_x emissions to the 0.20 – 0.35 lb/MMBtu range with low furnace CO levels (less than 200 ppm) while burning ROM/Waste Coal blends with up to 55% waste coal.

- Demonstration of SO_2 removal efficiencies of at least 90 percent at low reagent consumption. The project will demonstrate activation and utilization of TRW combustor-generated FCM waste for SO_2 removal in the Activated Recycle SDA System. In most SO_2 control processes, the calcium-based product from the particulate collection equipment is sent to disposal. In this innovative process, the product is recycled to provide additional SO_2 removal in the SDA system. The successful demonstration of this combined process will help promote the use of the TRW-B&W integrated system in areas where a minimum 90 percent reduction is required, and to effectively compete with other high removal efficiency processes that are more costly.

- Demonstration of SO_2 reduction in the furnace by limestone injection into the exit of the TRW combustor. The current Healy test program provides for a demonstration of in-furnace SO_2 reduction for extremely low sulfur coals. For high sulfur coals, SO_2 removal efficiencies of 50 to 70% within the furnace have already been demonstrated using an industrial scale TRW combustion system and furnace.

- Control of overall particulate, and that portion of particulate matter typically below 10 microns in size (PM_{10}) to levels below current NSPS requirements.

- Low cost waste disposal or reuse. Waste disposal will be made easier by the production of a vitreous slag waste from the combustors and a dry powdery waste from the SDA system that will set up into a high strength, stable waste material that can be easily disposed of in a conventional landfill operation, or potentially used in commercial applications such as road base material.

In addition, data generated from the Demonstration Test Program will be used as follows:

- A comparison of utility-scale TRW Multi-stage Clean Coal Combustor (350 MMBtu/hr) performance with the industrial-scale combustor tests (20-40 MMBtu/hr) conducted at Cleveland, Ohio will be made in order to verify scaling methodology and allow extrapolation of combustion system performance to other coals and operating regimes.

2.2 DEMONSTRATION TEST PROGRAM TASKS AND SCHEDULE

The HCCP Demonstration Test Program (DTP) was initiated in early 1998. The overall test program schedule is shown in Figure 2-1. As shown, the test program was comprised of several test activities including Coal-firing Trials (Task 1), Compliance Testing (Task 2), TRW Combustion System Characterization Testing (Task 3), B&W SDA Technology Characterization Testing (Task 4), Boiler Characterization Testing (Task 5), Coal Blend Testing (Task 6), Performance Guarantee Testing (Task 7), 90 Day-Commercial Operation Test (Task 8), and Long-term Commercial Operation Demonstration (Task 9).

The TRW Combustion System Characterization Test Activities (Task 3), initiated in May 1998, consisted of three separate test series:

Test Series 1: Initial Performance Characterization Tests
Test Series 2: Operating Envelope Characterization Tests
Test Series 3: Steady-State Operation Characterization Tests

Approximately 4-cumulative months of combustor characterization testing were performed during 1998, as shown in Figure 2-1. The majority of the Combustion System test activities took place during May, July, October, November, and December 1998. During this period of time, 100% of Test Series 1 was completed, 70% of Test Series 2 was completed, and Test Series 3 was initiated. In general, combustor characterization testing was performed concurrently with other plant start-up activities and operational tests. These activities included a variety of coal-firings, system modifications/adjustments, component replacement and maintenance, operational changes and personnel training.

Approximately 2 cumulative months of combustor characterization testing were performed during 1999. During March thru May 1999, an additional 10% of Test Series 2 was completed bringing overall completion of this test series to 80%, and 50% of Test Series 3 was completed. Similar to 1998, combustor characterization testing was performed concurrently with other plant operational tests, including the Boiler and SDA Performance Guarantee tests. During August through November 1999, the long-duration 90-Day Test was performed. This test essentially completed Test Series 3 of the Combustor Characterization Test Series.

As shown, the originally planned coal-firing start-up and test activity schedule was based on a very aggressive approach to accomplishing the goals of the project in a very short one and a half years from the start of coal-firing, concluding in the summer of 1999. The actual schedule was extended an additional 5 months in order to complete all of the requisite testing.

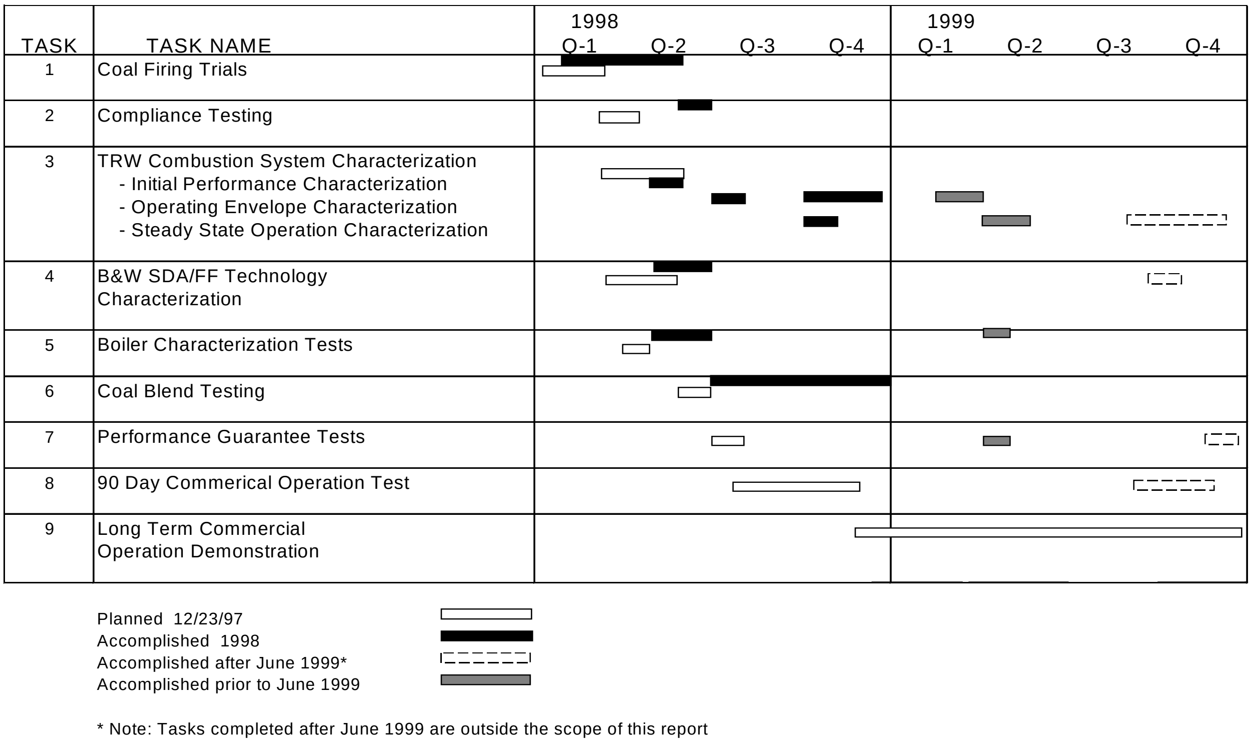


FIGURE 2-1 HCCP DEMONSTRATION TEST PROGRAM SCHEDULE

3.0 HCCP TECHNOLOGY DESCRIPTION

The Healy Clean Coal Project integrates a slagging, multi-staged coal combustor system with an innovative sorbent injection / spray dryer absorber / baghouse exhaust gas scrubbing system. Twin 350 MMBtu/lb combustors designed by TRW are used to supply hot gases to a conventional Foster Wheeler bottom-fired boiler. The flue gas cleaning equipment was supplied by Babcock & Wilcox (B&W) based on technology developed by Joy Environmental Technologies of Houston, Texas and NIRO Atomizer of Denmark.

The first step in the Healy Clean Coal Project combustion process, shown in schematic format in Figure 3-1, is the pulverized coal feed system which consists of coal silos, Foster Wheeler MBF 21.5 coal pulverizers and exhauster fans, and the TRW coal feed system. The purpose of this pulverized dry coal system is to ensure a steady feed of coal (over a wide range of physical properties) to both combustion stages. The second step in this process is the TRW multi-staged coal combustor which utilizes a multi-staged combustion process to minimize the formation of nitrogen oxides while burning a wide variety of coals including "hard to burn" coals. This combustor system melts and removes most of the coal mineral contaminates as slag. Pulverized limestone is injected prior to the combustor-boiler interface to provide for SO_2 removal from the combustion gases. The limestone is converted by heat in the combustion gases to flash calcined material (high surface area lime + ash particles, called FCM) which reacts with the SO_2 in the combustion gases and removes the SO_2 as calcium sulfate. The unreacted FCM and sulfates are captured and recycled within the B&W spray-dryer absorber system downstream of the boiler to further reduce the SO_2 content in the combustion gases prior to the exhaust stack.

At HCCP, the two coal combustors are installed side by side and fire the boiler from the bottom upwards. An isometric view of the boiler and combustion system used in the HCCP is shown in Figure 3-2. Each combustor has its own dedicated coal storage, grinding, and feed system. Crushed coal is discharged from a storage silo into a pulverizer via a coal feeder/weighing scale. The pulverized coal and pulverizer sweep air (or primary air) is boosted in pressure to 60 i.w.g. (1.15 atm) by the mill exhauster fan. This pressure is necessary to overcome the pressure drop through a non-storage coal feed/splitter subsystem that enables the coal to be split and fed into the precombustor and slagging stage. The coal feed / splitter subsystem also separates a major portion of the primary air and diverts this air to NO_x ports located in the boiler furnace. This helps in reducing the amount of cold air going into the combustor, thereby increasing the temperature of the combustion gases to promote slagging conditions over the entire range of coal ash melting temperatures.

Pulverized coal is fed to both the precombustor and slagging stages of the combustor. The precombustor portion of the coal is fed directly to a coal burner located in the headend of the precombustor. The slagging stage portion of the coal is split into six parts and injected into the head-end of the slagging stage via six injection ports. From the slagging stage, the combustion gases enter the slag recovery section where the gases are directed vertically upwards into the furnace through an interface opening in the sloping bottom of the furnace. The fuel-rich combustor exhaust is intercepted by the boiler NO_x port air, where final air is added to complete combustion. Optional over-fire-air can also be introduced to provide further air staging for supplemental NO_x and temperature control.

In the boiler, approximately 490,000 lb/hr of superheated steam is generated at 1300 psig and 955 ^{o}F. The flue gases exit the boiler bank and flow through a high temperature air heater, an economizer, and a low temperature air heater. The flue gases then enter the spray dryer absorber and bag filter, where the majority of SO_2 and particulate matter is removed from the gas stream prior to the stack.

A single limestone feed subsystem services both combustors. Pulverized limestone, stored in a silo, discharges via a weigh scale feeder to a rotary air-lock and a two-way splitter. A separate air-driven eductor is used at each leg of the splitter to transport the limestone-air mixture to a single limestone injector located on the side of the slag recovery section of each combustor. The limestone particles flash-calcine to highly reactive lime with high surface area. These particles remove some of the SO_2 from the combustion gases as they pass through the furnace. The FCM particles are collected and utilized by the B&W spray dryer absorber system to remove most of the remaining SO_2 in the combustion products, typically resulting in less than 10% of the sulfur contained in the coal exiting as SO_2 with the plant stack gases. Final FCM and fly ash particulate control is accomplished in the baghouse.

Figure 3-3 presents typical Healy Clean Coal Project combustion side gases and solids flows when each combustor unit is operated at a firing rate of 315 MMBtu/hr on a Usibelli ROM / Waste Coal blend. The flow rates presented in Figure 3-3 are for the total plant, which includes two coal feed systems, one pulverized limestone feed system and two coal combustor systems. The coal feed system provides coal and a portion of the mill air directly to the precombustor and slagging combustor stages with the remaining mill air sent to the boiler NO_x ports. The warm combustion air from the air heater section is delivered to the boiler NO_x and over-fire air (OFA) ports and to both coal combustion stages. The limestone flow is set to control the overall Ca/S molar ratio in the range of 1.5 to 2.0. In general, higher levels of slag and ash recovery in the combustor and boiler reduces the amount of inert ash entering the SDA, which in turn allows the plant to operate at a lower Ca/S ratio.

3.1 TRW MULTI-STAGE CLEAN COAL COMBUSTION SYSTEM

3.1.1 Development History

The multistage clean coal combustion technology demonstrated at the Healy Clean Coal Project (HCCP) power plant started at TRW with Low-NO_x utility oil burners in the 1970s and with pressurized magnetohydrodynamic (MHD) coal combustors in the early 1980s. Initial tests at TRW of an atmospheric pressure coal combustor at 10 MMBtu/hr in 1982 were followed by testing of a 40 MMBtu/hr industrial size combustor using a wide variety of coals to obtain extensive data on combustion, slag removal, NO_x and SO_2 emission and particulate carry over. A retrofit demonstration at a Cleveland, Ohio manufacturing plant was started in 1984 and over 10,000 hours of operation were accumulated while providing plant steam at high availability. Fifteen different coals with a wide range of physical properties were tested in this industrial-size coal combustor:

Moisture	1.36 % to 31.7 %
Ash	4.39 % to 27.32 %
Volatiles (dry, ash free)	10.6 % to 60.8 %
Nitrogen (dry, ash free)	0.95 % to 1.9 %
Sulfur (dry, ash free)	0.48 % to 4.59 %
Higher Heating Value (HHV)	7,358 Btu/lb to 13,061 Btu/lb
Ash Fusion Temp. (T_{250})	2,118 ^{o}F to 2,900 ^{o}F

During the early 1990s, a utility-scale prototype version of the Healy precombustor and a 7.5 ton/hour direct coal feed system were successfully tested at TRW's Fossil Energy Test Site as part of the Healy Clean Coal Project. More than five years of planning and permitting culminated in spring 1995 with the start of construction on the 50 MW_e (net) HCCP power generation unit. During the summer of 1995, earthwork, foundation and structural steel work began with construction and erecting of all equipment continuing through late 1997. Construction was completed in November 1997, with coal-fired operations starting in January 1998. The HCCP is the first utility-scale demonstration of the TRW Clean Coal Combustion System.

3.1.2 Functional Description

Figure 3-4 illustrates an isometric view of one of the two 350 MMBtu/hr (88 million kcal/hr) TRW multistage slagging combustors designed for the HCCP. It consists of a precombustor, a slagging stage and a slag recovery section. The main chamber of the slagging stage is approximately 9 feet in diameter by 16 feet in length. The walls of the combustor were fabricated using tube-membrane construction, primarily with 1.5 inch SA213 T2 tubing and SA387 Grade 11 fin material. The combustors are cooled by a two-phase forced circulation system directly integrated with the boiler drum (1400 psia, 585 ^oF). The twin combustors were fabricated at Foster Wheeler's facility in Dansville, NY, per TRW specification drawings and were transported to the plant in several subassemblies. The combustors are suspended from the boiler (top-supported).

The combustors are positioned in a symmetrical arrangement (mirror image). Two independent fuel trains (including coal silo, coal feeder, pulverizer, exhauster fan, and TRW coal feed system) are located east of the boiler. Each fuel train can be operated separately for loads up to 50%, and the two are operated together for loads in the 50-100% range.

A functional schematic of the combustion system is shown in Figure 3-5. Pulverized coal is injected in both the precombustor and slagging stage. The precombustor is used to boost the combustion air temperature from the air heater (typically 500 - 700°F) to 2,300 to 3400°F by burning 30 to 45% of the total pulverized coal flow rate. The precombustor is a vital component of the system because it controls the temperature and velocity of the oxygen-rich combustion gases entering the slagging stage for optimum combustion and slag removal. It is designed to ensure stable, efficient combustion of a wide variety of coals, and to prevent slag freezing within the slagging stage while burning high fusion temperature coals under fuel-rich conditions. Low volatility coals can be accommodated by firing a larger portion of the coal in the precombustor.

In the initial HCCP design, the combustion process in the precombustor was accomplished in two stages. In the primary combustion zone, coal was burned at a stoichiometric ratio of 0.8 to 1.0 followed by a mixing section where additional secondary air was added, resulting in a stoichiometric ratio greater than 2.0 (fuel lean) at the exit of the precombustor. During the Demonstration Test Program, this process was modified by relocating the additional secondary air to the headend region of the slagging stage. For this configuration, the precombustor combustion chamber was operated at a stoichiometric ratio of 1.0 to 1.2. These changes increased the precombustor exit temperature (up to 3400 ^oF) to provide additional operating margin to ensure slagging conditions while burning high ash fusion temperature waste coals. A more detailed description of the various precombustor secondary air configurations is provided in Section 3.1.4.

The high temperature combustion gases from the precombustor enter the slagging stage tangentially, generating a high velocity, high temperature confined vortex flow. The balance of the pulverized coal (55 to 70%) is injected through a multi-port injector at the head end of the slagging stage. The high gas temperature produced by the precombustor promotes a hot slagged surface on the interior of the slagging stage, which combined with the strong recirculation patterns, ensures stable ignition and combustion. The multi-port injector helps distribute the coal evenly for better coal/air mixing and combustion. The slagging stage is operated at fuel-rich conditions at stoichiometric ratios typically in the range 0.70 to 0.90. Carbon conversion to gases is maximized and NO_x emissions are minimized by controlling the mixing and stoichiometric conditions in the slagging stage.

The precombustor, slagging stage, and the slag recovery section are operated in a slagging mode, i.e., the coal ash melts to form a molten slag layer which coats the inside surfaces. The coal particles are combusted at a high enough temperature to melt the residual coal ash contained within each particle. Slag droplets are produced, which are centrifuged to the walls of the combustor, forming a self-replenishing slag layer. This slag layer is molten on the surface and frozen at the tubewall interface. The frozen slag layer is approximately 0.5 to 1.5 inches thick and protects the water-cooled metal body of the combustor from erosion, abrasion and corrosion, and also reduces the heat transferred to the water in the combustor body. The molten slag is transported along the walls by shear and gravity forces. The molten slag flows through a key slot, along the bottom to the slag tap opening located in the slag recovery section. Up to 90% of the slag is discharged through the slag tap by gravity. A dipper skirt arrangement is used to provide a water seal and pressure seal for the system. The molten slag drops into the water, where it shatters upon contact and is rapidly quenched, yielding a granular glass-like product. The slag is removed from the slag tank by a drag chain conveyor.

Only 10 to 25% of the original coal ash enters the boiler. Because of the aerodynamics of the cyclonic slagging stage, the majority of this entrained slag will be molten droplets of less than 10 microns in size. As the fine slag droplets solidify at lower temperatures in the furnace, spherical shaped particles are formed that are expected to have lower fouling and erosion characteristics than conventional flyash particles, potentially increasing the life of the furnace and its convective tubes.

NO_x emissions are reduced in the TRW coal combustion process by the use of both fuel and air staging within the integrated combustor / boiler system. The combustor is primarily operated under carefully controlled, fuel-rich conditions. These conditions minimize the formation of NO_x by balancing the production rates of reduced and oxidized fixed nitrogen species (NH_i and NO, respectively). TRW test data and analytical model calculations indicate that combustor NO_x production is minimized by operating the combustor at a stoichiometric ratio (actual air/theoretical air) in the range of 0.70 to 0.85 (fuel-rich). For stoichiometric ratios above 0.85, excess NO is produced, while for stoichiometric ratios below 0.70, excess reduced nitrogen species (amines - NH_i type species, HCN) are produced, which subsequently oxidize to NO within the boiler furnace.

As the fuel-rich combustion gases exit the TRW combustor and enter the furnace, the addition of the final combustion air is delayed until the gas temperature is reduced by radiative cooling to the walls. This reduces the peak temperatures in the furnace and helps to further minimize NO_x formation. NO_x emissions at the HCCP during the 1998 and 1999 Demonstration Test activities have typically been in the 0.20 to 0.30 lb/MMBtu range (125-190 ppm).

Using this staged combustion process, CO emissions are also typically lower than conventional low NO_x burner systems. In a low NO_x burner system, both solid fuel combustion and CO oxidation are accomplished within the furnace. CO emissions are typically in the 200-1000 ppm range due to both delayed secondary air mixing as well as low excess O_2 (2-3% O_2) within the furnace. With the TRW combustor, solid fuel combustion is essentially completed before the combustion gas enter the furnace. The furnace is used primarily for CO oxidation (gas-gas reaction), which is primarily dependent on efficient gas-gas mixing, rather than particle residence time and temperature history within the furnace. CO emissions at the HCCP during 1998 have typically been in the 10 to 50 ppm range (0.01 to 0.05 lb / MMBtu).

The slagging combustor / boiler system also functions as a limestone calciner and first stage SO_2 removal device in addition to its combustion, heat recovery, and NO_x control functions. Pulverized limestone (primarily $CaCO_3$) is injected in the upper region of the slag recovery section. The limestone particles are calcined in the furnace, resulting in highly reactive flash-calcined lime (CaO) particles. By the time these lime particles mix and move with the combustion products to the exit of the boiler, a portion of the flue gas SO_2 is absorbed to form gypsum ($CaSO_4$). The amount of SO_2 removal in the furnace is dependent upon the amount of sulfur in the coal and the Ca/S ratio. For low sulfur coal (less than 1% sulfur), the SO_2 removal in the furnace is typically 15 to 30%. For higher sulfur coal (2 to 4% sulfur), the SO_2 removal can be as high as 50 to 70%.

3.1.3 Design Description

The precombustor, shown in Figure 3-5, consists of four major sections:

- Primary Burner and Windbox.
- Combustion Chamber (also referred to as "PC Combustion Can") with Integral Baffle
- Secondary Air Mix Annulus and Windbox
- Round to Rectangular Transition Section including Swirl Damper Blades

The PC combustion chamber, baffle, and transition section are all tube waterwall components fabricated from 1.5 inch diameter SA213 T2 tubing and SA387 Grade 11 fin material. The gas-side surfaces of these components are covered with 3/8 inch diameter studs and a 1 to 2 inch sacrificial silicon-carbide refractory layer. These components are all cooled with boiler feed water, nominally 1400 psig, 585°F.

The water-cooling circuits are designed to be drainable. In the HCCP, the heat absorbed by the cooling water is recovered by directly integrating the combustor cooling water with the water in the steam drum through a separate forced-circulation circuit.

The precombustor mill air ports are integral with the PC transition section. There are six 6 inch ports, fabricated from SS304 "squashed" pipes. Seal boxes filled with castable refractory surround each port.

The swirl damper blades are tube waterwall components, fabricated from SA106, Grade B pipe and SA516, Grade 70 fin material. During the Demonstration Test Program, an Inconel 625 weld overlay, 0.10 inch thick, was applied along a 1.5 inch wide surface on the downstream edge of the blades in order to minimize localized particle erosion along this surface. The blades are cooled with water from the low pressure cooling circuit of the plant condensate system, nominally 350 to 380 psia, 100 ^oF.

For most of the Demonstration Test Program, there were two coal flame scanners and one oil flame scanner installed on the Precombustor for safety and flame monitoring purposes. Initially, the oil flame scanner was located along the centerline of the oil ignitor and the primary coal flame scanner was located on the windbox looking at the flame centerline. Ultimately, the oil flame scanner was moved to the coal flame scanner location, looking at the flame centerline, and the primary coal flame scanner was installed further outboard on the precombustor burner windbox, looking at the flame outer boundary. The secondary coal flame scanner was installed on an unused PC mill air port, downstream of the PC combustion chamber. During 1999, an additional flame scanner was installed at the exit of the precombustor, just downstream of the swirl dampers.

The slagging combustor, or slagging stage, shown in Figure 3-5, is comprised of four major sections:

- Headend, including 6 Coal Injectors and 6 Secondary Air Ports
- Tangential Air Inlet Section
- Cylindrical Chamber Section
- Keyslot Baffle

All of the slagging stage combustion-side components are tube membrane waterwall construction. The headend, air inlet, and cylindrical chamber section are fabricated from 1.5 inch diameter SA213 T2 tubing and SA387, Grade 11 fin material. The baffle is fabricated from SA 213 T22 and SA387 Grade 22 fin material. All of the components are cooled with boiler feed water, nominally 1400 psig, 585 ^{o}F. The gas side surfaces are covered with 3/8 inch diameter studs and a ¾ inch thick sacrificial silicon-carbide refractory.

The coal injectors are located at a 52.5 inch diameter on the headend and the secondary air ports are located at a 74 inch diameter. The coal injectors are installed flush with the refractory surface of the headend. During the Demonstration Test Program, one of the coal injector ports was deliberately blocked off due to a strong flow recirculation pattern in this region of the headend. The current configuration has 5 coal injector ports and seven secondary air ports.

For the test program, there were three coal flame scanners installed on the headend. They were located on the Secondary air ports, at the 3 o'clock, 11 o'clock (or 1 o'clock), and 9 o'clock locations.

The slag recovery section, shown in Figure 3-5, is comprised of 4 vertical walls, tube membrane waterwall construction, fabricated from SA213 T2 tubing and SA387 Grade 11 fin material. All 4 walls are cooled with boiler feed water, nominally 1400 psig, 585 ^{o}F. The gas side surfaces are covered with 3/8 inch diameter studs and a ¾ inch thick sacrificial silicon-carbide refractory. The limestone injector is located flush with the refractory surface at approximately 4 ft below the furnace inlet.

The dipper skirt, fabricated from duplex stainless steel, forms the gas and water seal. The skirt is protected from direct radiation and convection by a tube membrane waterwall shield. The shield, fabricated from duplex stainless steel tubes and fin material, is cooled by the low temperature cooling circuit of the plant condensate system, nominally 350 to 380 psig, 100 ^{o}F.

3.1.4 Precombustor Hardware Configuration Changes

The following sections provide a general summary of the hardware configurations evaluated during the Operating Envelope Characterization Test Series. From July through December 1998, a total of four different secondary air injection configurations were evaluated. It should be noted that all of the configuration changes implemented during this test series were only temporary in order to simplify installation and removal, and the best configuration was eventually chosen and made permanent.

3.1.4.1 Mix Annulus Configuration

For the original mix annulus configuration shown in Figure 3-6a, all of the secondary air (nominally 750 ^{o}F) was injected into two locations within the precombustor: 1) PC burner, and 2) PC mix annulus. The PC burner air provided the combustion air for the precombustor coal burner. The mix annulus air was injected downstream of the precombustor combustion can (within the precombustor transition section) and provided the remaining combustion air for the slagging combustor coal burner. A portion of the total mill air (135 ^{o}F) was also injected through six injection ports downstream of the precombustor combustion can, along with a small portion of coal fines from the CFS cyclone exhaust.

3.1.4.2 Mix Elbow Configuration

Figure 3-6b illustrates the basic mix elbow configuration. A number of short radius 90 degree elbows were installed at the downstream end of the mix annulus in order to direct the mix annulus secondary air into the core flow of the precombustor combustion products. The primary goal of the mix elbow configuration was to enhance the mixing of the mix annulus secondary air with the primary combustion chamber flow and thus minimize the low temperature zones in the precombustor transition section and tangential inlet.

3.1.4.3 Secondary Air Injection in the Slagging Stage Headend

The basic configuration is shown in Figure 3-6c, in which the precombustor mix annulus opening was completely blocked off with metal plates and refractory and the mix annulus secondary air was ducted to unused ports on the slagging combustor headend. For both tests conducted during November 1998, four-6 inch ports on the headend, as well as the annular region surrounding the slagging combustor oil ignitor, were used for injecting the secondary air. For this configuration, a portion of the total mill air was still injected through the PC NO_x ports. The nominal precombustor exit temperature for this configuration was approximately 3200-3300 ^{o}F.

During late November 1998 (prior to 98-SC-AIR-4), provisions were made to completely transfer the precombustor mill air flow from the PC NO_x ports to the boiler NO_x ports following warm up of the boiler. This configuration, shown in Figure 3-6d, reduced the total amount of air injected in the precombustor, which in turn lowered the stoichiometry closer to unity and increased the precombustor operating temperature to approximately 3400-3500 ^{o}F. Another advantage of this change was that is eliminated the need to continuously measure and control the PC mill air flow rate during steady-state operation, a non-trivial task due to the fine particulate present within this air stream. Two additional air injection ports were made available in the headend of the slagging stage to accommodate the higher secondary air flow required to make up for the loss of the PC mill air flow.

3.2 COAL FEED SYSTEM

The HCCP Coal Feed System (CFS) is divided into three parts:

1. The plant CFS, which includes all the equipment required to process the raw coal from the pile and store it in the run hoppers,

2. The FWEC-supplied CFS, consisting of the pulverizer and exhauster fan,

3. The TRW CFS, consisting of the equipment required to control the split of air and coal between the precombustor, slagging stage, PC NO_x ports and the boiler NO_x ports.

The overall system is shown schematically in Figure 3-7. In the plant CFS (Part 1), the coal is loaded, crushed, transported, and stored in two separate silos, one for each Combustor. From there, the coal enters the FWEC-supplied CFS (Part 2), where it discharges from the Silo into a pulverizer via a coal feeder/weighing scale. The pulverizer dries and grinds the coal to a nominal 50 to 70% through 200 mesh grind at 135 ^{o}F. The pulverized coal with its carrier or primary air from the pulverizer is boosted in pressure to up to 60 i.w.g. by the mill exhauster fan. From the outlet of the exhauster fan, the pulverized coal is transported to the TRW coal feed splitter system.

The function of the TRW portion of the CFS is to split the coal between the precombustor and slagging stage, and separate a major portion of the primary air and divert it to NO_x ports. This separation and diversion of a portion of the primary air flow provides the capability of controlling the flow rate of combustor carrier air independent of the amount of total mill air. For example, at the HCCP, the required primary air flow rate is higher than most pulverized coal systems (up to a 3:1 air to coal mass ratio) in order to ensure correct functioning of the mill while grinding and drying the typical HCCP coal blends, that have high moisture content, high volatility, high ash, and low grindability. By separating out a portion of the mill air, the amount of cold air going into the combustor is reduced, thereby increasing the combustion gas temperature to promote high carbon burnout, efficient ash melting, and continuous slag flow and tapping.

The TRW CFS consists of a 2-way splitter, two blowdown cyclones, a 6-way splitter, and associated transport piping, dampers, and valves. Each CFS serves one combustor. The pressurized flow of pulverized coal and primary air from the outlet of the exhauster fan is split into three primary streams: the precombustor, the slagging stage, and the NO_x ports. The streams sent to the precombustor and slagging stage contain about 95% of the total coal and 20 to 30% of the primary air. The remaining 5% of the coal and 70 to 80% of the primary air is sent to the NO_x ports.

Coal and air exit the exhauster fan and flow through a 40 inch diameter vertical piping system to the 2-way splitter system. Coal entering the splitter remains on the walls, spiraling 180 degrees like a ram's horn out through separate discharge ducts to the two blowdown cyclones. Flow splitter dampers located within the discharge ducts control the velocity and mass flow split entering the precombustor and slagging stage blowdown cyclones. The blowdown cyclones separate out 70 to 80% of the primary air and 5% of the fine coal particles through the vent ports at the top of the cyclones. The remaining 20 to 30% of the primary air and 95% of the total coal flow exit through the bottom of the cyclones and flow directly to the precombustor and slagging stage. The vent ports at the top of the precombustor and slagging combustor cyclones are manifolded together and the total amount of vent air flow is controlled by a damper. The vent air and 5% coal fines are conveyed to the precombustor during start-up and shut-down and the furnace NO_x ports during normal operation

The slagging stage portion of the coal (~ 55 to 70% of the coal) is further split into six parts, as illustrated in Figure 3-8, and injected into the head-end of the slagging stage via six injection ports. The precombustor portion of the coal (30 to 45% of the total coal) is fed to the coal burner section of the precombustor. Transport lines are sized to prevent pulverized coal saltation and to control the carrier air flow split between the precombustor and slagging stage. Combustor shut-off valves (dust-tight) are mounted in the precombustor and slagging combustor transport lines as close to the combustor as possible.

3.3 LIMESTONE FEED SYSTEM

The Limestone Feed System (LFS), shown in Figure 3-9, supplies pulverized limestone to the TRW combustors. The limestone is injected into the outlet of the slag recovery section of the combustors, just prior to the furnace inlet. A single limestone feed subsystem services both combustors.

The pulverized limestone, nominally 70% through 200 mesh grind size, is transferred to the LFS silo via a pneumatic conveying system. The system includes a baghouse to remove the fine limestone particles from the air prior to discharge of the transport air to the atmosphere. The bottom of the silo has a vibrating bin activator that promotes the flow of limestone and relieves compaction at the discharge. From the silo, the pulverized limestone is discharged via a weigh scale feeder and an airlock to a two-way splitter. The air lock provides an even distribution of limestone across the two-way flow splitter and protects the mass weigh feeder from abnormal operating conditions. The flow splitter equally divides the total flow between the two combustors or it can be positioned to direct all the limestone flow to either combustor. A separate air-driven eductor (not shown) is used at each leg of the splitter to transport the limestone-air mixture to the single limestone injector located near the exit of each slagging combustor.

3.4 SPRAY DRYER ABSORBER AIR POLLUTION CONTROL SYSTEM

As noted above, pulverized limestone is fed into each combustor for SO_2 control. While passing into the boiler most of the limestone is decomposed to flash calcined lime by the following reaction:

$$CaCO_3 + \text{heat} \Rightarrow CaO + CO_2 \quad (1)$$

The mixture of this lime flyash, called flash calcined material (FCM), is distributed throughout the combustor exit gases. Depending on the initial sulfur level in the coal, the Ca/S ratio, and the limestone grind size, 15% to 70% sulfur removal can be achieved in the furnace. The secondary sulfur removal process, up to 90% removal, is through the multiple step process described below, of spray drying the slurried and activated FCM solids.

The flue gas desulfurization system, shown schematically in Figure 3-10, is comprised primarily of a spray dryer absorber and pulse-jet baghouse. Auxiliary systems include a reagent (FCM) storage, preparation and feed system and an ash conveying system. Use of the FCM as the sole SO_2 scrubbing reagent is a unique feature of the process, resulting in significant cost savings over the conventional use of pebble lime as the reagent, which is typical for most dry flue gas desulfurization systems.

Combustion gases discharged from the air heater outlet of the unit is directed to a dedicated 100% capacity spray dryer absorber (SDA) and PulseFlo® pulse-jet baghouse system wherein SO_2 removal and particulate collection takes place.

The combustion gases enter the SDA module via the roof gas disperser, which distributes the incoming flue gas symmetrically around the rotary atomizer. The roof gas disperser promotes mixing (i.e. gas liquid contact) of the combustion gases and reagent slurry to promote drying, maximize SO_2 removal and minimize solids deposition inside the SDA. The SDA utilizes a NIRO F-350 rotary atomizer to atomize the feed slurry (i.e. a mixture of FCM, reaction products, flyash and water) into a fine spray and inject it into the incoming combustion gases.

The finely atomized feed slurry mixes with the combustion gases, resulting in the evaporation of water and the removal of SO_2 via chemical reaction with the hydrated lime component of the slurry. The chemical reactions that occur as the hydrated lime ($Ca(OH)_2$) component of the FCM feed slurry reacts with the SO_2 produces reaction products in the form of calcium sulfite ($CaSO_3.½ H_20$) and calcium sulfate ($CaSO_4.2H_20$).

As the flue gas and feed slurry mixture pass through the spray dryer absorber, the concentration of the SO_2 is reduced substantially and the spray drying of the reagent slurry and reaction products is completed.

The combustion gases and entrained particles of calcium sulfite, calcium sulfate, unreacted reagent and flyash exit the SDA module into the PulseFlo® pulse-jet baghouse wherein the final step of the SO_2 and particulate removal processes takes place. The PulseFlo® pulse-jet baghouse removes >99.9% of the boilers exhaust solids, reaction products and recycled FCM before discharging the combustion gases to the stack.

Depending on percent ash removal in the combustor, coal sulfur content and Ca/S ratio, approximately 60-90% of the solids (i.e. reaction products, unreacted reagent, inerts, and flyash) collected in both the SDA module hopper and the pulse-jet baghouse hoppers is conveyed by the ash transport system to the flue gas cleaning system's FCM recycle surge bin. The remaining solids are rejected as waste.

Overall SO_2 removal efficiencies greater than 90% have been demonstrated when operating at furnace calcium to sulfur ratios in the range of 1.1 to 1.8.

3.5 BAGHOUSE PARTICULATE CONTROL

Particulate emissions control on the HCCP is achieved through a combination of the slagging combustors, the boiler, the SDA, and by the PulseFlo® pulse-jet baghouse. As previously noted, a significant portion of the coal ash never enters the furnace with the flue gases, since up to 90 percent of the ash in the coal leaves the slagging combustors as slag. Smaller amounts of wet and dry flyash is also removed from hoppers located at the bottom of the furnace, at the bottom of the boiler bank, and at the bottom of the air heater. A hopper is also located underneath the SDA. Final particulate control is accomplished using the PulseFlo® pulse-jet baghouse located between the SDA and the ID fan. Each of ten fabric filter compartments contains 225 six-inch diameter fiberglass bags. The effective length of each bag is 20 feet-0 inches and the gross air-to-cloth ratio is 2.8:1.

3.6 INSTRUMENTATION, CONTROLS, AND DATA ACQUISITION

The Plant Control System (PCS) provides control of the plant and serves as the system integrator for control, monitoring, and data collection. The PCS was provided by Bailey Controls and consists of Infi90 control components. All of the Combustion System, Coal Feed System, and Limestone Feed System control and monitoring equipment are standard plant components.

The PCS is capable of providing on-line monitoring and trending capabilities for pre-selected operating parameters for each plant system. A separate ODMS (On-line Data Management System) computer program by Bailey Controls provides the capability of: 1) monitoring on-line trends for any parameter that is recorded and 2) displaying requested parameters versus time in an Excel format (using the "At A Glance" data reduction program module). The ODMS system is only capable of storing approximately 2 weeks worth of data. Therefore, this system is backed up by transferring the data to Microsoft Access format and storing it on CDs.

For the majority of data trends reported during the DTP, the data is from the ODMS "At A Glance" data reduction program. Typically, the test data was retrieved from the ODMS on a daily basis and saved as 30 minute averages in an Excel File format. The majority of data used to prepare this report were retrieved by on-site TRW engineering personnel in this format. If additional data analysis was required during this report preparation, the CDs were utilized.

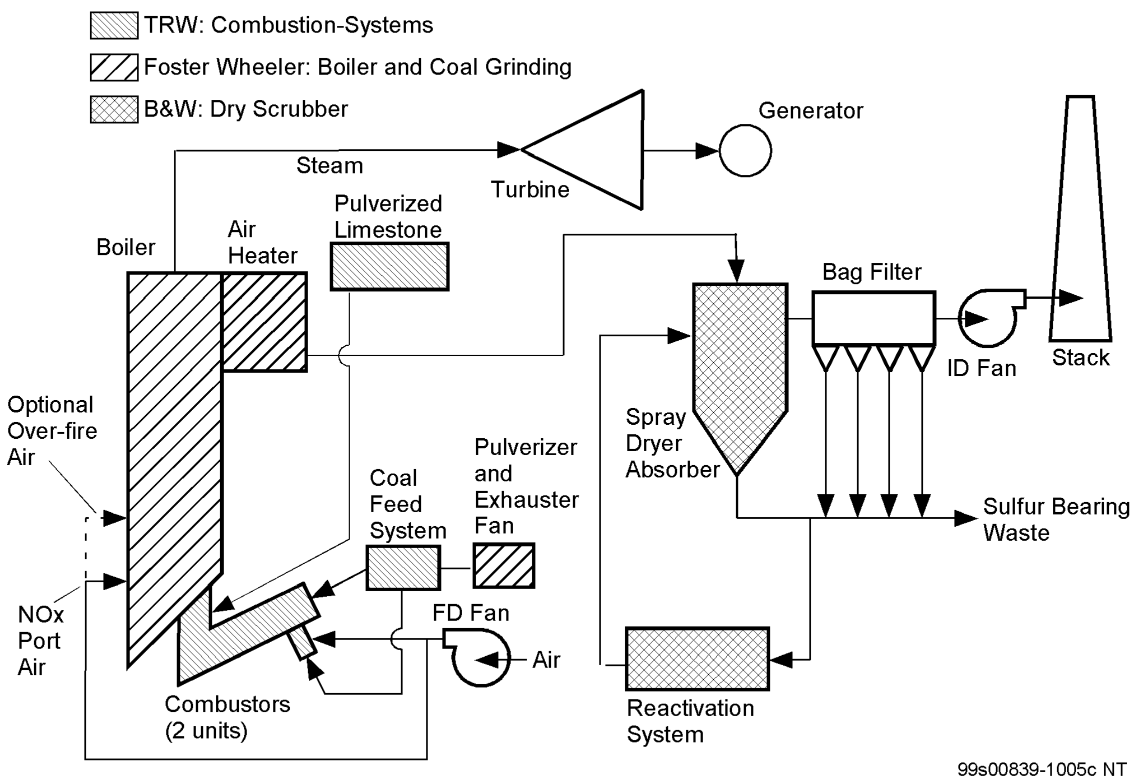


FIGURE 3-1 HCCP INTEGRATED SYSTEM

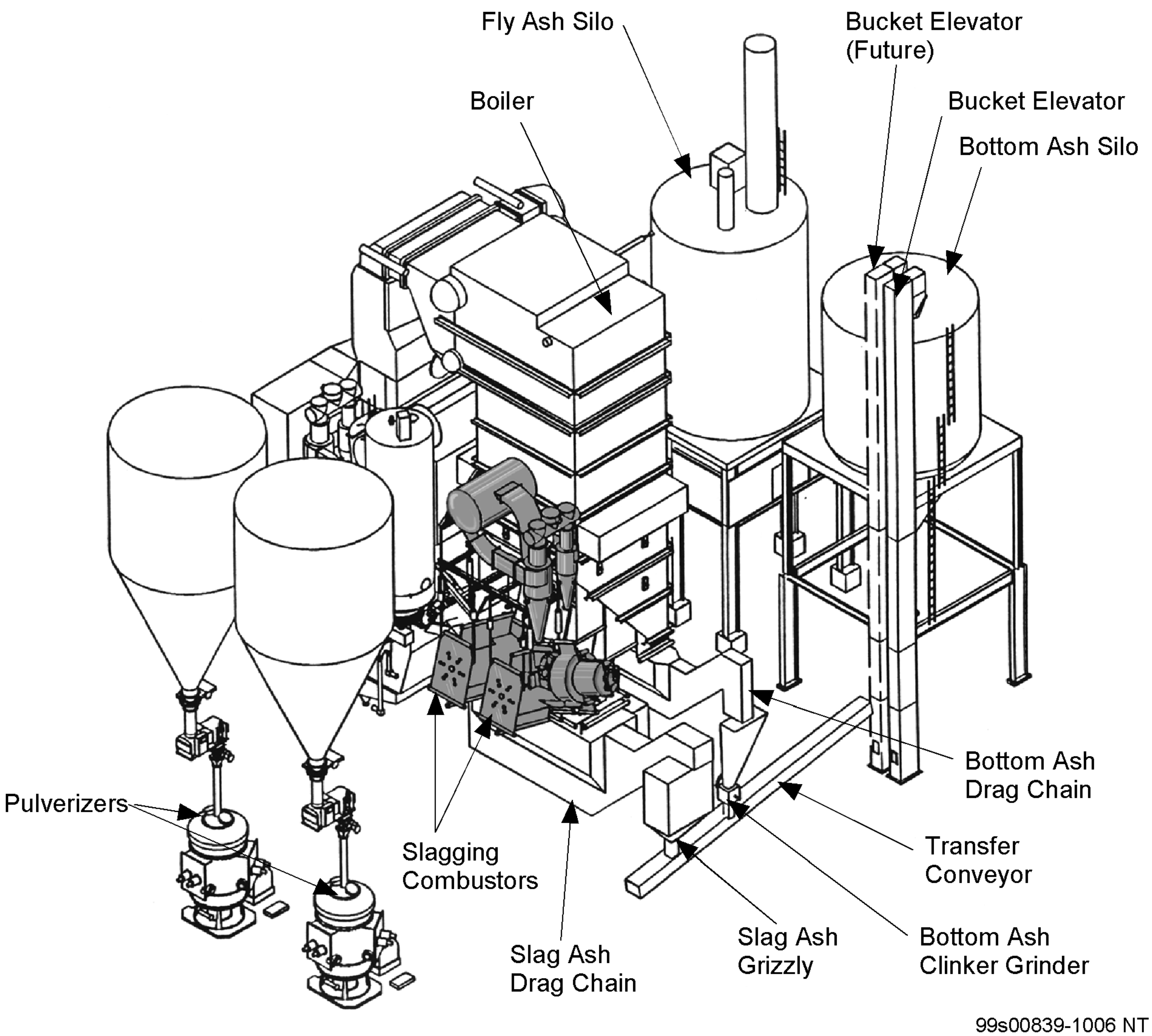


FIGURE 3-2 ISOMETRIC VIEW OF COMBUSTOR, BOILER, AND COAL FEED SYSTEM

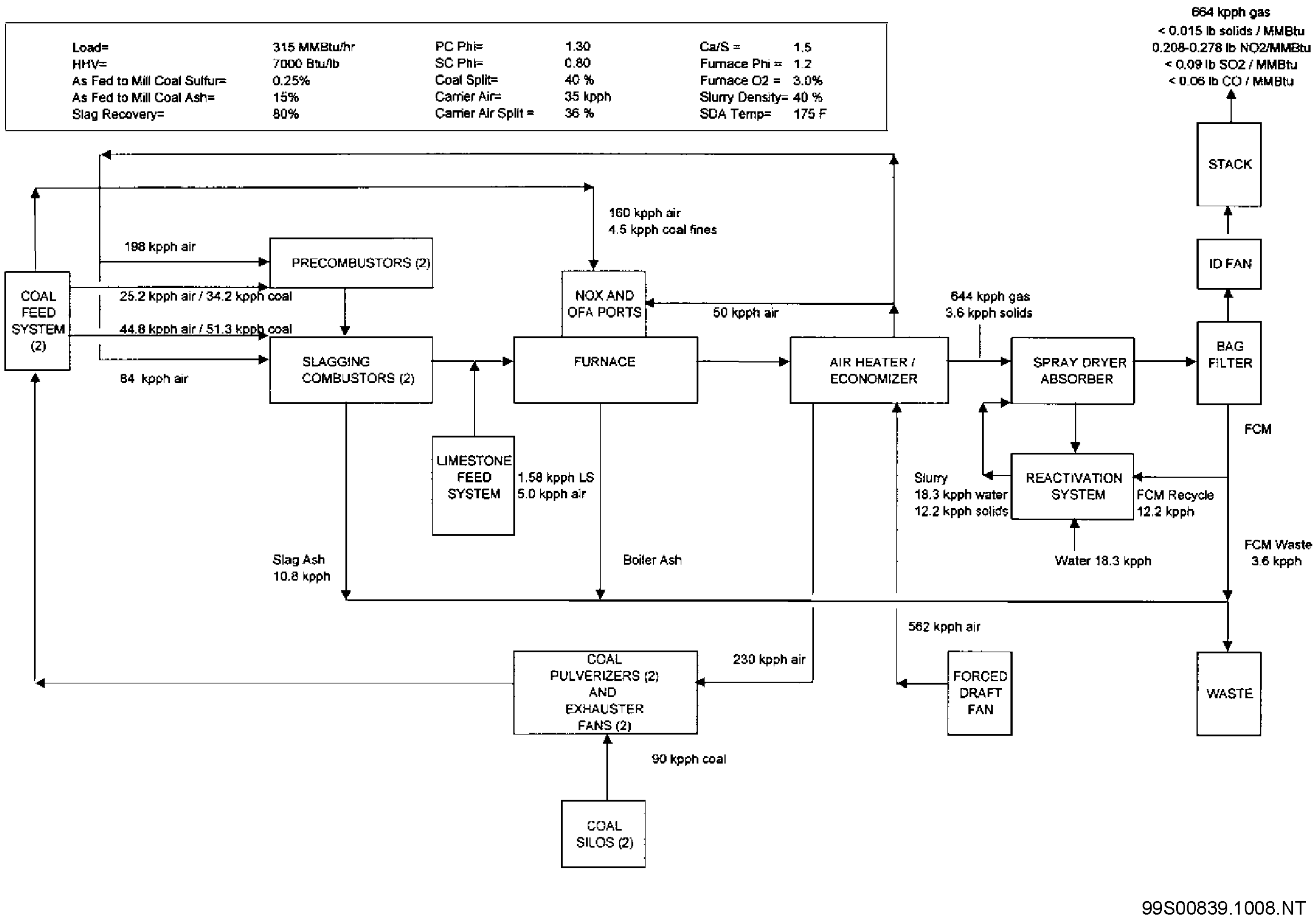


FIGURE 3-3 HCCP COMBUSTION SIDE GASES AND SOLIDS FLOWS

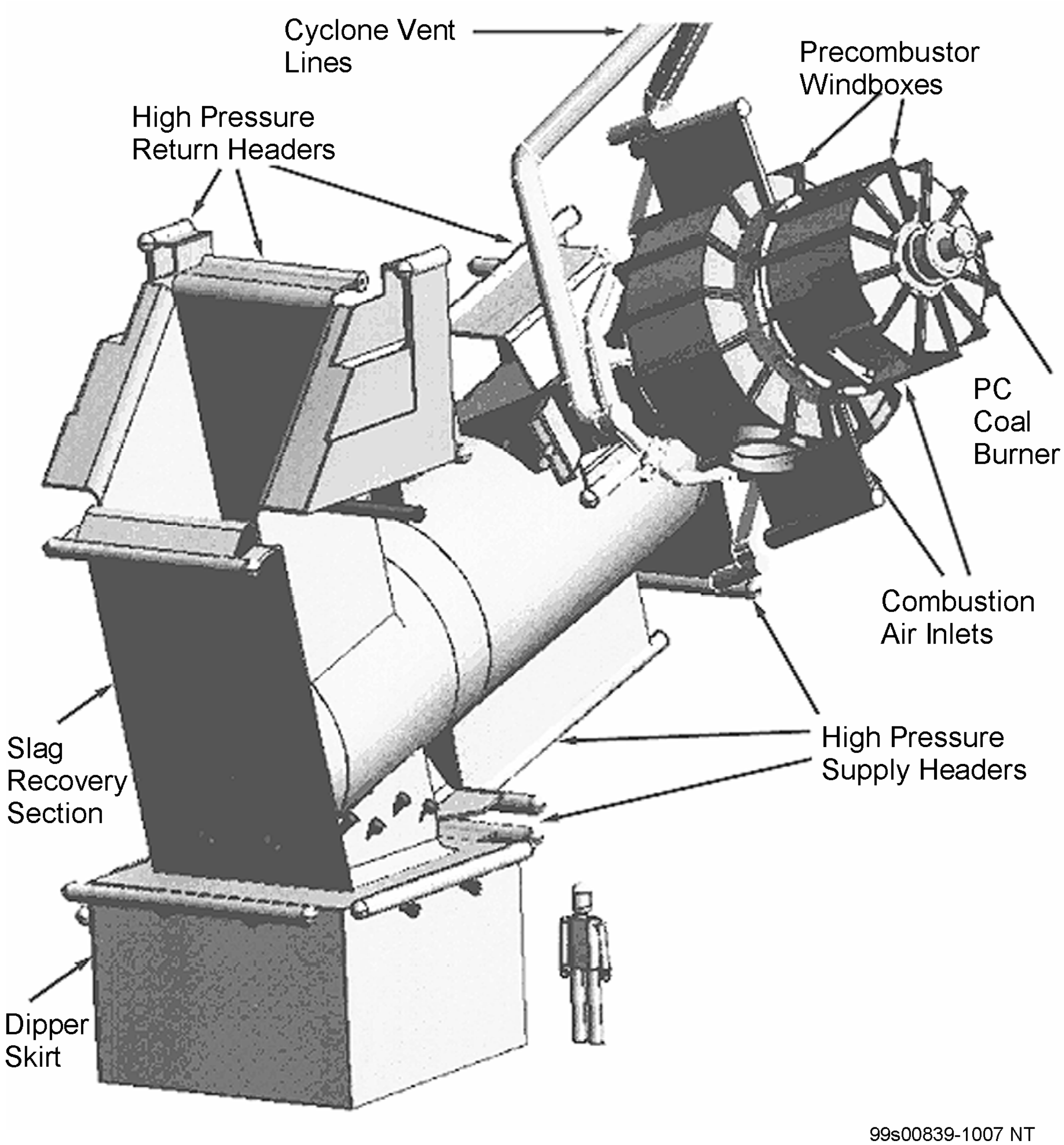


FIGURE 3-4 ISOMETRIC VIEW OF ONE OF THE TWO 350 MMBTU/HR TRW SLAGGING COMBUSTORS

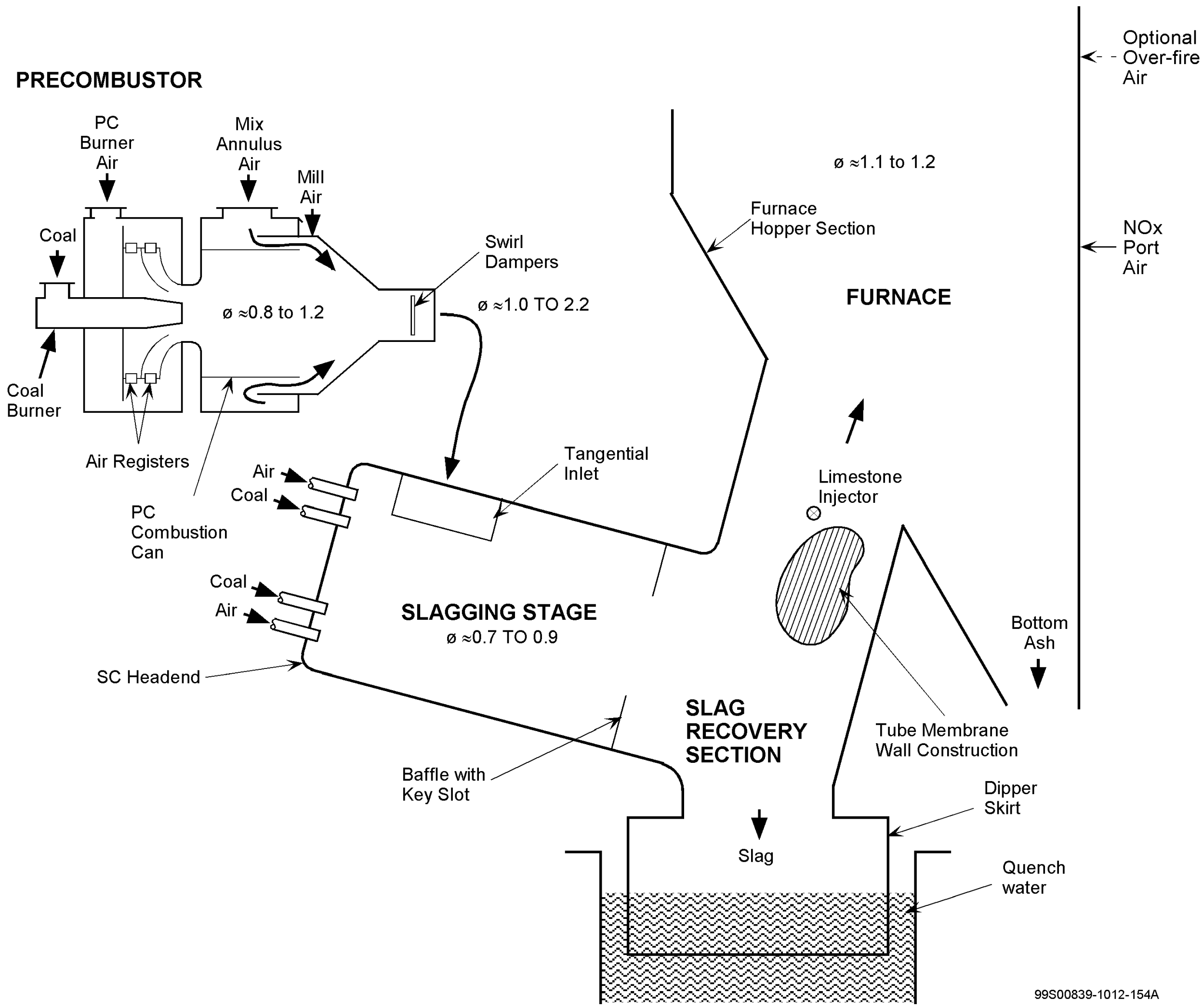


FIGURE 3-5 FUNCTIONAL SCHEMATIC OF TRW COMBUSTION SYSTEM

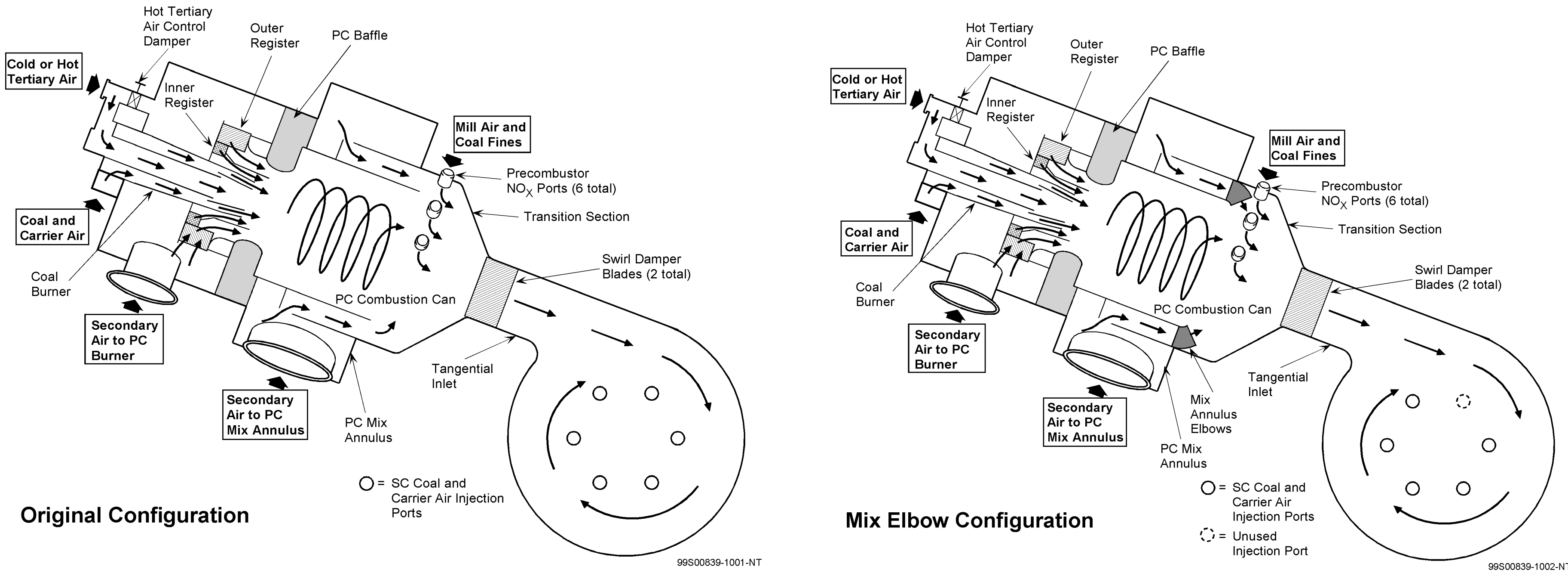
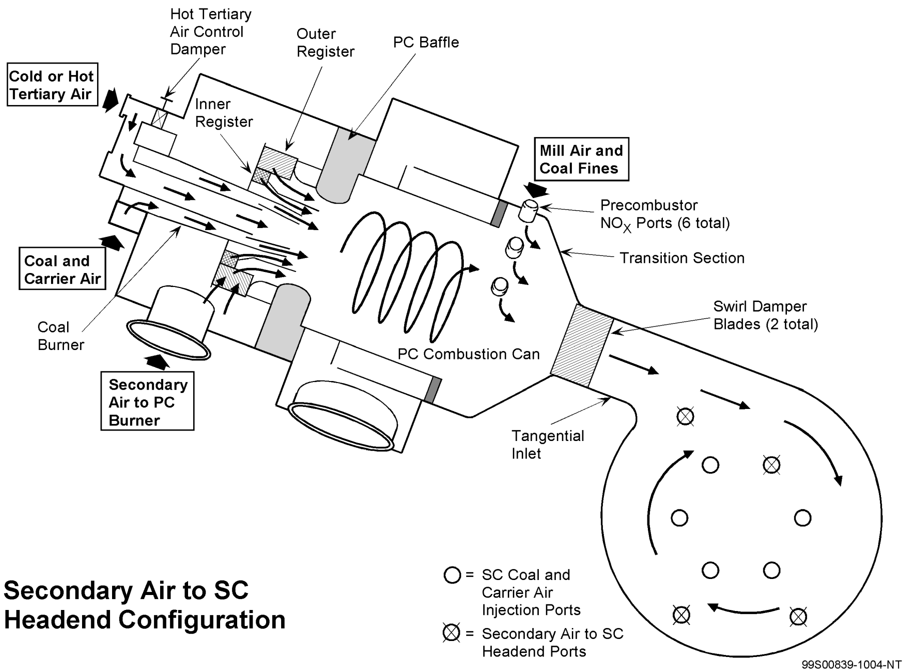


FIGURE 3-6 A,B PRECOMBUSTOR HARDWARE CONFIGURATION CHANGES



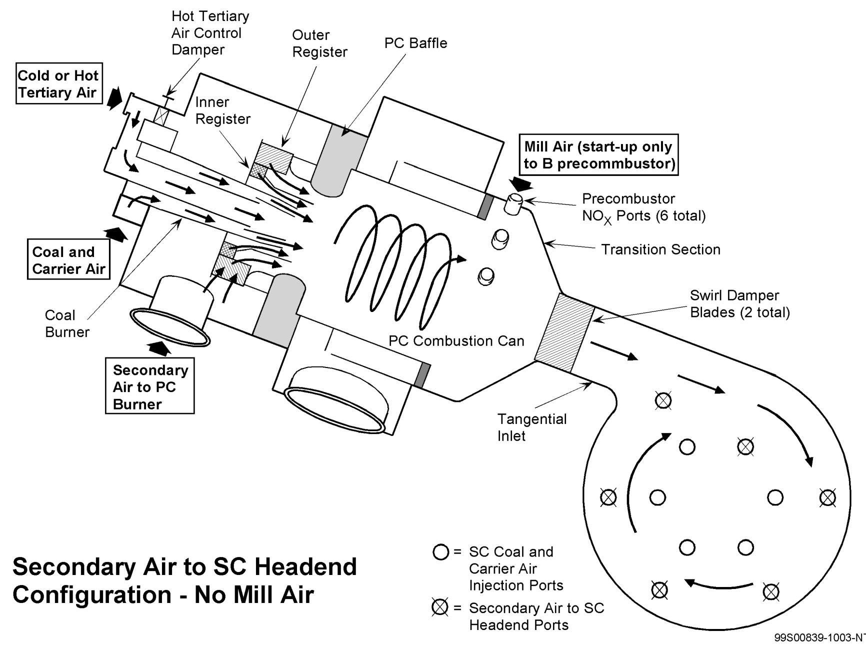


FIGURE 3-6 C,D PRECOMBUSTOR HARDWARE CONFIGURATION CHANGES

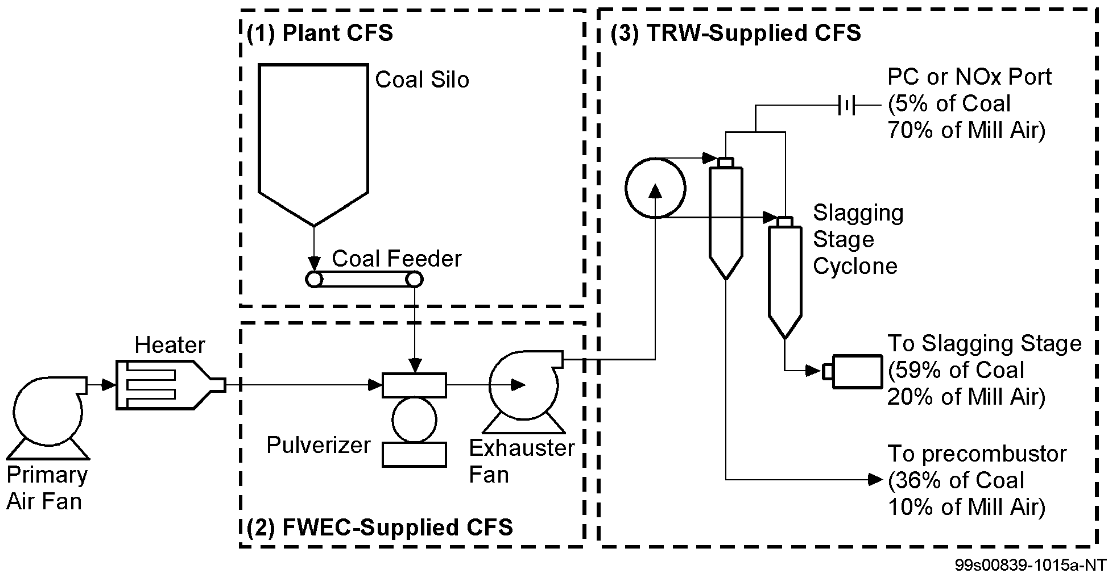


FIGURE 3-7 HCCP COAL FEED SYSTEM (CFS)

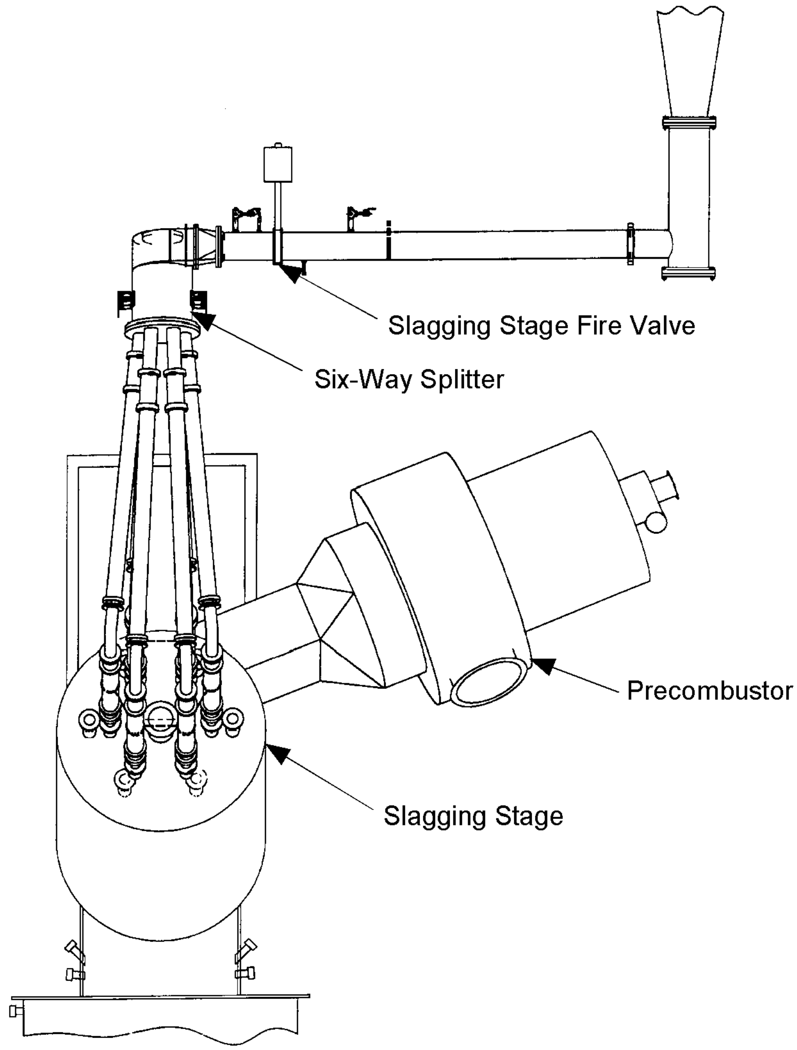


FIGURE 3-8 TRW SLAGGING STAGE COAL SPLITTER

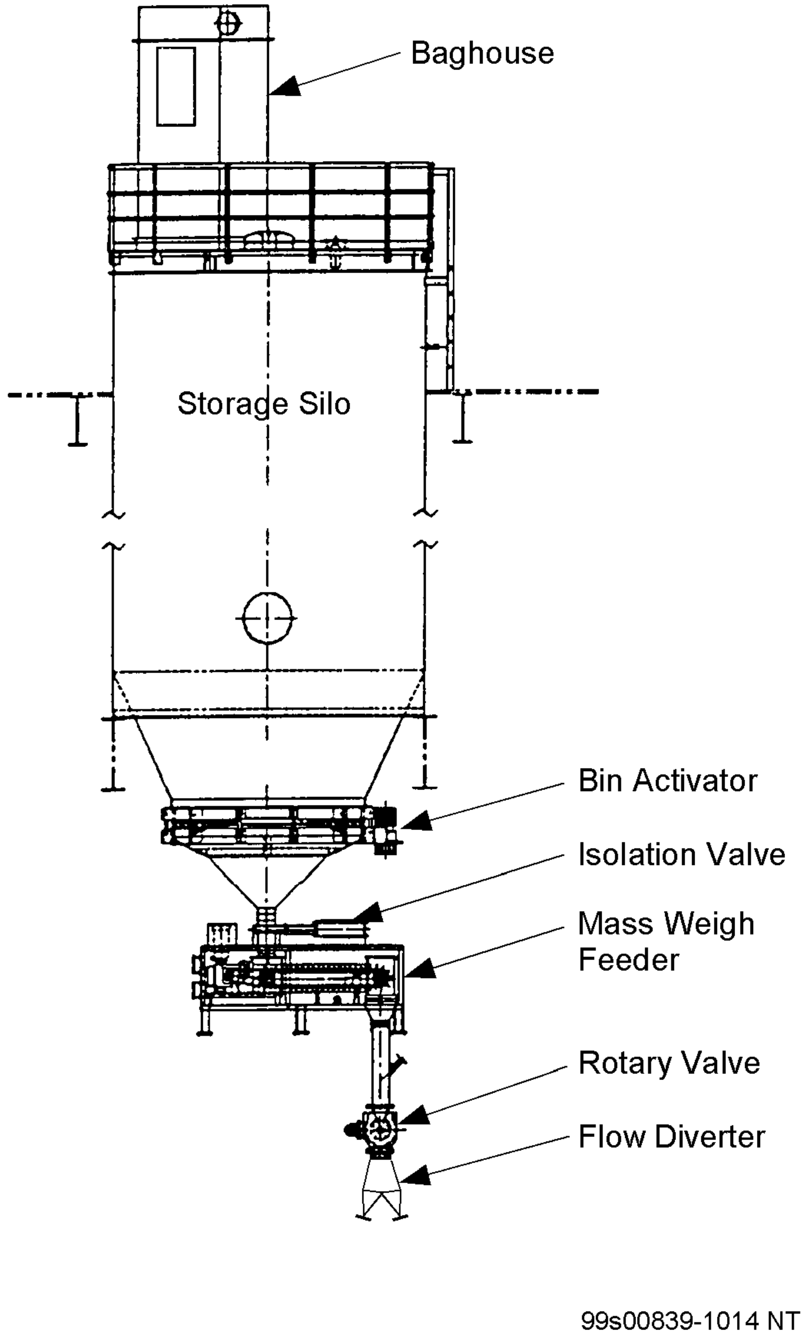


FIGURE 3-9 LIMESTONE FEED SYSTEM

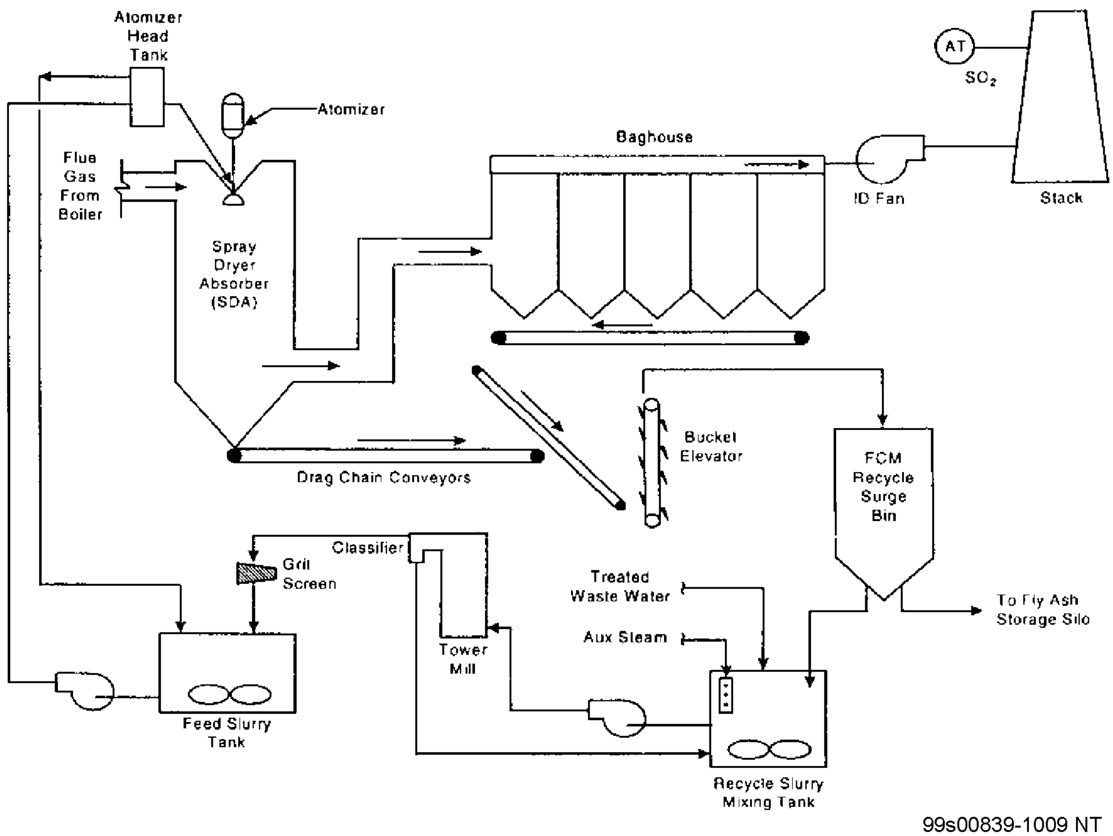


FIGURE 3-10 FLUE GAS DESULFURIZATION SYSTEM

4.0 TEST MATRIX AND APPROACH

The HCCP Demonstration Test Program was initiated in early 1998. The overall test program is comprised of several test activities including:

Task 1: Coal-firing Trials
Task 2: Compliance Testing
Task 3: TRW Combustion System Characterization Testing
Task 4: B&W SDA Technology Characterization Testing
Task 5: Boiler Characterization Testing
Task 6: Coal Blend Testing
Task 7: Performance Guarantee Testing
Task 8: 90-Day Commercial Operation Test
Task 9: Long-Term Commercial Operation Demonstration.

The TRW Coal Combustor Characterization test activities (Task 3), initiated in May 1998, were comprised of three distinct test series:

Test Series 1: Initial Performance Characterization Tests
Test Series 2: Operating Envelope Characterization Tests
Test Series 3: Steady-State Operation Characterization Tests

Approximately 4 cumulative months of Coal Combustion System Characterization test activities were performed during 1998. The majority of the test activities were performed during May, July, October, November, and December 1998. The Initial Performance Characterization Test Series was initiated and completed in May 1998, at the end of the Plant "Coal-firing Trials" operations. The second test series, Combustor Operating Envelope Characterization, was initiated in July 1998 and continued during October, November, and December 1998, when sufficient quantities of waste coal was available. This test series was approximately 70% complete at the end of 1998. The third test series, Steady-State Operation Characterization, was initiated in October 1998 and was approximately 20% complete by the end of 1998.

During 1999, approximately 2 months of Coal Combustor Characterization test activities were performed. The characterization test activities were performed during March through May 1999, in conjunction with the Boiler Performance Guarantee Test and other plant test activities. By early May 1999, the Combustor Operating Envelope Characterization test series (Test Series 2) was 80% complete and the Steady-State Operation Characterization (Test Series 3) was 50% complete. During August through November 1999, the long-duration 90-day Test was performed, which essentially completed Test Series 3.

By the end of 1999, all of the planned Technology Characterization and Performance Guarantee testing (Tasks 4, 5, and 7) had been completed. The 90-day Commercial Operation Test (Task 8) was initiated in August 1999 and successfully completed in November 1999. The Long-term Commercial Operation Demonstration (Task 9) was not completed prior to the DOE reporting deadline.

4.1 INITIAL COMBUSTOR PERFORMANCE CHARACTERIZATION TESTS

The objective of the Initial Combustor Performance Characterization tests was to establish the baseline performance of the Combustion System while burning Run-of-Mine (ROM) and ROM / Waste Coal blends. During this first phase of the test series, the combustor performance was evaluated for the baseline configuration at the nominal "design" operating conditions specified for ROM and Performance Coal (a ROM/Waste coal blend). Following this baseline characterization, variations were made in the key combustor operating conditions, including slagging stage stoichiometry, precombustor stoichiometry, precombustor coal split, and slagging stage inlet velocity. The operating ranges were limited to that required to achieve reasonable performance of the combustor in terms of gaseous emissions at the stack, slagging behavior, and slag recovery. Key performance parameters were on-line emission measurements of NO_x, SO_x, O_2, and CO, online indications of slagging behavior including slag quality and quantity on the drag chain and combustion chamber pressure indications, and coal feed system pressure drops. In addition, for several steady-state tests of at least 12 hours in duration, the combustor slag was weighed in order to determine the baseline slag recovery at "nominal" operating conditions.

Diagnostic measurements required to support this test series included: on-line gas analyzers for NO_x, SO_2, and CO_2 at the stack and O_2 and CO in the furnace, daily on-line sampling of coal to determine ash, moisture, and Btu content, low pressure cooling system flow and temperature measurements, and coal feed system pressure measurements. Also, during this initial test series, a method for visually observing the slagging behavior of the precombustor internal surfaces during operation was evaluated. This method entails observing the slag movement during coal-firing and/or subsequent oil-firing only conditions by looking through the aspirating doors located in the precombustor mill air ports, and tangential air inlet. At the end of each approximately two week test segment, physical access to the combustors was provided to allow evaluation of the slagging behavior in areas that were not visible through the aspirating doors (i.e., the headend and main chamber of the slagging combustor, the precombustor combustion chamber, the keyhole baffle in the slagging stage and the tangential inlet to the slagging combustor).

This initial test series was initiated in May 1998 and completed in June 1998, when the combustion system was operated continuously, while burning run-of-mine coal, for a 2-week time period during which time the Environmental Compliance testing was performed.

4.2 COMBUSTOR OPERATING ENVELOPE CHARACTERIZATION TESTS

The objective of the second test series was two-fold: 1) characterize the performance of the combustor over a broad operating envelope and 2) optimize the performance of the combustor for the HCCP coal properties and integrated plant system characteristics. The test matrix for this test series is shown in Table 4-1, which lists the specific combustor operating parameters evaluated, the planned range of operation for each parameter, and the actual range of operation evaluated during the DTP. This test series focused on characterizing the combustion system performance over a wide range of operating conditions including stoichiometry (both precombustor and slagging combustor), precombustor exit conditions (temperature, stoichiometry, and velocity), coal feed characteristics (coal carrier flowrates, coal grind), secondary air injection locations and mixing characteristics, limestone Ca/S ratio, furnace stoichiometry, and load. Diagnostic measurements included on-line exhaust gas measurements (CO_2, NO_x, and SO_2) recorded on the PCS, on-line furnace gas measurements (CO and O_2) recorded on the PCS, on-line SO_2 measurements upstream of the SDA recorded on the PCS, sampling and analysis of slag and flyash, pressure loss measurements, and on-line and post-test observations of slagging behavior including overall slag coverage on the precombustor and slagging stage combustor internal surfaces, furnace interface, and slag recovery tap.

In order to map the combustor operating envelope, each of the operating variables were typically varied independently during this characterization test series. When completed, the data from this phase of the test series was used to

- Determine the boundaries for each operating parameter. For example, the broader the boundary for stoichiometry in the precombustor and slagging combustor, the less adjustment of coal feed split will be required for changes in load and/or coal properties.

- Determine the best location for secondary air injection. Key considerations include precombustor performance parameters (stoichiometry, temperature, and exit velocity), slagging behavior (precombustor and slagging stage), carbon burn-out, and NOx.

- Evaluate and update alarm parameters and alarm and trip levels

- Provide a basis for comparison of the HCCP combustor performance to that of the TRW 40 MMBtu/hr Cleveland Combustor in order to verify scaling methodology as well as extrapolation to other coal types and process conditions. The HCCP combustor scaling is based on the 40 MMBtu/hr Cleveland Combustor test data and various TRW-developed computer models, which were used to define the HCCP combustor operating envelope in terms of firing rate, stoichiometric ratio, and coal flow split, as well as predicting pressure drop, slagging behavior (fouling limits), slag recovery, carbon burnout, and gaseous emissions. This "predicted" operating envelope and performance limits will be compared to the actual operating envelope mapped during the HCCP test series.

- Obtain design, configuration, operational, and performance data for future TRW Multi-stage Clean Coal Combustor and Coal Feed System designs

- Determine the optimal operating conditions for long-term commercial operation at Healy. This includes determination of the "best" conditions for the combustion system in terms of performance (CO emissions, NO_x emissions, SO_2 emissions prior to SDA, carbon burnout, slag recovery, slagging behavior and air side pressure losses), as well as the "best" conditions for integrated system operation.

The test matrix, as shown in Table 4-1, is comprised of approximately 55 individual "test conditions". As shown, approximately 48 of the parametric test conditions were completed. During 1998, complete characterization of the precombustor operating parameters (i.e. precombustor coal split, precombustor stoichiometry, coal carrier flow rate and PC mill air flow rate) and partial characterization of the slagging stage and furnace operating parameters was performed. The initial characterization of the slagging combustor stoichiometry was performed during early1998, however a complete characterization of the slagging combustor stoichiometry with the final combustor configuration was not completed. Furnace operating parameters (i.e., furnace excess air flowrate and injection location) were also not completely characterized.

During 1999, limestone and coal blend parametric tests as well as load sweep tests were completed. Completion of these tests occurred in conjunction with the 90-day Commercial Operation Test, SDA Performance Characterization Tests, and Turbine Performance Guarantee Tests, which were performed during the latter part of 1999. Following these test series, the only remaining combustor characterization tests will be the characterization and optimization of the slagging stage and furnace operating parameters for minimizing NO_x emissions.

The coal grind tests were eliminated from the test matrix due to limited capability at the HCCP to accurately control and measure the coal grind. For all tests, the coal grind varied from 50% to 70% through 200 mesh for the same setting on the mill classifier. The coal grind also appears to vary somewhat as a function of coal type.

4.3 STEADY-STATE OPERATION CHARACTERIZATION TESTS

The objective for the third test series is to evaluate the combustion system operating conditions during longer-term steady-state operation. After determination of the "best" configuration and operating conditions for the combustor system based on the results of the second test series, a minimum of two steady-state tests were conducted, one at part-load and one at full load. The specific operating conditions were determined based on the test results obtained during the second test series.

Representative slag samples should be analyzed to confirm environmental characteristics (e.g., non-leachable, non-hazardous). This analysis will provide useful information regarding potential commercial applications, as well as meeting environmental requirements for disposal. Although there are currently not any commercial uses for the slag generated at the Healy site, potential uses at other locations include recycling as a construction material additive (e.g., concrete mix aggregate, asphalt road paving material, etc), abrasives, and architectural media (e.g.,. ceramic roofing tiles). The viability of these potential applications are all site specific.

As noted above, this third test series of the TRW Combustor Characterization task was initiated in October 1998 but was only 50% complete by the end of June 1999. Completion of the third test series occurred in conjunction with the 90-day Commercial Operation Test, which was performed during the latter part of 1999. The results from the 90-day Test will be released in a separate topical report prepared by AIDEA.

Also during the 90 Day-Commercial operation test series, preliminary tracking of the O&M costs associated with the HCCP was initiated. In addition to the standard O&M tracking, a separate category was added to track infant mortality and "new" technology problems separately. For example, since this is a Demonstration Test Program, it is anticipated that there may be reduced system availability due to components that require re-design, operator error, or other similar problems. By tracking these O&M costs separately, there will be a better baseline for projecting future HCCP as well as "next plant" O&M costs and performing comparisons to other technologies. In addition, operational or process changes which have an impact on O&M costs will be noted on the log, such that the economic impact of these changes can be determined (at least on a relative basis) at the end of the Demonstration Test Program. The 90-day test results will be released in a separate topical report prepared by AIDEA.

TABLE 4-1 COMBUSTOR OPERATING ENVELOPE CHARACTERIZATION TEST MATRIX

Operating Parameter	Operating Range	Conditions Tested to Date	Tests Remaining	Performance Parameter	Diagnostics
1 Slagging Combustor Stoichiometry	0.76 0.78 0.80 0.82 0.84 0.86 0.88 0.90	 x x x x	"a" x x x x x x	Gaseous Emissions (Nox, SO2, CO) Slagging Behavior (Slag Coverage, Fouling at Coal Injectors, and Furnace Opening) Slag Recovery Heat Load	Gas Analyzers Cooling System, Flow, and Temperature Metal Thermocouples Slag Weight Carbon Content of Slag Post Test Visual Observations of Slagging
2 Precombustor Chamber Stoichiometry	0.60 0.70 0.80 0.90 1.00 1.10 1.20	x x x x x x x		Gaseous Emissions (Nox, CO) PC Slagging Behavior (Slagging and Fouling within PC and Inlet to SC PC Heat Flux Gas Temp at Inlet to SC	Same as above plus temporary gas thermocouple at inlet to Slagging Combustor
3 Precombustor Coal Split (or Fraction)	0.30 0.34 0.38 0.42 0.46	x x x x x		Same as both items above	Same as above
4 Slagging Combustor Inlet Velocity (ft/s)	250 280 310 340 370	x x x x x		Pressure Losses Slagging Behavior (Slag Coverage and Fouling) Slag Recovery Heat Load	Same as above
5 Limestone Ca/S	1 2 3 max	x x x x	"b" x x x x	Feed System Stability SO2	Gaseous Emissions (SO2) Post Test Slagging Behavior in Region of Limestone Injector
6 Coal Grind	50-70 % thru 200 mesh (typical range observed during testing)	x		Slag Recovery Carbon content in slag Carbon content in flyash CO and smoke limits Coal Feed Stability Heat Load Slagging Behavior	On-Line Isokinetic Coal Sampling and Particle Size Measurement Slag Weight Slag and Flyash Sampling and Measurement Gas Emissions Coal Feed System Pressure and Flow Measurements Cooling System, Flow, and Temperature Metal Thermocouples Post-test visual observations
7 Coal Blend	ROM Perf Blend 55/45 Blend	x x x		Slag Recovery Carbon content in slag Carbon content in flyash Slagging Behavior Coal Feed Stability	On-Line Isokinetic Coal Sampling and Particle Size Measurement Slag Weight Slag and Flyash Sampling and Measurement Gas Emissions Coal Feed System Pressure and Flow Measurements Post-test visual observations
8 Coal Carrier Flow Rate (kpph)	30 35 40 45	x x x x		Coal Feed Stability Slagging Behavior (fouling in region around coal injectors, slag coverage) Slag Recovery Carbon content in slag	Coal Feed System Pressure and Flow Measurements Post-test visual observations Slag Weight Slag sampling and analysis
9 Precombustor NOX Port Air Flow Rate (kpph)	0 20 25 30 35 40	x x x x x x		NOX Slagging Behavior Gas Temp at SC Inlet	Gas Analyzers Post test visual observations
10 Furnace Excess Air (kpph)	3.0 3.5 4.0 4.5 5.0	 x x x	"a" x x	NOX CO and smoke limits Furnace Deposits Boiler Efficiency	Gas Analyzers
11 Load Sweep	50 60 80 100 %	 x	"c" x x x x	Determine optimum stoichiometry and velocity for each load Determine optimum rate of change of load Steam Control Slagging Behavior Slag Recovery	Same as items noted in Slagging Combustor stoichiometry above

Notes
a - not currently planned
b - completed later in 1999 during the SDA Performance Characterization Tests
c - completed later in 1999 during the 90-Day Test, and also the Dispatch Tests

5.0 TEST PROCEDURES

In general, the test procedures for the Combustion System Characterization Testing were identical to the overall test procedures developed during the Coal-Firing Trials. The only additional procedures performed during the Combustion System Characterization Tests related to additional diagnostics. The following sections provide an overview of the test procedures.

5.1 START-UP AND SHUT-DOWN

The combustion system startup and shutdown operations are similar in principal to conventional pulverized coal burner operations. The combustion system control logic essentially consists of controlling precombustor, slagging combustor, and furnace stoichiometry at pre-determined levels throughout each step of the start-up process. The basic steps are:

- Start-up of oil ignitors,
- Increase oil ignitor firing rate to maximum
- Inerting of mill and CFS,
- Start-up of mill exhauster fan,
- Open precombustor mill air, precombustor, and slagging combustor shut-off valves,
- Establish correct coal carrier air flowrate by adjusting mill air split between coal carrier air and cyclone vent air
- Start coal pulverizer,
- Start coal feeder,
- Increase coal feed rate and decrease oil feed rate,
- Transfer mill air from precombustor to furnace when coal flow is greater than 25,000 lb/hr and/or steam flow is greater than 200,000 lb/hr
- Increase coal load with oil ignitors at minimum,
- Oil ignitors shut-off,
- Increase coal feed rate to full load

These basic steps of the start-up process are shown graphically in Figure 5.1, which illustrates thermal load of oil and coal as a function of the start-up process. Figure 5.2 provides a summary of the typical mass flows of air, coal, and oil for each step in the start-up process.

In May 1998, the start-up process was automated such that increasing the oil ignitor firing rate to maximum, opening of the combustor shut-off valves, establishing the correct coal carrier air flowrate, increase of coal feedrate and decrease of oil feedrate, transfer of mill air to furnace NO_x ports, increase of coal load and oil ignitor shut-off occurred automatically as specified permissives were met. Throughout each step of the process, the control logic automatically adjusted and controlled the stoichiometry to ensure safe operating conditions. This automated logic simplified the start-up process and reduced the start-up time significantly. By the end of 1998, coal start-up times (from inerting mills through full coal load) of less than 1 hour had been demonstrated.

5.2 STEADY-STATE OPERATION

Steady-state operation is similar to a conventional pulverized coal boiler. For the Demonstration Test Program, approximately 100 parameters related to the Combustion System and associated consumable feed systems are monitored on-line on the PCS. The majority of these parameters are for diagnostic purposes, not plant operation. For the majority of parameters, pre-determined alarm and trip levels were established. Alarms include visual alarms that are displayed on the alarm screen, as well as audible alarms for certain critical parameters.

During the Combustor Characterization Test Series, the only "special" procedures related to diagnostics. The diagnostics were listed for each test series in the test matrix presented in Table 4.1. Additional details related to the diagnostics are presented below:

- For all of the tests, gas emissions at the stack were required. The gas emissions were included as parameters on the PCS. These included CO and O_2 measured at the inlet to the high temperature air heater, as well as the typical stack analyzers for NO_x, SO_2, and CO_2. In addition, SO_2 was measured upstream of the SDA in order to determine the SO_2 concentration exiting the boiler / furnace. This data was also available on the PCS.

- For several tests, sampling of coal, slag, flyash, and limestone was required. Details on the sampling procedures are contained in Section 5.4

- For several tests, measurement of slag recovery was required. In order to determine slag recovery, the ash content of the coal and the slag weight must be determined. The ash content was typically determined from proximate analysis of the coal sample taken by the automatic coal sampler during the daily coal loading process. Initially, the slag weight was determined by measuring the actual slag accumulated during a steady-state 12 to 24 hour period. This was accomplished by dumping the slag ash into a dump truck that contained a load cell, every 12 to 24 hours. Ultimately, the load cell on the slag ash hopper was used to determine the slag weight. It should be noted that, in both cases, the slag weight included the slag ash, bottom ash, and pyrites, since all of these constituents were dumped into the slag tank.

5.3 SAMPLING

As part of the Combustor Characterization Test Series, sampling and chemical analysis of consumable and waste streams was implemented. Typical samples taken for specific tests included coal, slag, flyash, and limestone. Table 5-1 is a summary of the typical chemical analysis performed on the samples.   Chemical analysis results can be found in Appendix C for coal, slag, and flyash, and Table 6-2 for limestone. Additional details on the sampling requirements and techniques are reported in the following sections.

5.3.1 Coal Sampling and Chemical Analysis

During the Combustor Characterization Test Series, special coal sampling procedures were implemented. Initially, coal samples were taken from a total of 5 separate locations within the coal feed system. All of the samples, with the exception of the coal belt automatic sampler, were grab samples. During the first month of the test series, it was determined that the most representative samples were those taken from the coal belt automatic sampler, coal feeders, and downstream of the coal pulverizer. Therefore, only these three samples were taken for the remainder of the test series.

1. Coal Pile - A shovel-full of coal was grabbed from the coal pile in the region that was being loaded for the current test. A sample of both the waste coal (or waste coal blend) and the ROM coal was obtained. The coal sample was then ground and blended in the lab to obtain a "representative" sample and a proximate analysis was performed.

2. Coal Belt Automatic Sampler - The automatic sampler continuously (every 3 minutes) grabs a small portion of coal off of the belt as the coal is being loaded in the plant coal silos. The sampler is operated continuously during the coal loading process and then the accumulated coal sample is removed and sent to the lab for analysis. Originally, during 1998, the coal sample was stored in a refrigerator prior to being sent to the lab for analysis. However, this was eliminated during late 1998, based on the recommendation of coal sampling experts.

3. Coal Belt upstream of Coal Silo - During coal loading, a sample of coal was manually grabbed from the belt just upstream of the coal silos. The samples were identified as either A or B Silo sample.

4. Coal Feeders - During operation, coal samples were grabbed from the A and B coal feeders using a specially designed "shovel" which scooped a representative sample from across the width of the belt feeder. A portion of this sample was placed in a plastic bag and sent to the lab for proximate analysis. In some cases, ultimate and ash mineral analysis was also performed on the samples. Originally, in 1998, the feeders samples were stored in the refrigerator until the samples were sent to the lab for analysis. However, refrigerated storage was eliminated during the latter part of 1998, based on the recommendation of coal sampling experts.

5. Downstream of Coal Pulverizer - During operation, an "isokinetic" pulverized coal sample was obtained from the 40 inch diameter vertical coal pipe downstream of the exhauster fan. The sample was not truly isokinetic since only the centerline of the pipe was sampled. However, the average velocity in the pipe and the average velocity in the sample probe were matched. The sample was then sent to the lab for proximate and sieve analysis. Originally, in 1998, the pulverized coal samples were stored in the refrigerator until the samples were sent to the lab for analysis. However, refrigerated storage was eliminated during the latter part of 1998, based on the recommendation of coal sampling experts.

The coal analysis results for each test are included in Appendix C.

5.3.2 Slag Sampling and Chemical Analysis

For several tests during the Combustion System Characterization Test series, a slag "grab" sample was obtained during the steady-state portion of the test. The sample was grabbed from the slag ash drag chain as it exited the slag tank. As noted previously, the slag ash hopper includes pyrites as well as the combustor slag. When practical, an attempt was made to take the slag sample during a period of time when the pyrite hoppers had not been dumped into the slag tank within the past hour. However, during operation with high waste coal blends, the pyrite hoppers were often dumped continuously and hence it was not feasible during tests with high waste coal blends to obtain a slag sample that did not include pyrites. In addition, beginning in late 1998, the filtering system for the slag ash water was modified such that the slag ash water always contains a high level of suspended solids, including pyrites.

The original intent of the slag sampling had been to determine the carbon content of the slag in order to estimate the overall combustion efficiency. However, due to the factors noted above, a truly "representative" sample of the slag was not obtained during the 1998 test series. This effort continued during 1999 but the same types of problems were experienced, especially during operation with high waste coal blends when pyrite dumping occurred several times per hour. For one slag sample taken during 1999, the sample was dried and separated into slag particles (black-colored, glassy, rounded particles) and pyrite particles (dull-colored, angular-shaped particles).

The slag particles were then analyzed for carbon content and the results are presented in Appendix C.

5.3.3 Flyash Sampling and Chemical Analysis

For several tests during the Combustion System Characterization Test series, a flyash grab sample was taken from the flyash surge tank, upstream of the SDA. A special “drop flask” was dropped into the vent pipe at the top of the silo, lowered into the flyash, and a sample was extracted. For selected tests, the flyash was analyzed for $CaCO_3$, CaO, and $CaSO_4$ content. The analysis results are included in Appendix C.

5.3.4 Limestone Sampling and Chemical Analysis

Limestone samples were taken from two locations: 1) A sample was taken from each limestone load delivered to the plant prior to loading in the silo and 2) Occasionally, grab samples were taken from the outlet of the limestone feeder. The sample taken from each limestone load was sent by GVEA to a lab for analysis of $CaCO_3$ content and grind size. Table 6-2 of Section 6.1.2 contains a summary of the limestone analysis results. In general, the $CaCO_3$ content of the limestone supplied for the 1998 Demonstration Test Program was 60 to 70%, which is well below the specification of 90% $CaCO_3$. During 1999, an alternative limestone supply was used for several tests (e.g., SDA Performance Guarantee Test) and during periods of time when the local limestone supplier could not supply a sufficient quantity of limestone on a continuous basis. This alternative limestone supply contained typically 90% or greater $CaCO_3$, however the limestone particle size often varied from the 70% through 200 mesh specification.

5.4 ON-LINE SLAGGING OBSERVATIONS

For the majority of tests, observations of the slagging behavior on the walls of the combustor and combustor / furnace interface were required. In order to observe slagging behavior, visual access to the combustor was required. On-line, these diagnostics were limited to visual observations through the rodding ports located on the precombustor mill air spool and the precombustor tangential exit. Increases and decreases in the precombustor chamber pressures also provided some on-line indication of the precombustor slagging behavior. For the majority of test series, physical access to the combustor for direct observation of the slagging behavior was required. This occurred, on average, approximately once every two to three weeks during 1998 and every four to six weeks during 1999. Typically, the combustor required 24 hours of cool down prior to access for post-test observation. A summary of slagging observations for testing in 1998 and 1999 can be found in Section 7.1.4 and Section 7.2.4, respectively.

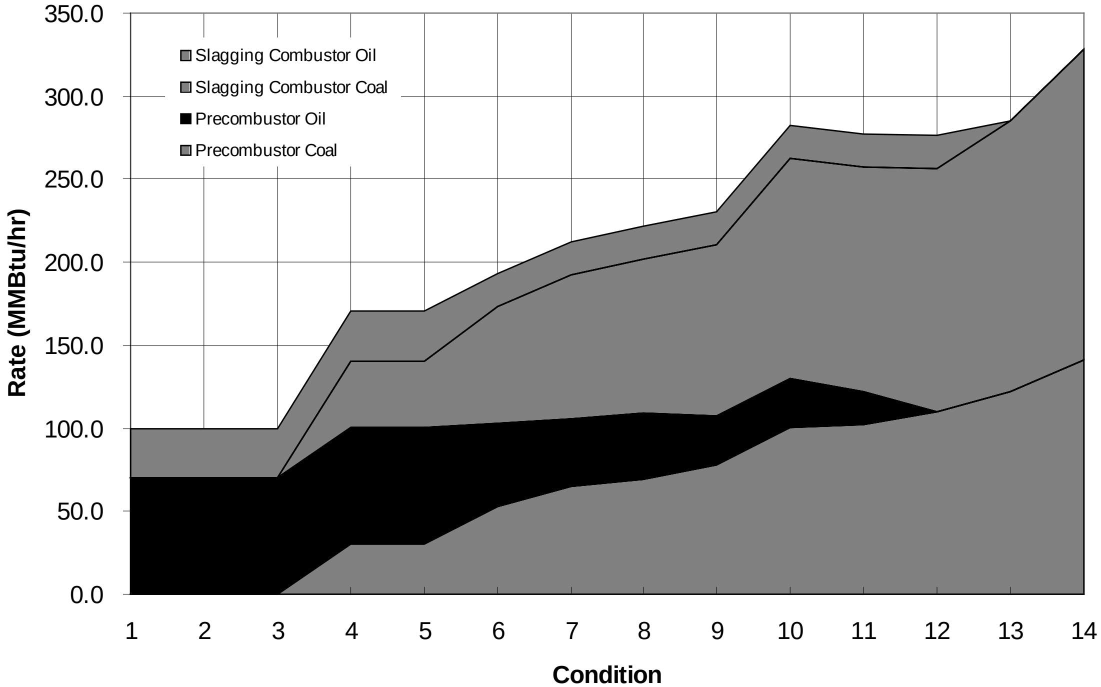


FIGURE 5-1 COMBUSTION SYSTEM START-UP

CONDITION		AR HHV=	7076	Split=	0.43	Cyc. Eff.=	0.95	Carrier Temp=		135	
		Total Load	Coal PPH	Coal MMBtu/hr	PC Coal MMBtu/hr	SC Coal MMBtu/hr	PC Oil MMBtu/hr	SC Oil MMBtu/hr	PC Can Phi	PC Exit Phi	PC Texit
Oil Only	1	100.0	1	0.0	0.0	0.0	70.0	30.0	1.30	1.30	3330
Mill Air Start	2	100.0	1	0.0	0.0	0.0	70.0	30.0	1.10	1.48	3185
Ready for Coal	3	100.0	1	0.0	0.0	0.0	70.0	30.0	1.10	2.08	2575
Coal Light Off	4	174.0	10458	74.0	30.2	40.1	70.0	30.0	1.10	1.75	2796
Ready for Oil-Coal Switch	5	174.0	10458	74.0	30.2	40.1	70.0	30.0	1.10	1.75	2796
Oil-Coal Switch	6	200.0	18372	130.0	53.1	70.4	50.0	20.0	1.10	1.70	2780
Minimum Oil	7	220.0	22612	160.0	65.4	86.6	40.0	20.0	1.10	1.66	2787
Mill Air to Furnace	8	230.0	24025	170.0	69.4	92.1	40.0	20.0	1.10	1.12	3417
Coal Up- Phidown	9	240.0	26851	190.0	77.6	102.9	30.0	20.0	1.10	1.12	3398
Coal Up Phi Trim	10	295.0	34624	245.0	100.1	132.7	30.0	20.0	1.10	1.12	3391
Coal Up Phi Hold	11	290.0	35331	250.0	102.1	135.4	20.0	20.0	1.10	1.13	3377
PC Oil Off	12	290.0	38157	270.0	110.3	146.2	0.0	20.0	1.10	1.13	3346
SC Oil off	13	300.0	42397	300.0	122.6	162.5	0.0	0.0	1.10	1.13	3346
Full Load	14	328.0	46354	328.0	141.0	187.0	0.0	0.0	1.09	1.09	3402

Note: Condition #2 is with Mill Air at 50000 #/hr

CONDITION		Coal Feed System Flow Rates, Lb/hr									
		Mill Air Flow	Vent Air Flow	Added Mill Air Moist.	Corrected Tot. Carrier	PC Carrier	PC Coal	SC Carrier	SC Coal	PC C/A Ratio	SC C/A Ratio
Oil Only	1	1	1	0	0	1	0	1	0	0.00	0.00
Mill Air Start	2	50,000	20,000	0	30,000	12,900	0	17,100	0	0.00	0.00
Ready for Coal	3	95,000	52,000	0	43,000	18,490	0	24,510	0	0.00	0.00
Coal Light Off	4	95,000	52,000	1,921	44,921	19,316	3,487	25,605	4,623	0.18	0.18
Ready for Oil-Coal Switch	5	95,000	52,000	1,921	44,921	19,316	3,487	25,605	4,623	0.18	0.18
Oil-Coal Switch	6	95,000	52,000	3,375	46,375	19,941	6,126	26,434	8,121	0.31	0.31
Minimum Oil	7	95,000	52,000	4,154	47,154	20,276	7,540	26,878	9,995	0.37	0.37
Mill Air to Furnace	8	110,000	75,000	4,414	39,414	16,948	8,011	22,466	10,620	0.47	0.47
Coal Up- Phidown	9	110,000	75,000	4,933	39,933	17,171	8,954	22,762	11,869	0.52	0.52
Coal Up Phi Trim	10	110,000	75,000	6,361	41,361	17,785	11,546	23,576	15,305	0.65	0.65
Coal Up Phi Hold	11	110,000	75,000	6,491	41,491	17,841	11,781	23,650	15,617	0.66	0.66
PC Oil Off	12	110,000	75,000	7,010	42,010	18,064	12,724	23,946	16,866	0.70	0.70
SC Oil off	13	110,000	75,000	7,789	42,789	18,399	14,137	24,390	18,740	0.77	0.77
Full Load	14	117,800	82,800	8,516	43,516	18,712	15,457	24,804	20,489	0.83	0.83

Note: All Pressures in In. H2O

CONDITION				AR HHV=	7076					These are not mandatory values		
		Damper	Veloc.	Air to PC Can	Air to Mix	Total Carrier	Air to Mill Ports	Mill Air to NOX	SC Phi	Fresh Air to NOX	Furnace Phi	Excess O2 (%)	PC LOAD
Oil Only	1	0.0	110	66,486	0	0	0	1	1.42	2,312	1.45	6.5	70.0
Mill Air Start	2	0.0	119	45,073	0	30,000	20,000	0	1.75	56,859	2.50	12.0	70.0
Ready for Coal	3	0.0	138	37,383	1	43,000	52,000	0	2.24	19,332	2.50	12.0	70.0
Coal Light Off	4	0.0	189	62,931	2,320	43,000	52,000	0	1.48	22,554	1.65	8.0	103.9
Ready for Oil-Coal Switch	5	16.0	286	62,931	2,320	43,000	52,000	0	1.48	22,554	1.65	8.0	103.9
Oil-Coal Switch	6	16.0	295	65,591	3,365	43,000	52,000	0	1.30	53,536	1.65	8.0	109.6
Minimum Oil	7	16.0	302	67,612	3,654	43,000	52,000	0	1.20	73,320	1.65	8.0	113.4
Mill Air to Furnace	8	16.0	243	75,005	1,950	35,000	0	75,000	0.87	65,580	1.65	8.0	109.4
Coal Up- Phidown	9	16.0	240	73,573	2,015	35,000	0	75,000	0.84	50,036	1.50	6.9	107.6
Coal Up Phi Trim	10	16.0	290	92,564	2,315	35,000	0	75,000	0.80	65,759	1.40	6.1	130.1
Coal Up Phi Hold	11	16.0	273	85,952	2,363	35,000	0	75,000	0.80	41,426	1.30	5.2	122.1
PC Oil Off	12	16.0	249	76,182	2,552	35,000	0	75,000	0.80	42,145	1.30	5.2	110.3
SC Oil off	13	16.0	276	86,541	2,836	35,000	0	75,000	0.80	47,014	1.30	5.2	122.6
Full Load	14	16.5	318	103,536	0	35,000	0	82,800	0.79	5,463	1.15	2.5	141.0

Note: Condition #2 is with Mill Air at 50000 #/hr

CONDITION		Inlet Pressures		Cyclone Vent Line Pressures				PC Feed Line Press.		SC Feed Line Pressures			Chamber Press.	
		Splitter Inlet	Cyclone Inlet	Cyclone Vent	BD Damper Inlet	BD Damper Outlet	PC Mill Air Supply	PC Cyc. Blowdown	PC Coal Inlet	SC Cyc. Blowdown	SC Splitter Inlet	SC Splitter Outlet	PC Pressure	SC Pressure
Oil Only	1	1.1	1.1	1.1	1.1	1.3	1.3	1.3	1.3	0.9	0.9	0.9	1.3	0.9
Mill Air Start	2	15.8	15.3	14.5	14.3	4.5	3.7	16.9	10.5	11.5	7.3	3.7	2.0	1.5
Ready for Coal	3	34.5	32.7	29.8	28.4	20.3	14.8	34.1	21.0	23.4	14.6	7.3	3.5	2.7
Coal Light Off	4	42.6	40.7	37.7	36.3	22.6	17.1	42.3	26.6	30.9	20.4	10.6	5.9	4.4
Ready for Oil-Coal Switch	5	44.2	42.3	39.3	37.9	25.1	19.6	44.8	29.2	31.6	21.1	11.3	8.4	5.1
Oil-Coal Switch	6	49.6	47.7	44.6	43.2	25.9	20.4	50.2	32.5	36.7	25.0	13.1	9.1	5.5
Minimum Oil	7	52.9	50.9	47.7	46.3	26.5	20.9	53.3	34.6	39.8	27.3	14.3	9.7	6.0
Mill Air to Furnace	8	41.1	38.5	34.3	31.3	16.6	5.1	36.9	23.3	28.5	19.4	9.5	5.1	3.1
Coal Up- Phidown	9	42.7	40.0	35.8	32.8	16.6	5.1	38.4	24.1	30.0	20.5	9.9	5.1	3.2
Coal Up Phi Trim	10	49.2	46.5	42.1	39.1	19.1	7.6	45.1	29.0	35.9	25.2	12.7	7.6	4.7
Coal Up Phi Hold	11	49.1	46.4	42.0	39.0	18.4	6.9	44.8	28.5	36.0	25.1	12.5	6.9	4.4
PC Oil Off	12	50.3	47.6	43.2	40.2	17.7	6.2	45.7	28.8	37.4	26.1	12.8	6.2	4.1
SC Oil off	13	53.8	51.0	46.6	43.6	18.8	7.3	49.2	31.3	40.5	28.5	14.1	7.3	4.7
Full Load	14	59.4	56.3	51.1	47.5	23.7	9.7	53.9	34.9	44.5	31.8	16.3	9.7	6.3

Note: All Pressures in In. H2O

FIGURE 5-2 START-UP COMBUSTOR MASS FLOWS

TABLE 5-1 TYPICAL COAL, SLAG, FLYASH AND LIMESTONE COMPOSITION
ANALYSIS PERFORMED

Material	Location	Analysis	Analysis Performed By
Coal	Pile	Proximate	Usibelli Coal Mine
	Belt Automatic Sampler	Proximate	" " "
	Belt Upstream of Coal Silo	Proximate	" " "
	Coal Feeder	Proximate	" " "
	" "	Proximate, Ultimate, Ash, T250	Commercial Testing and Engineering
	Downstream of Pulverizer	Proximate, Sieve	Usibelli Coal Mine
	" " "	Proximate, Ultimate, Sieve, Ash, T250	Commercial Testing and Engineering
Slag	Conveyor	Proximate, Ultimate, Ash, T250	Commercial Testing and Engineering
Flyash	Furnace	Proximate, Ultimate, Ash, T250	Commercial Testing and Engineering
	Air Preheater	" " " "	" " " "
	Boiler Hopper	" " " "	" " " "
	Flyash Surge Bin	Proximate, Ultimate, Ash, T250 CaO, CaCO3, CaSO4, C	" " " "
Limestone	Silo, Feeder	Carbonate, Sieve CaO, CaCO3, CaSO4, C	Golden Valley Electric Association Commercial Testing and Engineering

6.0 OPERATION SUMMARY

Section 6 describes the TRW Combustion System Characterization Test activities, which were initiated in May 1998, and continued intermittently through the beginning of May 1999, accumulating a total of approximately six months of testing. Section 6.1 and 6.2 describe the 1998 Operation and 1999 Operation, respectively.

The TRW Combustion System Characterization Test activities were divided into three test series:

Test Series 1: Initial Performance Characterization Tests (May, June 1998)
Test Series 2: Operating Envelope Characterization Tests (July, Oct – Dec 1998, Mar - Apr 1999)
Test Series 3: Steady-State Operation Characterization Tests (October 1998, May 1999)

The focus of the Combustion System Characterization Testing was to (1) establish the baseline performance of the combustion system while burning ROM and ROM / Waste Coal blends, (2) map the combustor performance characteristics over a broad range of operating conditions and hardware configurations, and (3) determine the best configuration and operating conditions for long-term operation.

6.1 1998 OPERATION RESULTS

6.1.1 Test Summary

Overall in 1998, a total of 27 “tests”, comprised of 50 operational runs, were conducted, accumulating 4,471 hours of cumulative coal burn time (not including oil-fired only start-up and shutdown time) on the Healy Coal Combustors. Of this total, 1,938 hours were on run-of-mine (ROM) coal and 2,533 hours were on ROM and ROM / Waste Coal blends. ROM coal was used primarily during: 1) plant coal-firing start-up tests in the January to April, 1998 time frame, 2) emissions source testing in June 1998, and 3) when waste coal was not available from UCM in August and September 1998. Note that for the purpose of this report, a “test” is defined as an operational period followed by a plant shut down, which included, at a minimum, an internal combustor inspection and possible hardware modifications. Numerous operational runs and several steady state conditions may be performed per “test”.

Table 6-1 summarizes the TRW Combustion System Characterization Test activities conducted during 1998 (excluding coal-firing start-up tests). A more detailed test summary table is provided in Appendix A-1, which provides operational and performance data for each test. The detailed test summary table also contains the actual test periods, hardware configuration descriptions, inspection dates, reasons for test termination, and representative coal properties. Appendix B provides definitions of various combustor parameters, and also describes the methodology for determining the actual combustor stoichiometric ratios during the test, based on actual coal analysis, air flows, and inferred precombustor coal split.

The Initial Performance Characterization Tests were performed primarily in May 1998. These tests were conducted with the baseline precombustor mix annulus configuration, as described in Section 3.1.4.1. Emission compliance testing was conducted in June 1998, also with the baseline mix annulus configuration. From April 23, 1998 through July 12, 1998, a total of 8 test runs were performed, accumulating 1006 hours. The longest continuous test run was 431 hours, or 18 days, conducted from June 8 through June 26, 1998. A total of 8 combustor inspections were also conducted during this test period.

During July 1998, the Operating Envelope Characterization Tests were initiated. These tests were primarily performed during July, October, November, and December 1998, when waste coal was available in sufficient quantities. During this period of time, several different secondary air injection configurations and operating regimes were evaluated. Also during October, the Steady-State Operation Characterization Tests were initiated. During portions of July, August, and September when waste coal was not available in sufficient quantities to support long duration combustor tests, the combustors were characterized with Run-of-Mine coal.

From July 16, 1998 through October 21, 1998, a total of 8 test runs were conducted, accumulating a total of 1554 test hours. The longest continuous test run was 582 hours, or 24.3 days, conducted from September 27 to October 21, 1998. This test was terminated by a planned shutdown. A total of 8 combustor inspections were also conducted during this test period. These tests were conducted with elbows installed in the mix annulus section to direct the mix annulus air radially inward and thus enhance the mixing between the primary precombustor flow and the secondary air, as described in Section 3.1.4.2.

From October 24, 1998 through December 21, 1998, a total of 4 test runs were conducted, accumulating a total of 1008 test hours. The longest continuous test run was 389 hours or 16.2 days, conducted from December 7 to December 19, 1998. Each test run conducted during this period was at least 100 hours in duration. A total of 4 combustor inspections were also conducted during this test period. These tests were conducted with the PC mix annulus blocked off, and the secondary air redirected to 4 or 6 injectors in the head end of the slagging stage, as described in Section 3.1.4.3.

6.1.2 Coal and Limestone Properties

In general, the composition of the ROM coal was fairly consistent from test-to-test, however, the blended coal composition varied significantly depending on the coal mining technique, the coal seam, and the type of coal blending technique used. A complete listing of daily coal analyses is provided in Appendix C, based on coal belt samples obtained daily by Golden Valley Electric Association (GVEA) personnel and analyzed by Usibelli Coal Mine.

The overall range of coal properties tested from May through December 1998, compared to the range of coal properties listed in the Design Specification, is as follows:

		Design Basis		
	Run-of-Mine	Performance	55/45 Blend	1998 Actuals (avg) (May – Dec 1998)
Higher Heating Value, (Btu/lb)	7815	6969	6874	6196 to 8271(7507)
Vol. Matter, (%)	34.6	30.8	30.4	25.0 to 37.5 (35.1)
Fixed Carbon, (%)	30.9	27.5	27.2	24.1 to 30.9 (27.9)
Moisture, (%)	26.4	25.1	25.0	22.5 to 29.4 (25.9)
Ash, (%)	8.20	16.6	17.4	5.7 to 24.0 (11.1)
Sulfur, (%)	0.17	0.15	0.15	0.11 to 0.36 (0.18)
T_{250} (^oF)	2228	2750	2800	2270 to 2900 (2497)

As shown in the above table, the actual ranges in coal properties tested in 1998 were broader than the range indicated by the three different coal types listed in the Design Specification: Run-of-

Mine, and two ROM / Waste Coal blends: 50% Waste / 50% ROM (also called "Performance Coal") and 55 % Waste / 45 % ROM.

During the initial waste coal blend tests in May and July 1998, the waste coal "blending" was performed by blending "pure" waste coal and "pure" ROM coal at an approximate 50/50 ratio during the coal crushing process. This blending process was not very effective and resulted in relatively large variations in coal composition with periods of time with pure waste coal and periods of time with pure ROM coal. During these initial waste coal blend tests, the "inferred" coal heating value (based on steam generation) varied significantly over a 24-hour period, with a typical variation of $\pm$ 500 Btu/lb. This variation is illustrated in Figure 6-1a. Due to this large variability in the blended waste coal composition, beginning in September 1998, tests were performed with a "blended" waste coal pile. The coal "blending" was performed by preparing a blended coal pile comprised of waste coal and ROM coal, which was then loaded into the coal crusher. The blended waste coal pile was comprised of "layers" of various waste and run-of-mine coals. The typical blended waste coal pile consisted of a 3 ft layer of waste coal, a 3 ft layer of waste coal fines (smaller coal chunks with excess rocks and sandstone), a 3 ft layer of ROM coal, a 3 ft layer of waste coal, a 3 ft layer of waste coal fines, etc. Although it was not originally intended for the HCCP to burn waste coal fines, this process was beneficial for Usibelli Coal Mine due to restrictions on burning of coal fines at other plants within Alaska. The blended waste pile typically had an average higher heating value in the range of 6800-7200 Btu/lb. The typical "inferred" coal heating value variation over a 24-hour period was $\pm$ 200 Btu/lb, as illustrated in Figure 6-1b.

In general, the "blended" coal pile was not any more difficult to maintain than the previous "general" waste coal pile. As each truck brought coal from the mine, it was dumped on the blended coal pile and spread out to form a "layer". When the operators loaded coal from the blended coal pile, they "scooped up" the coal from the bottom to the top of the pile in order to get a full distribution of each layer.

Also included in Appendix C are additional coal analyses performed by Usibelli for samples taken at the mill feeder, as well as "isokinetic" samples taken between the exhauster fan and the combustor coal feed system (pulverized coal). For the "isokinetic" pulverized coal samples, the average moisture content was 11.2 % (compared to a design target of 11%), however, the range of as-fired coal moisture content from sample to sample was observed to be quite large (4.7 to 16.2%). Higher as-fired coal moisture content was observed during December 1998, and appeared to be related to the increased usage of raw coal fines, which generally have a higher moisture content compared to the larger coal chunks found in the coal pile. In addition, during the winter time, the raw coal fines often resulted in large frozen coal "chunks", that caused problems during coal loading and/or coal feeding. The higher moisture levels can result in higher relative humidity in the coal feed system, which in turn can lead to coal particle agglomeration and subsequent ignition delay within the precombustor.

Limestone analyses provided by GVEA are shown in Table 6-2. The average $CaCO_3$ content was 67.5%, significantly lower than the 90% value assumed during the design phase. The limestone properties were also quite variable during the test program. At times, a significant amount of silica was present in the limestone (up to 20%), while at other times, a significant amount of MgO (up to 20%) was present. To compensate for the lower $CaCO_3$ content, a higher limestone flow rate was required to obtain the desired Ca / S ratio (1.0 to 2.0).

Finally, Appendix C contains some preliminary slag, pyrite, and flyash analyses.

6.1.3 Combustor Operating Conditions

Table 6-3 summarizes the range of combustor operating conditions characterized during the various test phases conducted during the 1998 test activities (excluding coal-firing start-up tests). The minimum, average, and maximum values listed in Table 6-3 were determined from the steady state conditions listed in Appendix A. The key combustor operating parameters that were characterized during 1998 testing included precombustor chamber stoichiometry, precombustor exit stoichiometry, precombustor coal split, precombustor exit temperature, slagging combustor stoichiometry, and calcium-to-sulfur (Ca/S) molar ratio.

During 1998, most of the tests were conducted at full load (57-62 MWe (gross), 50-55 MWe (net)). In order to generate a gross power output of 62 MWe, the combustors were each operated at 315 MMBtu/hr (630 MMBtu/hr total thermal input) for most coals. To generate a gross power output of 57 MWe, the combustors were each operated at 300 MMBtu/hr (600 MMBtu/hr total thermal input). During off-nominal conditions, the combustors were operated at a thermal input as high as 350 MMBtu/hr without any noticeable operational problems or degradation in performance.

The precombustor chamber stoichiometry was varied over a wide range during 1998, primarily to determine its effect on precombustor chamber flame and slagging characteristics. The initial setpoint was 0.85. During the Initial Performance Tests, the precombustor chamber stoichiometry was decreased to as low as 0.60, in an attempt to eliminate slagging within the precombustor chamber. While the rate of slag formation appeared to decrease, this operational change did not totally eliminate slagging within the precombustor chamber. When the mix annulus air was relocated to the slagging stage (see Section 3.1.4.3), the precombustor chamber stoichiometry was subsequently increased to the 1.0 to 1.1 range. This was required to maintain sufficient air flow in the precombustor in the absence of the mix annulus air and the precombustor NO_x port air. This change was implemented for tests in November and December 1998.

The precombustor exit stoichiometry, precombustor coal split, and precombustor exit temperature were also varied over a wide range during Combustion System Characterization Tests. The precombustor exit stoichiometry is used to control the precombustor exit temperature and precombustor slagging behavior. During the Combustion System Characterization Tests, the precombustor exit stoichiometry was varied parametrically from 2.03 down to 0.98, with corresponding calculated precombustor exit temperatures ranging from 2420 to 3572 ^oF. The fraction of coal fed to the precombustor was also varied over the range of 29 to 48%.

The slagging combustor stoichiometry is primarily used to control operating temperatures and NO_x formation within the slagging stage and slag recovery section. At full load, this parameter was varied from 0.76 to 0.90. Most of the tests were operated at slagging combustor stoichiometries in the range of 0.79 to 0.85, which represents a good compromise between NO_x emissions, carbon burnout, and slagging characteristics.

The overall Ca/S molar ratio was varied over the range of 0.75 to 6.13 during full load, steady-state tests. During the earlier tests, there were difficulties with accurately controlling the limestone feedrate at low flowrates and, therefore, the Ca/S ratio was typically 2 to 6. This resulted in extremely low SO_2 emission levels at the stack, typically 1 to 10 ppm. Beginning in September 1998, a modification was made to the limestone feeder to enable accurate feedrate control at the lower flowrates. Following this modification, the typical Ca/S ratio was 1 to 2, with typical SO_2 emission levels at the stack of 15 to 30 ppm (0.03 to 0.07 lb/MMBtu). During the Demonstration Test Program, the sulfur content of the coal varied from 0.11-0.33%.

6.1.4 Causes of Test Terminations

As noted in the Data Summary Table in Appendix A, there were a variety of reasons for the termination of an operational run. During the tests performed during the 1998 TRW Combustor Characterization Test activities, a total of 14 terminations occurred by normal shutdowns and 15 terminations occurred by trips. None of the 15 trips were attributed to the TRW Combustion System. Of the 14 tests terminated due to a requested or planned shut-down, only 5 of the shutdowns were requested by TRW. All 5 of these shut-downs were requested in order to modify the precombustor secondary air injection configuration (3 in July, 1 in September, and 1 in November). For most of the inspections, any "excess" slag found in the precombustors were removed, in order to provide a clean baseline for the next planned test condition.

6.1.5 Availability

As mentioned previously, the primary focus of the Combustor Characterization Testing was to characterize the performance of the combustors over a broad operating envelope and to identify the best operating conditions and hardware configuration for long-term operation. While it will take at least a 90-day continuous test period under commercial operating conditions to assess combustor availability, there was sufficient data gathered in 1998 to perform a preliminary evaluation of combustor availability. The test period from April 23, 1998 through December 31, 1998 was reviewed in order to identify the cause(s) of each plant shut-down, as well as to estimate the amount of time the combustors were unavailable during a plant shut-down. The test period prior to April 23, 1998 was not included in this review because this time period was dominated by plant start-up activities.

Appendix D contains preliminary plant and combustor availability data, including a detailed accounting of operating hours, reasons for test terminations, a summary of combustor work performed, and estimated combustor inspection and work hours. The following is a brief summary of this data.

There were 6,060 hours of elapsed time from April 23, 1998 through December 31, 1998, which included approximately 3,590 hours of coal-fired operating hours and 2470 hours of planned and unplanned plant shut-downs (latter values includes plant start-up / shut-down time). As noted previously, a number of these plant shut-downs were incorporated into the test planning activities in order to inspect the combustor internal slagging characteristics and/or implement any configuration changes. Over the time period considered, it was estimated that Combustor A was not available for approximately 1392 hours and Combustor B was not available for 1546 hours, yielding overall combustor availabilities of approximately 77.0% and 74.5%, respectively. However, it should be noted that the majority of unscheduled combustor down-time during this period was related to a problem with slag freezing within the precombustor subsystem. Significant progress was made during 1998 in controlling the precombustor slagging behavior. When combustor down-times attributed to the precombustor slag freezing program are excluded, the corresponding availability for the remaining combustor subsystems was estimated to be approximately 94% for both combustors. A more accurate determination of combustor availability was made during the long-duration 90-day Test performed during August through November 1999, with a resulting plant availability of greater than 97% and capacity factor of approximately 95%. The 90-day test results will be released in a separate topical report prepared by AIDEA.

6.1.6 1998 Operational Issues

During the 1998 HCCP Demonstration Test Program, some site-specific integrated plant operational and/or hardware durability problem areas were identified. The following table summarizes the site-specific issues identified during 1998 and the resolutions implemented during 1999.

Problem Area	Planned Resolution
Ash/slag accumulation on the Furnace Hopper Slope; Ash/slag fall into the water-filled slag hopper results in trips on high Furnace pressure	Installation of a water lance on the Furnace Hopper Slope to mitigate ash accumulation in this region
Slag on internal surfaces occasionally obscuring flame scanner view angle	Integrate slag rodding capability on all flame scanner ports; provide additional scanner locations to ensure continuous flame monitoring
Erosion at leading edge of swirl dampers	Weld overlay
Cooling water leaks in dipper skirt vent line	Elimination of vent line
Erosion of blades and outer casing on mill exhauster fans	Incorporate improved erosion resistant materials on blades and outer casing; establish inspection program and provide spare materials

6.2 1999 OPERATION RESULTS

6.2.1 Test Summary

Overall from January through June 1999, a total of 7 tests, including 22 operational runs, were conducted, accumulating 2008 hours of cumulative coal burn time (not including oil-fired only start-up and shutdown time) on the Healy Coal Combustors. In general, all of the test operations during 1999 were conducted with ROM / Waste Coal blends. The only exceptions to this occurred when: 1) waste coal was not available from the Usibelli Coal Mine and 2) there were problems loading waste coal into the external coal loading system due to outside weather conditions and/or coal quality problems (e.g., extremely wet coal “fines” that would occasionally plug in the external coal loading system).

Table 6-4 summarizes the TRW Combustion System Characterization Test activities conducted during 1999. A more detailed test summary table is provided in Appendix A-2, which provides operational and performance data for tests performed from March through June 1999, including actual test periods, hardware configuration descriptions, inspection dates, reasons for test termination, representative coal properties, combustor operating conditions, and performance for each test.

During January and February 1999, only limited testing was conducted due to various facility problems, including insufficient quantity of limestone supply to support continuous test operations. The TRW Combustion System Characterization Tests were performed intermittently during March through May 1999, in conjunction with other plant operation activities. During this period of time, the secondary air injection configuration remained constant and the Precombustor Burner configuration was varied, including evaluation of various inner and outer air register flow swirl conditions, flow turbulator devices, and tertiary air flowrate and temperature conditions. All of these tests were conducted with the precombustor mix annulus blocked off, and the secondary air redirected to 6 injectors in the head end of the slagging stage, as described in Section 3.1.4.3. By the end of April, the final Precombustor Burner configuration had been determined. During early May, variations to the Slagging Combustor inlet velocity were evaluated. There were not any changes made to the Combustor configuration and operating regime after mid-May 1999.

The longest continuous operational run during January through June 1999 was 282 hours, or 12 days, conducted from March 18th to March 30th. This test was terminated by a trip due to a high furnace pressure spike that resulted from the sudden fall of hot ash/slag into the slag tank, which had accumulated on the Furnace Hopper Slope. This was the cause of the majority of the test trips during January through June 1999. This problem was more prevalent in 1999 compared to 1998 due to extended duration runs with Waste coal. This problem was resolved in July 1999 by the installation of a water lance on the Furnace Hopper Slope to mitigate ash accumulation in this region.

6.2.2 Coal and Limestone Properties

During 1999, the composition of the ROM / Waste Coal Blend Pile was significantly more consistent during each individual test, as well as from test-to-test, than had been observed during the 1998 ROM /Waste Coal Blend tests. However, even with the Waste Coal Blend Pile, the blended coal composition varied depending on the coal seam, coal mining technique, and the specific location being mined within the coal seam. A complete listing of daily coal analyses is provided in Appendix C, based on coal belt samples obtained daily by Golden Valley Electrical Association (GVEA) personnel and analyzed by Usibelli Coal Mine.

The overall range of coal properties tested from March through June, 1999, compared to the range of coal properties tested during 1998, is as follows:

	1998 Actuals			1999 Actuals	
	ROM (avg)	ROM /Waste	(avg)	Mar - Jun 1999	(avg)
Higher Heating Value, (Btu/lb)	7925	6196 to 8271	7507	6766 to 7826	7328
Vol. Matter, (%)	37.0	25.0 to 37.5	35.1	33.39 to 37.92	36.16
Fixed Carbon, (%)	29.4	24.1 to 30.9	27.9	23.28 to 28.00	25.64
Moisture, (%)	25.2	22.5 to 29.4	25.9	23.21 to 30.55	26.25
Ash, (%)	8.5	5.7 to 24.0	11.1	8.02 to 19.08	11.76
Sulfur, (%)	0.22	0.11 to 0.36	0.18	0.12 to 0.29	0.20
T_{250} (^oF)	2300	2270 to 2900	2497	2275 to 2852	2415

As shown in the above table, the range in ROM / Waste Coal Blend properties tested in 1999 showed less variation than the range in ROM / Waste Coal Blend properties tested in 1998. This is attributed to the improved coal blending procedures that were implemented during the latter part of 1998. Specifically, beginning in September 1998, tests were performed with a “blended” waste coal pile. This coal pile blending process continued throughout the testing conducted during 1999. The coal “blending” was performed by preparing a blended coal pile comprised of waste coal and ROM coal, which was then loaded into the coal crusher. The blended waste coal pile was comprised of “layers” of various waste and run-of-mine coals. The typical blended waste coal pile consisted of a 3 ft layer of waste coal, a 3 ft layer of waste coal fines (smaller coal chunks with excess rocks and sandstone), a 3 ft layer of ROM coal, a 3 ft layer of waste coal, a 3 ft layer of waste coal fines, etc. During 1999, the blended ROM / waste coal pile typically had an average higher heating value in the range of 7328 ± 242 Btu/lb. The typical "inferred" coal heating value variation over a 24-hour period was 7160 ± 186 Btu/lb.

Note that although the average ROM / Waste Coal Blend properties in 1999 showed less variation than in 1998, the variation in coal quality was still quite high. Coal heating values below 6400 Btu/lb and ash contents as high as 19.0% were still tolerated at times. Daily average coal analysis results were typically not available until after the coal was burned. Therefore, the average "inferred" coal heating value (based on steam output and assumed boiler efficiency) was the only on-line method for providing some cognizance of the changing coal quality situation. The combustion system was robust enough to tolerate these occasional wide variations in coal quality. Future improvements could include using the coal density output signal from the individual coal feeders to provide an on-line indication of overall coal quality changes as well as differences in coal quality between the two combustion systems.

Also included in Appendix C are additional coal analyses performed by Usibelli for samples taken at the mill feeder, as well as a few "isokinetic" samples taken between the exhauster fan and the combustor coal feed system (pulverized coal). As noted during 1998, the "as received" coal moisture content varied significantly during the test program and appeared to be related to the increased usage of raw coal fines, which generally have a higher moisture compared to the larger coal chunks found in the coal pile and weather conditions during mining and/or coal storage. The higher moisture levels result in higher relative humidity in the coal feed system, which in turn can lead to coal particle agglomeration and subsequent ignition delay within the precombustor.

During 1999, the limestone was supplied from two different sources and the $CaCO_3$ content varied from approximately 65% to 99.3%. The higher $CaCO_3$ content limestone was consistent with the Design Specification and was used for the SDA Performance Guarantee Tests conducted in June 1999, as well as during periods of time when a continuous supply of limestone from the local mine was not available.

Appendix C also contains analysis results for the slag, pyrite, and flyash samples taken during 1999. As noted in Section 5.2, in most cases, the slag samples contain some pyrites since the pyrite hopper discharged directly into the slag tank

6.2.3 Combustor Operating Conditions

Table 6-5 summarizes the range of combustor operating conditions characterized during the continuation of the Combustor Characterization Test activities conducted during 1999. The minimum, average, and maximum values listed in Table 6-5 were determined from the steady-state conditions listed in Appendix A-2. Although not specifically listed in Table 6-5, additional precombustor operating parameters that were characterized during 1999 testing included precombustor burner inner and outer air register swirl and tertiary air temperature and flowrate.

During 1999, most of the tests were conducted at 57 MWe (gross), 50 MWe (net). In order to generate a gross power output of 57 MWe, the combustors were each operated at 305 ± 5 MMBtu/hr (610 MMBtu/hr total thermal input) for most coals. During off-nominal conditions, the combustors were operated at a thermal input as high as 350 to 375 MMBtu/hr without any noticeable operational problems or degradation in performance.

The precombustor burner air register configuration and tertiary air flow characteristics were varied during the 1999 test activities, primarily to improve the precombustor near-zone flame characteristics and slagging characteristics. Specific changes to the burner air injection configuration during 1999 included: 1) the burner inner air register swirl was increased by installation of an air swirler device at the burner exit, 2) the burner outer air register swirl was decreased, and 3) air flow turbulators were installed in the burner coal fines injector exit. The increase in swirl at the exit of the inner register duct and installation of the air flow turbulators at the exit of the coal fines duct provided improved mixing of coal and air and, hence, improved near zone flame attachment. The decrease in swirl on the outer register reduced the potential for sticky flyash/char particles to accumulate on the Precombustor Chamber inner walls. The final setting on the Outer Air Register was 55 to 60% open.

Following the changes to the precombustor burner air injection configuration, the tertiary air flow characteristics were varied in order to optimize the precombustor near-zone flame characteristics. The initial Precombustor Burner tertiary air damper setting was 10% open on the “cold” air valve, which uses nominal 120°F tempering air. During the 1999 Precombustor Burner characterization, the tertiary air temperature and flowrate was varied over a wide range. Through a combination of “hot” and “cold” tertiary air dampers, the tertiary air temperature could be varied from 120°F to 800°F, and the flowrate could be varied from approximately 1000 to 6000 lb/hr. Near zone flame characteristics were improved with hotter tertiary air temperatures (typically 350 to 550°F) and approximately 50% of maximum tertiary air flowrate, or 2000 to 3000 lb/hr.

The precombustor chamber and exit stoichiometry, precombustor coal split, and precombustor exit temperature were held constant throughout the January through June 1999 test activities.

The slagging combustor stoichiometry was also held relatively constant during the 1999 test activities. The variation in slagging combustor stoichiometry indicated in Appendix A-2 was due to variable coal properties (e.g., coal oxygen content and coal heating value), rather than a deliberate parametric variation in stoichiometry. The slagging combustor inlet velocity was varied during the 1999 Combustion System Characterization Tests. The slagging combustor inlet velocity affects slagging stage swirl (and, hence combustion and carbon burnout characteristics), slag recovery, and, to a secondary degree, NO_x emissions. During the 1999 Combustion System Characterization Tests, the slagging combustor inlet velocity was varied parametrically from 250 to 320 ft/s, with a corresponding calculated slagging combustor swirl ranging from 1.87 to 2.32.

During 1999 test activities, the overall Ca/S molar ratio varied over the range of 1.5 to 4.6 during full-load, steady-state tests. During the March through April test period, tests were performed with a limestone supply with nominal $CaCO_3$ content of 68%, and the typical Ca/S ratio was 2.6. During the May through June test activities, the nominal $CaCO_3$ content was greater than 90%, and the typical Ca/S ratio was 3.2%. During the latter tests performed with the higher $CaCO_3$ content limestone, the minimum Ca/S ratio was limited by the minimum feedrate capability of the limestone feeder.

6.2.4 Causes of Test Terminations

As noted in the Data Summary Table in Appendix A-2, there were a variety of reasons for individual test terminations during the 1999 test activities. During 1999, the majority of the test trips were due to a common cause: high furnace pressure spike that resulted from an abrupt fall of accumulated flyash/slag from the Furnace Hopper Slope into the slag tank. This problem was resolved in July 1999 by the installation of a water lance on the Furnace Hopper Slope to mitigate ash accumulation in this region. The remaining test trips that occurred during 1999 were due to instrumentation problems or operator error. Following most of the post-test inspections, any "excess" slag found in the precombustors was removed, in order to provide a clean baseline for the next planned test condition. However, from May 6 to June 12, 1999, there was not any slag removed from the precombustors following the post-test inspection.

6.2.5 Availability

As mentioned previously, the primary focus of the Combustor Characterization Testing during 1998 and 1999 was to characterize the performance of the combustors over a broad operating envelope and to identify the best operating conditions and hardware configuration for long-term operation. While it will take at least a 90-day continuous test period under commercial operating conditions to assess combustor availability, there was sufficient data gathered in 1998 and early 1999 to perform a preliminary evaluation of combustor availability. As described in Section 6.1.6, a preliminary assessment of combustor availability was performed for the test period from April 23, 1998 through December 31, 1998. The test period prior to April 23, 1998 was not included in this review because this time period was dominated by plant start-up activities. Over the 1998 time period considered, it was estimated that Combustor A and Combustor B availability was approximately 77.0% and 74.5%, respectively.

During 1999 test activities, a similar assessment of combustor availability was performed. The period of time from January 18 through June 12, 1999 was reviewed in order to identify the cause(s) of each plant shut-down, as well as to estimate the amount of time the combustors were unavailable during a plant shut-down. Over the time period from January through June, it was estimated that both Combustors A and B availability was approximately 92%. A more accurate determination of combustor availability was made during the long-duration 90-day Test performed during August through November 1999, and resulted in a calculated plant availability of greater than 97% and a capacity factor of approximately 95%. The 90-day test results will be released in a separate topical report prepared by AIDEA.

6.2.6 1999 Operational Issues

During the 1998 HCCP Demonstration Test Program, some site-specific integrated plant operational and/or hardware durability problem areas had been identified that had not been completely resolved by the end of the year. These site-specific issues and planned resolutions were identified in the table included in Section 6.1.7. By the end of June 1999, all of the planned improvements and/or modifications had been implemented in preparation for the 90-day continuous operation test. Verification that these issues had been resolved occurred during the 90-day continuous operation test performed during August through November 1999. The long-duration 90-day Test results will be released in a separate topical report prepared by AIDEA.

TABLE 6-1 1998 TRW COMBUSTION SYSTEM CHARACTERIZATION TEST ACTIVITIES

Test Phase	Secondary Air Injection Method	Test Period	Number of Test Runs	Number of Test Hours	Number of Internal Inspections	Longest Continuous Run	Number of Runs Over 100 hours
Initial Performance Characterization Tests	Mix Annulus	23-Apr-98 to 12-Jul-98	8	1006	8	431 hours or 18.0 days	2
Operating Envelope Characterization Tests / Steady State Operation Characterization Tests	Mix Elbows	16-Jul-98 to 21-Oct-98	8	1554	8	582 hours or 24.3 days	5
	SC Headend	24-Oct-98 to 21-Dec-98	4	1008	4	389 hours or 16.2 days	4
Overall	Overall	23-Apr-98 to 21-Dec-98	20	3568	20	582 hours or 24.3 days	11

Notes
1. A test run is defined as a period of continuous operation on one or both combustors. A test run is terminated by either a planned shutdown, or a plant trip.
2. A total of 903 hours of steady state coal-fired operation was accumulated prior to the start of Combustor Characterization Test activities (Coal Firing Trials conducted between January 13, 1998 and April 22, 1998).
3. Total steady state coal-fired hours for 1998 was approximately 4471 hours. This does not include start-up and shut-down hours Total combustor thermal hours (coal-fired or oil-fired) is estimated to be approximately 5000 hours.

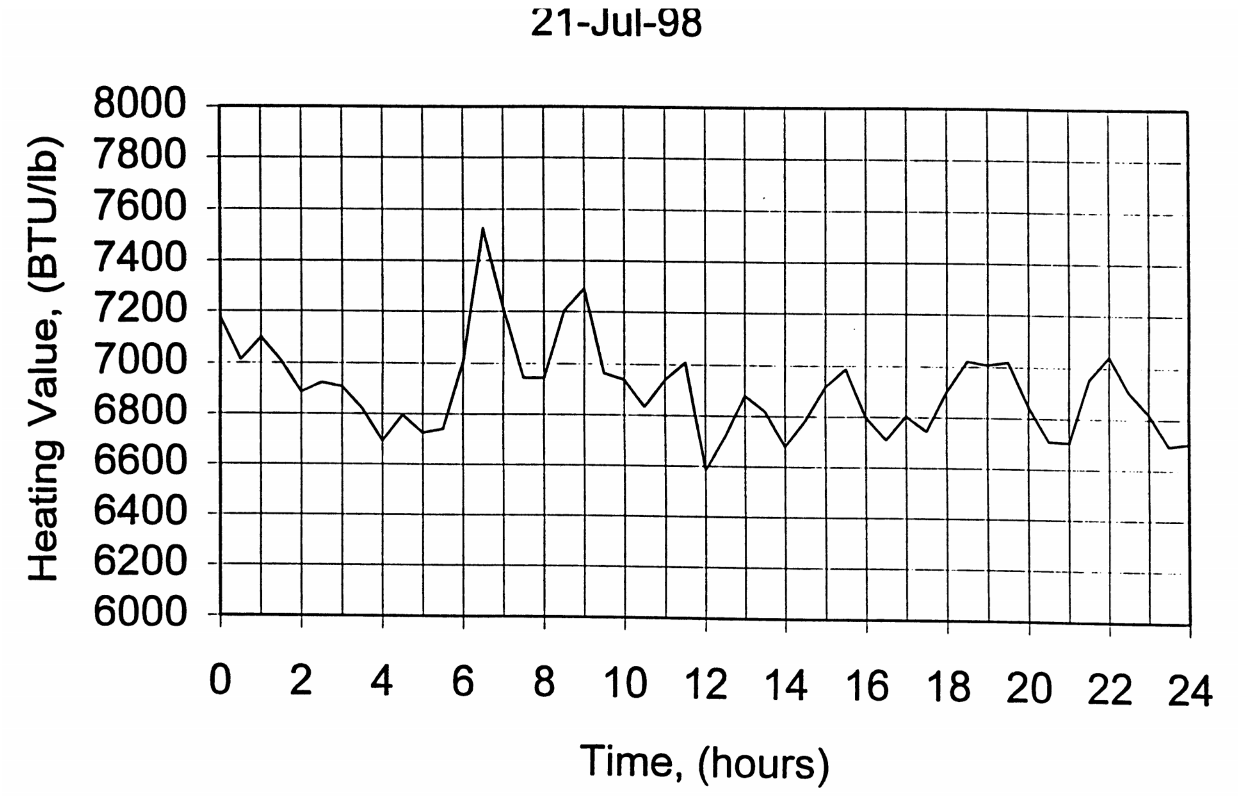


FIGURE 6-1A REPRESENTATIVE DAILY VARIATION IN "INFERRED" COAL BTU VALUE WITH WASTE COAL

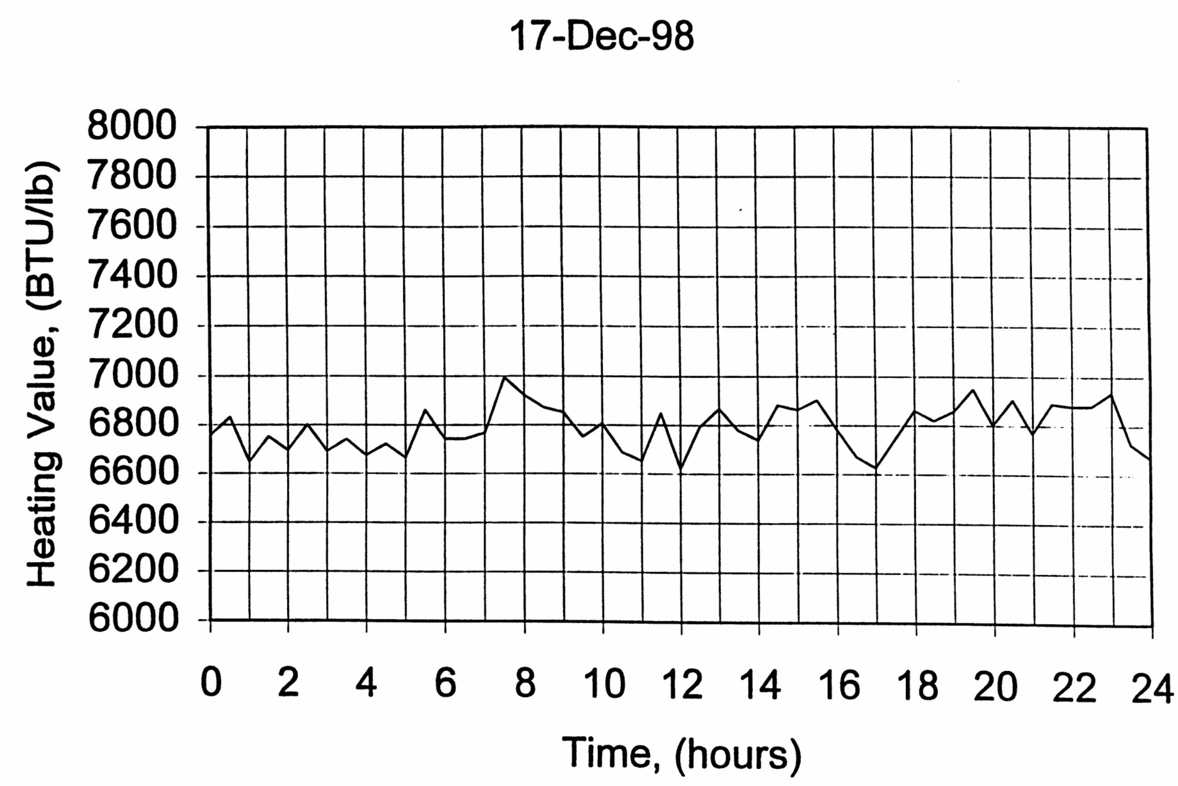


FIGURE 6-1B REPRESENTATIVE DAILY VARIATION IN “INFERRED” COAL BTU VALUE WITH COAL PILE BLENDED WASTE/ROM COAL

TABLE 6-2 LIMESTONE ANALYSIS PROVIDED BY GVEA

Limestone Analysis by Golden Valley Electric Association (GVEA)

Date	ID	SiO2 (%)	MgO (%)	CaO (%)	LOI (%)	CaCO3 * (%)	Grind (% thru 200 mesh)
4/30/98							87.00
5/4/98							88.00
5/20/98	HCCP106	1.69	18.49	32.17	45.62	60.00	57.45
5/24/98	HCCP106	1.86	18.17	33.57	45.10	60.00	59.95
5/25/98	HCCP5-1-98					59.46	59.46
5/25/98	HCCP5-3-98					59.40	59.40
5/25/98	HCCP5-3-98					60.38	60.38
6/6/98	HCCP119	1.72	18.19	33.36	45.51	60.00	59.57
6/13/98	HCCP120	1.85	18.02	32.34	45.73	60.00	57.75
6/13/98	HCCP121	1.81	17.84	32.67	45.71	60.00	58.34
6/13/98	HCCP122	1.80	17.84	32.73	45.62	60.00	58.45
6/13/98	HCCP123	1.81	18.04	32.77	45.62	60.00	58.52
6/21/98	HCCP132	10.50	4.32	43.45	40.03	77.50	77.59
6/21/98	HCCP133	9.39	6.61	41.60	40.03	74.25	74.29
7/3/98	HCCP135	9.18	3.61	45.19	42.48	80.66	80.70
7/3/98	HCCP136	4.91	13.87	36.19	39.20	64.59	64.63
7/22/98	HCCP140	17.33	2.88	40.86	35.35	73.00	72.96
7/22/98	HCCP141	19.48	3.40	38.35	34.06	69.00	68.48
7/22/98	HCCP142	19.71	2.86	39.07	33.90	70.00	69.77
7/22/98	HCCP143	19.72	3.70	38.06	33.31	68.00	67.96
7/22/98	HCCP144	17.12	3.74	39.73	35.24	71.00	70.95
8/7/98	HCCP145	15.42	3.84	40.35	36.13	72.00	72.05
8/7/98	HCCP146	17.20	4.60	39.10	35.79	69.70	69.82
8/7/98	HCCP149	15.47	3.97	40.46	36.17	72.20	72.25
8/14/98	HCCP150	14.65	5.30	39.26	36.86	69.88	70.11
8/14/98	HCCP151	13.99	4.66	40.91	37.21	72.82	73.05
8/14/98	HCCP152	14.00	5.69	39.29	37.32	69.94	70.16
9/2/98	HCCP159	6.88	14.00	34.86	41.82	62.22	62.25
9/2/98	HCCP160	5.05	15.31	34.61	42.78	61.77	61.80
9/2/98	HCCP161	5.63	14.32	35.27	42.69	62.95	62.98
9/21/98	HCCP164	8.41	11.53	36.79	40.58	65.67	65.70
9/21/98	HCCP165	6.79	12.79	36.74	41.39	65.58	65.61
9/21/98	HCCP166	6.21	14.18	35.62	41.73	63.58	63.61
10/3/98	HCCP170	5.09	9.67	40.82	42.26	72.65	72.89
10/3/98	HCCP 98-2	5.48	10.28	39.40	42.15	70.13	70.36
10/31/98	HCCP171	4.87	9.34	40.84	42.54	72.89	72.93
10/31/98	HCCP172	4.59	9.40	41.07	42.73	73.30	73.34
11/20/98	HCCP173	4.87	8.98	41.63	42.33	74.30	74.34
11/20/98	HCCP174	4.96	8.75	41.86	42.27	74.72	74.75
11/20/98	HCCP175	4.95	9.33	40.78	42.36	72.79	72.82
	avg	8.70	9.93	38.05	40.56	67.54	68.31
	std (%)	69.58	55.93	9.30	9.54	9.00	11.29

* - Based upon the measured CaO

Limestone Samples Taken by AIDEA, and Analysis Performed by Commercial Testing and Engineering

Date	Time	Ca (Wt %)	CO3 (Wt %)	Mg (Wt %)	Inerts (Wt %)	Total (Wt %)	CaCO3 * (Wt %)	Grind (% thru 200 mesh)
6/8/99	800	38.93	59.22	0.42	1.19	99.76	97.13	87.71
6/8/99	1200	39.75	58.84	0.27	0.63	99.49	99.18	87.38
6/9/99	400	39.59	59.13	0.30	0.60	99.62	98.78	86.67
6/9/99	1800	39.80	58.70	0.34	0.55	99.39	99.30	87.54
6/10/99	400	39.70	58.85	0.35	0.54	99.44	99.05	84.43
6/10/99	1400	39.58	59.15	0.33	0.53	99.59	98.75	87.24
6/11/99	400	39.78	59.04	0.23	0.51	99.56	99.25	87.85
6/11/99	1400	39.71	59.23	0.22	0.45	99.61	99.08	86.15
avg		39.61	59.02	0.31	0.63	99.56	98.81	86.87
std (%)		0.72	0.34	21.69	37.55	0.12	0.72	1.31

* Assuming all the Ca is in the form of CaCO3

TABLE 6-3 RANGE OF COMBUSTOR OPERATING CONDITIONS

Test Phase	Secondary Air Injection Method	Test Period		COMBUSTOR OPERATING CONDITIONS									
				Load (MMBtu/Hr)	Inferred Heating Value (Btu/lb)	PC Chamber Stoich.	PC Exit Stoich.	SC Stoich.	PC Coal Split (%)	PC Exit Temp (F)	PC Exit Velocity (Ft/s)	Limestone Flow (#/min)	Ca/S Molar Ratio
Initial Performance Characterization Tests	Mix Annulus	23-Apr-98 to 12-Jul-98	Average Max Min	294 309 264	7159 7873 6710	0.77 0.96 0.59	1.85 2.03 1.56	0.84 0.88 0.77	35 46 29	2576 2840 2420	282 313 259	38 82 14	2.79 4.12 1.53
Operating Envelope Characterization Tests / Steady State Operation Characterization Tests	Mix Elbows	16-Jul-98 to 21-Oct-98	Average Max Min	319 350 301	7306 8028 6693	0.98 1.05 0.93	1.51 1.62 1.40	0.83 0.87 0.76	46 48 42	2902 3015 2786	354 385 338	14 28 4	2.27 6.13 0.84
	SC Headend	24-Oct-98 to 21-Dec-98	Average Max Min	299 302 294	6967 7429 6408	0.96 1.10 0.83	1.17 1.29 0.98	0.85 0.90 0.76	47 48 42	3306 3572 3150	322 358 253	16 33 6	1.34 2.46 0.75
Overall	Overall	23-Apr-98 to 21-Dec-98	Average Max Min	302 350 264	7151 8028 6408	0.95 1.10 0.59	1.36 2.03 0.98	0.84 0.90 0.76	43 48 29	3085 3572 2420	330 385 253	19 82 4	2.00 6.13 0.75

TABLE 6-4 1999 TRW COMBUSTION SYSTEM CHARACTERIZATION TEST ACTIVITIES

Test Phase	Secondary Air Injection Method	Test Period	Number of Test Runs	Number of Test Hours	Number of Internal Inspections	Longest Continuous Run	Number of Runs Over 100 Hours
Steady State Operation Characterization Tests	SC Headend	18-Jan-99 to 12-Jun-99	7	2008	7	282 hours or 12 days	6

TABLE 6-5 RANGE OF COMBUSTOR OPERATING CONDITIONS FOR COMBUSTION SYSTEM CHARACTERIZATION TESTS IN 1999

				COMBUSTOR OPERATING CONDITIONS									
Test Phase	Secondary Air Injection Method	Test Period		Load (MMBtu/Hr)	Inferred Heating Value (Btu/lb)	PC Chamber Stoich.	PC Exit Stoich.	SC Stoich.	PC Coal Split (%)	PC Exit Temp (F)	PC Exit Velocity (Ft/s)	Limestone Flow (#/min)	Ca/S Molar Ratio
Steady State Operation Characterization Tests	SC Headend	5-Mar-99 to 12-Jun-99	Average Max Min	304 311 286	7160 7527 6738	1.46 1.59 1.38	1.46 1.59 1.38	0.8 0.88 0.78	31 33 28	3073 3170 2939	285 324 240	30 54 19	2.89 4.6 1.5

7.0 PERFORMANCE SUMMARY

Section 7 describes the performance results demonstrated during the TRW Combustion System Characterization Test activities, which were initiated in May 1998, and continued intermittently through the beginning of May 1999, accumulating a total of approximately six months of testing. Section 7.1 and 7.2 describe the 1998 Performance Results and 1999 Performance Results, respectively.

7.1 1998 PERFORMANCE SUMMARY

This section summarizes system performance during coal-fired test operations from June 12 through December 21, 1998. During this period of time, approximately 3300 hours of plant thermal operation was accumulated, with approximately 3200 hours of coal-fired operation. The majority of test operations were at full load, net 50 MW_e. The emission data presented includes all coal-fired operations during this period of time, including, in most cases, start-up and shutdown operations. Not included herein is emission data during: 1) January through June 11, 1998, which primarily consisted of coal-firing start-up and shake down activities and was prior to certification of the Continuous Emissions Monitoring System (CEMS) and, 2) oil-fired only operation.

7.1.1 Emissions

From June through December 1998, the demonstrated environmental performance while burning ROM or ROM/Waste Coal Blends was as follows:

NO_x Emissions:	0.208 to 0.278 lb NO_x / MMBtu (0.245 average)
SO_2 Emissions:	0.01 to 0.09 lb SO_2 / MMBtu (0.036 average)
CO Emissions:	0.01 to 0.13 lb CO / MMBtu (0.038 average)
Ash Removal:	80 to 90% (including less than 5% bottom ash)

If published data from the Continuous Emission Monitoring system is used, which includes oil-fired only data during start-up and shutdown, the average NO_x emissions over this time period is 0.25 lb NO_x / MMBtu versus the 0.245 average shown in the table above. The NO_x emission levels presented above were achieved prior to any optimization of furnace air staging or furnace O_2 levels. In general, the lowest NO_x emission levels at full load were achieved at lower furnace O_2 levels (3.0-3.5%), without any significant increase in plant CO emissions. The CO emissions were measured by a CO analyzer located at the furnace exit. This analyzer is not part of the Continuous Emission Monitoring System.

Table 7-1 presents a summary of the Coal Combustion System and SDA performance goals, New Source Performance Standards (NSPS), and HCCP Air Quality Permit requirements compared to the performance results demonstrated during coal-fired test operations from June 12 through December 21, 1998. As noted above, the emission data presented in the table includes all coal-fired operations during June 12 through December 21, 1998, including in most cases, coal-fired start-up and shutdown operations, but does not include oil-fired only operations. The average values for NO_x, SO_2, CO, and Opacity listed in Table 7-1 were determined by averaging the emission data recorded on the plant data recording system (referred to as ODMS) during the approximately 3200 hours of coal-fired operation from June 12,1998 through December 21,1998. The NO_x emission data presented in the table is based on a 30-day rolling average, whereas the SO_2, CO, and opacity data averages are based on 30-minute averages. As shown, the performance results for NO_x, SO_2, and CO demonstrated during coal-fired operations from June 12 through December 21, 1998, met or exceeded all performance goals, and are lower than permitted emission limits. As noted in the table, during 1998, the opacity and particulate matter were higher than anticipated due to a problem with the baghouse. Following modification of the baghouse in December 1998, the opacity and particulate matter emissions are meeting performance goals as shown in Table 7-1.

Figure 7-1 provides a frequency distribution of the stack NO_x emissions (30 day average) for data over the period from June 12 through December 21, 1998. Figure 7-2 provides a frequency distribution of the stack SO_2 emissions over the same time period.

Figure 7-3 plots the key plant parameters (power, boiler $\%O_2$) and stack emissions (NO_x, SO_2) as a function of time for 13 days of an 18-day continuous run conducted with both combustors at full load burning ROM coal from June 8 though June 26, 1998 (remaining data from test run not available). Figure 7-4 shows the same parameters for a 24-day continuous test run from September 27 to October 21, 1998 on a ROM / Waste Coal blend conducted primarily at part load with only one combustor in operation. The key statistics from these extended test runs are provided below:

	Run of Mine	**Waste Coal Blends**
Test Period	6/12/98 – 6/25/98	9/27/98 – 10/21/98
Test Hours	312 hours	580 hours
Average NO_x in Exhaust	0.233 lb/MM Btu	0.204 lb/MMBtu
Average SO_2 in Exhaust	0.030 lb/MM Btu	0.035 lb/MMBtu
Average O_2 in Boiler	3.50 %	6.75 %
Average Gross MW_e	59.9 MW_e (2 combustors at full load)	29.8 MW_e (1 Combustor at full load)

During the continuous runs, the plant produced 58-62 MW_e (gross) with two combustors in service and 28-30 MW_e (gross) with only one combustor in service. As illustrated by the stack emission trends indicated in Figures 7-3 and 7-4, the emission levels of NO_x, and SO_2 were very consistent during the steady-state portion of the test.

7.1.2 Carbon Burnout

A preliminary determination of carbon burnout was calculated at 99.7% based upon a slag carbon content measured at 0.3% and a flyash carbon content of 0.01%. The slag and flyash ultimate analysis results are given in Appendix C.

7.1.3 Slag Recovery

Figure 7-5 presents preliminary slag recovery data acquired between October 30 and December 19, 1998. A "total" slag recovery value was determined for a cumulative test period covering the equivalent of 45 operating days, during which 4 tests were conducted (including 4 start-up and shutdown periods). Slag recovery was determined to be approximately 80-85% over this 45-day period, based on ash hopper load cell measurements. This value includes bottom ash, which is estimated to contribute less than 5% to the total ash capture. This reduction in the quantity of coal ash entering the furnace has several benefits, including: 1) reduction in ash loading through the boiler convective pass, 2) reduction in ash loading on the baghouse bags, and 3) reduction in total ash loading to the SDA which reduces the limestone flow requirements.

7.1.4 Slagging Characteristics

The slagging characteristics of the slagging stage and slag secovery section were, in general, excellent. In particular, during all post test inspections, the slagging stage had 100% slag coverage without any bare regions. In general, the slag layer was uniform in thickness, varying from 1 to 3 inches thick along the axial length. The thickest slag layer was observed in the air inlet footprint region and the thinnest slag layer was observed in the headend.

In general, the slag quality and quantity observed on the drag chain was excellent. The majority of the slag was small (less than 0.25 inches in diameter) and granular. During tests conducted with a higher percentage of waste coal with a high T_{250} ash fusion temperature, the slag size increased to a nominal 1.5 inches in diameter. On occasion, slag clinkers were observed. Typically, the occasional slag clinker could be attributed to off-nominal stoichiometry operating conditions. The random slag clinkers were carried out of the slag tank via the drag chain, during the test, and did not disrupt overall test operations.

During 1998, the precombustor slagging behavior varied during the test series and was dependent on type of coal burned (i.e., percent of waste coal), precombustor secondary air injection method, precombustor coal split, and precombustor stoichiometry. The precombustor slagging behavior was typically well controlled while burning ROM coal, with the internal surfaces covered with a uniform thickness, molten slag layer. In early testing with ROM / Waste Coal blends with heating values below 7400 Btu/lb in combination with wide coal property variations (particularly heating value, ash content, ash T_{250}), slag freezing in specific areas of one or both of the two operating precombustors would occur over a period of several days. Several secondary air injection modifications were evaluated in order to minimize this slag freezing phenomena: 1) Improved secondary air mixing by injecting the air into the core flow of the precombustor combustion products through high velocity discrete air jets, and 2) Relocated a portion of the secondary air from the precombustor to the headend of the slagging stage. Ultimately, precombustor slag freezing was minimized by relocating the secondary air injection to the slagging stage and by transferring the excess mill air (i.e., the additional mill air not required for coal transport) to the boiler after start up. These changes not only eliminated the mixing of air downstream of the precombustor combustion chamber, but it also effectively increased the precombustor operating temperature to the 3200-3500 ^oF level. During 1999, additional adjustments to the precombustor coal burner configuration (e.g., adjustment of coal fines injection velocity and inner and outer air register settings) were made in order to broaden the operating envelope when burning ROM / Waste Coal blends.

7.2 1999 PERFORMANCE SUMMARY

This section summarizes system performance during coal-fired test operations from February 18 through June 30, 1999. During this period of time, approximately 2014 hours of plant thermal operation was accumulated, with approximately 1852 hours of coal-fired operation. The majority of test operations were at 50 MW_e (net). The emission data presented includes coal-fired operations during this period of time, including, in most cases, start-up and shutdown operations. Not included herein is emission data during: 1) January 1 through February 18, 1999, when test operations were limited due to various facility problems, including insufficient limestone supply for continuous test operations, 2) NO_x emission data from March 5 through April 22, 1999, when there was a leak in the CEMs CO_2 sampling system, which affected the CO_2 values and resulted in erroneous values for NO_x and SO_2, in terms of lb/MMBtu output, and 3) oil-fired only operation. Note that the SO_2 emission data from March 5 through April 22, 1999 is included in this section since the SO_2 emissions were calculated from the ppm data rather than the lb/MMBtu data. The NO_x data was not recorded as ppm and, therefore, could not included.

7.2.1 Emissions

From April 23 through June 30, 1999, the demonstrated environmental performance while burning ROM/Waste Coal Blends was as follows:

NO_x Emissions:	0.228 to 0.271 lb NO_x / MMBtu (0.247 average)
SO_2 Emissions:	0.002 to 0.067 lb SO_2 / MMBtu (0.040 average)
CO Emissions:	0.061 to 0.082 lb CO / MMBtu (0.077 average)
Ash Removal:	nominal 81% (including less than 5% bottom ash)

The NO_x emission levels presented above were achieved without any optimization of furnace air staging or furnace O_2 levels. The location of the excess air addition, as well as the amount of excess air, is important in controlling peak furnace temperatures and, hence, NO_x formation within the furnace. Minimum NO_x is typically achieved if the excess air is added after reduction of the combustion gas temperature by radiative cooling to the furnace walls and the furnace O_2 level is between 2 to 3%. At the HCCP, the majority of the excess air is added through the lower furnace NO_x ports, with only a relatively small amount of purge air added through the overfire air ports. During 1999, the typical furnace O_2 level at full load (50 MWe net) was 4 to 5%. The higher furnace O_2 levels at HCCP are attributed to: 1) high purge air flowrates through the closed dampers on the over-fire air ports and clean air NO_x ports, 2) high purge air flowrates through the PC NO_x port piping after transfer of the Mill Air to the furnace, and 3) higher Mill Air flowrates to ensure correct functioning of the Mill while grinding the high moisture blended coal.

Figure 7-6 provides a frequency distribution of the stack NO_x emissions (daily average) for data over the period from May 6 through June 12, 1999. Figure 7-7 provides a frequency distribution of the stack SO_2 emissions from March 5 through June 12, 1999.

During the 90-day test performed from August through November 1999, additional emission data was collected to characterize the integrated HCCP performance over longer operational periods. The 90-day test emission levels were consistent with previous test data. The 90-day test results will be released in a separate topical report to be prepared by AIDEA.

7.2.2 Carbon Burnout

As described in Section 5.3.2, due to the difficulty in obtaining a representative slag sample, only limited sampling of slag was performed during the Combustor Characterization Test Series in 1998 and 1999. During 1998, a preliminary determination of carbon burnout was calculated at 99.7% based upon a slag carbon content measured at 0.3% and a flyash carbon content of 0.01%. The slag and flyash ultimate analysis results were given in Appendix C. During 1999, additional slag sampling and carbon burnout calculations were performed and the results were similar. Specifically, carbon burnout was determined to be 99.9%, based upon a slag carbon content of 0.1% and a flyash carbon content of 0.03%.

7.2.3 Slag Recovery

Slag recovery is primarily a function of coal particle size, combustion efficiency, and Precombustor exit velocity. At higher Precombustor exit velocities, there is a trade-off between higher slag recovery and higher Precombustor pressure drop. Figure 7-8 presents preliminary slag recovery data acquired between May 6 and June 12, 1999, during operation with a Precombustor exit velocity of 320 ft/sec. A "total" slag recovery value was determined for a cumulative test period covering the equivalent of 28 operating days, during which 2 tests were conducted (including 6 start-up and shutdown periods). Slag recovery was determined to be approximately 81% over this 28-day period, based on ash hopper load cell measurements. This value includes bottom ash, which is estimated to contribute less than 5% to the total ash capture.

Figure 7-9 illustrates the impact of Precombustor exit velocity on slag recovery. During the 1999 Combustor Characterization Test Series, the Precombustor exit velocity was varied by off-line adjustments to the Precombustor Swirl Dampers. As shown, as the Precombustor exit velocity increased from 250 to 320 ft/sec, the slag recovery increased from nominally 60 to 75%. This reduction in the quantity of coal ash entering the furnace has several benefits, including: 1) reduction in ash loading through the boiler convective pass, 2) reduction in ash loading on the baghouse bags, and 3) reduction in total ash loading to the SDA which reduces the limestone flow requirements.

7.2.4 Slagging Characteristics

Similar to the 1998 Demonstration Test Program, the slagging characteristics of the slagging stage and slag recovery section were, in general, excellent throughout the 1999 Demonstration Test Program. In particular, during all post test inspections, the slagging stage had 100% slag coverage without any bare regions. In general, the slag layer was uniform in thickness, varying from ½ to 3 inches thick along the axial length and varying ½ to 2 inches thick around the circumference. The thickest slag layer was observed in the air inlet footprint region and the thinnest slag layer was observed on the headend, the keyhole baffle, and along the top surface of the chamber. The majority of the slag recovery section was covered with a thin uniform slag layer with distinct flow lines visible. Typical slag layer thickness varied from 1 inch along the majority of the SRS surface to 5 inches along the bottom 2 feet of the target wall located within the slag tap region. On occasion, thicker slag layers were also observed directly opposite the limestone injector, near the SRS/Furnace interface. Typically, the slag layer was black and glassy with a slight gray-brown tint in the slagging stage and a slight greenish tint in the Slag Recovery Section. On occasion, while burning waste coal blends with high silica content, the slag coverage in the slagging stage would be somewhat thicker (i.e., 1 to 4 inches thickness) and appear nearly white in color.

In general, the slag quality and quantity observed on the drag chain was excellent. The majority of the slag was small (less than 0.25 inches in diameter) and granular. During tests conducted with a higher percentage of waste coal with a high T_{250} ash fusion temperature, the slag size increased to a nominal 1.5 inches in diameter. On occasion, slag clinkers were observed. Typically, the occasional slag clinker could be attributed to off-nominal stoichiometry operating conditions. The random slag clinkers were carried out of the slag tank via the drag chain, during the test, and did not disrupt overall test operations.

The precombustor slagging behavior during the 1999 test series was, in general, well controlled with a uniform slag layer throughout the precombustor, without any bare regions. The slag coverage was relatively consistent from test-to-test and from one combustor to the other. Unlike the early 1998 test series, the slagging behavior was relatively independent of the type of coal burned (e.g., percentage of waste coal) and there was little, if any, evidence of slag freezing within localized regions of the precombustor. The improvement in precombustor slagging behavior during 1999, while burning ROM / Waste Coal blends with heating values below 7400 Btu/lb is attributed to the following combination of configuration changes that were implemented during late 1998 and early 1999: 1) relocating the secondary air injection to the slagging stage and transferring the excess mill air (i.e., the additional mill air not required for coal transport) to the boiler after start up, which eliminated the mixing of air downstream of the precombustor combustion chamber and effectively increased the precombustor operating temperature to the 3200-3500 ^{o}F level and 2) adjustments to the precombustor coal burner configuration (e.g., adjustment of the tertiary air injection velocity and temperature, increased swirl on the inner air register setting, improved mixing of the coal fines, and decreased swirl on the outer air register), which improved the near zone flame attachment and minimized the potential for slag/char particles to be swirled to, and attach to, the inner chamber walls. Both of these changes effectively broadened the precombustor operating envelope when burning ROM / Waste Coal blends and provided consistent slagging behavior over a wide and varying range of coal properties (e.g., low coal Btu content and high T_{250}).

TABLE 7-1 HCCP PERFORMANCE GOALS AND RESULTS

PARAMETER	New Source Performance Standards (NSPS) [1]	HCCP AIR QUALITY PERMIT	CONTRACT GOALS	DEMONSTRATED IN 1998 (June - December, 1998)	
				RANGE	TYPICAL
NOX	0.5 lb/MMBtu (prior to 7/97) 0.15 lb/MMBtu (modified after 7/97) 1.6 lb/MWhr (new plant after 7/97)	0.350 lb/MMBtu (30 day rolling average)	< 0.35 lb/MMBtu	0.208-0.278 lb/MMBtu 30-day rolling ave. [9], [10]	0.245 lb/MMBtu 30-day rolling ave. [9], [11]
CO	Dependent on ambient CO levels in local region (Title V of 1990 CAAA)	0.20 lb/MMBtu, (hourly average) (202 ppm CO @ 3.0% O2)	< 200 ppm (dry basis) at 3.5% O2 (dry basis) [2] (<206 ppm CO @ 3.0% O2)	<130 ppm at 3.0% O2 [6], [8]	30-40 ppm at 3.0% O2 0.036 lb/MMBtu [5], [8]
SO2	90 % removal and less than 1.2 lb/MMBtu 70% removal when emissions are less than 0.60 lb/MMBtu	0.086 lb/MMBtu, (annual average) 0.10 lb/MMBtu, (3-hour average) 65.8 lb/hr max, (3-hour average)	70 % Removal (minimum) 79.6 lb/hr SO2 (maximum)	< 0.09 lb/MMBtu (<35 ppm @ 3% O2) [6], [8]	0.038 lb/MMBtu (15 ppm @ 3% O2) (25 lb/hr) [5], [8]
OPACITY	20% Opacity (6 min. average)	20% Opacity, (3 min average) 27% Opacity (one 6 min period per hour)	20% Opacity, 3 min average	<10 % Opacity [6]	5.6% Opacity (Jun - Dec 1998) [5],[15] 2.3% Opacity (1999) [15]
PARTICULATE MATTER	0.03 lb/MMBtu	0.02 lb/MMBtu, (hourly average)	0.015 lb/MMBtu		0.0047 lb/MMBtu (1999) [14], [15]
CARBON BURNOUT	NA	NA	> 99% at 100% MCR for Perf., ROM, and 55/45 Blend [3] >98% at 100% MCR for Waste Coal	NA	99.7% [4]
SLAG RECOVERY	NA	NA	> 70% at 100% MCR for all coals [3]	78-87% [7]	83% [7]
NET POWER PRODUCTION	NA	NA	50 MWe for all coals	NA	50-55 MWe [12],[13]

NOTES
[1] From 40CFR60.40a - 40CFR60.49a; New NOx Standards based on 62 FR 36948
[2] From minimum to 100% MCR (Maximum Continuous Firing Rate)
[3] 100% MCR for Performance Coal is 315 MMBtu/Hr, ROM Coal is 306 MMBtu/Hr, Waste Coal is 322 MMBtu/Hr, 55/45 Waste/ROM Coal is 316 MMBtu/Hr
[4] Measured for one test based upon slag and flyash carbon contents
[5] Average of available 30 min. (average) test data, June 12,1998 to December 21, 1998 (total of 3100 hours of run time)
[6] 95% of CO, SO2, and opacity data are observed to be less than these reported value (using available 30 min average test data)
[7] Slag weight corrected for 6% moisture content.
[8] Data corrected to 3% O2
[9] 30-day rolling average determined from available 30 min (average) test data, June 12, 1998 to December 21, 1998, total of 3100 hours (5480 data points).
30-day rolling average only includes days in which power was generated.
[10] Represents minimum and maximum of 30-day rolling average data described in Note [9]
[11] Represents the average of 30-day rolling average data described in Note [9]
[12] Nominal power set point from April through September, 1998 was 60-62 MWe (gross), 53-55 MWe (net);
[13] Nominal power set point in November and December, 1998 was 57 MWe (gross), 50 MWe (net)
[14] Based on independent particulate matter testing performed on March 10-11, 1999 by Haas, Morgan & Hudson
[15] Opacity and particulate matter emissions during 1998 were higher than expected due to a problem with premature baghouse filter bag failure, which was corrected in 1999

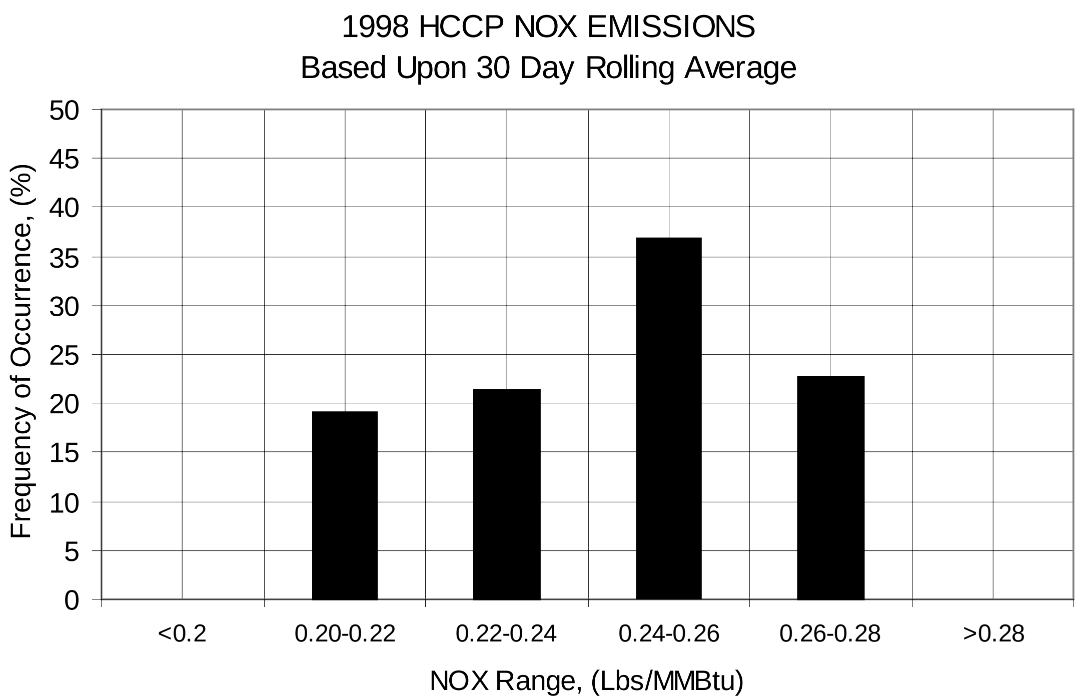


FIGURE 7-1 FREQUENCY DISTRIBUTION OF THE STACK NOX EMISSIONS (30 DAY AVE)

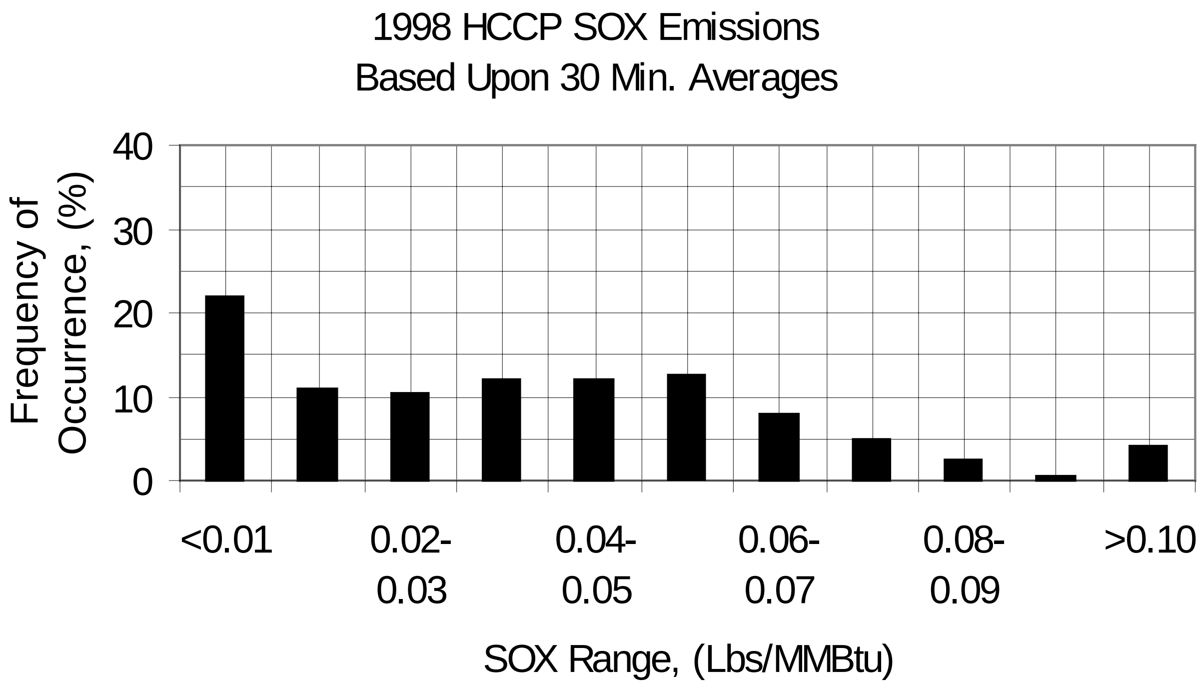


FIGURE 7-2 FREQUENCY DISTRIBUTION OF THE STACK SO2 EMISSIONS (30 MIN. AVE.)

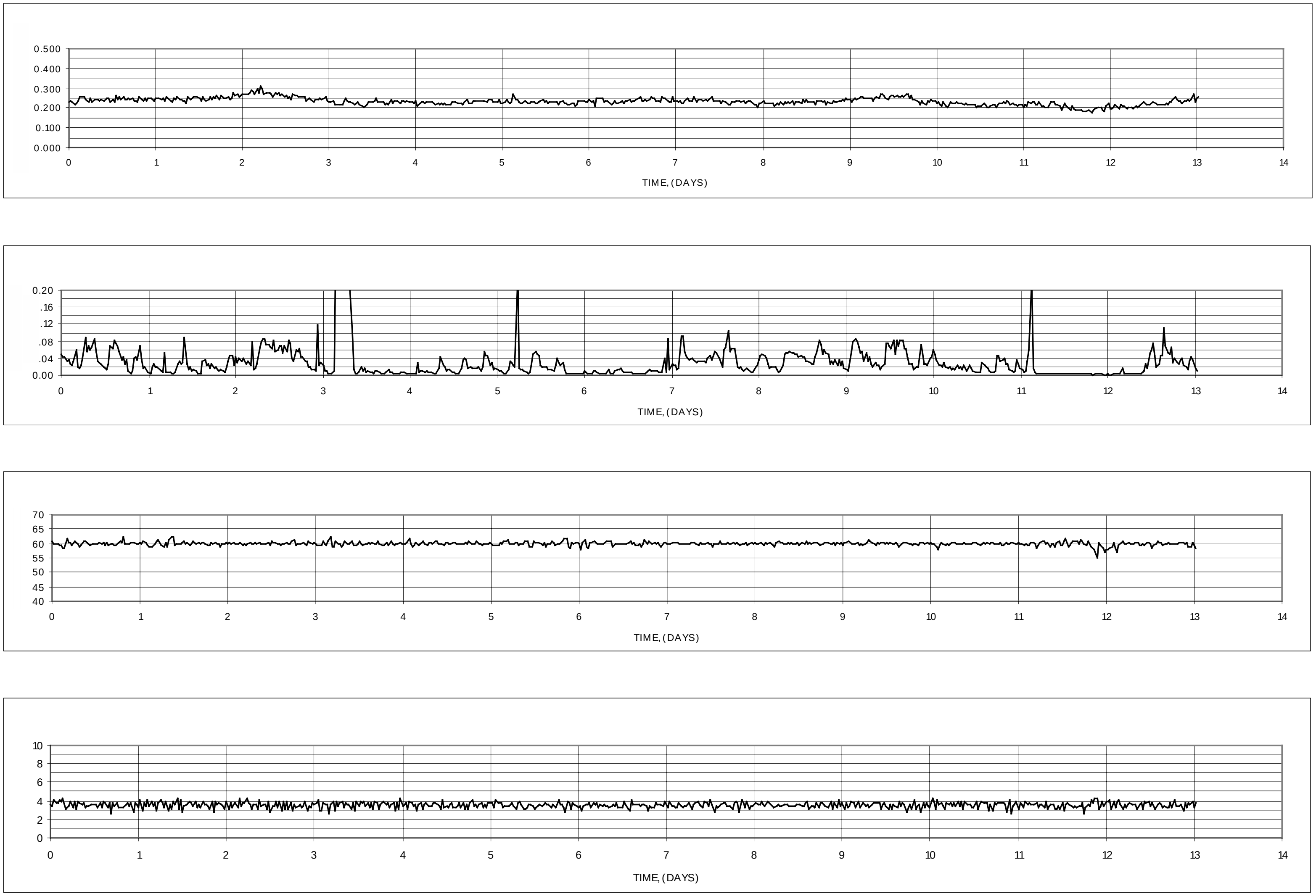


FIGURE 7-3 HCCP EMISSIONS DURING 13 DAYS OF CONTINUOUS OPERATION WITH RUN OF MINE COAL (BOILER AT FULL LOAD – 2 COMBUSTORS) JUNE 12, 1998 TO JUNE 25, 1998

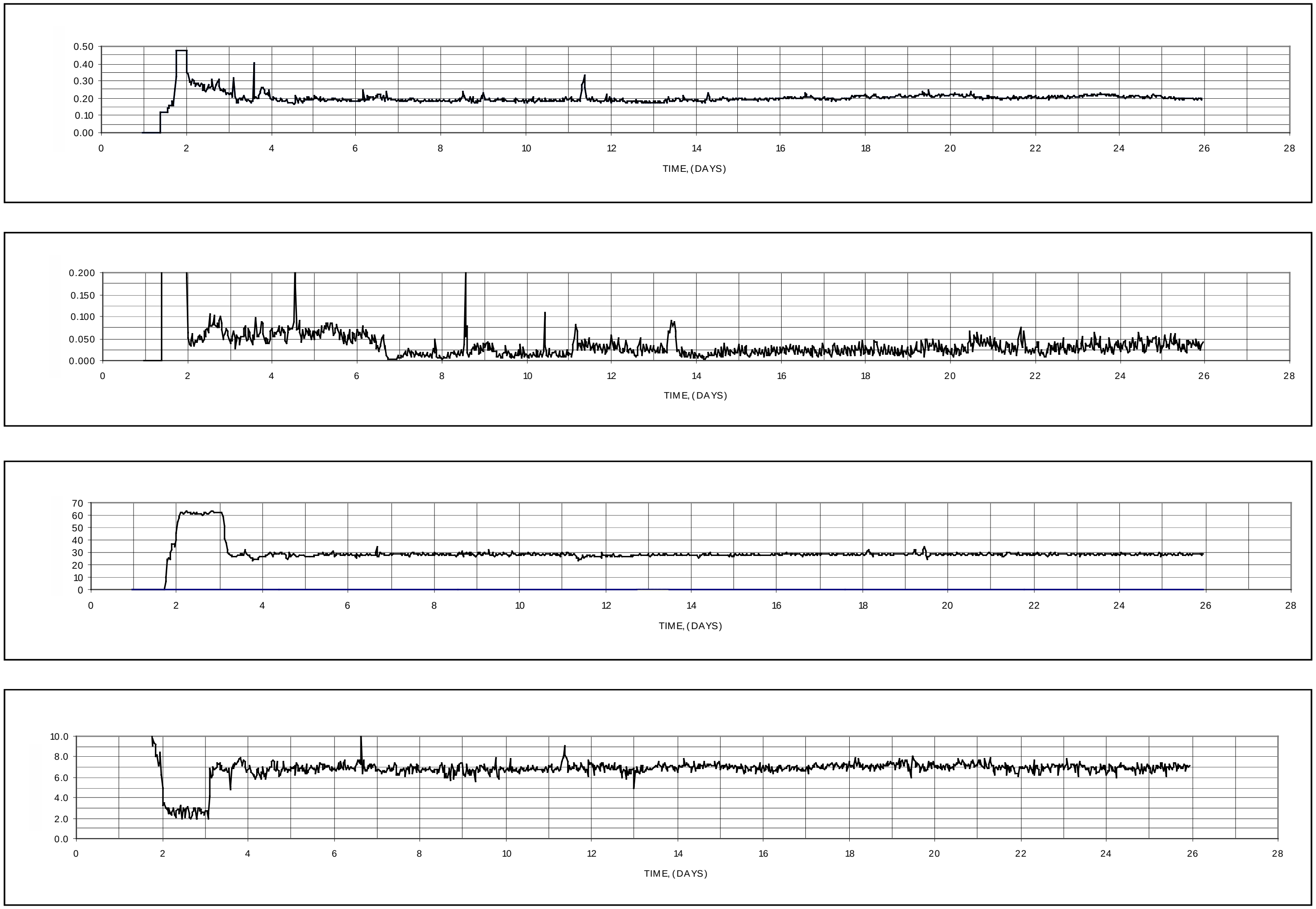


FIGURE 7-4 HCCP EMISSIONS DURING 24 DAYS OF CONTINUOUS OPERATION WITH WASTE COAL BLEND (BOILER AT PART LOAD – 1 COMBUSTOR) SEPT. 27, 1998 TO OCT. 21, 1998

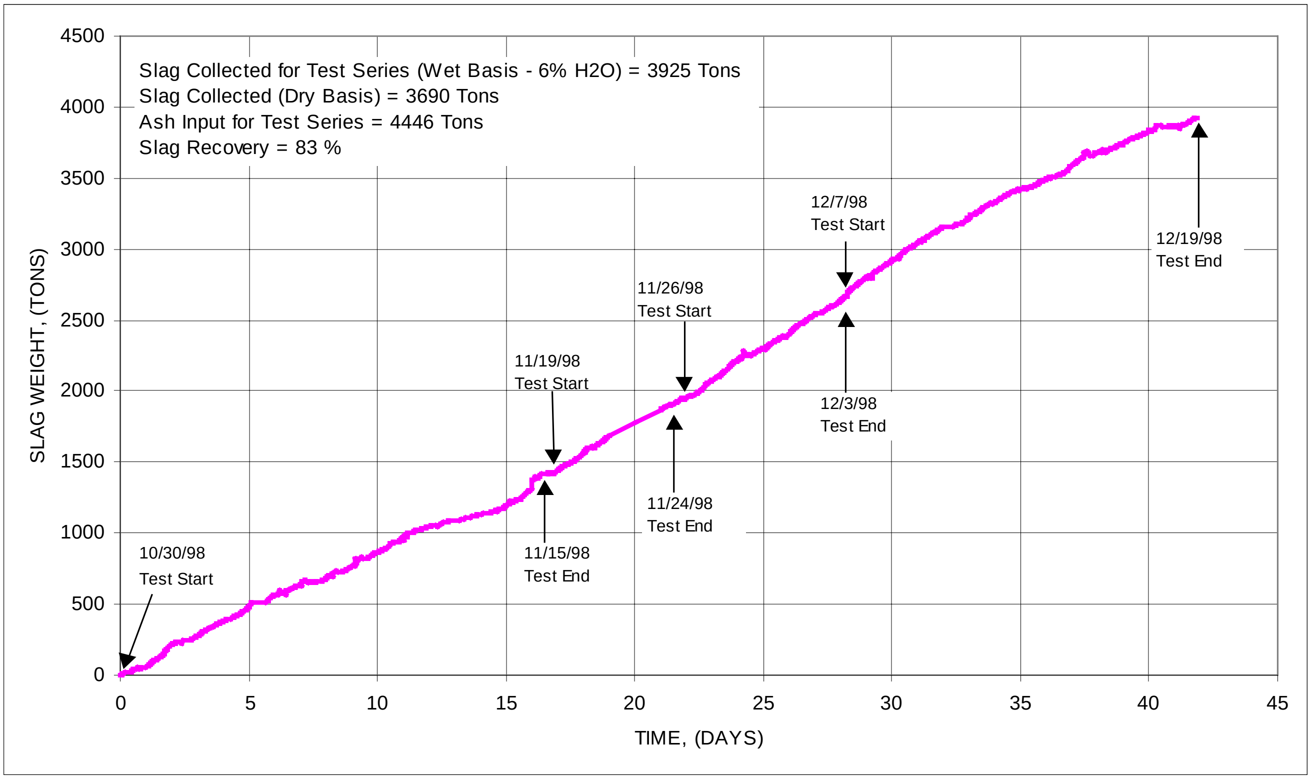


FIGURE 7-5 DEMONSTRATION OF SLAG COLLECTION OVER 4 TESTS OVER A 42 DAY PERIOD BASED ON SLAG ASH HOPPER LOAD CELL READINGS

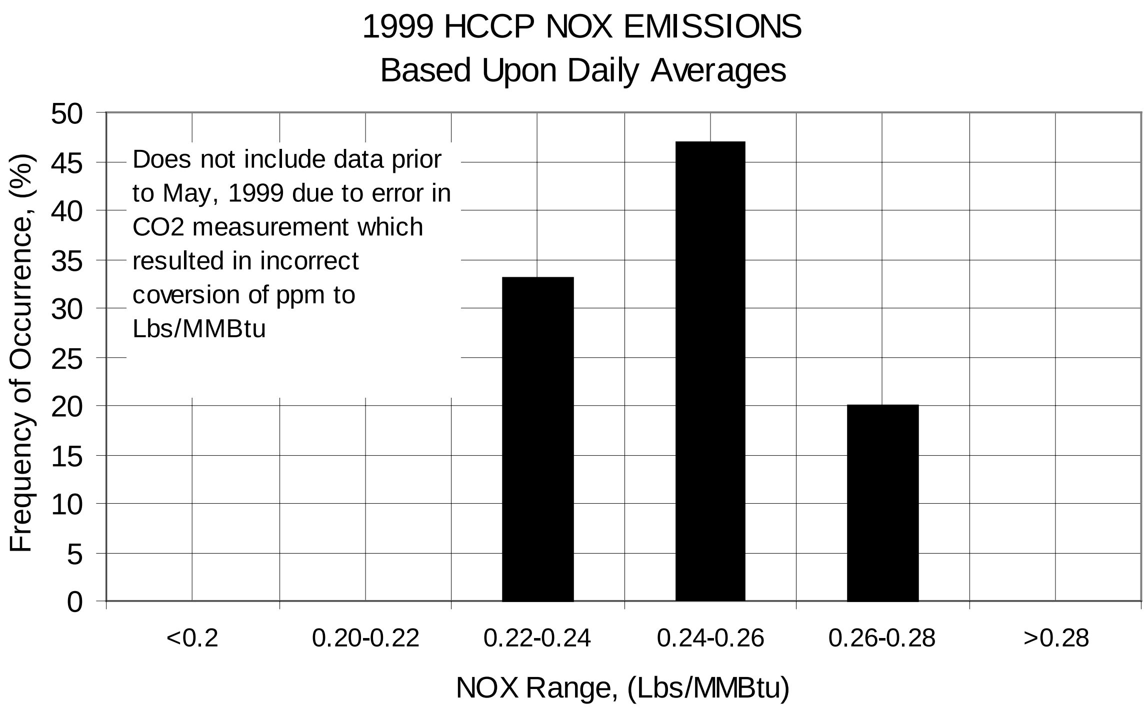


FIGURE 7-6 NOX FREQUENCY DISTRIBUTION (DAILY AVE) FROM MAY TO JUNE, 1999

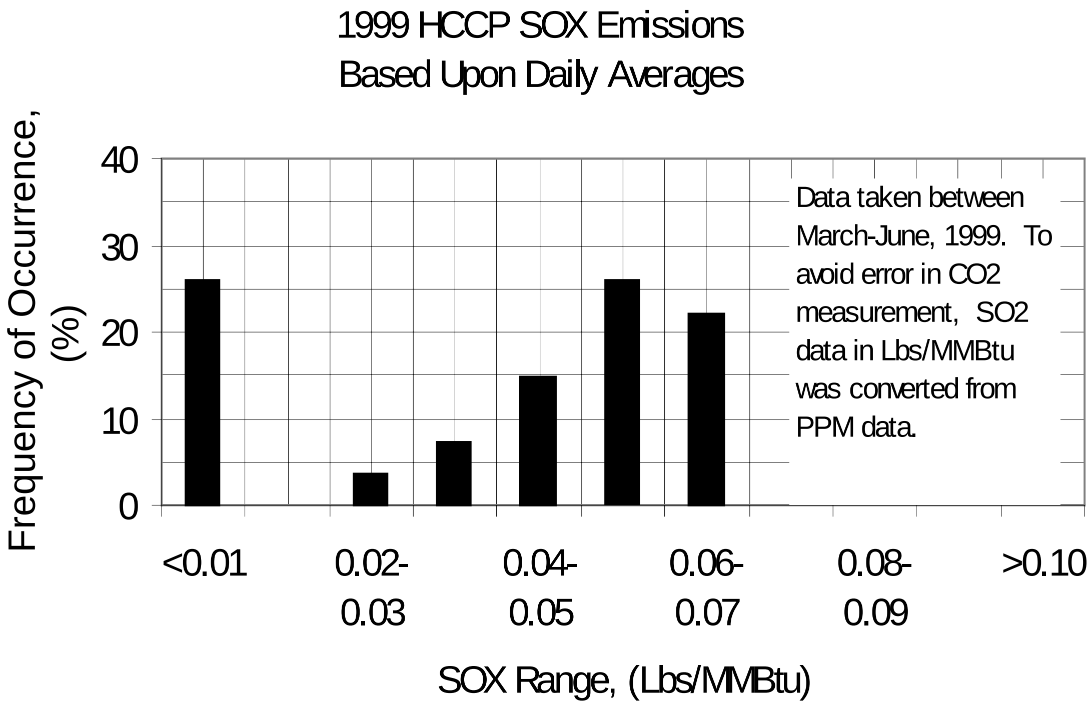


FIGURE 7-7 SO2 FREQUENCY DISTRIBUTION (DAILY AVE) FROM MARCH TO JUNE, 1999

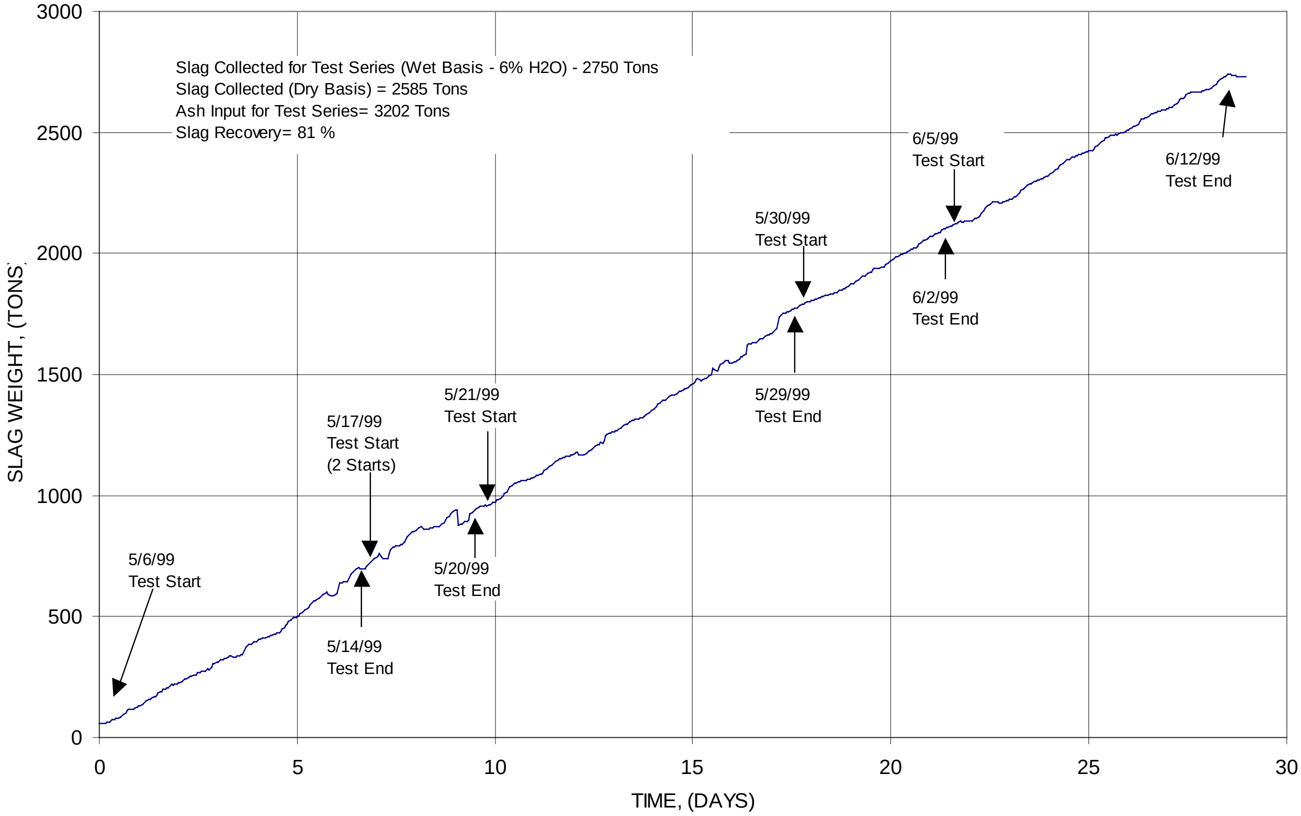


FIGURE 7-8 SLAG RECOVERY DATA ACQUIRED BETWEEN MAY 6TH AND JUNE 12TH, 1999

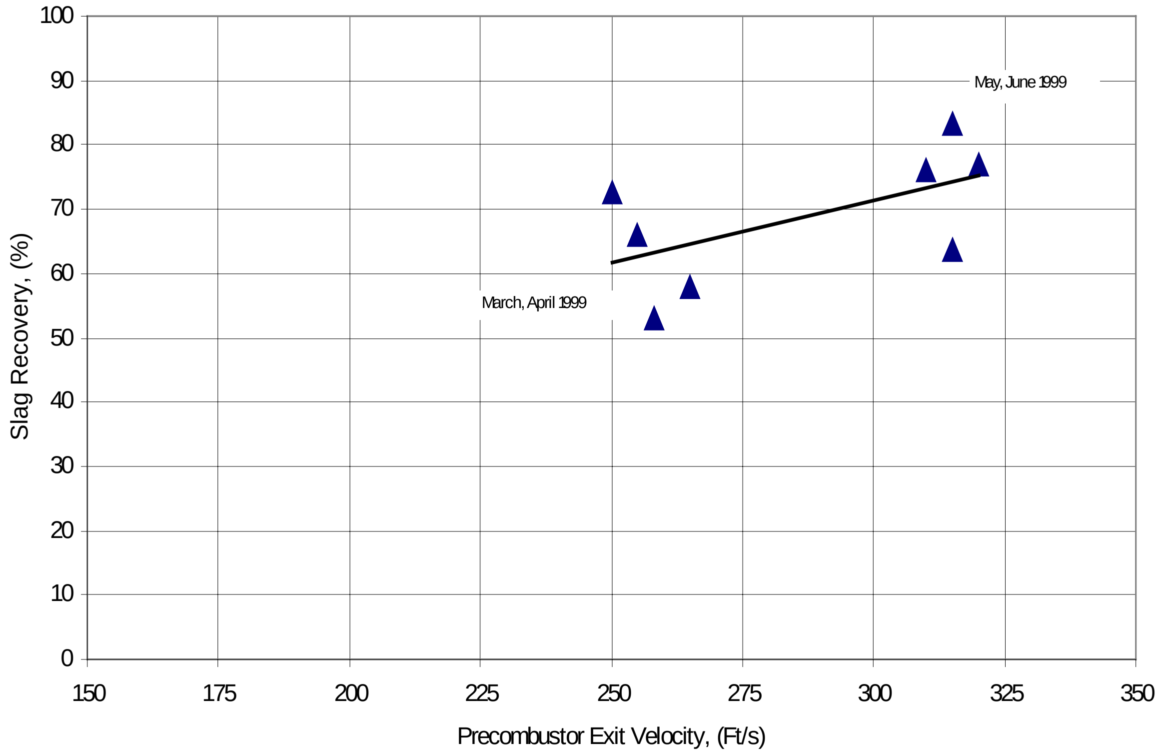


FIGURE 7-9 EFFECT OF PRECOMBUSTOR EXIT VELOCITY ON SLAG RECOVERY

8.0 SUMMARY OF TEST ACCOMPLISHMENTS

This section provides a summary of the test accomplishments during 1998 and 1999.

8.1 SUMMARY OF 1998 TEST ACCOMPLISHMENTS

During 1998, approximately 5,000 hours of plant thermal operation were accumulated, with approximately 4,500 hours of coal-fired operating time. Both run-of-mine (ROM) and ROM / Waste Coal blends were tested in the combustion system. Typically, the ROM / Waste Coal blends had caloric heating values ranging from 6,200 to 7,500 Btu/lb, ash contents ranging from 10 to 24%, and ash fluid temperatures ranging from 2300 to 2900 ^oF.

A key performance goal of the test program, demonstrating the capability to meet the emission limit goals while burning both ROM and ROM / Waste Coal blends, was met. The NO_x and SO_2 emission goals were met while burning all coal blends. In particular, the NO_x emissions appeared to be independent of the coal type, with low NO_x emissions demonstrated for all coal blends tested. Table 1 in the executive summary provides a summary of these preliminary performance results, including a comparison to the NSPS standards, HCCP Air Quality Permit emission limits, and HCCP performance specifications. The emission levels of NO_x and SO_2 and particulate matter from this 50 MW_e (net) power plant were significantly lower than permitted emission limits.

During 1998, the testing demonstrated:

- ability to achieve low NO_x emissions simultaneously with low CO emissions and high carbon burnout
- good combustion efficiency and high slag removal prior to the furnace
- good limestone calcination efficiency
- consistent achievement of SO_2 emissions less than 0.10 lb / MMBtu.

All combustor performance parameters met or exceeded expectations. NO_x emissions were typically in the 0.20 to 0.30 lb/MMBtu range, for furnace O_2 levels between 3.0 and 4.5% at full load (300 to 315 MMBtu/hr per combustor). Based on preliminary analysis of the carbon in the slag and the flyash, carbon burnout is very high (>99%), indicating excellent combustion. Carbon monoxide (CO) emissions were also very low, typically in the 10-50 ppm range, compared to the permit value of 0.20 lb/MMBtu (200 ppm @ 3.5%O_2). Slag recovery was determined to be approximately 80-85% over 45 cumulative days of operation (combination of 4 consecutive test runs, including 4 start-up and shutdown periods).

The slagging stage of the combustor performed extremely well and continuously demonstrated the capability to reliably burn ROM and ROM / Waste Coal blends over a broad range of operating conditions, while maintaining a thin molten slag layer over the entire tubewall surface. The precombustor performed very well with ROM coal but exhibited more variable performance, in terms of slagging behavior, during the initial tests with ROM / Waste Coal blends. Localized slag freezing was observed in the precombustor during the test program. A combination of hardware configuration and operational changes were made which were demonstrated to minimize precombustor slag freezing. The key changes made were as follows: (1) relocating the secondary air from precombustor mix annulus to the headend of the slagging stage and (2) completely transferring the precombustor mill air to the boiler NO_x ports following the boiler warm up. These changes eliminated the mixing of excess air downstream of the precombustor combustion chamber to minimize local slag freezing, and increased the precombustor operating temperature in order to provide additional temperature margin. The mill air change had the added benefit of simplifying combustor operation by eliminating the need to monitor and control the coal-laden mill air flow to the precombustor mill air ports during steady-state operation.

The operation of the TRW coal feed system was very steady and reliable during the DTP, which is the first utility-scale demonstration of this pulverized coal feed splitter system. The system operated within its established pressure budget (<60 i.w.g.), and demonstrated the capability to deliver various splits of the coal to the precombustor and the slagging combustor. The blowdown cyclone control approach also worked well, demonstrating that the system is capable of maintaining sufficient transport velocities in each transport line under different coal splits, coal types, boiler load, and back pressure conditions.

The limestone feed system also performed very well, once some initial problems with accurately controlling the low end feed rate were diagnosed and resolved. The system demonstrated that it can continuously feed limestone over the required range to ensure overall plant SO_2 compliance.

Preliminary data was also gathered in 1998 to assess combustor availability. The test period from April 23, 1998 through December 31, 1998 was reviewed in order to identify the cause(s) of each plant shut-down, as well as to estimate the amount of time the combustors were unavailable during a plant shut-down. During this period, no plant trips were attributed to the TRW coal feed and coal combustor systems. As noted previously, a number of these plant shut-downs were incorporated into the test planning activities in order to inspect the combustor internal slagging characteristics and/or implement any configuration changes. Over the time period considered, it was estimated that Combustor A was not available for approximately 1392 hours and Combustor B was not available for 1546 hours out of the 6060 total elapsed hours, corresponding to overall combustor availabilities of approximately 77.0% and 74.5%, respectively. However, it should be noted that the majority of unscheduled combustor downtime during this period was related to the previously mentioned problem of slag freezing within the precombustor subsystem. Significant progress was made during 1998 in controlling the precombustor slagging behavior. When combustor downtimes attributed to the precombustor slag freezing program are excluded, the corresponding availability for the remaining combustor subsystems was estimated to be approximately 94% for both combustors.   A more accurate determination of combustor availability was made during the long-duration 90-day Test performed during August through November 1999, and the resulting calculated availability was greater than 97% with a capacity factor of approximately 95%. The 90-day test results will be released in a separate topical report prepared by AIDEA.

Another on-going goal of the test program had been to increase the reliability of the combustor instrumentation and control equipment, as well as simplify the operation as much as possible. In May 1998, most of the combustor start-up and shut-down operations were automated. During steady-state operation, slagging combustor stoichiometry can also be programmed to adjust automatically to changes in coal load and coal type. In addition, all of the key combustor operating parameters have alarm levels to alert the operator of upset conditions, and additional diagnostic pages have been included on the Plant Control System (PCS) to assist with process monitoring and troubleshooting. Additional flame scanners were also added to the combustion flame monitor system to provide additional system redundancy and enhance system safety. Efforts are also underway to provide redundant and/or independent measurements for various flow parameters in order to increase operational reliability.

Overall, the combustor operation and performance demonstrated during the 1998 Combustor System Characterization Test Series was quite encouraging given it is the first utility-scale demonstration of this promising new technology. The overall system met or exceeded all goals for achieving low NOx and SO_2 emissions at the stack, with extremely low CO levels in the furnace, very high carbon burnout, and removal of the majority of ash prior to entering the furnace, while burning both ROM and ROM / Waste Coal blends. Major strides were made in controlling precombustor slagging behavior while burning ROM / Waste Coal blends, through both changes in operating conditions and hardware configuration.

By the end of 1998, the majority of the Combustor Characterization testing had been completed. Some additional Combustor Characterization testing was required in order to complete the Combustor Operating Envelope Test Matrix (Figure 4-1) and enable extrapolation of the test data to other coal types and/or future designs. In particular, additional tests were required to complete the operating envelope characterization for slagging combustor stoichiometry, furnace O_2, load sweep, and limestone Ca/S ratio. As was the case during 1998, these additional tests were scheduled concurrent with other plant operational activities.

8.2 SUMMARY OF 1999 TEST ACCOMPLISHMENTS

From January through June 1999, approximately 2200 hours of plant thermal operation were accumulated, with approximately 2000 hours of coal-fired operating time. The majority of 1999 test operations were conducted with ROM / Waste Coal blends. Typically, the ROM / Waste Coal blends had caloric heating values ranging from 6766 to 7826 Btu/lb, ash contents ranging from 8 to 19%, and ash fluid temperatures ranging from 2275 to 2852 ^oF.

Similar to 1998 results, the NO_x and SO_2 emission goals were met for all full load operating conditions, while burning all coal blends. In particular, the NO_x emissions appeared to be independent of the coal type, with low NO_x emissions demonstrated for all coal blends tested. Testing during 1999 continued to demonstrate the ability to achieve low NO_x emissions simultaneously with low CO emissions and high carbon burnout, good combustion efficiency and high slag removal prior to the furnace, and good limestone calcination efficiency with consistent achievement of SO_2 emissions less than 0.10 lb / MMBtu.

All combustor performance parameters met or exceeded expectations. NO_x emissions were typically in the 0.228 to 0.271 lb/MMBtu range, for furnace O_2 levels between 3.9 and 4.9 % at near full load (300 to 315 MMBtu/hr per combustor) operating conditions. Based on preliminary analysis of the carbon in the slag and the flyash, carbon burnout is very high (>99.9%), indicating excellent combustion. Carbon monoxide (CO) emissions were also very low, typically in the 10-90 ppm range, compared to the permit value of 0.20 lb/MMBtu (200 ppm @ 3.5%O_2). Slag recovery was determined to be approximately 81% over 28 cumulative days of operation (combination of 2 consecutive test runs, including 6 start-up and shutdown periods) at nominal precombustor exit velocity of approximately 300 ft/sec.

The slagging stage of the combustor performed extremely well and continuously demonstrated the capability to reliably burn ROM / Waste Coal blends over a broad range of operating conditions, while maintaining a thin molten slag layer over the entire tubewall surface. The precombustor also performed very well with ROM / Waste Coal blends, without any significant slag freezing exhibited during operation with nominal 7000 Btu/lb coal blend. This was a significant improvement over the early 1998 performance and is attributed to a combination of hardware configuration and operational changes made during 1998 and 1999 including: (1) relocating the secondary air from precombustor mix annulus to the headend of the slagging stage,

(2) completely transferring the precombustor mill air to the boiler NOx ports following the boiler warm up, and 3) improvements to the precombustor burner air injection and coal/air mixing characteristics.

The operation of the TRW coal feed system continued to be very steady and reliable during the 1999 DTP. As noted in Section 3, the TRW coal feed system only consists of equipment required to control the split of air and coal between the precombustor, slagging stage, PC NO_x ports and the boiler NO_x ports, and does not include other plant equipment such as the coal crusher, run hoppers, coal feeders, pulverizers, and exhauster fans. The TRW coal feed system operated within its established pressure budget (<60 i.w.g.), and demonstrated the capability to deliver various splits of the coal to the precombustor and the slagging combustor. The blowdown cyclone control approach also worked well, demonstrating that the system is capable of maintaining sufficient transport velocities in each transport line under different coal splits, coal types, boiler load, and back pressure conditions.

In general, the limestone feed system also performed very well. The system demonstrated that it could continuously feed limestone over the required range to ensure overall plant SO_2 compliance. There are still some issues related to continuous operation at the low end of the limestone feeder flowrate, with belt speeds at or below 10%. This only occurred during operation with a limestone supply with high CaCO3 content (i.e. greater than 95% CaCO3) and coal with a low sulfur content (i.e. less than 0.20% sulfur).

Additional data was also gathered in 1999 to assess combustor availability. The period of time from January 18 through June 12, 1999 was reviewed in order to identify the cause(s) of each plant shut-down, as well as to estimate the amount of time the combustors were unavailable during a plant shut-down. Over the time period from January through June, it was estimated that both Combustors A and B availability was approximately 92%. A more accurate determination of combustor availability was made during the long-duration 90-day Test performed during August through November 1999, and resulted in a calculated plant availability of greater than 97% and a capacity factor of approximately 95%. The 90-day test results will be released in a separate topical report prepared by AIDEA.

Overall, the combustor operation and performance demonstrated during the 1999 Combustor System Characterization Test Series continued to be quite encouraging given it is the first utility-scale demonstration of this promising new technology. The overall system has met or exceeded all goals for achieving low NO_x and SO_2 emissions at the stack, with extremely low CO levels in the furnace, very high carbon burnout, and removal of the majority of ash prior to entering the furnace, while burning both ROM and ROM / Waste Coal blends. Demonstrated slagging behavior in the precombustor, slagging stage, and slag removal section is very good, with 100% slag coverage, no bare regions, and no evidence of excessive slag freezing in localized areas.

The majority of tests in the original Combustor Operating Envelope Test Matrix (Figure 4-1) were completed. The load sweep tests and Ca/S ratio variation tests were completed during the "Dispatch Tests" and SDA Performance Characterization Tests respectively, performed during late 1999. The additional tests required to complete the operating envelope characterization for the slagging combustor stoichiometry and furnace O_2 sweep are not currently planned. As noted previously, these test parameters are key performance parameters for the optimization of the NOx emissions from the combustion system.

9.0 TECHNICAL DISCUSSION

This section presents a comparison of the HCCP Combustor Performance Characterization Test results to the HCCP performance goals and analytical predictions. As noted in Section 2.1, one of the DTP goals was to accumulate sufficient data at HCCP to provide a comparison of utility-scale TRW Multi-stage Clean Coal Combustor (350 MMBtu/hr) performance with the industrial-scale combustor tests (20-40 MMBtu/hr) conducted at Cleveland, Ohio (References [1] and [2]). This comparison is also included herein.

9.1 COMPARISON OF HCCP COMBUSTOR PERFORMANCE TEST RESULTS TO GOALS

During January 1998 through June 1999, approximately 7200 hours of plant thermal operation were accumulated, with approximately 6500 hours of coal-fired operating time. Both run-of-mine (ROM) and ROM / Waste Coal blends were tested in the combustion system. An additional 2200 hours of coal-fired operating time were accumulated during the 90-day Test, which brings the total coal-fired operating time up to approximately 8700 hours, or the equivalent of approximately 1-year continuous operation.

Table 9-1 provides a comparison of the Combustor Design and Performance Goals (as provided in the 1992 technical specification) and the performance range demonstrated during the Combustor Performance Characterization Test Program. The following data was not available at the time of this writing and, hence, is not included in the table: 1) Limestone supply $CaCO_3$ content and grind size during March through June 1999, 2) Minimum coolant mass velocity, and 3) Auxiliary Power Consumption.

Over 80% of the coal-fired operating time was conducted at 50 MWe net power production. Typically, the ROM / Waste Coal blends had average (12 hour average) caloric heating values ranging from 6200 to 8300 Btu/lb, ash contents ranging from 6 to 24%, and ash fluid temperatures ranging from 2270 to 2900 ^{o}F, based on UCM (Usibelli Coal Mine) analysis of the average values for the "representative" coal sample obtained from the automatic coal sampler during coal loading operations. The "inferred" coal heating value, based on steam production rates and boiler efficiency, indicated that the coal caloric heating value varied over a wider range, including periods of operation with "pure" waste coal. At the time of this writing, the discrepancy between the coal heating value determined based on the "representative" coal sample obtained by the automatic sampler and the coal heating value determined based on steam production rates and boiler efficiency had not been resolved.

During 1998, the limestone supply was from Cantwell Limestone with an average $CaCO_3$ content of 67.5%. This did not meet the technical specification requirements for limestone $CaCO_3$ content of 90% and grind size of 70% thru 200 mesh. Beginning in June, 1999, the limestone was supplied from a new source with an average $CaCO_3$ content of greater than 95%.

During the Combustor Performance Characterization Test Program, all combustor performance parameters met or exceeded expectations. As described in Section 6, a key performance goal of the DTP, demonstrating the capability to meet the emission limit goals while burning both ROM and ROM / Waste Coal blends, was met. The NO_x, SO_2, and CO emission goals were met while burning all coal blends during operation at full load (net 50 MWe). The testing consistently demonstrated the ability to achieve low NO_x emissions (0.20 to 0.30 lb/MMBtu for furnace O_2 levels between 3 and 5% at 290 to 315 MMBtu/hr) simultaneously with low CO emissions (10 to 90 ppm) and high carbon burnout (>99%), good combustion efficiency and high slag removal prior to the furnace (typically 78 to 85%), and good limestone calcination efficiency with consistent achievement of greater than 80% SO_2 removal.

The operation of the TRW coal feed system was very steady and reliable during the DTP, which is the first utility-scale demonstration of this novel pulverized coal feed splitter system. The system operated within its established pressure budget (<60 i.w.g.), and demonstrated the capability to deliver various splits of the coal to the precombustor and the slagging combustor. The blowdown cyclone control approach also worked well, demonstrating that the system is capable of maintaining sufficient transport velocities in each transport line under different coal splits, coal types, boiler load, and back pressure conditions.

The air supply to the Combustion System met the established flow (600,000 lb/hr) and temperature (650 ^oF minimum) design specifications, but operated slightly outside the pressure budget (<40 i.w.g.). The slightly higher air supply system pressure drop is attributed to the temporary piping installed to duct the Secondary Air from the Precombustor to the headend of the Slagging Stage. The air supply pressure drop is expected to be well within the pressure budget when the permanent air piping is installed in January 2000.

Availability and Design Life goals are long-term operational goals that could not be demonstrated during the Demonstration Test Program. Preliminary availability data gathered during the Combustor Performance Characterization Test Series indicated the overall combustor availability during 1998 was approximately 75 to 77%, and during 1999 was 92%. This is reasonable availability performance for the first two years of new plant operation. Initial availability data for long duration operation was acquired during the 90-day test performed during August through November 1999, and resulted in a calculated plant availability of greater than 97% with a capacity factor of approximately 95%. The 90-day Test results will be released in a separate topical report prepared by AIDEA.

9.2 ANALYTICAL MODEL COMPARISONS

The test data used for the analytical model comparisons presented in this section encompass a test period that was broader than that used for the performance results presented in Section 6. In particular, during May 1998 (prior to certification of the continuous emission monitoring equipment), parametric tests were performed in order to: 1) determine the boundaries for key operating variables (e.g., slagging combustor stoichiometry) and 2) provide a basis for comparison to analytical model predictions of the HCCP combustor performance. Although this data was not presented in the Section 6.2.1, which discusses emission performance results, it is presented in this section in order to show a comparison between "predicted" performance and "actual" performance. In addition, single combustor test data from August and September 1999 has been included, although this time period was outside the scope of this report.

Figure 9-1 presents the TRW NO_x model predictions for the Healy combustor as a function of slagging stage stoichiometry. Superimposed on the model are data points from tests conducted at Healy with a ROM / Waste Coal blend during May 1998 when the slagging stage stoichiometry was varied in order to map NO_x as a function of stoichiometry. In general, good agreement was obtained between model predictions and actual test results. The combustor stoichiometry was observed to be the most important combustor operating parameter for NO_x control, while changes to the combustor coal split and air split had secondary effects. Most of the full load tests were conducted at combustor air / fuel stoichiometries between 0.80 and 0.85. This stoichiometric range was selected since it yielded low NO_x emissions while still maintaining high slag recovery, high carbon burnout and low CO emissions. According to the model, it may be possible to further reduce NO_x through additional optimization of the combustor operating conditions. NO_x data obtained during 1998 also indicated that the furnace O_2 may have been higher than optimal (typical range was 3.5% to 4.5%) for minimum NO_x formation.

Figure 9-2 presents the TRW NO_x model predictions for the Healy combustor as a function of combustor coal load. Superimposed on the model are data points from single combustor tests conducted at Healy with a ROM / Waste Coal blend. The single combustor tests provide an approximate value for NO_x emissions from the combustor only (i.e. without furnace NO_x contribution), since, during single combustor operation, the contribution to NO_x formation by the furnace is minimized due to the high furnace O_2 levels and low overall temperatures. Single combustor tests were performed during July and October, 1998 and during August and September 1999. The two theoretical curves in Figure 9-2 bracket the NO_x emissions as a function of coal load for a slagging stage stoichiometry between 0.79 to 0.80. In general, good agreement was obtained between model predictions and actual test results. Although the two analytical curves bracket a very tight range of slagging combustor stoichiometry (0.79 to 0.80), the data points appear to cover a fairly broad range, 0.74 to 0.89. This apparent discrepancy is most likely due to inaccuracies in determining the "actual" combustor stoichiometry due to variations in coal properties, including higher heating value and oxygen content, rather than actual changes in combustor stoichiometry. For all the data points indicated, the stoichiometry setpoint was held constant at 0.78 to 0.80. According to the model and empirical data, the NO_x emissions from the combustor are approximately 0.18 to 0.23 lb/MMBtu during operation at typical coal loads of 305 to 315 MMBtu/hr.

Based on the NO_x analytical model correlations presented above, it may be possible to further reduce NO_x through 1) additional optimization of the combustor operating conditions, in particular slagging combustor stoichiometry, and 2) characterization and optimization of the furnace O_2 level and injection location.

Figure 9-3 presents the TRW model for in-situ sulfur capture in the furnace as a function of Ca/S ratio and coal sulfur content. Superimposed on the model are data points from tests conducted at Healy with a ROM / Waste Coal blend with 0.3% sulfur coal and 74 micron median size limestone injection, during May 1998. During this period of time, the limestone feeder was not accurately calibrated, and, therefore, the limestone flowrate was determined based on several grab samples taken during the test. These grab samples were used to develop a correlation between limestone feeder belt speed and limestone flowrate. The sulfur reduction shown for the Healy test data was determined by comparing the baseline SO_2 emissions at the furnace exit without any limestone flowrate to the SO_2 emissions at the furnace exit with limestone flowrate at various Ca/S ratios. Also included in Figure 9-3 is the data from the industrial size combustor tests in Cleveland and TRW's Capistrano Test Site (CTS) where fine sized (7-25 micron) limestone was used with high sulfur coals (~3%) (Reference [2]). Due to use of low sulfur coal at Healy, the combustors and furnace are primarily being used for calcination of the limestone and only a relatively low level of sulfur capture occurs in the furnace. At HCCP, the utilization of the in-situ flash-calcined lime particles is further enhanced by the back end flue gas desulfurization system and baghouse, which results in up to 99% sulfur capture. However, based on the data from the industrial size combustor tests, during operation with higher sulfur coals, additional sulfur capture within the furnace is expected for a given Ca/S ratio.

9.3 COMPARISON OF HCCP COMBUSTOR PERFORMANCE TO CLEVELAND COMBUSTOR PERFORMANCE

The HCCP 350 MMBtu/hr Utility-scale combustor scaling is based on TRW's 40 MMBtu/hr Industrial-scale "Cleveland" combustor test data (Reference [1]) and the various TRW-developed analytical models, which were used to define the HCCP combustor operating envelope and performance predictions. This section presents a comparison of the HCCP performance to that of the "Cleveland" combustor performance in order to verify the scaling methodology as well as provide a method for extrapolation of the HCCP performance to other coal types and process conditions. The section is divided into two parts. The first part provides a comparison of the utility-scale (HCCP, 350 MMBtu/hr) combustor performance to that of the industrial-scale (Cleveland, 40MMBtu/hr) in terms of stack emissions, carbon burnout, slag recovery, slagging characteristics, and calcination efficiency. The results of this comparison are then used to predict the performance at the utility-scale combustor with different coals.

9.3.1 Emissions

Figure 9-4 provides a frequency distribution of the stack NO_x emissions from the HCCP and Cleveland combustion systems for steady state operating conditions. For both the Cleveland and HCCP tests, the NO_x emissions are typically in the range of 0.20 to 0.26 lb/MMBtu. As shown, the Cleveland NO_x emissions cover a broad range (from <0.20 to >0.36 lb/MMBtu), with a peak frequency at NO_x levels of 0.22 to 0.24 lb/MMBtu. The HCCP NO_x emissions are concentrated between 0.20 and 0.28 lb/MMBtu, with a peak frequency at NO_x levels between 0.24 and 0.26 lb/MMBtu. The broader range observed during the Cleveland tests is most likely due to a wider variation of operating parameters. As noted in Section 7, the HCCP NO_x emission data is prior to any optimization of combustor stoichiometry and furnace air staging and O_2 levels.

Figure 9-5 presents the TRW analytical model predictions for in-situ sulfur capture in the furnace as a function of Ca/S ratio. Superimposed on the model are data points and data ranges from the HCCP and Cleveland combustor tests. For the HCCP, the data points are from tests conducted in May 1998 with ROM / Waste blend coal (nominally 0.3% sulfur) and a limestone with 68% CaCO3 concentration and coarse grind size of 74 micron median size. For the Cleveland tests, the data ranges shown are from tests conducted with an Ohio coal (nominally 2 to 2.5% sulfur) and a limestone with 80% CaCO3 concentration and two different grind sizes, coarse (74 micron median size, or 70% through 200 mesh) and fine (7 to 25 micron). For the HCCP tests, the SO_2 removal indicated was determined by comparing the baseline emissions measured at the furnace exit without any limestone flowrate to the SO_2 emissions measured at the furnace exit with limestone flowrate at various Ca/S ratios. Therefore, this SO_2 removal data does not include the contribution to SO_2 removal provided by the calcium content in the coal itself, nor does it include any SO_2 removal performed by downstream equipment including the SDA and baghouse. For the Cleveland tests, the sulfur capture shown includes the SO_2 removal in the baghouse. Several observations can be made from the comparison:

- There is a fairly good correlation between the empirical data and analytical predictions. Both the HCCP and Cleveland data from tests performed with coarse limestone indicate slightly higher sulfur removal in the furnace than predicted by the model.
- Due to the use of low sulfur coal at Healy, the combustors and furnace are primarily used for calcination of the limestone and only a relatively low level of sulfur capture (10 to 20%) occurs in the furnace. With the higher sulfur coal used at Cleveland (2 to 2.5% sulfur), the sulfur capture in the furnace was 35 to 45% for a Ca/S ratio from 2 to 3.

- Use of finer grind limestone (7 to 25 micron median size) results in a significant increase in the percentage of sulfur capture in the furnace, with greater than 50 to 60% capture demonstrated.

Figure 9-6 presents in-situ sulfur capture in the furnace during HCCP and Cleveland tests plotted as a function of the empirical correlation square root (S) x Ca/S where S is the sulfur content of the coal. The HCCP data is from tests with a ROM/Waste coal blend, with sulfur content of approximately 0.3%, and a "coarse" limestone grind size (70% through 200 mesh). The Cleveland data is from tests with an Ohio coal (Reference [2]), with sulfur content of 1.5 and 2.5%, and coarse limestone grind size (70% through 200 mesh). As noted above, the sulfur capture indicated for the HCCP tests does not include any sulfur capture contribution from the Ca content of the coal itself as well as any sulfur capture contribution from equipment downstream of the furnace including the SDA and baghouse. The sulfur capture indicated for the Cleveland tests does include the baghouse sulfur capture. As shown, for tests with similar limestone characteristics (i.e. $CaCO_3$ content and grind size), there is a very good correlation between the furnace sulfur capture demonstrated at Cleveland and that demonstrated at HCCP.

9.3.2 Carbon Burnout

Figure 9-7 presents a frequency distribution of the carbon burnout measured during HCCP and Cleveland tests (Reference [1]). The HCCP data is from tests performed with a ROM / Waste coal blend with nominal coal heating value of 7350 Btu/lb. The Cleveland data is from tests performed with a ROM / Waste coal blend with nominal coal heating value of 6700 Btu/lb. As noted in Section 5.2, the carbon burnout data from the HCCP is limited due to the difficulty with obtaining a representative slag sample that had not been "contaminated" with pyrites. The carbon burnout data from Cleveland ranged from 96 to 99%, with over 90% of the data above 98%. The carbon burnout from HCCP was higher than Cleveland, with all data above 99%. The improved carbon burnout data at HCCP is attributed to the higher combustion efficiencies at the larger scale.

9.3.3 Slag Recovery

Figure 9-8 presents a frequency distribution of the slag recovery measured during Cleveland tests (Reference [1]). The Cleveland data is from all tests performed at Cleveland with the ROM / Waste coal blend. The bar chart indicates the frequency distribution of the Cleveland tests. Superimposed on the bar chart are three data points from the HCCP tests. The HCCP data is from three test series performed during 1998 with three different Secondary Air injection configurations and both ROM and ROM / Waste coal blends. The slag recovery data presented is based on the slag ash load cell and is cumulative over several consecutive tests, including start-up and shutdown periods. As shown, although there is a wide degree of scatter in the Cleveland slag recovery results, the majority of tests yielded 76 to 90% slag recovery. This is consistent with the HCCP data, where the three test series averaged 78 to 86% slag recovery. The higher degree of scatter with the Cleveland tests is most likely due to a wider range of operating conditions during the parametric tests as well as the shorter time averaging period.

9.3.4 Slagging Characteristics

Figure 9-9 provides a qualitative comparison of the slagging characteristics of the Cleveland combustor and HCCP combustor, while burning ROM / Waste coal blends. During the Cleveland tests with Healy ROM / Waste coal blends (Reference [1]), there was evidence of porous ash accumulations at the exit of the precombustor and headend / air inlet of the slagging stage following 23 hours of operating time. Downstream of the air inlet, the slag coverage was molten and uniform in thickness. These types of ash/slag accumulations had not been observed during operation with Ohio and other coals at Cleveland and TRW's Capistrano Test Site (CTS). The ash accumulations observed at Cleveland during operation with the Healy ROM / Waste coal blends were partially attributed to the limitations of the Cleveland air and coal supply systems, including limited air preheat temperature and limited coal load. As described in Section 7.1, during the initial coal-fired operations at HCCP with ROM / Waste coal blends, there were frequent occasions when one or both of the operating precombustors would experience localized slag freezing within the precombustor following approximately 100 hours of continuous operation. However, after configuration modifications to remove the secondary air and mill air injection from the precombustor, there was not any evidence of excessive slag or ash accumulations within the precombustor. Throughout all test operations at HCCP, the slagging stage slagging behavior was excellent, with a uniform molten slag coverage extending from the headend through the slag tap.

9.3.5 Flyash Characteristics

Figure 9-10 provides a comparison of the flyash particle size distribution during tests at HCCP and CTS (Reference [3]). The HCCP data is from tests performed with a ROM / Waste coal blend, with nominal grind size of 70% through 200 mesh (~74 micron median size) and a "coarse" limestone injection with nominal grind size of 74 micron median size distribution. The flyash sample was taken from the convective pass of the boiler. The CTS data is from tests performed with Pittsburgh #8 coal, with a nominal grind size of 70% through 200 mesh and a fine limestone injection with nominal particle size of 9 to 13 microns. The flyash median particle size for the HCCP tests was 12 microns and for the CTS tests was 4 microns. Approximately 80% of the flyash particles generated at HCCP are less than 20 microns diameter.

Figure 9-11 provides a comparison of the flyash particle morphology for both the HCCP and CTS tests. As shown, in both cases, the majority of particles are spherical in shape. The overall relatively small flyash particle size and spherical shape of the majority of flyash particles are anticipated to be less erosive to the furnace gas-side surfaces.

9.4 COMBUSTOR PERFORMANCE PREDICTIONS FOR OTHER COAL TYPES AT 350 MMBTU/HR

9.4.1 NO_X Model Prediction for Ohio Coal at 350 MMBtu/Hr and 40 MMBtu/Hr

As noted previously, the HCCP performance predictions were based on the TRW-developed analytical models, which had been anchored to the demonstrated performance of the 40 MMBtu/hr Cleveland combustor. The preceding section presented a comparison of the demonstrated performance of the 350 MMBtu/hr utility-scale HCCP combustor to the analytical model predictions, as well as a comparison to the demonstrated performance of the 40 MMBtu/hr Cleveland combustor. As shown, the correlations for NO_x and SO_x were very good and essentially validate the accuracy of the analytical models for predicting performance. Based on this validation, the analytical models were then used to predict the emission performance of the 350 MMBtu/hr utility-scale HCCP combustor during combustion of other coals. Figure 9-12 presents the TRW NO_x model predictions for the 350 MMBtu/hr utility-scale HCCP combustor and 40 MMBtu/hr industrial scale Cleveland combustor as a function of slagging stage stoichiometry for Ohio coal. Superimposed on the model are data points from tests conducted at Cleveland with Ohio Coal. In general, good agreement was obtained between model predictions and actual test results at 40 MMBtu/hr. As shown, the analytical model predicts similar NO_x emission levels at 350 MMBtu/hr and 40 MMBtu/hr.

9.4.2 Performance Prediction for Operation with Coals with Lower Heating Values and Higher Ash at 350MMBtu/hr

The HCCP utility-scale combustion system was operated with coal heating value varying from 6196 to 8271 Btu/lb and ash contents varying from 5.7 to 24% (on an "as received" basis). The Cleveland industrial-scale combustion system was operated with several different coal types (i.e., Ohio, Wyoming, Pittsburgh, Utah, Illinois, West Virginia, Healy Alaska, and Kentucky coal) encompassing a wide range of coal heating values varying from 7300 to 13,600 Btu/lb and ash contents from 4.4 to 27.3% (on an "as burned" basis). Based on the results of these test programs, the following predictions can be made for a utility-scale combustion system operating with coal heating value from 5800 to 6900 Btu/lb and ash contents higher than 15%:

- Based on empirical data, it is anticipated that higher coal ash contents, up to approximately 27%, will have minimal impact on combustion system performance. As the coal ash content increases, the coal flowrate will typically increase, in order to maintain the same thermal input, and there will be a corresponding increase in the slag flowrate. Operating conditions would likely be adjusted in order to maintain the same gas temperatures (i.e. slight increase in air-to-fuel stoichiometry) and the same calcium-to-ash ratio (i.e. slight increase in limestone flowrate). Since gas temperatures and calcium-to-ash ratios would remain constant, the NO_x and SO_2 emission levels would also remain relatively constant. Due to the slightly higher stoichiometry, there may be a slight increase in NO_x emissions, but it is anticipated to be relatively minor. In addition, the SDA operating parameters may need to be adjusted slightly. Empirical data supports these predictions. In particular, in June 1998, an 18-day test was conducted at HCCP, with the first 14 days burning ROM coal and the last 4 days burning a waste coal blend. The ROM coal had an average Btu content of approximately 7925 Btu/lb and an average ash content of 8.5%. The waste coal blend had an average Btu content of 6940 Btu/lb and an average ash content of 15%. There was not any significant change in NO_x, SO_2, or CO over the 18-days of the test as a function of the 1000 Btu/lb change in coal heating value and nearly doubling of coal ash content.
- An increase in ash content will not affect the combustion system lifetime. Since all of the walls of the combustion system are covered with a self-replenishing molten slag layer, the higher ash content will not affect erosion rates within the combustion system. The overall slagging behavior (i.e. slag coverage on the internal walls of the combustion system and slag flow thru the tap) is not anticipated to change significantly as a result of the higher ash content. The slag flow into the slag tap will increase in quantity and the slag layer thickness may increase slightly. The slag layer thickness is primarily a function of gas temperature and ash composition rather than ash quantity, however, it is anticipated that there will be a slight increase in the slag layer thickness as a function of increasing coal ash content. The increase in slag layer thickness will simply provide additional erosion protection.
- Based on empirical data, it is anticipated that there will be minimal impact on combustion system performance during operation with coal Btu down to 6600 Btu/lb. The primary impact of a decrease in coal Btu content is that the coal flowrate must increase in order to maintain the same thermal input level. When the coal Btu changes, the combustion control logic automatically increases or decreases the coal flowrate in order to maintain the same MW_e output. If required, the combustion control logic will also adjust the combustion air in order to maintain the same air-to-fuel stoichiometry.
- Testing to date has resulted only in limited operating experience with coal Btu significantly

below 6600 Btu/lb. There have been periodic excursions, typically less than 12 hrs in duration, when the coal heating value has dropped from a nominal 7000 Btu/lb to 6200 Btu/lb (or below) and the combustion system has maintained acceptable performance in terms of NO_x, SO_2, CO, and slagging behavior. Based on the experience gained during the HCCP Precombustor Burner Characterization Tests performed during March and April 1999, it is likely that minor operational changes will be required for sustained operation with coals below 6600 Btu/lb. This would possibly include reduction in the Precombustor coal split as well as "tuning" of Precombustor and Slagging Combustor stoichiometry for lower coal Btu. The Precombustor and Slagging Combustor stoichiometry could then be automated to track with inferred coal Btu.

- For the coal feed system, the higher ash content will likely have an impact on wear rates. Nearly all components within the TRW coal split system are lined with an abrasion resistant liner. This approach for minimizing erosion has proven acceptable. Detailed inspections of the CFS hardware performed following the 90-day test identified that over 95% of the components within the TRW coal split system, when operated under normal conditions, had experienced little or no wear during the 8600 hours of cumulative run time with an average 12% ash coal. High wear rates, which had been identified in local areas in 5% of the CFS components, had been successfully addressed by installation of improved erosion-resistant liners. For an increase in ash content from nominally 12% to 27%, the wear rate will likely increase by approximately 20 to 50%. However, based on the negligible wear observed within the majority of the TRW portion of the coal feed system during over 8600 hours of operation at normal coal/air velocities with coal ash content of nominally 12%, it is anticipated that the increase in wear rate during operation with coal with higher ash contents will still result in a reasonable overall equipment lifetime, prior to the need for any major refurbishment.

In summary, based on empirical data, an increase in coal ash content up to approximately 27% will simply result in higher slag flowrate into the slag tank and will have minor, if any, impact on the overall combustion system performance parameters, including NO_x, SO_2, and CO emission levels and slagging behavior, as well as equipment lifetime. A decrease in coal heating value down to approximately 6600 Btu/lb will have minimal impact on combustion system performance. There is only limited sustained operating experience with coal ash contents higher than 27% and/or coal heating value less than 6600 Btu/lb. Based on the experience gained during the HCCP DTP, it is likely that minor operational changes (i.e., slight adjustments to precombustor coal split and/or precombustor and slagging combustor stoichiometry) will be required for sustained operation with coals with heating values significantly below 6600 Btu/lb and/or ash contents significantly above 27%. Although the higher ash content will likely increase CFS wear rates, the overall equipment lifetime, prior to any major refurbishment, is expected to be reasonable. Overall, an increase in ash content and/or decrease in coal heating value will have minor if any impact on combustion system capacity, availability, and staffing requirements.

TABLE 9-1 COMPARISON OF ACTUAL PERFORMANCE VERSUS DESIGN GOALS

Parameters	Contract Requirements	June - Dec., 1998		March - June, 1999		Meets Contract Requirement	Notes
		Range	Typical	Range	Typical		
Net Power Production	50 Mwe	23-55	50	49-52	51	yes	
Firing Rate	325 MMBtu/Hr Nominal 350 MMBtu/Hr Max	264-350	302	286-311	304	yes	TRW Performance Fill-in Data Performance Coal - 315 MMBtu/Hr Run of Mine Coal - 306 MMBtu/Hr 55/45 Blend Coal - 316 MMBtu/Hr Waste Coal - 322 MMBtu/Hr
Fuels	Operate in a satisfactory manner with …… Performance Coal, 6960 Btu/#, 25.11% H2O, 16.60% Ash Run of Mine Coal, 7815 Btu/#, 26.35% H2O, 8.20% Ash 55/45 Blend Coal, 6874 Btu/#, 24.98% H2O, 17.44% Ash	Coal Analysis 6196-8271	7507	6766-7826	7328	yes	Coal analysis performed by Usibelli Coal Mine
	Also operate with ….. Waste Coal, 6105 Btu/#, 23.87% H2O, 25.00% Ash 70% or less thru 200 mesh	Inferred HHV 6408-8028	7151	6738-7527	7160		
Limestone	Cantwell Limestone, CaCO3 90.4%	59.4-80.7	67.5			no	
	70% thru 200 mesh	57-88% -200	68%-200			yes	
NOX Emissions	< 0.35 #/MMBtu	0.208-0.278	0.245	0.259-0.263	0.261	yes	Based on a 30 day rolling average 99 data for April 23 - June 12, 1999
SO2 Emissions	> 70% Removal	84-100	93	83-99	89	yes	
	< 79.6 #/hr SO2	*****	25	*****	24	yes	
CO Emissions	< 200 ppm at 3.5% O2 Dry Basis	< 126 ppm at 3.5% O2	35 ppm at 3.5% O2	64-88 ppm at 3.5% O2	82 ppm at 3.5% O2	yes	
Opacity	20% Opacity, 3 min. average	<10%	5.60%	<9.3%	4.69%	yes	Based on 30 min. average data
Particulate Matter	< 0.015 #/MMBtu	*****	*****	*****	0.0047 #/MMBtu	yes	Source test performed Mar 10-11, 1999 by Haas, Morgan & Hudson. Particulates during 1998 were high due to a baghouse filter bag failure
Carbon Burnout	Unburned carbon in the combustor slag ash shall not exceed 1%	*****	0.30%	*****	0.10%	yes	TRW Performance Fill-in Data > 99% at 100% MCR for Perf, 55/45 Blend, ROM > 98% at 100% MCR for Waste
Slag Recovery	> 70% at 100% MCR for all coals	78-87	83	53-83	75	yes	53% corresponds to low PC exit vel. test
Coal Feed System Pressure Drop	< 60" H2O	*****	*****	46.9-49.9	48.4	yes	Data from CFS A only, May-June period (latest config.)
Air Side Pressure Drop	< 40" H2O	*****	*****	41.5-44.5	42.9	no	Data from May-June period (latest config.)
Forced Draft Fan Air Flow	< 600 kpph	*****	*****	542-556	550	yes	Data from May-June period (latest config.) Based upon individual combustor flows. Assumes 1 kpph per purge line (28 lines total per comb.)
Combustion Air Temperature	650 Deg. F minimum at exit of preheater	*****	*****	715-780	769	yes	630 - 730 Deg F per Ref. [A] Data from May '99 only
Coolant Conditions	590 Deg. F, 1400 psig	*****	*****	580-584 F 1301-1328 psi	550 F 1323 psi		Data from May-June, 1999. Temp. taken at the outlet of the HP cooling pump
Minimum Coolant Mass Velocity	600,000 #/ft2/hr						
Auxillary Power	< 510 Kwe						
Availability	Goal of 100% with one 10 day outage per year	*****	75	*****	90		
Design Life	30 years	*****	0.5	*****	0.5		

References
[A] - "Combustor Design Criteria Report", TRW Report No. 96.HP.SKU-103, February 26, 1996, Table 1-1 on page 1-2.
[B] - "Combustor and Auxiliary System", Purchase Order No. 02765-P201X, Alaska Industrial Development and Export Authority, Section 1 Technical Requirements

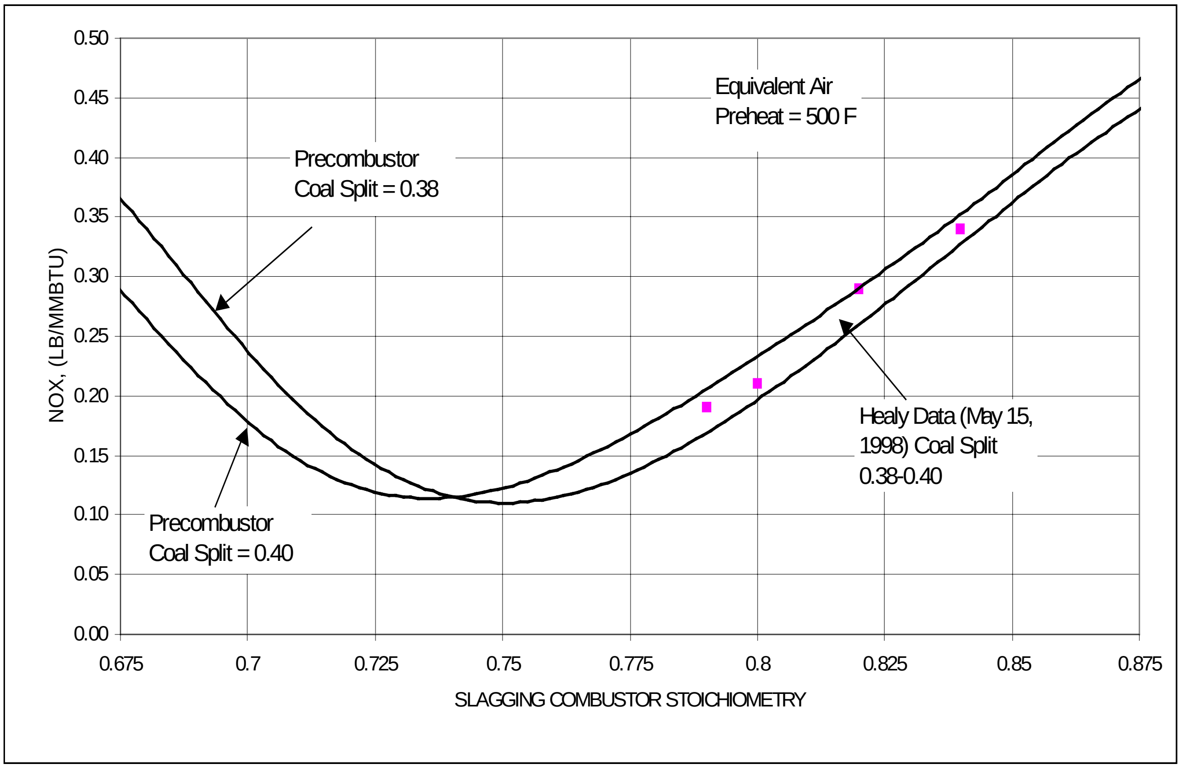


FIGURE 9-1 COMPARISON OF HEALY NOX DATA WITH TRW NOX MODEL (350 MMBTU/HR)

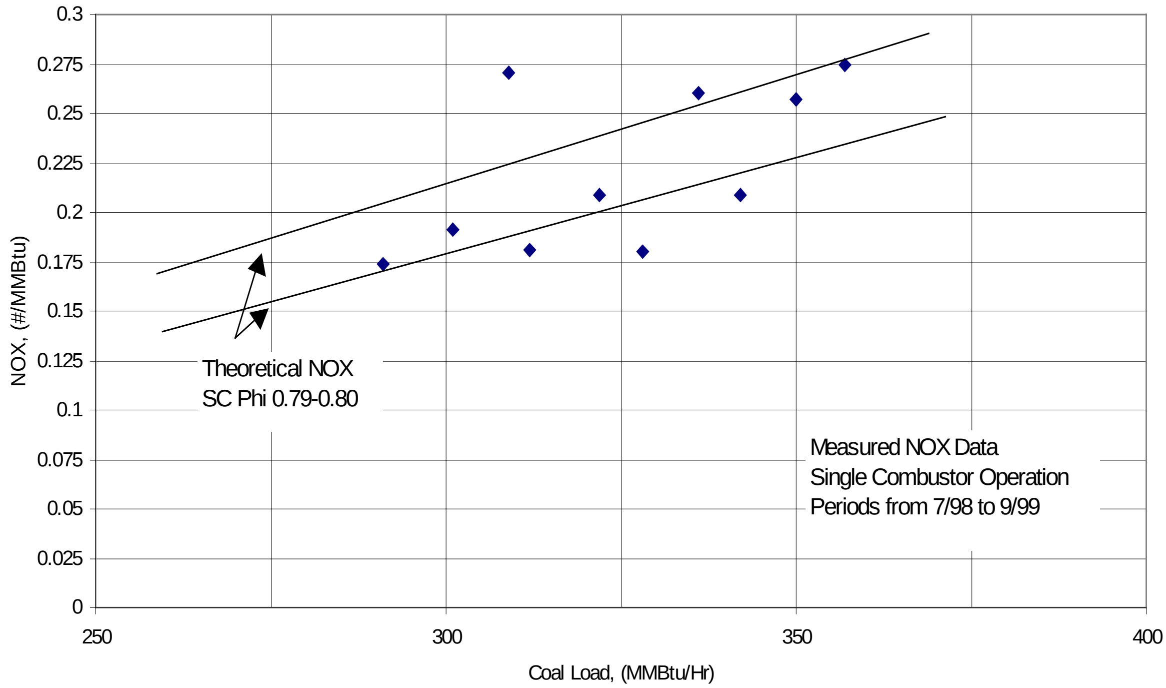


FIGURE 9-2 TRW NOX MODEL PREDICTIONS FOR THE HEALY COMBUSTOR AS A FUNCTION OF COMBUSTOR LOAD

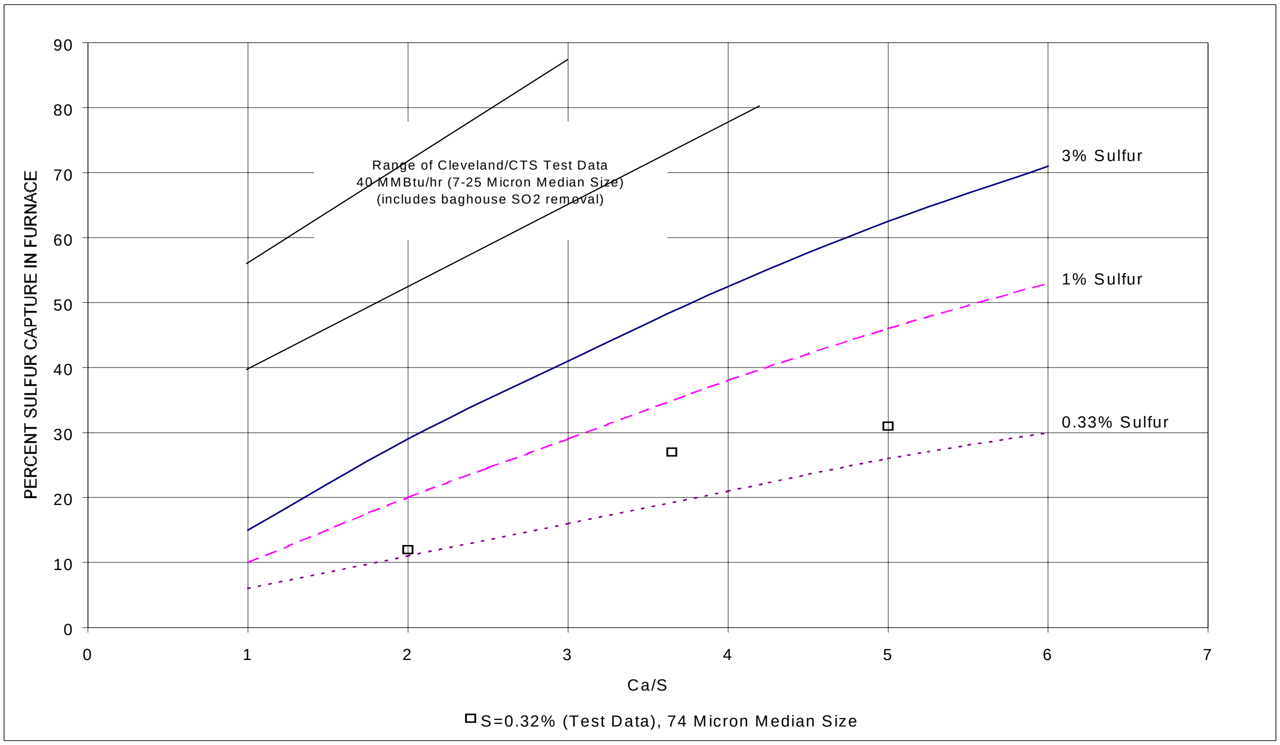


FIGURE 9-3 COMPARISON OF HEALY FURNACE SULFUR CAPTURE WITH TRW SULFUR CAPTURE MODEL PREDICTIONS

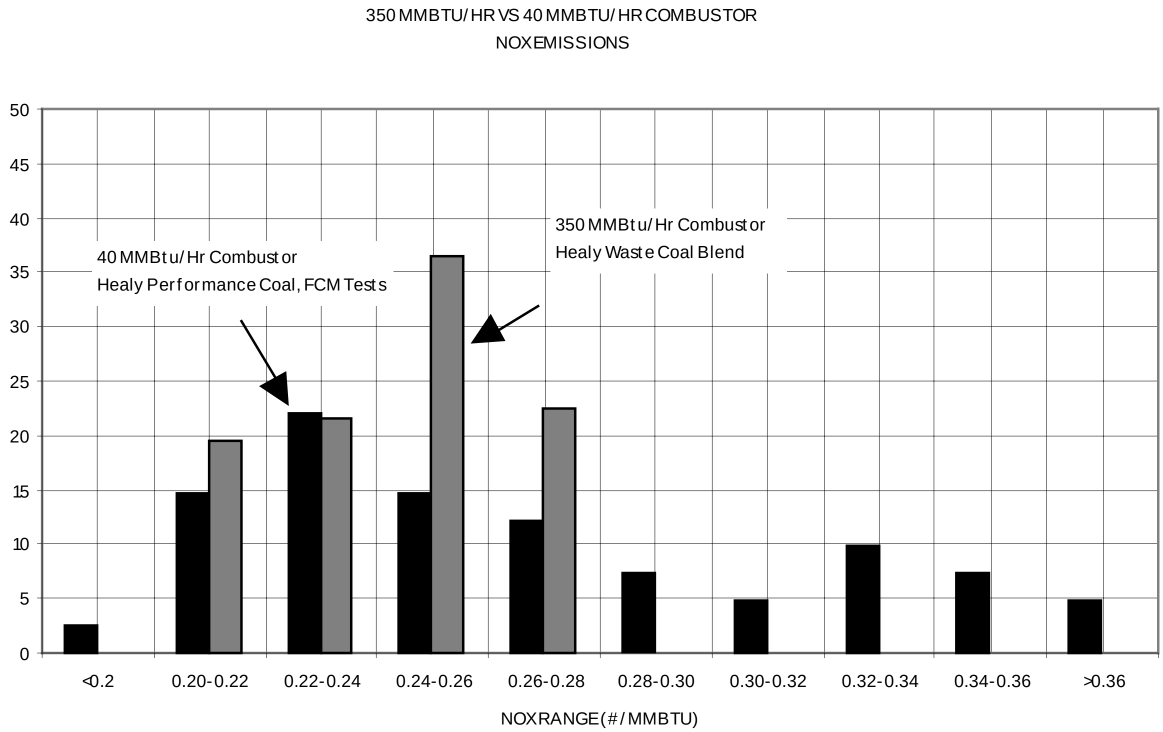


FIGURE 9-4 FREQUENCY DISTRIBUTION OF THE STACK NOX EMISSIONS FROM THE HCCP AND CLEVELAND COMBUSTION SYSTEMS

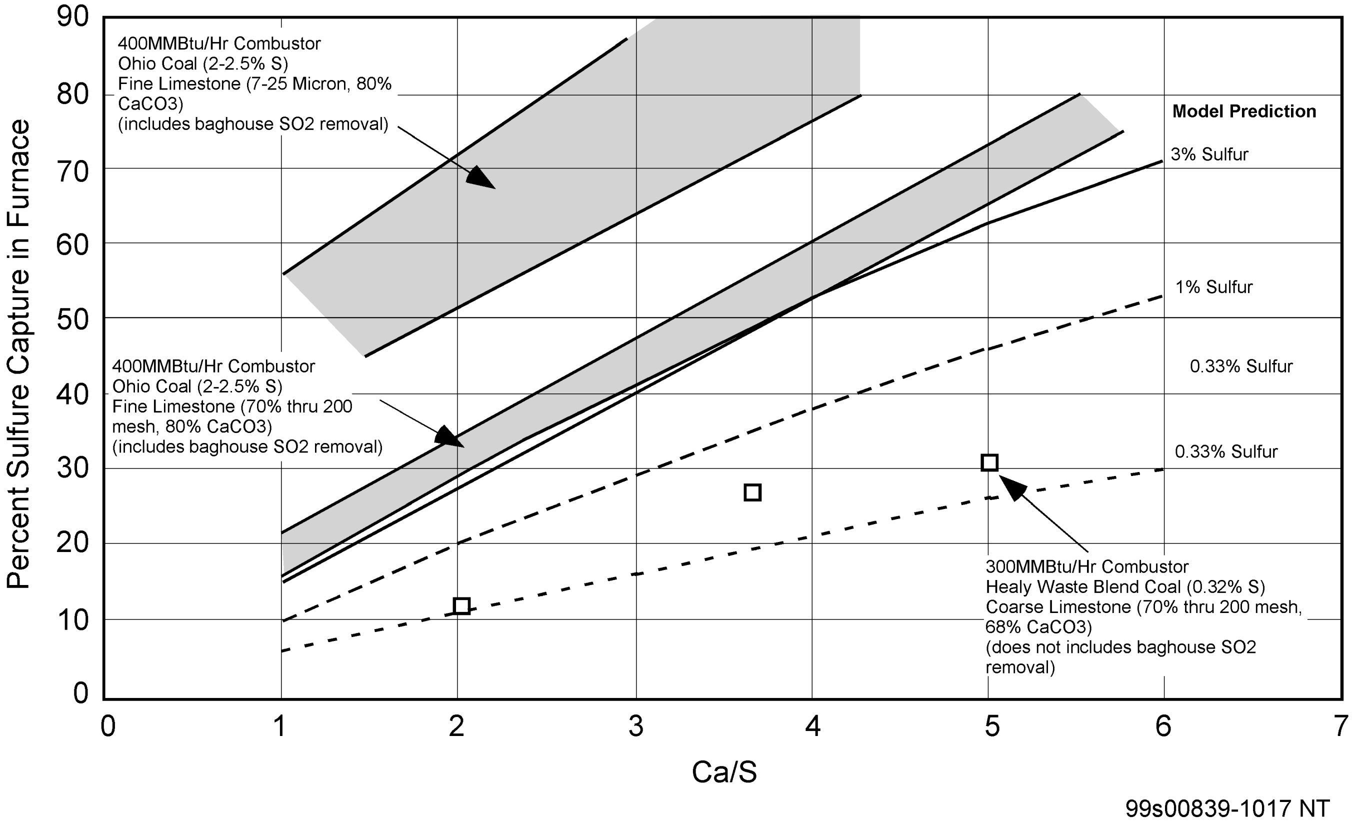


FIGURE 9-5 COMPARISON OF HCCP AND CLEVELAND COMBUSTOR SULFUR CAPTURE WITH TRW SULFUR CAPTURE MODEL PREDICTIONS

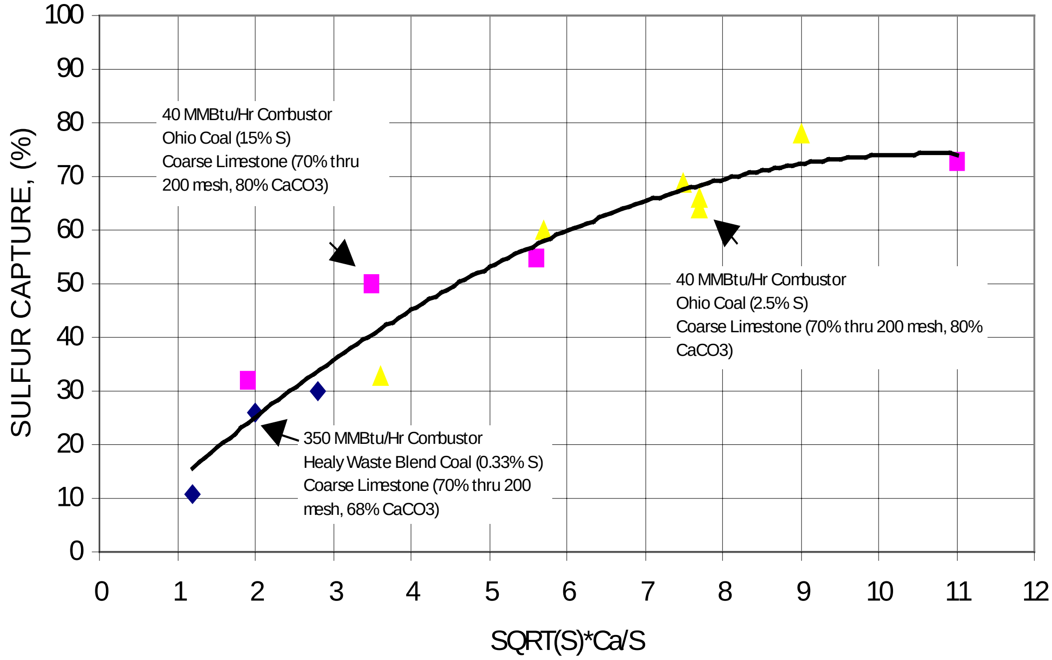


FIGURE 9-6 IN-SITU SULFUR CAPTURE IN THE FURNACE DURING HCCP AND CLEVELAND TESTS PLOTTED AS A FUNCTION OF THE EMPIRICAL CORRELATION SQRT(S)*Ca/S

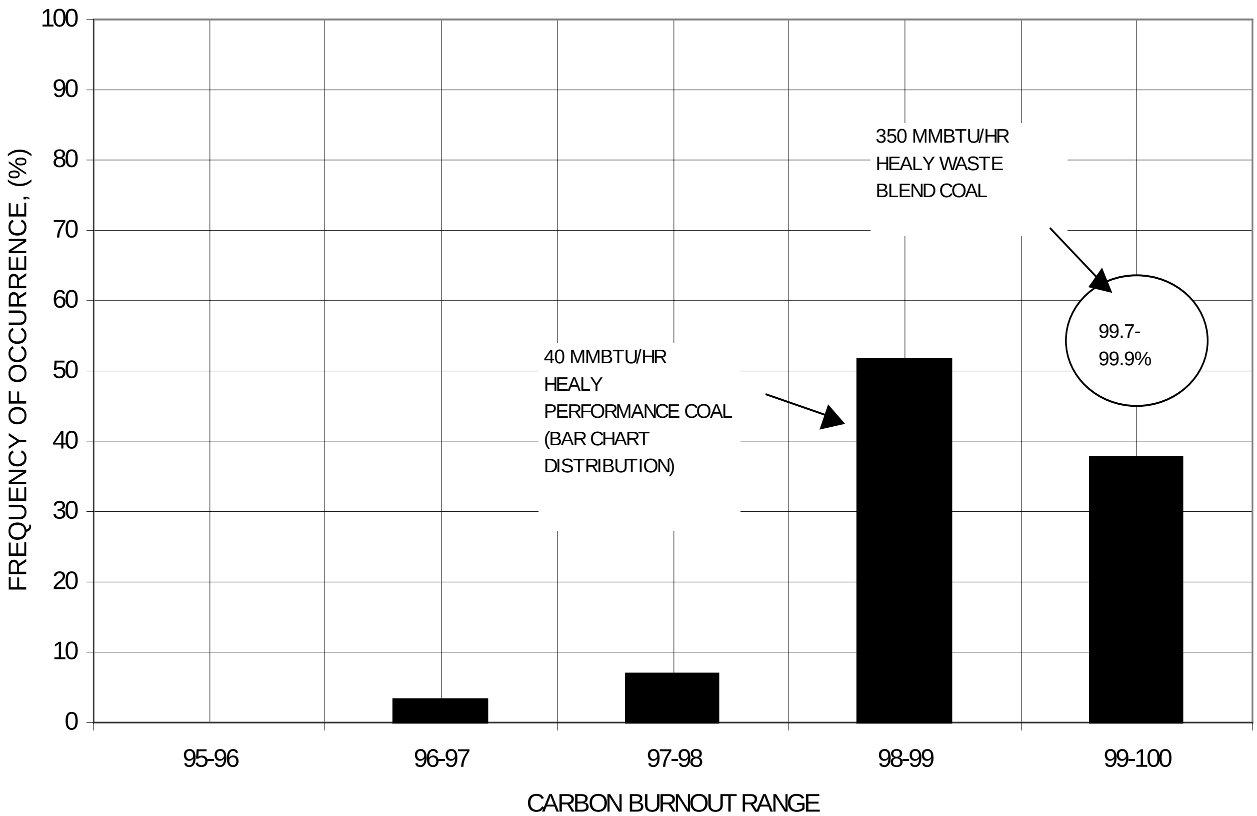


FIGURE 9-7 FREQUENCY DISTRIBUTION OF CARBON BURNOUT MEASURED DURING HCCP AND CLEVELAND TESTS

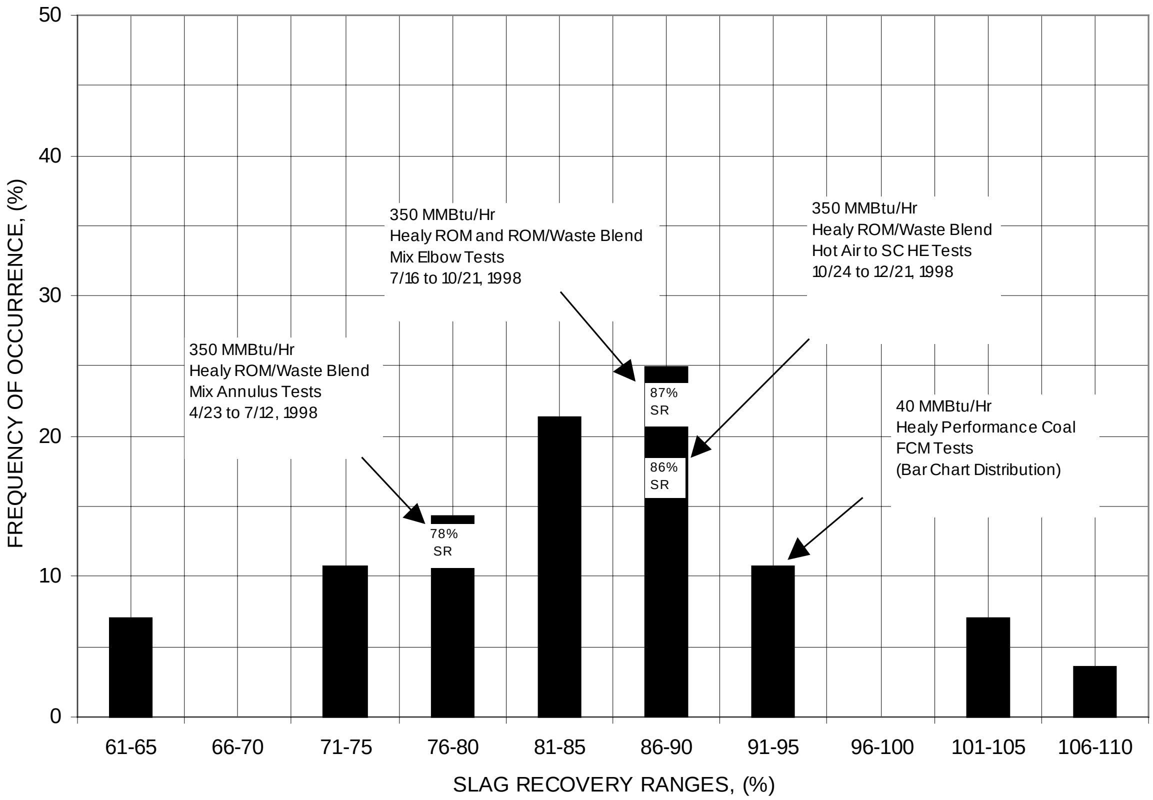


FIGURE 9-8 FREQUENCY DISTRIBUTION OF THE SLAG RECOVERY MEASURED DURING HCCP AND CLEVELAND TESTS

	350 MMBTU/HR HEALY HEALY COAL	40 MMBTU/HR CLEVELAND HEALY COAL	40 MMBTU/HR CAPISTRANO TEST SITE OHIO COAL
PRECOMBUSTOR	ROM COAL - UNIFORM, MOLTEN WASTE BLEND - UNIFORM, MOLTEN AFTER MOVING MIX ANNULUS AIR AND MILL AIR AWAY FROM PC	ASH ACCUMULATION AT EXIT	
SLAGGING COMBUSTOR			
HEADEND	UNIFORM (1" THICK), MOLTEN	POROUS ASH ACCUMULATION	EXCELLENT, UNIFORM, COMPLETE COVERAGE, NO GROWTHS
AIR INLET	UNIFORM (3" THICK), MOLTEN	POROUS ASH ACCUMULATION	
BAFFLE	UNIFORM (1" THICK), MOLTEN	UNIFORM, MOLTEN	
SLAG TAP	NO FOULING	SOME ACCUMULATIONS, NO PLUGGING WITH PERFORMANCE COAL, ONE INCIDENCE OF PLUGGING WITH TBR COAL AT OFF NOMINAL CONDITIONS	
SLAG RECOVERY SECTION	NO FOULING		

FIGURE 9-9 QUALITATIVE COMPARISON OF THE SLAGGING CHARACTERISTICS OF THE CLEVELAND COMBUSTOR AND HCCP COMBUSTOR

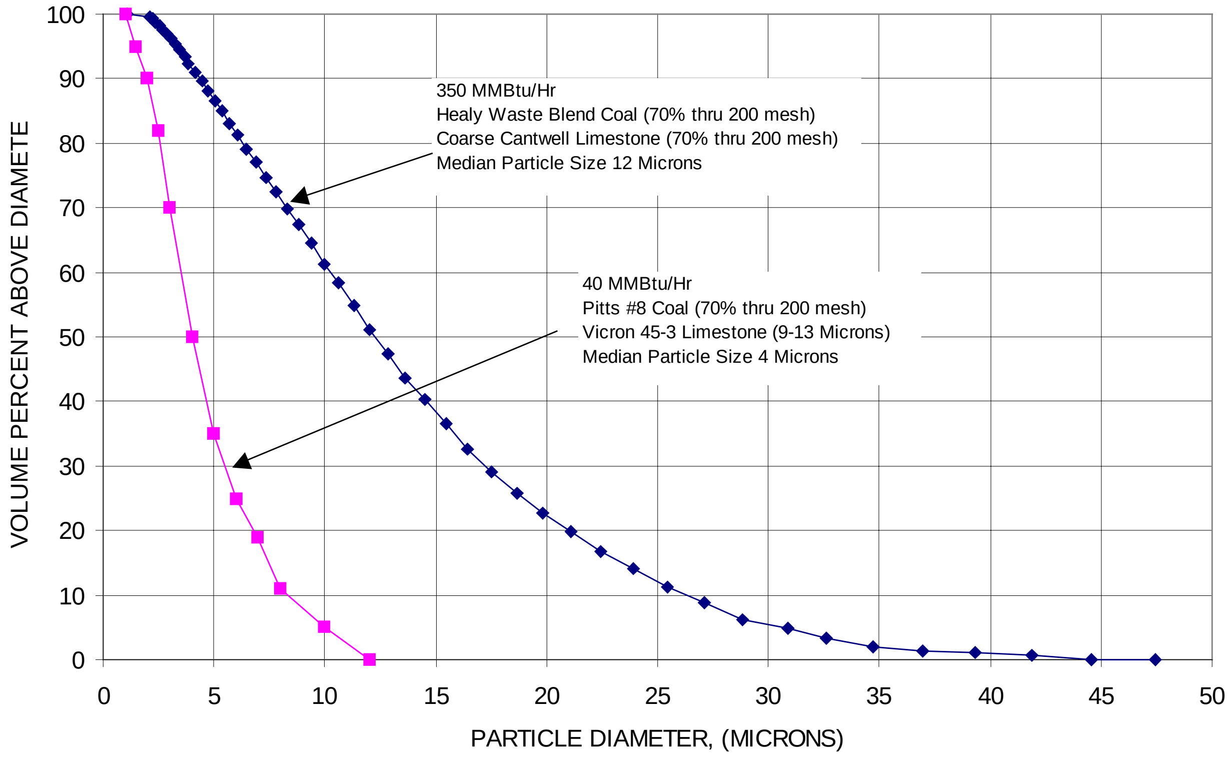
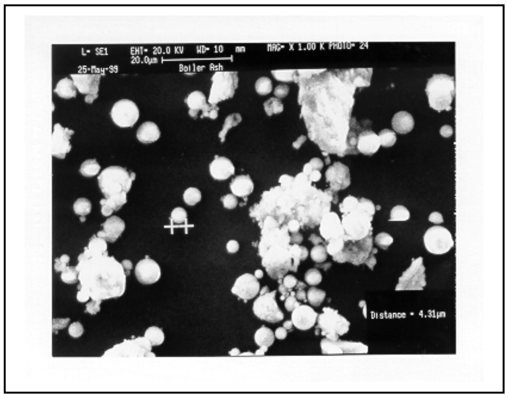
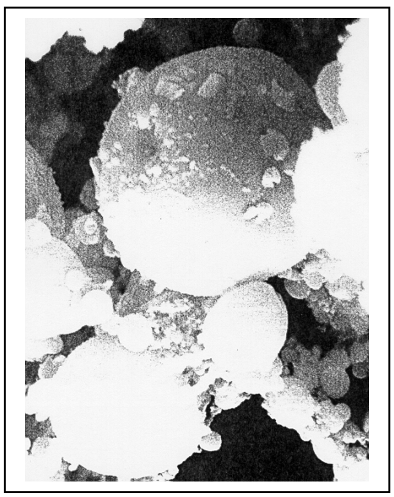


FIGURE 9-10 COMPARISON OF THE FLYASH PARTICLE SIZE DISTRIBUTION DURING TESTS AT HCCP AND CLEVELAND



350 MMBtu/Hr
Healy Waste Blend Coal (70% thru 200 mesh)
Coarse Cantwell Limestone (70% thru 200 mesh)
Median Particle Size 12 Microns



40 MMBtu/Hr
Pitts #8 Coal (70% thru 200 mesh)
Vicron 45-3 (9-13 Microns)
Median Particle Size 4 Microns

FIGURE 9-11 COMPARISON OF THE FLYASH PARTICLE MORPHOLOGY FOR BOTH THE HCCP AND CLEVELAND TESTS

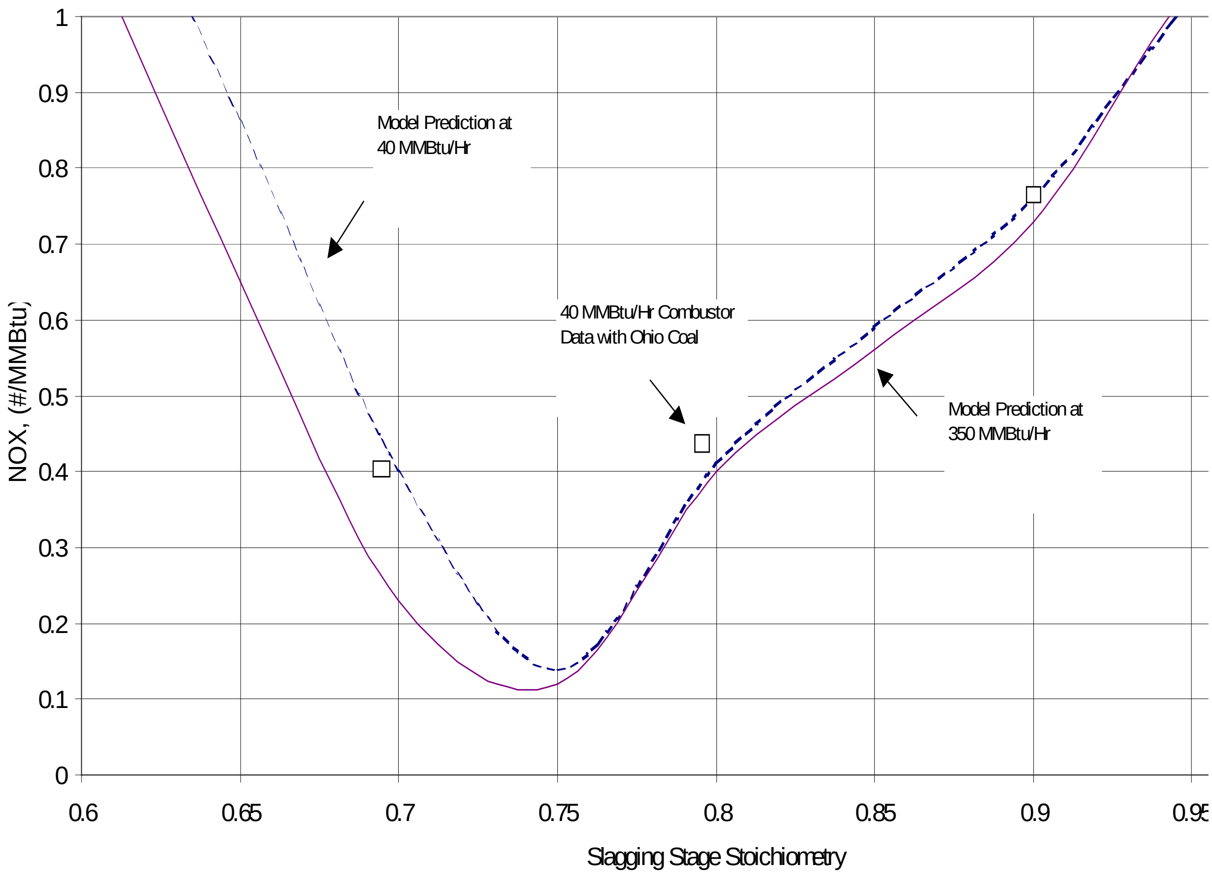


FIGURE 9-12 TRW NOX MODEL PREDICTION FOR THE 350 MMBTU/HR AND 40 MMBTU/HR COMBUSTORS AS A FUNCTION OF SLAGGING STOICHIOMETRY FOR OHIO COAL

10. CONCLUSIONS

The HCCP Demonstration Test Program was initiated in early 1998. The TRW Combustion System Characterization Testing was initiated in May 1998 and continued intermittently through May 1999, accumulating approximately 6 months total of test activities. By June 1999, approximately 6500 hours of coal-fired operating time had been accumulated on the HCCP combustion system and the majority of the Combustion System Characterization Test Program had been completed. During July through November 1999, an additional 2200 hours of coal fired operation were accumulated, bringing the total to 8700 hours of coal-fired operation, or the equivalent of approximately 1 year of continuous operation. Conclusions of the test activities include:

- The objectives of the Combustion System Characterization Test Program were successfully accomplished during the 1998 and 1999 test activities. In particular: 1) The baseline performance of the combustion system while burning ROM and ROM / Waste Coal Blends was established, 2) The combustor performance characteristics were mapped over a broad range of operating conditions and hardware configurations and 3) The "best" hardware configuration and operating conditions for long duration operation with ROM / Waste Coal Blends were identified.

- The combustion system operation and demonstrated performance was extremely encouraging given that it is the first utility-scale demonstration of this promising new technology. All combustion system performance parameters met or exceeded performance goals while burning ROM and ROM / Waste Coal blends at 50 MWe (net). The 1998 and 1999 test activities demonstrated: 1) The ability to achieve low NO_x emissions (0.20 to 0.30 lb/MMBtu) simultaneously with low CO emissions (less than 200 ppm) and high carbon burnout (>99%), 2) good combustion efficiency and high slag removal prior to the furnace (78 to 85%), and 3) good limestone calcination efficiency with consistent achievement of SO_2 emissions less than 0.10 lb/MMBtu and >80% SO_2 removal efficiency. The demonstrated NO_x, SO_2, and CO emission levels were lower than permitted emission levels.

- The demonstrated NO_x emission performance of 0.20 to 0.30 lb/MMBtu, for furnace O_2 levels between 3 and 5% at 50 MWe (net), occurred over a broad range of operating conditions for all ROM / Waste coal blends tested. These NO_x emission levels were achieved without any optimization of slagging combustor stoichiometry, furnace air staging, or furnace O_2 levels. In general, the lowest NO_x emission levels were achieved at lower furnace O_2 levels (3.0 to 3.5%) without any significant increase in plant CO emissions. Based on empirical data and analytical model predictions, it is anticipated that the HCCP NO_x emissions can be reduced further through 1) additional optimization of the combustor operating conditions, in particular slagging combustor stoichiometry and 2) additional characterization and optimization of the furnace air staging and O_2 levels.

- The combustion system was tested over a broad range of operating conditions and hardware configurations, including variations in Secondary Air injection configuration, Precombustor coal split and stoichiometry, Slagging Combustor stoichiometry and inlet velocity. Throughout the test program, the slagging stage of the combustion system performed extremely well and continuously demonstrated the capability to reliably burn ROM / Waste Coal blends over a broad range of operating conditions. The precombustor performed very well with ROM coal but initially exhibited more variable performance, in terms of slagging behavior, during the initial tests with ROM / Waste Coal blends. During 1998 and early 1999, a combination of hardware configuration and operational changes were made which successfully resolved this problem. The key changes made were as follows: (1) relocating the secondary air from precombustor mix annulus to the headend of the slagging stage, (2) completely transferring the precombustor mill air to the boiler NO_x ports following the boiler warm up and 3) modifying the precombustor burner air injection configuration in order to improve air/coal mixing characteristics.

- Following the Precombustor hardware configuration changes noted above, the combustion system slagging behavior was acceptable. The tube wall slag retention design features, including studding pattern, stud material selection, and refractory-type, worked very well. The slagging behavior of the slagging stage was very good throughout the Combustor Performance Characterization Test Program, continuously maintaining a thin molten slag layer over the entire tubewall surface while burning ROM and ROM / Waste Coal blends over a broad range of operating conditions. The slagging behavior of the Precombustor was acceptable following the combination of hardware changes and operational changes made in late 1998 and early 1999. Throughout all test operations, there was never any problem with slag pluggage in the slag tap area. In general, the slag quality and quantity observed on the drag chain was excellent. The majority of the slag was small (less than 0.25 inches in diameter) and granular. During tests conducted with a higher percentage of waste coal with a high T_{250} ash fusion temperature, the slag size increased to a nominal 1.5 inches in diameter. On occasion, slag clinkers were observed. Typically, the occasional slag clinker could be attributed to off-nominal stoichiometry operating conditions. The random slag clinkers were carried out of the slag tank via the drag chain, during the test, and did not disrupt overall test operations.

- The operation of the novel TRW pulverized coal feed splitter system was very steady and reliable throughout the test activities. The system operated within its established pressure budget (<60 i.w.g.) and demonstrated the capability to deliver various splits of coal to the precombustor and slagging combustor. The blowdown cyclone control approach worked well, demonstrating that the system is capable of maintaining sufficient transport velocities in each transport line under different coal splits, coal types, boiler load, and back pressure conditions.

- The air supply to the Combustion System met the established flow (600,000 lb/hr) and temperature (650 ^{o}F minimum) design specifications, but operated slightly outside the pressure budget (<40 i.w.g.). The slightly higher air supply system pressure drop is attributed to the temporary piping installed to duct the Secondary Air from the Precombustor to the headend of the Slagging Stage. The air supply pressure drop is expected to be well within the pressure budget when the permanent air piping is installed in January 2000.

- Combustion system availability and design life goals are long-term operational goals that could not be demonstrated during the Demonstration Test Program. Preliminary availability data gathered during the Combustor Performance Characterization Test Series indicated the overall combustor availability during 1998 was approximately 75 to 77%, and during 1999 was 92%. This is reasonable availability performance for the first two years of operation of a new technology within a new plant. Initial long duration operation availability data was acquired during the 90-day test performed during August through November 1999, and resulted in a calculated plant availability of greater than 97% with a capacity factor of approximately 95%.

- The demonstrated HCCP combustor performance correlated well with analytical model performance predictions. Since the TRW-developed analytical models had been anchored to the demonstrated performance of the industrial-scale 40 MMBtu/hr Cleveland combustor, this essentially validated the combustion system scaling methodology. The correlations between empirical data and predicted performance for NO_x emissions and in-situ sulfur capture in the furnace while burning ROM / Waste Coal blends at 350 MMBtu/hr were very good and lends credibility to analytical model performance predictions for combustion system performance while burning other coals.

Potential future improvements at HCCP:

Potential future improvements at HCCP include optimization of combustor and furnace operating conditions to further reduce NO_x emissions. Based on empirical data and analytical model predictions, additional NO_x reduction can be achieved by additional characterization and optimization of the combustor and furnace operating parameters. In particular, NO_x emissions can be reduced further through 1) reduction in slagging combustor stoichiometry from nominally 0.80 to 0.77, 2) reduction in furnace O_2 levels from 4.2 to 3.0%, and 3) increase in furnace air staging. These changes are anticipated to have negligible impact on other combustion system performance parameters, including CO emissions, slagging behavior, and SO_2 emissions. The combustion system operational changes can be implemented with no cost impact, whereas the furnace operational changes will require some minor hardware modifications. Additional details, including relative cost impact of the changes, are provided below:

- For the combustion system, a reduction in Slagging Combustor stoichiometry from nominally 0.80 to 0.77 is predicted to result in a decrease in NO_x emissions from nominally 0.26 lb/MMBtu to approximately 0.21 to 0.22 lb/MMBtu. The lower slagging combustor stoichiometry is anticipated to have minimal impact on combustion system slagging behavior, furnace CO emissions, or SO_2 emissions. Specifically, 1) CO levels within the combustion system will increase, however the gas-gas reaction to complete combustion from CO to CO_2 occurs within the furnace and, therefore, there is anticipated to be minimal, if any, increase in CO levels within the furnace, 2) The decrease in slagging combustor stoichiometry and resulting lower gas temperature will not impact SO_2 emissions; and 3) The reduced Slagging Combustor gas temperature will result in a slightly thicker slag layer within the Slagging Combustor, however, based on the extremely thin slag layer (<1/2" nominal thickness) observed during all post test inspections, there is significant margin for reducing gas temperature before there will be any detrimental impact on slagging behavior. The reduction in Slagging Combustor stoichiometry can be implemented without any cost impact.

- Additional reductions in NO_x emissions from the combustion system can also be achieved by optimization of the slagging combustor swirl, in particular the tangential inlet velocity. The slagging combustor tangential inlet velocity has a secondary impact on NO_x emissions. Based on empirical data and analytical model predictions, NO_x emissions will decrease at higher tangential inlet velocities. At the higher velocities, there is a trade-off between a decrease in NO_x emissions and an increase in precombustor pressure drop. There is currently sufficient margin on precombustor pressure drop to allow a further increase in velocity. This increase in tangential inlet velocity can be accomplished by inserting the swirl dampers slightly. The change in velocity will not have a negative impact on either CO or SO_2 emissions and can be implemented with no cost impact.

- For final “fine tuning” of NO_x emissions levels from the combustion system, the excess purge air flows through aspirating doors on viewports and other miscellaneous purges within the combustion system and coal feed system can be reduced. Empirical data indicates that these purge flows account for up to 25,000 lb/hr (per combustor) of excess air flow into the combustion system that is not accounted for in the stoichiometry calculations.

- The furnace NO_x contribution can be estimated by comparing NO_x emission levels, on a lb/MMBtu basis, during single combustor full load operation to that of two combustor full load operation. During single combustor full load operation, the contribution to NO_x formation in the furnace is minimized due to the low overall furnace gas temperatures. Based on empirical data from single combustor tests conducted at HCCP, the NO_x emission level from one combustor operating at full load is 0.18 to 0.22 lb/MMBtu. This is consistent independent of which of the two combustors is operating. Since the total NO_x emissions when operating two combustors at full load is approximately 0.24 to 0.27 lb/MMBtu, this implies that the furnace is generating ~ 20 to 25 % of the total NO_x during operation with two combustors at full load. Methods to reduce the furnace NO_x contribution include: 1) Reduce the furnace excess oxygen from 4.2% to 3%. Currently approximately 60,000 lb/hr or 41% of the total amount of additional air added in the furnace is due to purge air flows through unused ports, including the Clean Air NO_x Ports and Overfire Air Ports. If all or a portion of these ports were blanked off by water-cooled refractory lined plates, the furnace excess oxygen could be reduced to 2 to 3%; 2) Redirect NO_x port air flow further up into the furnace to allow the combustion gases to cool down further prior to mixing with the excess air and completion of combustion. This will reduce the peak furnace combustion temperature and corresponding NO_x levels; and 3) relocate a portion of the NO_x port air to the Overfire Air ports (approximately 10 ft higher in furnace) in order to allow additional cooling of the combustion gases prior to completion of combustion. Of these 3 approaches, the least expensive and simplest to implement would be items 1 and 2.
- If NO_x emission levels down to the latest New Source Performance Standards (NSPS) are desired, then analytical model predictions and bench-scale empirical data indicate that this is achievable by injecting ammonia (or urea) into the high temperature region of the combustor. At the utility scale, NO_x reductions down to 0.10 to 0.15 lb/MMBtu level appear to be achievable at a NH_3:NO molar ratio of 2 to 3. Since the ammonia (or urea) is injected in the combustion system prior to the final air addition and combustion within the furnace, there is no risk of “ammonia slip” occurring. Any excess ammonia from the combustion system would simply be converted to NO_x within the furnace.

Lessons learned from HCCP include:

- Mixing of cold air streams within the Precombustor should be avoided in order to minimize the potential for slag freezing in localized areas
- Precombustor burner performance (i.e. combustion and near-flame characteristics) while burning high ash, high T_{250}, waste coal blends, can be improved by 1) increasing inner register swirl, 2) decreasing outer register swirl, 3) improving coal fines mixing (e.g., flow turbulators), and 4) increasing tertiary air temperature.
- Combustion System performance is adequate over a broad range of slagging combustor inlet velocities; it is not necessary to adjust the swirl dampers to maintain inlet velocity within a tight range of operating conditions.
- Vent and drain lines should not be included on components located within the slag tank, since they are susceptible to damage from slag falls.

- The ends of the Swirl Damper Blades should be weld overlayed with Inconel to minimize localized material erosion from particle impact
- When burning wet waste coal “fines”, the Mill Outlet should be maintained at a high enough temperature to sufficiently dry the coal and minimize the potential for wet coal particle agglomeration, in order to ensure consistent Precombustor combustion characteristics, including flame scanner signals and slagging behavior
- Only 5 coal injectors are required within the slagging stage. The injectors do not have to be equally spaced on the headend plate. Locating an injector within the strong vortex recirculation region on the headend plate should be avoided.
- It is acceptable to mix “cold” Secondary Air streams within the headend region of the slagging stage. Although slag fans may occasionally form surrounding the air jets, the fans are self-limiting in length.
- Use of smart flame scanners significantly improve the flame scanner signals within a slagging environment and minimize erroneous “loss of flame” signals
- Flow annubar devices installed in “dirty” (i.e. contains coal particles) air streams are susceptible to coal plugging and particle erosion. Use of delta-pressure transmitters (with periodic air purges to keep the ports clean) to measure flowrate in dirty air streams provides a much more reliable method for flow measurement

Improvements for future applications include:

- Eliminate combustion system high pressure circulation pumps; use natural circulation
- For applications where high ash content coal will be burned, increase the Precombustor combustion chamber diameter to minimize concerns with slag/ash impact on walls of the Precombustor chamber
- Simplify the design and construction of the Precombustor, incorporating only one Secondary Air Windbox and one coal inlet
- For many applications, the Precombustor design can be further simplified by eliminating the Precombustor Swirl Dampers and operating with a constant cross-sectional area for the tangential inlet
- Evaluate alternate design approaches for providing pressurized coal/air at the inlet of the pulverized coal feed split system, including use of pressurized Mill and/or eductor boost. This would eliminate the need for the Exhauster Fans in a highly abrasive coal environment
- For some applications, it may be beneficial to have separate Mills for the Precombustor and Slagging Combustor. This would eliminate the need to split the coal stream between Precombustor and Slagging Combustor as well as enable use of different coal types in Precombustor and Slagging Combustor (e.g., operate Slagging Combustor on pure waste coal and Precombustor on ROM coal)

REFERENCES

[1] "Healy Coal Firing at TRW Cleveland Test Facility", by TRW Applied Technology Division, for Alaska Industrial Development and Export Authority, SN 58175, August 1991.

[2] "Test Program at TRW's Cleveland, Ohio Entrained Coal Combustion Facility", by TRW Combustion Business Unit, for Ohio Coal Development Office, December 1990.

[3] "Advanced Slagging Coal Combustion System", by TRW Applied Technology Division, for U.S. Department of Energy, DOE/PETC DE-AC22-84PC60422, June 1989.

APPENDIX A – TEST SUMMARY TABLE OF OPERATIONAL AND PERFORMANCE DATA

HCCP 1998 Data Summary Table

	SYSTEM CHARACTERIZATION TEST SERIES											COAL PROPERTIES AS FED TO MILL - USIBELLI COAL PROXIMATE ANALYSIS LIMESTONE PROPERTIES - GVEA ANALYSIS								
												Coal							Limestone	
	Test Matrix Designation	Test Name	Condition No.	Selected Steady State Test Conditions	Description	Period	Total Duration (Hours)	Maximum Continuous Duration (Hours)	Inspection Date	Reason for Test Termination	Type	HHV (Btu/lb)	Moisture (%)	Ash (%)	Sulfur (%)	Grind (% Thru 200 Mesh)	Ash T250 (F)	LS CaCO3 (%)	LS Grind (% Thru 200 Mesh)
MIX ANNULUS TESTS	ROM-S4-TRIAL	ANNULUS-1	1 2 3	4/25 A B 4/26 A B 4/27 0100 A B	A, B PC - Baseline Mix Annulus Configuration PC Phi 0.65-0.76, Coal Split 37-45%	4/23/98 to 4/27/1998	87	87	4/28/98	Trip due to river inlet blockage resulting in loss of pump suction	ROM/Waste Blend Seam 4	7745 7373 7735	23.47 22.50 24.03	11.90 16.24 11.37	0.26 0.29 0.25	66.7-74		 60.00	87.00
	PERF-S4-2 PERF-S4-3	ANNULUS-2	4 5	5/3 2000 A B 5/4 0000 A B	A, B PC - Baseline Mix Annulus Configuration PC Phi 0.75-0.77, Coal Split 37-46%	5/1/98 to 5/5/1998	87	69	5/6/98	Trip during attempt to implement turbine follow logic (drum level trip)	ROM/Waste Blend Seam 4	7412 7412	25.47 25.47	13.29 13.29	0.29 0.29	59	2776	60.00 60.00	88.00
	PERF-S4-4-1 PERF-S4-7 PERF-S4-3	ANNULUS-3	6 7	5/15 A B 5/17 0000 A B	A, B PC - Baseline Mix Annulus Configuration PC Phi 0.95-1.0, Coal Split 37-45%	5/14/98 to 5/18/98	96	96	5/19/98	High furnace pressure trip	ROM/Waste Blend Seam 4	7432 7311	24.64 24.05	14.42 14.43	0.34 0.30			 60.00	
	PERF-S4-1	ANNULUS-4	8 9	5/21 A B 5/22 1000 A B	A, B PC - Baseline Mix Annulus Configuration PC Phi 0.7, Coal Split 30-32%	5/21/98 to 5/22/98	16	16	None	High furnace pressure trip	ROM/Waste Blend Seam 4	7410 7410	23.77 23.77	14.34 14.34	0.33 0.33			 60.00	
	PERF-S4-3	ANNULUS-4	10	5/23 2200 A B	A, B PC - Baseline Mix Annulus Configuration PC Phi 0.7, Coal Split 30-32%	5/22/98 to 5/23/98	30	30	5/25/98	Planned shut down	ROM/Waste Blend Seam 4	7212	24.19	15.60	0.33			60.00	
	PERF-S4-9	ANNULUS-5	11	5/30 2200 A B	A, B PC - Baseline Mix Annulus Configuration PC Phi 0.6, Coal Split 29-32% PC Exit Velocity 250 Ft/s	5/26/98 to 5/31/98	102	59	6/1/98	Accidental trip of feedwater pump	ROM/Waste Blend Seam 4	7510	24.75	12.15	0.32			60.00	
	ROM-S4-1	ANNULUS-6	12 13	6/17 2200 A B 6/22 2200 A B	A, B PC - Baseline Mix Annulus Configuration PC Phi 0.6, Coal Split 30-32%	6/8/98 to 6/26/98	431	408	6/28/98	High furnace pressure trip	ROM/Waste Blend Seam 4	7972	25.90	7.31	0.19	48.1-50.8		67.54	
	PERF-S4-1A	ANNULUS-7			A, B PC - Baseline Mix Annulus Configuration PC Phi 0.6, Coal Split 30-32%	7/1/98 to 7/6/98	116	116	7/7/98	TRW decision to install mix annulus blank off plates	ROM/Waste Blend Seam 4	7439	26.80	10.50	0.20				
	PERF-S4-1-7000	ANNULUS-8	14 15	7/11 2200 A B 7/12 A B	A PC - 45 Deg. Openings on each side of Mix Annulus B PC - Offline PC Phi 0.58, Coal Split 30-32%	7/10/98 to 7/12/98	41	41	7/13/98	TRW decision to install mix elbows	ROM/Waste Blend Seam 3	6903 7325	25.37 26.27	16.14 16.14	0.16 0.16		2589	67.54	

HCCP 1998 Data Summary Table

SYSTEM CHARACTERIZATION TEST SERIES					COMBUSTOR OPERATING CONDITIONS																
	Test Matrix Designation	Test Name	Condition No.	Selected Steady State Test Conditions	Load (MMBtu/Hr)	Inferred Heating Value (BTU/lb)	PC Can Phi	PC Exit Phi	SC Phi	PC Coal Split (%)	PC Exit Temp (F)	PC Exit Velocity (Ft/s)	Inner Register (%)	Outer Register (%)	Burner Tip Setting (in. adjust)	PC Tertiary Air (Hot or Cold)	SC Tertiary Air (Hot or Cold)	Head End Damper (in.)	Furnace Side Damper (in.)	Limestone Flow (#/min)	Ca/S Molar Ratio
	ROM-S4-TRIAL	ANNULUS-1	1	4/25 A																	
				B																	
			2	4/26 A																	
				B																	
			3	4/27 0100 A	296	7789				37			20	70	0	Cold	Cold	24	8		
				B	296					45			20	70	0	Cold	Cold	16	8		
	PERF-S4-2	ANNULUS-2	4	5/3 2000 A	299	6897							20	70	0	Cold	Cold	16	8		
	PERF-S4-3			B	306								20	70	0	Cold	Cold	16	8		
			5	5/4 0000 A	292	6885	0.96	1.97	0.88	37	2469	273	20	70	0	Cold	Cold	16	8		
				B	302		0.77	1.56	0.86	46	2840	313	20	70	0	Cold	Cold	16	8		
	PERF-S4-4-1	ANNULUS-3	6	5/15 A																	
	PERF-S4-7			B																	
	PERF-S4-3		7	5/17 0000 A	289	6904				37			20	60-70	0	Cold	Cold	22	8		
				B	292					45			20	60-70	0	Cold	Cold	22	8		
	PERF-S4-1	ANNULUS-4	8	5/21 A																	
				B																	
MIX ANNULUS TESTS			9	5/22 1000 A	295	6710				30			20	50-60	0	Cold	Cold	22	8	82	2.79
				B	295					32			20	50-60	0	Cold	Cold	22	8		
	PERF-S4-3	ANNULUS-4	10	5/23 2200 A	299	6875				31			20	50-60	0	Cold	Cold	22	8		
				B	300					32			20	50-60	0	Cold	Cold	22	8		
	PERF-S4-9	ANNULUS-5	11	5/30 2200 A	265	7210				29			20	70	0	Cold	Cold	8	8	37	1.53
				B	264					32			20	70	0	Cold	Cold	8	8		
	ROM-S4-1	ANNULUS-6	12	6/17 2200 A	309	7873				32			20	70	0	Cold	Cold	22	3"-8"	14	4.12
				B									20	70	0	Cold	Cold	22	3"-8"		
			13	6/22 2200 A	306	7635				31			20	70	0	Cold	Cold	22	3"-8"		
				B									20	70	0	Cold	Cold	22	3"-8"		
	PERF-S4-1A	ANNULUS-7											20	70	0	Cold	Cold				
	PERF-S4-1-7000	ANNULUS-8	14	7/11 2200 A	291	6808	0.59	2.03	0.77	32	2420	259	20	70	0	Cold	Cold	22	8	17	2.71
				B																	
			15	7/12 A																	
				B																	

HCCP 1998 Data Summary Table

	SYSTEM CHARACTERIZATION TEST SERIES				COMBUSTOR PERFORMANCE								
					Power		Emissions						
	Test Matrix Designation	Test Name	Condition No.	Selected Steady State Test Conditions	Gross Output (MWe)	Net Output (Mwe)	NOX Stack (Lb/MMBtu)	SO2 Stack (ppm)	SO2 Stack (Lb/MMBtu)	SO2 Furnace (ppm)	SO2 Removal Stack (%)	O2 Furnace (%)	CO Furnace (ppm)
MIX ANNULUS TESTS	ROM-S4-TRIAL	ANNULUS-1	1	4/25 A B	40	35							
			2	4/26 A B	55	48							
			3	4/27 0100 A B	56	49	*	*	*	126		4.1	8.8
	PERF-S4-2 PERF-S4-3	ANNULUS-2	4	5/3 2000 A B	57	50	*	*	*	231		3.9	17.5
			5	5/4 0000 A B	57	50	*	*	*	265		4.0	15.5
	PERF-S4-4-1 PERF-S4-7 PERF-S4-3	ANNULUS-3	6	5/15 A B									
			7	5/17 0000 A B	58	51	*	*	*	213		4.0	14.5
	PERF-S4-1	ANNULUS-4	8	5/21 A B									
			9	5/22 1000 A B	58	51	*	*	*	230		4.1	12.4
	PERF-S4-3	ANNULUS-4	10	5/23 2200 A B	58	51	0.243	*	*	338		3.5	12.5
	PERF-S4-9	ANNULUS-5	11	5/30 2200 A B	50	44	0.360	*	*	253		4.7	1.3
	ROM-S4-1	ANNULUS-6	12	6/17 2200 A B	60	53	0.232	5	0.012	166	97	3.4	1.0
			13	6/22 2200 A B	60	53	0.220	9	0.022	183	95	3.7	0.7
	PERF-S4-1A	ANNULUS-7											
	PERF-S4-1-7000	ANNULUS-8	14	7/11 2200 A B	27	23	0.174	0	0.000	108	100	6.8	2.0
			15	7/12 A B									

* Data accuracy unknown; variable operating conditions
** Slag recovery is the average value for all tests performed w/Mix Annulus configuration, slag weight corrected for 6% moisture

HCCP 1998 Data Summary Table

	SYSTEM CHARACTERIZATION TEST SERIES										COAL PROPERTIES AS FED TO MILL - USIBELLI COAL PROXIMATE ANALYSIS LIMESTONE PROPERTIES - GVEA ANALYSIS	Coal						Limestone	
	Test Matrix Designation	Test Name	Condition No.	Selected Steady State Test Conditions	Description	Period	Total Duration (Hours)	Maximum Continuous Duration (Hours)	Inspection Date	Reason for Test Termination	Type	HHV (Btu/lb)	Moisture (%)	Ash (%)	Sulfur (%)	Grind (% Thru 200 Mesh)	Ash T250 (F)	LS CaCO3 (%)	LS Grind (% Thru 200 Mesh)
MIX ELBOWS TESTS	PERF-S3-1B-7000	ELBOW-1	16	7/17 2200 A	A PC - 14 Mix Annulus elbows, All PC NOX ports open B PC - **Offline** PC Phi 0.58-0.85, Coal Split 32-41%	7/16/98 to 7/18/98	27	27	7/18/98	TRW decision to reconfigure mix elbows	ROM/Waste Blend Seam 3	7633	24.89	11.18	0.12			67.54	
	PERF-S3-2-7000	ELBOW-2	17	7/22 2200 A	A PC - 12 Mix Annulus elbows, All PC NOX ports open B PC - **Offline** PC Phi 0.85-1.0, Coal Split 41-43%	7/19/98 to 7/23/98	86	86	7/24/98	Planned plant outage	ROM/Waste Blend Seam 3	7935	24.38	9.21	0.11		2324	67.54	
	PERF-S3-3-7000	ELBOW-3			A PC - 12 Mix Annulus elbows, No PC NOX ports open B PC - 8 Mix Annulus elbows, All PC NOX ports open PC Phi 1.0, Coal Split 43%	8/4/98 to 8/11/98	150	93	8/12/98	o Turbine checkout test o Loss of pulverizer seal air o Loss of main plant power o Planned shutdown	ROM/Waste Blend Seam 3	7515	26.10	11.10	0.17			67.54	
	ROM-S3-1	ELBOW-4	18	8/22 1500 A B	A PC - 8 Mix Annulus elbows B PC - 8 Mix Annulus elbows	8/13/98 to 8/30/98	398	248	8/31/98	o Pulverizer oil skid trip o Coal in blanked-off PC NOx ports	ROM Seam 3	7925	25.92	7.72	0.12			67.54	
	ROM-S3-1	ELBOW-5	19	9/2 1200 A B	All PC NOX ports open	9/1/98 to 9/6/98	123	123	9/8/98	o TRW decision to reconfigure mix elbows	ROM Seam 3	7944	26.22	7.62	0.14			62.31	
	BLEND-1	ELBOW-6	20	9/12 1200 A B	A PC - 5 Mix Annulus elbows B PC - 6 Mix Annulus elbows All PC NOX ports open	9/10/98 to 9/13/98	76	76	9/14/98	o Over load slag ash drag chain	ROM/Waste Blend	7453	25.18	12.93	0.14	59.5 60.9	2451	67.54	
	BLEND-1	ELBOW-7			A PC - 5 Mix Annulus elbows B PC - 6 Mix Annulus elbows All PC NOX ports open	9/15/98 to 9/20/98	112	112	9/21/98	o Internal boiler tube leak	ROM/Waste Blend								
	BLEND-2	ELBOW-8	21 22 23 24	10/6 0000 A B 10/11 0000 A B 10/15 0000 A B 10/18 0000 A B	A PC - 4 Mix Annulus elbows - **Offline** B PC - 5 Mix Annulus elbows All PC NOX ports open	9/27/98 to 10/21/98	582	582	10/22/98	o Excessive mill exhauster fan vibrations o planned shut down	ROM/Waste Blend	7750 7471 7507 7464	26.95 26.52 26.10 26.30	8.61 10.97 11.30 11.82	0.12 0.14 0.12 0.13	63.8		67.54 67.54 67.54 67.54	

HCCP 1998 Data Summary Table

SYSTEM CHARACTERIZATION TEST SERIES					COMBUSTOR OPERATING CONDITIONS																
	Test Matrix Designation	Test Name	Condition No.	Selected Steady State Test Conditions	Load (MMBtu/Hr)	Inferred Heating Value (BTU/lb)	PC Can Phi	PC Exit Phi	SC Phi	PC Coal Split (%)	PC Exit Temp (F)	PC Exit Velocity (Ft/s)	Inner Register (%)	Outer Register (%)	Burner Tip Setting (in. adjust)	PC Tertiary Air (Hot or Cold)	SC Tertiary Air (Hot or Cold)	Head End Damper (in.)	Furnace Side Damper (in.)	Limestone Flow (#/min)	Ca/S Molar Ratio
MIX ELBOWS TESTS	PERF-S3-1B-7000	ELBOW-1	16	7/17 2200 A	309	6743				42			20	50	0	Cold	Cold	22	8	24	4.81
	PERF-S3-2-7000	ELBOW-2	17	7/22 2200 A	350	7549	0.93	1.40	0.76	45	3015	371	20	50	0	Cold	Hot	22	8	28	6.13
	PERF-S3-3-7000	ELBOW-3											20	70	0			22	8		
	ROM-S3-1	ELBOW-4	18	8/22 1500 A B	316 316	8028	0.96 0.99	1.45 1.43	0.81 0.77	47 45	2958 2981	357 339	25 25	70 70	0 0			22 22	8 8	N/A	N/A
	ROM-S3-1	ELBOW-5	19	9/2 1200 A B	311 311	7322	1.00 1.05	1.53 1.60	0.86 0.87	47 45	2871 2803	354 349	25 25	70 70	0 0			22 22	8 8	22	1.83
	BLEND-1	ELBOW-6	20	9/12 1200 A B	320 319	7412	0.94 0.99	1.45 1.54	0.82 0.84	48 46	2960 2870	357 350	25-30 25-30	50-70 50-70	0 0			22 22	6 6	12	1.08
	BLEND-1	ELBOW-7											25-30 25-30	50-70 50-70	0 0			22 22	6 6		
	BLEND-2	ELBOW-8	21	10/6 0000 A B	312	6958	1.03	1.62	0.86	45	2786	338	25-30	50-70	0		Hot	22	6	6	1.19
			22	10/11 0000 A B	301	6693	0.98	1.56	0.86	46	2840	341	25-30	50-70	0		Hot	22	6	7	1.19
			23	10/15 0000 A B	322	7547	0.95	1.51	0.82	46	2900	355	25-30	50-70	0		Hot	22	6	4	0.84
			24	10/18 0000 A B	342	7500	0.95	1.47	0.83	48	2943	385	25-30	50-70	0		Hot	22	6	6	1.09

HCCP 1998 Data Summary Table

	SYSTEM CHARACTERIZATION TEST SERIES				COMBUSTOR PERFORMANCE								
					Power		Emissions						
	Test Matrix Designation	Test Name	Condition No.	Selected Steady State Test Conditions	Gross Output (MWe)	Net Output (Mwe)	NOX Stack (Lb/MMBtu)	SO2 Stack (ppm)	SO2 Stack (Lb/MMBtu)	SO2 Furnace (ppm)	SO2 Removal Stack (%)	O2 Furnace (%)	CO Furnace (ppm)
MIX ELBOWS TESTS	PERF-S3-1B-7000	ELBOW-1	16	7/17 2200 A	27	24	0.271	1	0.003	95	99	7.5	0.8
	PERF-S3-2-7000	ELBOW-2	17	7/22 2200 A	30	26	0.257	1	0.003	110	99	7.8	0.8
	PERF-S3-3-7000	ELBOW-3											
	ROM-S3-1	ELBOW-4	18	8/22 1500 A B	62	54	0.255	1	0.002	82	99	2.9	0.5
	ROM-S3-1	ELBOW-5	19	9/2 1200 A B	61	54	0.284	6	0.014	152	96	3.1	0.6
	BLEND-1	ELBOW-6	20	9/12 1200 A B	62	55	0.215	13	0.030	121	92	3.0	0.7
	BLEND-1	ELBOW-7											
	BLEND-2	ELBOW-8	21	10/6 0000 A B	29	25	0.181	6	0.018	66	94	6.5	-0.2
			22	10/11 0000 A B	28	24	0.191	7	0.023	74	94	7.6	0.0
			23	10/15 0000 A B	29	25	0.209	6	0.019	69	94	7.5	-0.2
			24	10/18 0000 A B	29	25	0.209	6	0.019	62	95	7.1	0.8

** Slag recovery is the average value for all tests performed w/Mix Elbow configuration, slag weight corrected for 6% moisture

HCCP 1998 Data Summary Table

	SYSTEM CHARACTERIZATION TEST SERIES											COAL PROPERTIES AS FED TO MILL - USIBELLI COAL PROXIMATE ANALYSIS LIMESTONE PROPERTIES - GVEA ANALYSIS								
												Coal							Limestone	
	Test Matrix Designation	Test Name	Condition No.	Selected Steady State Test Conditions	Description	Period	Total Duration (Hours)	Maximum Continuous Duration (Hours)	Inspection Date	Reason for Test Termination	Type	HHV (Btu/lb)	Moisture (%)	Ash (%)	Sulfur (%)	Grind (% Thru 200 Mesh)	Ash T250 (F)	LS CaCO3 (%)	LS Grind (% Thru 200 Mesh)
HOT AIR TO SC HE	BLEND-3	SC-AIR-1			A PC Mix Annulus blocked off, elbows packed with refractory Combustion air to SC Headend (4 ports) All PC NOX ports open	10/24/98 to 10/25/98	19	19	10/27/98	Coal fire in silo	ROM/Waste Blend								
	BLEND-4	SC-AIR-2	25	11/2 0000 A B	PC Mix Annulus blocked off, elbows packed with refractory Combustion air to SC Headend (4 ports) All PC NOX ports open	10/29/98 to 11/15/98	389	389	11/16/98	o Coal silo liner debond o TRW decision to remove PC mix elbows	ROM/Waste Blend	7404	26.81	10.81	0.13	67.9 74.1	2488	67.54	
			26	11/2 1200 A B								7567	26.71	10.36	0.14			67.54	
			27	11/6 0600 A B								7510	26.71	10.50	0.13			67.54	
			28	11/8 1200 A B								7265	26.49	11.22	0.14			67.54	
	BLEND-5	SC-AIR-3	29	11/21 1200 A B	PC Mix Annulus blocked off, elbows removed Combustion air to SC Headend (4 ports) All PC NOX ports open	11/19/98 to 12/3/98	174	174	12/4/98	o High furnace pressure o Exhauster fan leak o Bucket elevator problem	ROM/Waste Blend	7379	27.07	9.73	0.13			73.77	
			30	11/28 1800 A B								7252	26.41	12.34	0.16			73.77	
	BLEND-6	SC-AIR-4	31	12/8 1500 A B	PC Mix Annulus blocked off, elbows removed Combustion air to SC Headend (6 ports) A - No PC NOX ports B - PC NOX ports open	12/7/98 to 12/21/98	303	285	12/22/98	o Fire in exhauster fan motor o coal feezing in hopper o planned shut down	ROM/Waste Blend	7246	25.69	13.23	0.16	76.8 66.5	2350	67.54	
			32	12/17 0900 A B								7235	27.73	10.44	0.18			67.54	

HCCP 1998 Data Summary Table

	SYSTEM CHARACTERIZATION TEST SERIES				COMBUSTOR OPERATING CONDITIONS																
	Test Matrix Designation	Test Name	Condition No.	Selected Steady State Test Conditions	Load (MMBtu/Hr)	Inferred Heating Value (BTU/lb)	PC Can Phi	PC Exit Phi	SC Phi	PC Coal Split (%)	PC Exit Temp (F)	PC Exit Velocity (Ft/s)	Inner Register (%)	Outer Register (%)	Burner Tip Setting (in. adjust)	PC Tertiary Air (Hot or Cold)	SC Tertiary Air (Hot or Cold)	Head End Damper (in.)	Furnace Side Damper (in.)	Limestone Flow (#/min)	Ca/S Molar Ratio
HOT AIR TO SC HE	BLEND-3	SC-AIR-1																			
	BLEND-4	SC-AIR-2	25	11/2 0000 A	301	7208	0.97	1.29	0.89	47	3150	355	25	40	0			22	13	9	1.07
				B	301		0.95	1.25	0.89	48	3200	356	25	40	0			27	8		
			26	11/2 1200 A	300	7429	0.93	1.23	0.85	47	3233	354	25	40	0			22	13	8	0.92
				B	300		0.94	1.24	0.88	48	3216	358	25	40	0			27	8		
			27	11/6 0600 A	294	7379	0.85	1.17	0.83	48	3300	341	25	40	0			22	13	6	0.75
				B	296		0.85	1.18	0.84	48	3290	344	25	40	0			27	8		
			28	11/8 1200 A	300	7052	0.83	1.15	0.84	48	3327	347	25	40	0			22	13	7	0.76
				B	300		0.87	1.19	0.86	47	3285	347	25	40	0			27	8		
	BLEND-5	SC-AIR-3	29	11/21 1200 A	298	6806	0.98	1.24	0.85	48	3216	317	25	35-40	0	hot		20	8.6	8	0.82
				B	297		1.00	1.23	0.86	47	3223	308	25	35-40	0	hot		20	8.6		
			30	11/28 1800 A	299	6408	1.05	1.22	0.86	48	3244	316	25	30-35	0	hot		20	8.6	24	1.88
				B	299		1.08	1.26	0.90	48	3193	323	25	30-35	0	hot		20	8.6		
	BLEND-6	SC-AIR-4	31	12/8 1500 A	300	6597	0.99	0.99	0.82	48	3558	278	25	30	0	hot		24	9	33	2.46
				B	300		0.98	0.98	0.80	48	3572	285	25	35	0	hot		28	3		
			32	12/17 0900 A	301	6853	1.04	1.04	0.76	42	3482	253	25	30	0	cold		24	9	31	2.06
				B	302		1.10	1.10	0.79	42	3404	262	25	28	0	cold		28	3	A&B	

HCCP 1998 Data Summary Table

	SYSTEM CHARACTERIZATION TEST SERIES				COMBUSTOR PERFORMANCE								
					Power		Emissions						
	Test Matrix Designation	Test Name	Condition No.	Selected Steady State Test Conditions	Gross Output (MWe)	Net Output (Mwe)	NOX Stack (Lb/MMBtu)	SO2 Stack (ppm)	SO2 Stack (Lb/MMBtu)	SO2 Furnace (ppm)	SO2 Removal Stack (%)	O2 Furnace (%)	CO Furnace (ppm)
HOT AIR TO SC HE	BLEND-3	SC-AIR-1											
	BLEND-4	SC-AIR-2	25	11/2 0000 A B	57	50	0.306	19	0.046	100	87	3.9	1.3
			26	11/2 1200 A B	57	50	0.262	17	0.041	94	89	3.7	0.7
			27	11/6 0600 A B	56	49	0.236	15	0.036	95	90	3.8	0.8
			28	11/8 1200 A B	57	50	0.287	24	0.059	106	85	4.0	0.8
	BLEND-5	SC-AIR-3	29	11/21 1200 A B	57	50	0.318	23	0.056	108	84	3.8	0.2
			30	11/28 1800 A B	57	50	0.246	26	0.068	112	85	4.8	0.0
	BLEND-6	SC-AIR-4	31	12/8 1500 A B	57	50	0.229	24	0.059		87	3.9	0.0
			32	12/17 0900 A B	57	50	0.233	32	0.084			4.8	0.5

** Slag recovery is the average value for all tests performed w/ Hot Air to SC configuration, slag weight corrected for 6% moisture

1999 HCCP Data Summary Table

	SYSTEM CHARACTERIZATION TEST SERIES											COAL PROPERTIES AS FED TO MILL - USIBELLI COAL PROXIMATE ANALYSIS LIMESTONE PROPERTIES - GVEA ANALYSIS								
												Coal							Limestone	
	Test Matrix Designation	Test Name	Condition No.	Daily Steady State Averages	Description	Period	Total Duration (Hours)	Maximum Continuous Duration (Hours)	Inspection Date	Reason for Test Termination	Type	HHV (Btu/lb)	Moisture (%)	Ash (%)	Sulfur (%)	Grind (% Thru 200 Mesh)	Ash T250 (F)	LS CaCO3 (%)	LS Grind (% Thru 200 Mesh)
HOT AIR TO SC HE (CONTINUED)	BLEND-10	SC-AIR-5	1	3/20 A B	PC mix annulus blocked off, no elbows Combustion air to SC headend (6 ports)	3/18/99 to 3/30/99	282	282	4/1/99	o High furnace pressure trip o Coal feeder trip	ROM/Waste	7322	27.41	10.01	0.24		2536		
			2	3/21 A B	A - No PC NOX ports B - PC NOX ports open							7057	27.33	12.00	0.27				
			3	3/22 A B	Moved FWEC burner inner sleeve back 1" Swirler added to inner passage of coal burner							7244	27.48	10.74	0.23				
			4	3/24 A B	East swirl damper 28", West 10"							7247	26.70	11.30	0.26				
			5	3/25 A B								7513	26.13	10.64	0.23				
			6	3/26 A B								7555	25.52	10.93	0.28				
			7	3/27 A B								7511	26.27	10.31	0.26				
			8	3/28 A B								7488	26.42	10.67	0.26				
			9	3/29 A B								7228	27.06	11.54	0.24				
	BLEND-11	SC-AIR-6	10	4/8 A B	Same as BLEND-10 except Mix annulus air duct plugged off	4/7/99 to 4/27/99	464	250	4/29/99	o High furnace pressure trip o Trip on PC A flame scanner	ROM/Waste	7646	25.55	10.85	0.17		2416		
			11	4/10 A B	A - PC NOX port opened 7th SC HE air port installed					o High furnace pressure trip o Planned shutdown - damage		7256	26.75	11.88	0.23				
			12	4/11 A B	East swirl damper 28", West 10"					to slag tank		7353	25.91	12.35	0.21				
			13	4/12 A B								7121	25.97	14.54	0.20				
			14	4/13 A B								7284	26.36	12.11	0.22				
			15	4/15 A B								7616	25.85	10.51	0.22				
			16	4/16 A B								7618	25.90	10.02	0.21				
	BLEND-12	SC-AIR-7	17	5/8 A B	Same as BLEND-11 except 7th SC HE air port closed	5/6/99 to 6/2/1999	566	211	6/4/99	o Low pressure cooling water low o Hopper slope ash fall	ROM/Waste Blend	7435	27.41	10.28	0.14				
			18	5/9 A B	East swirl damper 32", West 14"					o Planned shut down		7277	27.58	10.80	0.14				
			19	5/11 A B								7355	26.79	10.96	0.17				
			20	5/12 A B								7401	26.28	10.69	0.19				
			21	5/26 A B								7053	27.27	12.45	0.15				
			22	5/27 A B								7141	27.45	11.75	0.15				
			23	5/28 A B								7333	27.20	10.67	0.15				
			24	5/31 A B								7591	25.46	11.24	0.15				
			25	6/1 A B								7575	25.29	11.03	0.15				
	BLEND-13	SC-AIR-8	26	6/6 A B	Same as BLEND-12	6/5/99 to 6/12/99	180	180	6/14/99	o Planned shut down	ROM/Waste Blend	7377	26.34	11.22	0.15		2393	98.81	86.87
			27	6/7 A B								7508	25.25	11.47	0.15				
			28	6/8 A B								7671	25.80	9.58	0.18				
			29	6/9 A B								7557	25.55	11.09	0.17				
			30	6/10 A B								7623	25.63	10.36	0.16				
			31	6/11 A B								7623	25.27	10.86	0.16				
				Ave.								7406	26.36	11.12	0.20				
				Max.								7671	27.58	14.54	0.28				
				Min.								7053	25.25	9.58	0.14				

1999 HCCP Data Summary Table

SYSTEM CHARACTERIZATION TEST SERIES					COMBUSTOR OPERATING CONDITIONS																
	Test Matrix Designation	Test Name	Condition No.	Daily Steady State Averages	Load (MMBtu/Hr)	Inferred Heating Value (BTU/lb)	PC Can Phi	PC Exit Phi	SC Phi	PC Coal Split (%)	PC Exit Temp (F)	PC Exit Velocity (Ft/s)	Inner Register (%)	Outer Register (%)	Burner Tip Setting (in. adjust)	PC Tertiary Air (Hot or Cold)	SC Tertiary Air (Hot or Cold)	Head End Damper (in.)	Furnace Side Damper (in.)	Limestone Flow (#/min)	Ca/S Molar Ratio
HOT AIR TO SC HE (CONTINUED)	BLEND-10	SC-AIR-5	1	3/20 A	303	7111	1.50	1.50	0.83	0.295	3022	255	50	35	-1	10 cold, 30 hot		28	10	33	2.20
				B	305		1.49	1.49	0.80	0.298	3037	257	50	35	-1	20 cold, 100 hot		28	10		
			2	3/21 A	304	6884	1.53	1.53	0.86	0.290	3015	255								26	1.50
				B	304		1.49	1.49	0.80	0.297	3052	254									
			3	3/22 A	304	7060	1.52	1.52	0.83	0.290	3021	254								37	2.50
				B	304		1.49	1.49	0.80	0.299	3055	253									
			4	3/24 A	304	7076	1.59	1.59	0.84	0.287	2939	256								44	2.70
				B	304		1.53	1.53	0.80	0.299	3006	253									
			5	3/25 A	306	7282	1.51	1.51	0.84	0.288	3023	251								54	3.70
				B	286		1.56	1.56	0.80	0.304	2964	240									
			6	3/26 A	304	7279	1.54	1.54	0.86	0.284	2998	249								39	2.30
				B	289		1.58	1.58		0.305	2956	241									
			7	3/27 A	304	7246	1.56	1.56	0.84	0.284	2965	250								46	2.80
				B	304		1.56	1.56	0.79	0.289	2965	251									
			8	3/28 A	303	7079	1.55	1.55	0.88	0.284	2975	249								38	2.30
				B	303		1.55	1.55	0.80	0.283	2978	251									
			9	3/29 A	307	7131	1.53	1.53	0.87	0.283	3009	251								36	2.40
				B	307		1.53	1.53	0.79	0.282	3005	252									
	BLEND-11	SC-AIR-6	10	4/8 A	298	7360	1.50	1.50	0.80	0.298	3023	250	50	50	-1	20 cold, 5 hot		28	10	27	2.70
				B	311		1.49	1.49	0.80	0.294	3038	264	50	50	-1	20 cold, 0 hot		28	10		
			11	4/10 A	304	7258	1.49	1.49	0.78	0.298	3032	258								39	2.70
				B	304		1.48	1.48	0.78	0.294	3040	258									
			12	4/11 A	308	7211	1.47	1.47	0.78	0.303	3057	263								41	3.10
				B	308		1.47	1.47	0.78	0.293	3059	264									
			13	4/12 A	310	7093	1.47	1.47	0.78	0.302	3053	265								42	3.20
				B	310		1.47	1.47	0.79	0.296	3051	265									
			14	4/13 A	304	7095	1.46	1.46	0.78	0.304	3058	260								43	3.10
				B	304		1.46	1.46	0.80	0.305	3065	261									
			15	4/15 A	305	7481	1.43	1.43	0.78	0.310	3104	263								40	3.00
				B	305		1.45	1.45	0.79	0.314	3083	265									
			16	4/16 A	304	7527	1.44	1.44	0.78	0.309	3089	261								21	1.70
				B	304		1.46	1.46	0.79	0.316	3064	264									
	BLEND-12	SC-AIR-7	17	5/8 A	304	7226	1.46	1.46	0.80	0.307	3067	306	50	50	-2	10 cold, 30 hot		32	14	20	3.30
				B	304		1.48	1.48	0.80	0.303	3047	309	50	50	-1	10 cold, 30 hot		32	14		
			18	5/9 A	303	7193	1.42	1.42	0.80	0.315	3107	310								21	3.30
				B	303		1.45	1.45	0.80	0.304	3079	313									
			19	5/11 A	303	7049	1.39	1.39	0.80	0.323	3156	314								20	2.60
				B	303		1.41	1.41	0.80	0.311	3127	319									
			20	5/12 A	304	7021	1.39	1.39	0.80	0.322	3155	315								20	2.30
				B	304		1.42	1.42	0.80	0.311	3125	320									
			21	5/26 A	304	6738	1.38	1.38	0.80	0.325	3170	318								24	3.30
				B	304		1.38	1.38	0.80	0.316	3165	321									
			22	5/27 A	304	6756	1.40	1.40	0.80	0.322	3149	316								33	4.60
				B	304		1.40	1.40	0.80	0.316	3151	319									
			23	5/28 A	304	6839	1.39	1.39	0.80	0.323	3156	316								27	3.80
				B	304		1.39	1.39	0.81	0.316	3154	319									
			24	5/31 A	304	7299	1.39	1.39	0.80	0.324	3157	315								21	3.20
				B	304		1.43	1.43	0.80	0.320	3101	322									
			25	6/1 A	304	7177	1.38	1.38	0.80	0.324	3161	314								19	2.60
				B	304		1.38	1.38	0.80	0.319	3165	317									
	BLEND-13	SC-AIR-8	26	6/6 A	303	7125	1.38	1.38	0.80	0.325	3169	315	50	50	-2	10 cold, 30 hot		32	14	23	3.40
				B	303		1.41	1.41	0.80	0.316	3129	321	50	50	-1	10 cold, 30 hot		32	14		
			27	6/7 A	304	7140	1.39	1.39	0.80	0.324	3151	314								26	3.90
				B	304		1.44	1.44	0.80	0.317	3100	321									
			28	6/8 A	304	7233	1.39	1.39	0.80	0.324	3155	314								24	3.00
				B	304		1.46	1.46	0.80	0.320	3080	323									
			29	6/9 A	304	7240	1.42	1.42	0.80	0.324	3122	311								22	2.90
				B	304		1.50	1.50	0.80	0.321	3035	321									
			30	6/10 A	304	7374	1.39	1.39	0.80	0.326	3152	314								20	2.90
				B	304		1.48	1.48	0.80	0.321	3054	324									
			31	6/11 A	304	7362	1.39	1.39	0.80	0.325	3147	314								19	2.70
				B	304		1.48	1.48	0.80	0.320	3053	324									
				Ave.	304	7160	1.46	1.46	0.80	0.31	3073	285								30	2.89
				Max.	311	7527	1.59	1.59	0.88	0.33	3170	324								54	4.60
				Min.	286	6738	1.38	1.38	0.78	0.28	2939	240								19	1.50

1999 HCCP Data Summary Table

	SYSTEM CHARACTERIZATION TEST SERIES				COMBUSTOR PERFORMANCE								
					Power		Emissions						
	Test Matrix Designation	Test Name	Condition No.	Daily Steady State Averages	Gross Output (MWe)	Net Output (Mwe)	NOX Stack (Lb/MMBtu) "a"	SO2 Stack (ppm)	SO2 Stack (Lb/MMBtu) "b"	SO2 Furnace (ppm)	SO2 Removal Stack (%)	O2 Furnace (%)	CO Furnace (ppm) "c"
HOT AIR TO SC HE (CONTINUED)	BLEND-10	SC-AIR-5	1	3/20 A B	58	51	NA	18	0.045	161	89	4.7	NA
			2	3/21 A B	58	51	NA	27	0.067	171	84	4.6	NA
			3	3/22 A B	58	51	NA	25	0.062	150	83	4.6	NA
			4	3/24 A B	58	51	NA	24	0.061	166	86	4.8	NA
			5	3/25 A B	56	49	NA	SDA Prob.	SDA Prob.	137	SDA Prob.	4.9	NA
			6	3/26 A B	56	49	NA	SDA Prob.	SDA Prob.	163	SDA Prob.	4.8	NA
			7	3/27 A B	58	51	NA	27	0.067	178	85	4.5	NA
			8	3/28 A B	58	51	NA	25	0.064	182	86	4.9	NA
			9	3/29 A B	59	51	NA	SDA Prob.	SDA Prob.	183	SDA Prob.	4.3	NA
	BLEND-11	SC-AIR-6	10	4/8 A B	58	51	NA	26	0.066	155	83	4.8	NA
			11	4/10 A B	58	51	NA	22	0.055	149	85	4.7	NA
			12	4/11 A B	59	52	NA	23	0.057	149	85	4.5	NA
			13	4/12 A B	59	52	NA	20	0.049	147	86	4.5	NA
			14	4/13 A B	58	51	NA	22	0.054	170	87	4.5	NA
			15	4/15 A B	58	51	NA	21	0.051	150	86	4.2	NA
			16	4/16 A B	58	51	NA	20	0.049	163	88	4.3	NA
	BLEND-12	SC-AIR-7	17	5/8 A B	58	51	0.228	14	0.034	118	88	4.1	62.0
			18	5/9 A B	58	51	0.231	14	0.034	131	89	4.2	78.0
			19	5/11 A B	58	51	0.247	24	0.057	163	85	4.0	81.0
			20	5/12 A B	58	51	0.250	24	0.057	149	84	3.9	80.0
			21	5/26 A B	58	51	0.269	20	0.048	137	85	4.1	77.0
			22	5/27 A B	58	51	0.271	SDA Prob.	SDA Prob.	135	SDA Prob.	4.2	79.0
			23	5/28 A B	58	51	0.269	24	0.059	141	83	4.3	82.0
			24	5/31 A B	58	51	0.238	10	0.025	127	92	4.4	78.0
			25	6/1 A B	58	51	0.237	1	0.002	127	99	4.3	81.0
	BLEND-13	SC-AIR-8	26	6/6 A B	58	51	0.231	1	0.002	135	99	4.1	78.0
			27	6/7 A B	58	51	0.241	2	0.005	132	98	4.2	80.0
			28	6/8 A B	58	51	0.242	1	0.002	151	99	4.3	82.0
			29	6/9 A B	58	51	0.245	1	0.002	152	99	4.2	81.0
			30	6/10 A B	58	51	0.252	1	0.002	125	99	4.1	81.0
			31	6/11 A B	58	51	0.255	2	0.005	133	98	4.2	84.0

Notes: a - NOX values not available are due to incorrect calibration. b - SOX values in Lbs/MMBtu were calculated

	Gross Output (MWe)	Net Output (Mwe)	NOX Stack (Lb/MMBtu)	SO2 Stack (ppm)	SO2 Stack (Lb/MMBtu)	SO2 Furnace (ppm)	SO2 Removal Stack (%)	O2 Furnace (%)	CO Furnace (ppm)
Ave.	58	51	0.247	16	0.040	149	89	4.4	78.9
Max.	59	52	0.271	27	0.067	183	99	4.9	84.0
Min.	56	49	0.228	1	0.002	118	83	3.9	62.0

APPENDIX B – DEFINITIONS OF COMBUSTOR PARAMETERS AND METHODOLOGY FOR COMBUSTOR STOICHIOMETRY DETERMINATION

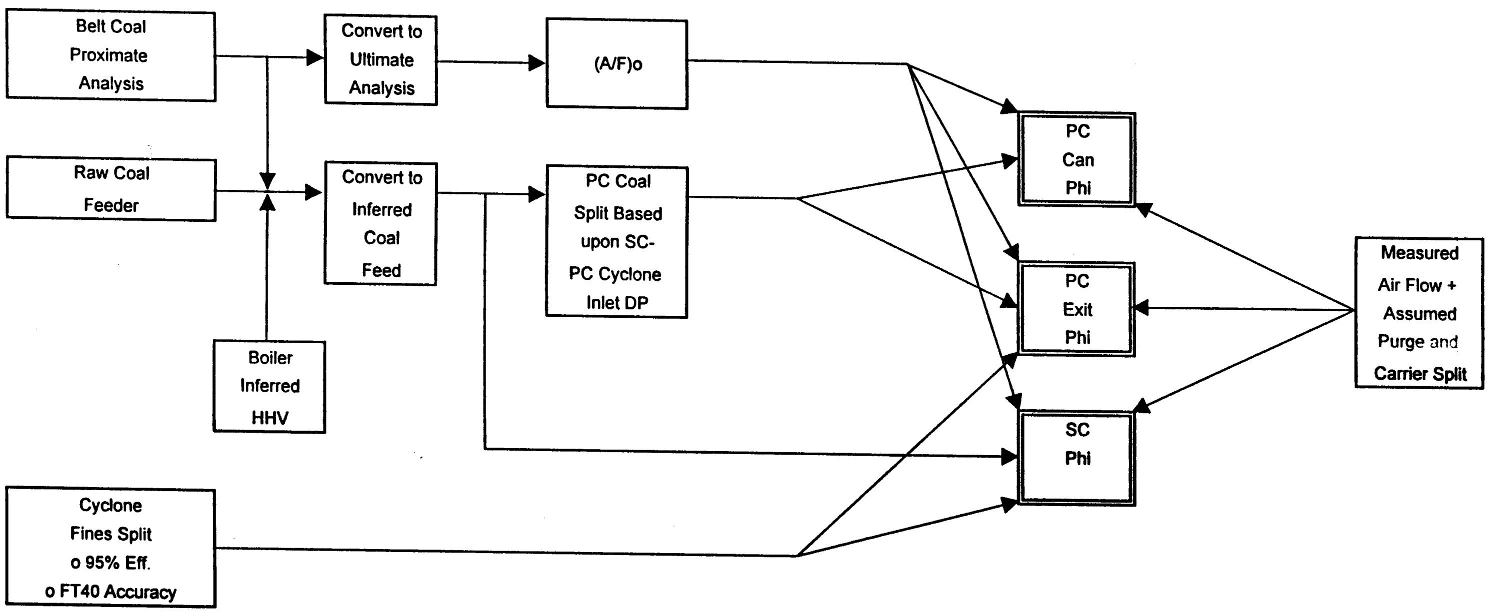
Equations for Combustor Operation and Performance

Variable Name	Equation List
R	1. Coal Firing Rate, MMBtu/Hr = Coal Feeder Speed, kpph * HHV, inferred /1000
PC PHI	2. PC Phi Can $= \dfrac{\text{(PC Burner Air + Total Carrier * PC Carrier Split / 100 + Tertiary + Purge)}}{\text{(A/F)o * R * Cyclone Eff / 100 * Alpha / 100}}$ PC Carrier Split assumed to be 36% Cyclone Efficiency assumed to be 95% (A/F)o is approximately 760 Lbs/MMBtu
SC PHI	3. SC Phi $= \dfrac{\text{(Total SC + PC Air)}}{\text{(A/F)o * R * (Cyclon Eff / 100 + (1 - Cyclon Eff / 100) * Mill Air PC / All Mill Air))}}$
FURNACE PHI	4. Furnace Phi $= \dfrac{\text{(Total SC + PC Air + Limestone Air + Overfire Air + Mill Air to NOX Port)}}{\text{(A/F)o * R}}$
Alpha	5. PC Coal Split, % = 38 + 4*X - 0.1*X^3, where X=SC-PC Cyclone Inlet DP, "H2O

Equations for Combustor Operation and Performance

Variable Name	Equation List
Ca/S	6. Ca/S Molar Ratio
	= (Limestone Flowrate, #/min * 60) * (%CaCO3) / MWCaCO3 ÷ R*10^6 / HHV, as fed to mill * (%S, as fed to mill) / MWS
Eta, S	7. SO2 Removal, %
	= (1 - (SO2, lbs/MMBtu Stack) ÷ (%S / 100) / MWS * MWSO2/HHV)) * 100
Eta, C	8. Carbon Burnout, %
	= (1 - (Slag Wt) * (Slag C, % /100) + (Flyash Wt) * (Flyash C, %/100)) ÷ (Coal Wt) * (Coal C, %/100)) * 100
SR	9. Slag Recovery, %
	= (Delta Slag Wt, tons * 2000 / Delta Time, Hrs) ÷ (Coal Feeder Speed, kpph * 1000 * (%Ash, as fed to mill / 100) * 100
Eta,Calcination	10. Calcination Efficiency, %
	= [CaO] + [CaSO4] * MW,CaO/MW,CaSO4 ÷ [CaO] + [CaSO4] * MW,CaO/MW,CaSO4 + [CaCO3] * MW,CaO/MW,CaCO3 * 1(

Combustor Stoichiometry Methodology



APPENDIX C – COAL, SLAG, PYRITE, AND FLYASH ANALYSIS RESULT

1998 Daily Coal Analysis by Usibelli Coal Mine (UCM)
Proximate Coal Analysis - Loader Samples

Ultimate Coal Analysis -
Based upon a model which assumes that the hydrogen to volatile matter, oxygen to carbon, nitrogen to carbon ratios are fixed based upon actual data.

Designator	Period	Date Loaded	Amount Loaded (M-lbs)	HHV (Btu/lb)	Volatiles (%)	Fixed C (%)	Moisture (%)	Ash (%)	Sulfur (%)	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Oxygen (%)	A/F	A/F (#Air/MMBTU)
ROM-S4-TRIAL	4/23/98 to	24	1252	7863	36.94	29.04	24.76	9.33	0.18	46.43	3.33	0.60	15.37	5.84	742.7
	5/1/1998	25	940	7745	36.29	28.43	23.47	11.90	0.26	45.46	3.27	0.59	15.05	5.72	739.1
		26	2072	7373	34.78	26.51	22.50	16.24	0.29	43.03	3.13	0.56	14.25	5.43	736.9
		27	1032	7735	36.59	28.10	24.03	11.37	0.25	45.43	3.30	0.59	15.04	5.73	740.7
		1	2357	7292	34.21	27.08	24.52	14.31	0.29	43.01	3.08	0.56	14.24	5.41	742.2
	avg			7602	35.76	27.83	23.86	12.63	0.25	44.67	3.22	0.58	14.79	5.63	740.3
	std %			3	3.35	3.68	3.79	21.27	17.74	3.49	3.42	3.49	3.49	3.43	0.3
PERF-S4-2	5/2/98 to	2	589	6196	29.69	22.60	23.89	24.02	0.27	36.57	2.67	0.47	12.11	4.62	745.9
PERF-S4-3	5/5/1998	3	688	7412	34.15	27.19	25.47	13.29	0.29	43.06	3.07	0.56	14.26	5.42	730.7
		4	1960	7676	35.68	28.37	25.53	10.50	0.27	45.00	3.21	0.58	14.90	5.66	737.3
	avg			7095	33.17	26.05	24.96	15.94	0.28	41.54	2.99	0.54	13.75	5.23	737.9
	std %			11	9.38	11.70	3.73	44.79	4.17	10.63	9.43	10.63	10.63	10.37	1.0
PERF-S4-4-1	5/14/98 to	14	799	7463	34.91	27.65	23.95	13.60	0.33	43.88	3.14	0.57	14.53	5.52	740.1
PERF-S4-7	5/18/98	15	1607	7432	34.27	26.78	24.64	14.42	0.34	42.79	3.08	0.55	14.17	5.39	725.8
PERF-S4-3		16	1572	7311	34.64	26.99	24.05	14.43	0.30	43.23	3.12	0.56	14.31	5.45	745.2
		17	1668	7273	34.16	26.72	25.24	13.99	0.32	42.69	3.07	0.55	14.13	5.38	739.7
		18	684	7410	35.06	26.94	23.77	14.34	0.33	43.46	3.15	0.56	14.39	5.49	740.2
	avg			7378	34.61	27.02	24.33	14.16	0.32	43.21	3.11	0.56	14.31	5.45	738.2
	std %			1	1.13	1.37	2.48	2.54	4.68	1.13	1.14	1.13	1.13	1.11	1.0
PERF-S4-1	5/21/98 to	21	219	7410	35.06	26.94	23.77	14.34	0.33	43.46	3.15	0.56	14.39	5.49	740.2
	5/22/98	22	1244	7391	35.15	26.68	23.29	15.00	0.36	43.29	3.16	0.56	14.33	5.47	740.4
	avg			7401	35.11	26.81	23.53	14.67	0.35	43.38	3.16	0.56	14.36	5.48	740.3
	std %			0	0.18	0.69	1.44	3.18	6.15	0.26	0.15	0.26	0.26	0.16	0.0
PERF-S4-3	5/22/98 to	21	219	7410	35.06	26.94	23.77	14.34	0.33	43.46	3.15	0.56	14.39	5.49	740.2
	5/23/98	22	1244	7391	35.15	26.68	23.29	15.00	0.36	43.29	3.16	0.56	14.33	5.47	740.4
		23	1109	7212	34.31	26.03	24.19	15.60	0.33	42.26	3.09	0.55	13.99	5.34	740.5
	avg			7338	34.84	26.55	23.75	14.98	0.34	43.00	3.13	0.56	14.24	5.43	740.4
	std %			1	1.32	1.77	1.90	4.21	5.09	1.51	1.32	1.51	1.51	1.47	0.0
PERF-S4-9	5/26/98 to	26	282	7212	34.31	26.03	24.19	15.60	0.33	42.26	3.09	0.55	13.99	5.34	740.5
	5/31/98	27	1735	7503	35.67	27.34	24.36	12.73	0.29	44.20	3.21	0.57	14.63	5.58	743.5
		28	1595	7277	34.78	26.08	24.70	14.57	0.32	42.62	3.13	0.55	14.11	5.39	740.9
		29	1571	7229	34.21	26.48	25.33	14.09	0.29	42.57	3.08	0.55	14.09	5.37	742.6
		30	1863	7510	35.59	27.61	24.75	12.15	0.32	44.33	3.20	0.57	14.68	5.59	744.3
		31	554	7510	35.59	27.61	24.75	12.15	0.32	44.33	3.20	0.57	14.68	5.59	744.3
	avg			7346	34.91	26.71	24.67	13.83	0.31	43.38	3.15	0.56	14.36	5.48	742.7
	std %			2	1.98	2.73	1.78	10.09	6.03	2.30	1.94	2.30	2.30	2.21	0.2
ROM-S4-1	6/8/98 to	8	260	7963	37.10	29.62	24.83	8.41	0.23	47.01	3.34	0.61	15.56	5.91	741.6
	6/26/98	9	1704	7963	37.20	29.62	24.83	8.41	0.23	47.01	3.35	0.61	15.56	5.91	741.9
		10	1454	7811	36.56	28.95	25.04	9.52	0.20	46.09	3.30	0.60	15.26	5.79	741.8
		11	1799	8021	37.18	30.23	24.63	8.03	0.21	47.45	3.35	0.61	15.71	5.95	742.0
		12	1734	7817	36.34	29.34	25.05	9.34	0.21	46.22	3.28	0.60	15.30	5.80	742.1
		13	1494	7846	36.67	29.30	24.85	9.25	0.19	46.43	3.31	0.60	15.37	5.83	743.3
		14	2066	7846	36.67	29.30	24.85	9.25	0.19	46.43	3.31	0.60	15.37	5.83	743.3
		15	1464	7988	37.51	29.36	26.09	7.09	0.20	47.05	3.38	0.61	15.58	5.92	741.2
		16	1813	7967	37.26	29.44	26.62	6.73	0.20	46.94	3.36	0.61	15.54	5.90	740.8
		17	1761	7972	37.39	29.46	25.90	7.31	0.19	47.04	3.37	0.61	15.57	5.92	742.1
		18	2051	7853	37.05	28.84	25.43	8.75	0.20	46.34	3.34	0.60	15.34	5.83	743.0
		19	2091	8050	37.23	29.89	24.68	8.16	0.22	47.31	3.36	0.61	15.66	5.94	737.7
		20	2593	7967	37.06	29.56	25.05	8.39	0.24	46.86	3.34	0.61	15.51	5.89	739.1
		21	1297	7988	37.28	29.39	25.01	8.38	0.25	46.87	3.36	0.61	15.52	5.90	738.3
		22	1752	7912	37.12	29.21	24.86	8.88	0.26	46.62	3.35	0.60	15.43	5.87	741.5
		23	941	7842	36.79	28.93	24.61	9.75	0.27	46.17	3.31	0.60	15.29	5.81	741.1
		24	2461	7443	35.01	27.73	26.39	10.96	0.19	44.12	3.16	0.57	14.61	5.55	745.3
		25	1422	7160	34.28	25.88	25.69	14.26	0.25	42.20	3.09	0.55	13.97	5.33	744.6
		26	2304	6722	32.53	25.17	26.69	15.74	0.30	40.43	2.93	0.52	13.39	5.10	758.8
	avg			7796	36.54	28.91	25.32	9.30	0.22	46.03	3.29	0.60	15.24	5.79	742.6
	std %			4	3.47	4.49	2.74	24.21	14.27	3.98	3.50	3.98	3.98	3.86	0.6
PERF-S4-1A	7/1/98 to	1	476	6722	32.53	25.17	26.69	15.74	0.30	40.43	2.93	0.52	13.39	5.10	758.8
	7/6/98	2	1267	7717	35.89	28.72	27.22	8.23	0.20	45.47	3.24	0.59	15.05	5.71	740.1
		3	1826	7531	34.12	28.25	27.74	8.95	0.20	44.67	3.08	0.58	14.79	5.58	740.3
		4	3276	7417	35.13	27.82	26.85	10.28	0.18	44.29	3.17	0.57	14.66	5.57	750.6
		5	1189	7806	36.14	29.36	25.44	9.13	0.13	46.16	3.26	0.60	15.28	5.79	741.3
		6	1183	7806	36.14	29.36	25.44	9.13	0.13	46.16	3.26	0.60	15.28	5.79	741.3
	avg			7439	34.76	27.86	26.79	10.47	0.20	44.53	3.16	0.58	14.74	5.59	745.4
	std %			6	4.24	5.78	3.19	29.03	30.60	4.82	4.20	4.82	4.82	4.61	1.0

Ultimate Coal Analysis -
Based upon a model which assumes that the hydrogen to volatile matter, oxygen to carbon, nitrogen to carbon ratios are fixed based upon actual data.

Designator	Period	Date Loaded	Amount Loaded (M-lbs)	HHV (Btu/lb)	Volatiles (%)	Fixed C (%)	Moisture (%)	Ash (%)	Sulfur (%)	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Oxygen (%)	A/F	A/F (#Air/MMBTU)
PERF-S3-1-7000	7/10/98 to	10	325	7475	34.63	28.10	24.45	12.92	0.11	44.19	3.13	0.57	14.63	5.54	741.2
	7/12/98	11	756	6903	33.01	25.61	25.37	16.14	0.16	41.18	2.98	0.53	13.63	5.19	751.5
		12	808	7325	34.16	27.25	26.27	12.39	0.11	43.26	3.08	0.56	14.32	5.43	741.6
	avg			7234	33.93	26.99	25.36	13.82	0.13	42.88	3.06	0.56	14.20	5.39	744.8
	std %			4	2.46	4.69	3.59	14.69	22.79	1.54	0.08	0.02	0.51	0.18	5.9
PERF-S3-1b-7000	7/16/98 to	16	8	7325	34.16	27.25	26.27	12.39	0.11	43.26	3.08	0.56	14.32	5.43	741.6
	7/18/98	17	412	7633	35.73	28.29	24.89	11.18	0.12	45.08	3.23	0.58	14.92	5.66	742.1
	avg			7479	34.95	27.77	25.58	11.79	0.12	44.17	3.16	0.57	14.62	5.55	741.8
	std %			3	3.18	2.65	3.81	7.26	6.15	2.90	3.17	2.90	2.90	2.96	0.0
PERF-S3-2-7000	7/19/98 to	19	296	7378	35.08	27.34	25.36	12.32	0.20	43.87	3.16	0.57	14.52	5.52	748.7
	7/23/98	20	875	7746	35.98	29.18	25.57	9.34	0.15	45.90	3.25	0.59	15.20	5.76	743.1
		21	1433	7769	36.02	28.91	25.06	10.09	0.16	45.71	3.25	0.59	15.13	5.74	738.6
		22	1086	7935	36.61	29.87	24.38	9.21	0.11	46.87	3.31	0.61	15.52	5.87	740.1
		23	300	7935	36.61	29.87	24.38	9.21	0.11	46.87	3.31	0.61	15.52	5.87	740.1
	avg			7707	35.92	28.83	25.09	10.24	0.16	45.84	3.26	0.59	15.18	5.75	742.1
	std %			3	1.76	3.71	2.07	14.06	23.85	2.68	1.80	2.68	2.68	2.48	0.5
PERF-S3-3-7000	8/4/98 to	4	1081	7312	34.13	26.73	24.30	14.96	0.22	42.74	3.08	0.55	14.15	5.38	735.9
	8/11/98	5	434	7641	35.03	28.29	25.16	11.61	0.14	44.59	3.16	0.58	14.76	5.59	732.1
		6	1506	7386	34.10	27.99	26.02	11.98	0.16	43.72	3.08	0.57	14.47	5.48	741.7
		7	1880	7133	34.49	25.97	25.91	13.75	0.18	42.45	3.11	0.55	14.05	5.36	751.7
		8	2557	7659	35.53	28.75	25.92	9.87	0.17	45.26	3.21	0.59	14.98	5.68	741.4
		9	1427	7824	36.15	29.25	26.01	8.66	0.15	46.07	3.26	0.60	15.25	5.78	738.5
		10	1527	7609	35.12	28.41	27.70	8.83	0.15	44.75	3.17	0.58	14.82	5.61	737.7
		11	624	7554	34.58	28.51	27.81	9.17	0.17	44.44	3.12	0.58	14.71	5.57	736.8
	avg			7515	34.89	27.99	26.10	11.10	0.17	44.25	3.15	0.57	14.65	5.56	739.5
	std %			3	2.03	3.91	4.51	21.34	14.88	2.77	2.06	2.77	2.77	2.58	0.8
ROM-S3-1	8/13/98 to	13	833	7375	34.44	27.24	26.14	12.28	0.17	43.38	3.11	0.56	14.36	5.45	739.5
	9/6/98	14	2141	7647	35.34	29.02	26.13	9.58	0.16	45.34	3.19	0.59	15.01	5.68	742.8
		15	2500	7860	35.98	29.69	26.30	8.08	0.14	46.30	3.25	0.60	15.33	5.80	737.5
		16	2689	7981	36.52	30.07	26.69	6.77	0.14	46.95	3.30	0.61	15.54	5.88	736.6
		17	1816	7941	37.17	29.97	27.26	6.66	0.13	46.57	3.36	0.60	15.42	5.86	738.0
		18	1741	7962	36.45	29.81	27.00	6.79	0.11	46.73	3.29	0.61	15.47	5.85	735.2
		19	1864	7495	34.88	27.62	25.93	11.65	0.17	43.98	3.15	0.57	14.56	5.53	737.5
		20	1420	7806	35.97	29.07	25.66	9.37	0.16	45.81	3.25	0.59	15.16	5.75	736.1
		21	1595	8117	37.06	30.52	25.38	7.09	0.14	47.65	3.35	0.62	15.78	5.97	735.0
		22	1811	7925	36.51	29.91	25.92	7.72	0.12	46.83	3.30	0.61	15.50	5.87	740.2
		23	1843	7962	36.59	29.96	25.67	7.83	0.14	46.92	3.30	0.61	15.53	5.88	738.2
		24	1890	7834	36.13	29.24	25.52	9.17	0.15	46.06	3.26	0.60	15.25	5.78	737.3
		25	1430	8171	37.32	30.77	26.22	5.73	0.11	48.04	3.37	0.62	15.90	6.01	735.9
		26	1837	8171	37.32	30.77	26.22	5.73	0.11	48.04	3.37	0.62	15.90	6.01	735.9
		27	2250	7876	35.98	29.63	25.81	8.64	0.12	46.27	3.25	0.60	15.32	5.79	735.4
		28	1774	8058	36.60	30.67	26.06	6.72	0.11	47.47	3.31	0.61	15.72	5.93	736.3
		29	1623	7901	36.00	30.00	26.06	7.99	0.13	46.55	3.25	0.60	15.41	5.82	736.9
		30	178	7901	36.00	30.00	26.06	7.99	0.13	46.55	3.25	0.60	15.41	5.82	736.9
		1	1022	8271	37.53	31.22	25.34	5.95	0.12	48.51	3.39	0.63	16.06	6.07	733.5
		2	2207	7743	35.33	29.35	26.05	9.35	0.14	45.59	3.19	0.59	15.09	5.70	736.7
		3	2032	7944	35.91	30.31	26.22	7.62	0.14	46.71	3.24	0.60	15.46	5.84	734.5
		4	1851	7957	36.09	30.15	26.46	7.35	0.14	46.72	3.26	0.61	15.47	5.84	734.2
		5	1943	7954	36.43	30.07	26.29	7.25	0.14	46.90	3.29	0.61	15.53	5.87	738.0
		6	1982	7877	36.04	29.60	26.30	8.11	0.14	46.28	3.25	0.60	15.32	5.80	735.8
		7	863	7879	36.12	29.63	26.37	7.94	0.14	46.35	3.26	0.60	15.34	5.81	736.8
	avg			7904	36.23	29.77	26.12	7.97	0.14	46.50	3.27	0.60	15.39	5.82	736.8
	std %			2	2.05	2.98	1.72	20.25	12.91	2.44	2.08	2.44	2.44	2.34	0.3
BLEND-1	9/10/98 to	10	190	7879	36.12	29.63	26.37	7.94	0.14	46.35	3.26	0.60	15.34	5.81	736.8
	9/20/98	11	1514	7720	35.38	28.60	26.15	9.94	0.14	45.07	3.19	0.58	14.92	5.65	732.3
		12	2089	7453	34.30	27.69	25.18	12.93	0.14	43.64	3.10	0.57	14.45	5.48	734.7
		13	1557	7263	33.58	26.96	25.31	14.27	0.16	42.58	3.03	0.55	14.10	5.35	736.1
		14	353	7263	33.58	26.96	25.31	14.27	0.16	42.58	3.03	0.55	14.10	5.35	736.1
		15	915	7363	34.22	27.22	26.83	11.82	0.16	43.23	3.09	0.56	14.31	5.43	737.7
		16	1820	7421	34.32	27.78	26.43	11.56	0.14	43.73	3.10	0.57	14.48	5.48	739.1
		17	2002	7106	33.15	26.29	26.24	14.43	0.14	41.81	2.99	0.54	13.84	5.26	739.5
		18	2006	7368	34.14	27.28	25.80	12.88	0.14	43.23	3.08	0.56	14.31	5.43	736.8
		19	1932	6904	32.12	25.26	25.98	16.78	0.13	40.34	2.90	0.52	13.35	5.07	734.9
		20	1532	6756	31.65	24.47	26.96	17.06	0.14	39.42	2.86	0.51	13.05	4.97	735.2
	avg			7318	33.87	27.10	26.05	13.08	0.14	42.91	3.06	0.56	14.20	5.39	736.3
	std %			4	3.80	5.28	2.32	20.86	7.17	4.55	3.81	4.55	4.55	4.40	0.3
BLEND-2	9/27/98 to	27	170	6756	31.65	24.47	26.96	17.06	0.14	39.42	2.86	0.51	13.05	4.97	735.2
	10/21/98	28	999	6887	32.69	25.95	26.11	15.38	0.14	41.23	2.95	0.53	13.65	5.18	752.5

Designator	Period	Date Loaded	Amount Loaded (M-lbs)	HHV (Btu/lb)	Volatiles (%)	Fixed C (%)	Moisture (%)	Ash (%)	Sulfur (%)	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Oxygen (%)	A/F	A/F (#Air/MMBTU)
		29	1641	7104	32.86	26.51	25.03	15.73	0.15	41.76	2.97	0.54	13.82	5.24	737.7
		30	1035	7735	35.02	28.55	26.19	10.32	0.15	44.78	3.16	0.58	14.82	5.61	725.6
		1	970	7649	34.96	28.94	26.09	10.09	0.15	45.03	3.16	0.58	14.91	5.64	736.8
		2	954	7764	35.24	29.48	26.91	8.43	0.12	45.65	3.18	0.59	15.11	5.71	735.1
		3	904	7796	35.45	29.70	26.09	8.82	0.11	45.97	3.20	0.60	15.22	5.75	736.9
		4	995	7588	34.97	28.57	26.08	10.46	0.14	44.76	3.16	0.58	14.82	5.61	739.3
		5	1036	7582	34.80	28.55	26.90	9.82	0.11	44.66	3.14	0.58	14.79	5.59	737.7
		6	945	7750	35.37	29.14	26.95	8.61	0.12	45.48	3.19	0.59	15.06	5.69	734.7
		7	888	7509	34.47	28.24	26.36	11.01	0.12	44.19	3.11	0.57	14.63	5.54	737.2
		8	1090	7402	34.67	27.61	29.44	8.35	0.12	43.87	3.13	0.57	14.52	5.51	744.3
		9	897	7477	34.70	27.93	25.24	12.22	0.12	44.11	3.13	0.57	14.60	5.53	740.2
		10	1092	7572	34.90	28.36	25.81	11.20	0.13	44.43	3.15	0.58	14.71	5.57	736.0
		11	953	7471	34.19	28.40	26.52	10.97	0.14	44.11	3.09	0.57	14.60	5.52	738.8
		12	953	7705	35.25	29.38	25.61	9.82	0.13	45.58	3.18	0.59	15.09	5.70	739.8
		13	922	7469	34.46	27.93	26.96	10.73	0.12	43.96	3.11	0.57	14.55	5.51	737.9
		14	997	7609	34.73	28.59	25.82	10.95	0.12	44.62	3.14	0.58	14.77	5.59	734.3
		15	964	7507	34.53	28.50	26.10	11.33	0.12	44.15	3.12	0.57	14.61	5.53	737.0
		16	1085	7653	35.14	28.64	25.83	10.47	0.12	44.95	3.17	0.58	14.88	5.63	736.0
		17	955	7528	34.53	27.91	25.95	11.69	0.13	43.98	3.12	0.57	14.56	5.52	732.8
		18	1057	7464	34.42	27.52	26.33	11.82	0.13	43.61	3.11	0.56	14.44	5.48	733.6
		19	1004	7220	33.15	26.86	27.24	12.85	0.13	42.25	2.99	0.55	13.99	5.30	734.0
		20	1011	7345	34.31	27.46	26.49	11.82	0.14	43.49	3.10	0.56	14.40	5.46	743.4
		21	661	7615	34.84	28.33	26.43	10.48	0.13	44.50	3.15	0.58	14.73	5.58	732.6
	avg			7486	34.45	28.06	26.38	11.22	0.13	44.02	3.11	0.57	14.57	5.52	737.2
	std %			3	2.67	4.14	3.19	19.35	9.19	3.37	2.69	3.37	3.37	3.22	0.7
BLEND-3	10/24/98 to 10/25/98			NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BLEND-4	10/29/98 to 11/15/98	29	1201	7462	34.66	27.92	26.18	11.33	0.14	44.06	3.13	0.57	14.59	5.53	741.0
		30	1910	7376	34.70	26.82	25.99	12.59	0.16	43.25	3.13	0.56	14.32	5.45	738.7
		31	2124	7465	34.50	27.79	26.97	10.83	0.13	43.87	3.11	0.57	14.52	5.50	737.3
		1	1792	7567	34.84	28.15	26.71	10.36	0.14	44.38	3.14	0.57	14.69	5.57	735.6
		2	1743	7404	34.68	27.78	26.81	10.81	0.13	43.99	3.13	0.57	14.56	5.52	745.8
		3	2262	7472	34.86	28.12	26.62	10.48	0.12	44.37	3.15	0.57	14.69	5.57	744.9
		4	1757	7616	35.18	28.84	26.02	10.14	0.12	45.05	3.18	0.58	14.91	5.64	741.1
		5	1742	7647	34.98	28.65	26.87	9.59	0.12	44.84	3.16	0.58	14.84	5.62	734.5
		6	1851	7510	34.47	28.39	26.71	10.50	0.13	44.31	3.11	0.57	14.67	5.55	738.7
		7	1771	7310	33.93	27.37	26.24	12.56	0.13	43.16	3.06	0.56	14.29	5.42	740.8
		8	1675	7265	34.99	27.38	26.49	11.22	0.14	43.89	3.16	0.57	14.53	5.52	760.1
		9	1047	7116	35.65	26.65	26.15	11.64	0.16	43.77	3.22	0.57	14.49	5.53	777.3
		10	689	7320	35.55	27.29	26.92	10.33	0.14	44.20	3.21	0.57	14.63	5.57	761.0
		11	1601	7154	35.42	26.98	27.02	10.66	0.15	43.88	3.20	0.57	14.53	5.53	773.6
		12	1162	6887	34.46	25.54	26.91	13.20	0.15	42.14	3.11	0.55	13.95	5.33	773.7
		13	2253	7053	34.73	26.42	27.26	11.68	0.14	42.99	3.13	0.56	14.23	5.42	769.0
		14	2272	6933	34.10	25.68	27.19	13.13	0.14	42.01	3.08	0.54	13.91	5.30	765.1
	avg			7327	34.81	27.40	26.65	11.24	0.14	43.77	3.14	0.57	14.49	5.50	751.7
	std %			3	1.34	3.50	1.52	9.62	9.09	1.91	1.34	1.91	1.91	1.68	2.0
BLEND-5	11/19/98 to 12/3/98	19	2048	7369	35.48	27.51	26.83	10.26	0.14	44.32	3.20	0.57	14.67	5.58	757.3
		20	924	7100	34.59	25.93	26.92	12.68	0.14	42.51	3.12	0.55	14.07	5.37	756.4
		21	2088	7379	35.31	27.97	27.07	9.73	0.13	44.55	3.19	0.58	14.75	5.60	758.7
		22	2256	7267	34.78	27.56	26.97	10.78	0.14	43.88	3.14	0.57	14.53	5.51	758.8
		23	1699	7316	34.98	27.31	27.33	10.45	0.13	43.85	3.16	0.57	14.52	5.52	754.1
		24	2233	7432	35.04	27.68	25.51	11.86	0.14	44.14	3.16	0.57	14.61	5.55	746.6
		25		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
		26	1281	7339	35.14	27.23	26.16	11.56	0.17	43.85	3.17	0.57	14.52	5.52	752.6
		27	1981	7210	35.00	26.60	26.36	12.13	0.16	43.30	3.16	0.56	14.33	5.46	757.7
		28	2068	7252	34.83	26.52	26.41	12.34	0.16	43.12	3.14	0.56	14.27	5.44	750.0
		29	2082	7401	35.15	27.68	26.08	11.18	0.16	44.20	3.17	0.57	14.63	5.56	751.1
		30	1666	7314	34.89	27.20	26.25	11.74	0.15	43.68	3.15	0.57	14.46	5.50	751.7
		1	1978	7516	36.00	28.05	25.23	10.81	0.15	45.06	3.25	0.58	14.92	5.67	754.6
		2	1957	7451	35.69	27.52	25.24	11.65	0.15	44.45	3.22	0.58	14.72	5.60	751.6
		3	1768	7159	34.59	26.36	25.01	14.16	0.16	42.82	3.12	0.55	14.18	5.40	754.6
	avg			7322	35.11	27.22	26.24	11.52	0.15	43.84	3.17	0.57	14.51	5.52	754.0
	std %			2	1.15	2.33	2.87	9.82	8.29	1.61	1.15	1.61	1.61	1.49	0.5
BLEND-6	12/7/98 to 12/21/98	7	596	7250	35.00	26.48	26.44	12.39	0.16	43.04	3.16	0.56	14.25	5.44	750.0
		8	1599	7246	34.49	26.70	25.69	13.23	0.16	43.01	3.11	0.56	14.24	5.42	747.7
		9	2043	7193	34.50	26.56	26.22	12.83	0.15	42.92	3.11	0.56	14.21	5.41	752.0
		10	2079	7323	34.94	26.92	26.30	11.94	0.18	43.47	3.15	0.56	14.39	5.48	748.2
		11	733	7470	35.49	27.78	26.68	10.13	0.17	44.51	3.20	0.58	14.73	5.60	749.7
		12	1340	7455	35.73	27.48	26.23	10.64	0.18	44.44	3.22	0.58	14.71	5.60	751.4
		13	2272	7230	34.94	26.52	26.76	11.87	0.17	43.19	3.15	0.56	14.30	5.45	753.9
		14	2847	7140	34.90	26.71	27.84	10.64	0.18	43.30	3.15	0.56	14.33	5.46	764.7
		15	2208	7125	34.95	26.06	28.07	11.02	0.18	42.84	3.15	0.55	14.18	5.42	760.1
		16	2089	7042	34.58	25.63	27.78	12.11	0.02	42.38	3.13	0.55	14.03	5.35	760.3
		17	2198	7235	35.06	26.85	27.73	10.44	0.18	43.52	3.16	0.56	14.41	5.49	758.5
		18	1915	7295	35.56	26.85	27.26	10.42	0.20	43.83	3.21	0.57	14.51	5.54	758.8
		19	191	7006	34.42	25.66	27.59	12.43	0.20	42.17	3.10	0.55	13.96	5.33	761.1
		20	322	7006	34.42	25.66	27.59	12.43	0.20	42.17	3.10	0.55	13.96	5.33	761.1
		21	246	7006	34.42	25.66	27.59	12.43	0.20	42.17	3.10	0.55	13.96	5.33	761.1
	avg			7232	34.97	26.63	26.97	11.55	0.16	43.13	3.15	0.56	14.28	5.44	755.9
	std %			2	1.20	2.31	2.89	9.01	27.81	1.74	1.24	1.74	1.74	1.63	0.7

1999 Daily Coal Analysis by Usibelli Coal Mine (UCM)
Proximate Coal Analysis - Loader Samples

Ultimate Coal Analysis
Based upon a model which assumes that the hydrogen to volatile matter, oxygen to carbon, nitrogen to carbon ratios are fixed based upon actual data.

Designator	Period	Date Loaded	Amount Loaded (M-lbs)	HHV (Btu/lb)	Volatiles (%)	Fixed C (%)	Moisture (%)	Ash (%)	Sulfur (%)	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Oxygen (%)	A/F	A/F (#Air/MMBTU)
BLEND-7	1/18/99 to	18	98	7567	36.43	27.83	26.71	9.10	0.26	45.12	3.28	0.58	14.94	5.69	752.5
	2/1/1999	19	1926	7131	34.92	26.24	27.72	11.21	0.27	42.90	3.15	0.56	14.20	5.42	760.5
		20	698	7240	34.87	26.84	28.27	10.10	0.26	43.32	3.14	0.56	14.34	5.46	754.7
		21	1365	7761	36.95	28.73	27.39	6.99	0.22	46.18	3.33	0.60	15.29	5.82	749.4
		22	1497	7553	35.79	27.85	27.37	9.06	0.24	44.72	3.23	0.58	14.81	5.63	745.8
		23	1857	7768	36.12	28.95	26.14	8.86	0.20	45.79	3.26	0.59	15.16	5.75	740.3
		24	1873	7786	36.99	28.32	26.79	7.96	0.28	45.86	3.33	0.59	15.18	5.79	743.2
		25	375	7764	36.90	28.44	27.04	7.69	0.26	45.90	3.33	0.59	15.19	5.79	745.3
		30	172	7764	36.90	28.44	27.04	7.69	0.26	45.90	3.33	0.59	15.19	5.79	745.3
		31	1849	8113	37.11	30.35	23.78	8.81	0.16	47.54	3.35	0.62	15.74	5.96	734.3
		1	1277	8319	37.78	31.39	24.99	5.87	0.15	48.79	3.41	0.63	16.15	6.10	733.7
		2	341	7661	36.34	28.46	26.45	8.82	0.26	45.53	3.27	0.59	15.07	5.73	748.3
	avg			7702	36.43	28.49	26.64	8.51	0.24	45.63	3.28	0.59	15.11	5.74	746.1
	std %			4	2.42	4.83	4.59	16.50	18.46	3.50	2.46	3.50	3.50	3.24	1.0
BLEND-8	2/18/99 to	18	737	7247	35.30	26.35	25.88	12.57	0.33	43.19	3.18	0.56	14.30	5.47	754.2
	2/23/99	19	2250	7333	35.16	26.75	27.05	11.13	0.29	43.43	3.17	0.56	14.38	5.48	747.9
		20	2322	7471	35.67	27.15	26.68	10.59	0.27	44.08	3.21	0.57	14.59	5.57	745.0
		21	1673	7260	35.35	26.43	26.15	12.16	0.29	43.32	3.18	0.56	14.34	5.48	754.7
		22	2774	7451	35.53	27.36	25.14	12.07	0.26	44.14	3.20	0.57	14.61	5.57	747.2
		23	865	7136	34.33	25.75	25.74	14.30	0.29	42.10	3.09	0.55	13.94	5.32	746.1
	avg			7316	35.22	26.63	26.11	12.14	0.29	43.38	3.17	0.56	14.36	5.48	749.2
	std %			2	1.34	2.20	2.62	10.60	8.33	1.71	1.36	1.71	1.71	1.62	0.6
BLEND-9	2/25/99 to	25	1064	7145	34.56	26.21	26.40	12.94	0.26	42.62	3.11	0.55	14.11	5.38	753.5
	3/14/99	26	980	7145	34.56	26.21	26.40	12.94	0.26	42.62	3.11	0.55	14.11	5.38	753.5
		27	801	7241	34.87	27.30	26.61	11.30	0.24	43.68	3.14	0.57	14.46	5.50	759.5
		5	717	6887	33.39	25.33	24.99	15.43	0.21	41.93	3.01	0.54	13.88	5.28	766.2
		6	1992	7141	34.28	26.14	26.84	12.84	0.27	42.38	3.09	0.55	14.03	5.35	749.3
		7	1415	7088	34.41	25.97	26.79	12.94	0.28	42.33	3.10	0.55	14.01	5.35	754.8
		8	1878	7179	NA	NA	26.46	12.85	0.28	NA	NA	NA	NA	NA	NA
		9	1260	6914	NA	NA	30.55	10.86	0.23	NA	NA	NA	NA	NA	NA
		11	2876	6981	NA	NA	25.03	14.72	0.28	NA	NA	NA	NA	NA	NA
		12	2387	7407	NA	NA	25.96	10.76	0.24	NA	NA	NA	NA	NA	NA
		13	1764	7576	NA	NA	28.66	8.02	0.19	NA	NA	NA	NA	NA	NA
		14	2208	7698	NA	NA	27.80	8.02	0.23	NA	NA	NA	NA	NA	NA
		15	780	7488	NA	NA	28.70	8.33	0.25	NA	NA	NA	NA	NA	NA
	avg			7222	34.35	26.19	27.01	11.69	0.25	42.60	3.09	0.55	14.10	5.37	756.1
	std %			3	1.48	2.43	5.77	20.73	11.32	1.38	1.46	1.38	1.38	1.36	0.8
BLEND-10	3/18/99 to	19	1470	6986	NA	NA	25.63	13.57	0.29	NA	NA	NA	NA	NA	NA
	3/30/99	20	1806	7322	NA	NA	27.41	10.01	0.24	NA	NA	NA	NA	NA	NA
		21	1730	7057	NA	NA	27.33	12.00	0.27	NA	NA	NA	NA	NA	NA
		22	2794	7244	NA	NA	27.48	10.74	0.23	NA	NA	NA	NA	NA	NA
		23	1041	7342	NA	NA	27.89	10.72	0.29	NA	NA	NA	NA	NA	NA
		24	2494	7247	NA	NA	26.70	11.30	0.26	NA	NA	NA	NA	NA	NA
		25	1630	7513	NA	NA	26.13	10.64	0.23	NA	NA	NA	NA	NA	NA
		26	2464	7555	NA	NA	25.52	10.93	0.28	NA	NA	NA	NA	NA	NA
		27	1421	7511	NA	NA	26.27	10.31	0.26	NA	NA	NA	NA	NA	NA
		28	2136	7488	NA	NA	26.42	10.67	0.26	NA	NA	NA	NA	NA	NA
		29	2258	7228	NA	NA	27.06	11.54	0.24	NA	NA	NA	NA	NA	NA
		30	918	6834	NA	NA	25.31	16.48	0.19	NA	NA	NA	NA	NA	NA
		31	1094	7267	NA	NA	26.04	12.14	0.23	NA	NA	NA	NA	NA	NA
		1	920	7269	NA	NA	26.91	10.95	0.21	NA	NA	NA	NA	NA	NA
	avg			7276	NA	NA	26.58	11.57	0.25	NA	NA	NA	NA	NA	NA
	std %			3	NA	NA	3.02	14.50	11.90	NA	NA	NA	NA	NA	NA
BLEND-11	4/7/99 to	7		7269	NA	NA	26.91	10.95	0.21	NA	NA	NA	NA	NA	NA
	4/27/99	8	1955	7646	NA	NA	25.55	10.85	0.17	NA	NA	NA	NA	NA	NA
		9	1811	7501	NA	NA	26.15	10.76	0.23	NA	NA	NA	NA	NA	NA
		10	1797	7256	NA	NA	26.75	11.88	0.23	NA	NA	NA	NA	NA	NA
		11	2175	7353	NA	NA	25.91	12.35	0.21	NA	NA	NA	NA	NA	NA
		12	1866	7121	NA	NA	25.97	14.54	0.20	NA	NA	NA	NA	NA	NA
		13	1679	7284	NA	NA	26.36	12.11	0.22	NA	NA	NA	NA	NA	NA
		14	2135	7471	NA	NA	24.18	12.52	0.20	NA	NA	NA	NA	NA	NA
		15	2508	7616	NA	NA	25.85	10.51	0.22	NA	NA	NA	NA	NA	NA
		16	1615	7618	NA	NA	25.90	10.02	0.21	NA	NA	NA	NA	NA	NA
		17	1506	7584	NA	NA	25.97	9.81	0.21	NA	NA	NA	NA	NA	NA
		18	1386	7471	NA	NA	26.20	10.28	0.23	NA	NA	NA	NA	NA	NA
		19	1512	7547	NA	NA	26.28	10.18	0.24	NA	NA	NA	NA	NA	NA
		20	1760	7592	NA	NA	26.60	9.03	0.21	NA	NA	NA	NA	NA	NA
		21	1109	7523	37.92	26.29	26.46	9.32	0.21	45.08	3.42	0.58	14.92	5.73	762.3
		22	1149	7436	37.66	25.36	26.25	10.73	0.23	44.19	3.39	0.57	14.63	5.64	758.1
		23	2335	7166	36.21	24.91	25.95	12.93	0.24	42.87	3.26	0.56	14.19	5.46	761.8

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Proximate Coal Analysis - Loader Samples

Ultimate Coal Analysis
Based upon a model which assumes that the hydrogen to volatile matter, oxygen to carbon, nitrogen to carbon ratios are fixed based upon actual data.

Designator	Period	Date Loaded	Amount Loaded (M-lbs)	HHV (Btu/lb)	Volatiles (%)	Fixed C (%)	Moisture (%)	Ash (%)	Sulfur (%)	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Oxygen (%)	A/F	A/F (#Air/MMBTU)
		24	1822	7041	35.97	24.36	25.42	14.25	0.25	42.29	3.24	0.55	14.00	5.39	766.0
		25	1736	7126	NA	NA	26.37	13.40	0.21	NA	NA	NA	NA	NA	NA
		26	1965	7118	35.37	24.42	25.82	14.39	0.21	41.96	3.19	0.54	13.89	5.34	750.2
		27	1601	7150	34.58	25.00	25.04	15.38	0.19	41.87	3.12	0.54	13.86	5.31	742.1
	avg			7376	36.29	25.06	25.99	11.72	0.22	43.04	3.27	0.56	14.25	5.48	756.8
	std %			3	3.57	2.84	2.32	15.85	8.49	3.05	3.57	3.05	3.05	3.13	1.2
BLEND-12	5/6/99 to	7	1084	7321	35.02	26.18	26.48	12.33	0.12	43.09	3.16	0.56	14.26	5.44	743.2
	6/2/99	8	2218	7435	35.79	26.52	27.41	10.28	0.14	43.85	3.23	0.57	14.52	5.54	745.5
		9	2157	7277	35.78	25.85	27.58	10.80	0.14	43.34	3.23	0.56	14.35	5.49	754.6
		10	2178	7317	35.98	25.97	25.92	12.13	0.17	43.55	3.25	0.56	14.42	5.52	754.3
		11	2071	7355	36.16	26.09	26.79	10.96	0.17	43.76	3.26	0.57	14.49	5.55	754.1
		12	1861	7401	37.08	25.95	26.28	10.69	0.19	44.27	3.34	0.57	14.66	5.63	760.2
		13	2113	7022	35.84	24.39	26.68	13.09	0.18	42.27	3.23	0.55	14.00	5.39	767.0
		14	905	6959	35.23	24.21	26.30	14.26	0.18	41.73	3.18	0.54	13.81	5.31	763.3
		17	906	6766	34.44	23.28	23.21	19.08	0.21	40.47	3.10	0.52	13.40	5.16	762.8
		18	1820	7065	35.42	24.47	24.82	15.29	0.20	42.04	3.19	0.54	13.92	5.35	757.2
		19	1807	7555	36.66	26.50	25.43	11.41	0.16	44.41	3.31	0.58	14.70	5.63	744.8
		20	2475	6798	34.62	23.34	24.88	17.17	0.22	40.63	3.12	0.53	13.45	5.18	762.5
		21	1057	6978	35.30	23.73	24.87	16.10	0.19	41.41	3.18	0.54	13.71	5.28	757.0
		22	2530	7235	36.30	24.79	25.26	13.65	0.17	42.89	3.27	0.56	14.20	5.46	755.0
		23	1929	7433	37.12	25.45	25.68	11.75	0.17	43.94	3.35	0.57	14.55	5.59	752.5
		24	2124	7433	36.54	26.19	25.36	11.92	0.16	44.09	3.30	0.57	14.60	5.59	752.2
		25	2156	7194	35.93	25.05	26.70	12.31	0.16	42.85	3.24	0.55	14.19	5.45	757.1
		26	1851	7053	35.66	24.63	27.27	12.45	0.15	42.34	3.22	0.55	14.02	5.39	763.8
		27	2061	7141	35.84	24.96	27.45	11.75	0.15	42.72	3.23	0.55	14.14	5.43	760.4
		28	2601	7333	36.91	25.23	27.20	10.67	0.15	43.64	3.33	0.57	14.45	5.56	757.7
		29	1516	7588	37.66	26.26	27.07	9.01	0.15	44.92	3.40	0.58	14.87	5.71	752.4
		30	1551	7697	36.93	27.40	26.03	9.64	0.15	45.27	3.33	0.59	14.99	5.72	743.4
		31	2662	7591	36.64	26.66	25.46	11.24	0.15	44.53	3.31	0.58	14.74	5.64	742.7
		1	1955	7575	36.65	27.02	25.29	11.03	0.16	44.80	3.31	0.58	14.83	5.67	748.0
		2	1158	7583	37.10	26.69	25.56	10.64	0.15	44.87	3.35	0.58	14.85	5.69	749.9
	avg			7284	36.10	25.47	26.04	12.39	0.17	43.27	3.26	0.56	14.32	5.49	754.5
	std %			4	2.29	4.51	4.06	19.33	14.06	3.06	2.32	3.06	3.06	2.85	0.9
BLEND-13	6/5/99 to	5	1352	7215	36.34	25.22	27.35	11.09	0.14	43.26	3.28	0.56	14.32	5.50	762.3
	6/12/99	6	1985	7377	36.40	26.23	26.34	11.22	0.15	43.90	3.29	0.57	14.53	5.57	754.7
		7	2083	7508	36.77	26.51	25.25	11.47	0.15	44.50	3.32	0.58	14.73	5.64	751.1
		8	1933	7671	37.53	27.09	25.80	9.58	0.18	45.43	3.39	0.59	15.04	5.76	750.5
		9	2256	7557	37.46	25.90	25.55	11.09	0.17	44.50	3.38	0.58	14.73	5.66	749.1
		10	1829	7623	37.26	26.75	25.63	10.36	0.16	45.01	3.36	0.58	14.90	5.71	748.5
		11	2123	7623	37.16	26.71	25.27	10.86	0.16	44.91	3.35	0.58	14.87	5.69	746.8
		12	607	7826	37.49	28.00	25.38	9.13	0.14	46.10	3.38	0.60	15.26	5.82	744.1
	avg			7550	37.05	26.55	25.82	10.60	0.16	44.70	3.34	0.58	14.80	5.67	750.9
	std %			2	1.31	3.10	2.75	7.93	9.01	1.97	1.30	1.97	1.97	1.81	0.7

Coal Analysis by Usibelli Coal Mine (UCM)
Proximate Coal Analysis - As Fed to Combustor (Isokinetic)

Ultimate Coal Analysis
Based upon a model which assumes that the hydrogen to volatile matter, oxygen to carbon, nitrogen to carbon ratios are fixed based upon actual data.

Period	Time	Pulverizer	HHV	Volatiles	Fixed C	Moisture	Ash	Sulfur	Carbon	Hydrogen	Nitrogen	Oxygen	A/F	A/F
			(Btu/lb)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(#Air/MMBTU)
5/1/98	9:55	A	7331	39.02	29.78	10.03	21.34	0.26	48.25	3.52	0.62	15.97	6.09	830.8
	9:45	B	8458	41.97	32.30	4.72	21.29	0.31	52.01	3.78	0.67	17.22	6.56	775.9
5/4/98		A	8419	39.75	30.80	13.23	16.34	0.32	49.50	3.58	0.64	16.39	6.24	741.3
		B	8389	39.92	30.71	14.39	15.10	0.25	49.60	3.60	0.64	16.42	6.25	745.5
5/30/98		A	9267	42.51	32.27	4.80	20.58	0.47	52.33	3.82	0.68	17.32	6.62	713.9
		B	9120	41.38	31.68	7.93	19.16	0.42	51.17	3.72	0.66	16.94	6.46	708.6
9/18/98	2:55	A	8978	44.36	35.63	6.54	13.57	0.19	56.32	4.00	0.73	18.65	7.07	787.4
	2:50	B	8644	44.03	35.00	7.19	13.88	0.19	55.63	3.97	0.72	18.42	6.99	808.6
12/11/98	8:35	A	8406	41.03	30.72	14.68	13.69	0.20	50.39	3.70	0.65	16.68	6.37	757.5
	8:40	A	8426	41.15	30.69	13.71	14.54	0.20	50.47	3.71	0.65	16.71	6.38	757.1
	8:50	B	8453	41.13	31.29	13.98	13.71	0.20	50.89	3.71	0.66	16.85	6.42	759.6
	8:56	B	8535	41.40	31.55	13.82	13.34	0.22	51.25	3.73	0.66	16.97	6.47	757.7
12/19/98	17:05	A	8311	41.37	30.48	16.15	12.10	0.24	50.43	3.73	0.65	16.70	6.38	768.0
	17:05	B	8417	41.96	30.53	15.85	11.76	0.23	50.87	3.78	0.66	16.84	6.45	765.8
3/11/99	16:55	A	7111	38.87	22.64	8.26	27.45	0.42	44.92	3.49	0.58	14.87	5.75	809.1
	17:00	B	7418	40.97	25.77	6.83	23.71	0.41	48.63	3.68	0.63	16.10	6.19	834.9
3/12/99	13:15	A	7910	41.30	25.36	9.38	21.25	0.42	48.54	3.71	0.63	16.07	6.19	783.1
	13:05	B	8374	41.15	26.81	9.50	19.86	0.30	49.58	3.71	0.64	16.41	6.29	751.3
4/14/99	13:45	A	8150	41.04	26.21	15.16	14.90	0.23	49.11	3.70	0.64	16.26	6.24	765.6
	13:30	B	8205	40.19	25.89	18.23	12.99	0.24	48.30	3.62	0.63	15.99	6.13	747.3
4/23/99	17:00	A	8537	43.98	29.10	9.85	17.07	0.29	51.21	3.96	0.66	16.95	6.54	766.5
	17:00	B	8351	43.15	28.57	12.10	16.18	0.30	50.25	3.89	0.65	16.63	6.42	768.9
avg			8328	41.44	29.72	11.20	16.99	0.29	50.44	3.73	0.65	16.70	6.39	768
std %			6	3.58	10.71	35.29	24.86	30.69	4.75	3.63	4.75	4.75	4.39	4

Coal Analysis by Usibelli Coal Mine (UCM)
Proximate Coal Analysis - As Fed to Combustor (Coal Feeder)

Ultimate Coal Analysis
Based upon a model which assumes that the hydrogen to volatile matter, oxygen to carbon, nitrogen to carbon ratios are fixed based upon actual data.

Period	Time	Pulverizer	HHV	Volatiles	Fixed C	Moisture	Ash	Sulfur	Carbon	Hydrogen	Nitrogen	Oxygen	A/F	A/F
			(Btu/lb)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)		(#Air/MMBTU)
6/9/98	22:44	A	7936	36.93	29.66	25.81	7.66	0.23	46.85	3.33	0.61	15.51	5.88	741.4
	22:49	B	8103	37.78	30.19	24.91	7.18	0.21	47.84	3.41	0.62	15.84	6.01	741.6
7/23/98	7:30	A	7986	37.06	29.45	24.66	8.90	0.17	46.82	3.34	0.61	15.50	5.88	736.6
	17:00	A	7671	36.30	28.06	23.93	11.81	0.21	45.22	3.27	0.59	14.97	5.70	742.9
9/5/98	1:45	B	8014	35.98	30.79	27.06	6.21	0.14	47.13	3.25	0.61	15.60	5.88	733.7
	1:50	A	8087	36.75	30.66	25.24	7.40	0.14	47.55	3.32	0.62	15.74	5.95	735.2
	3:45	A	7854	35.76	29.53	26.48	8.29	0.14	46.03	3.23	0.60	15.24	5.76	733.6
	3:50	B	7844	35.62	29.42	26.55	8.47	0.14	45.85	3.22	0.59	15.18	5.74	731.7
	5:45	B	7968	36.19	30.34	26.47	7.05	0.15	46.92	3.27	0.61	15.53	5.87	736.1
	5:50	A	7965	36.41	29.89	25.85	7.90	0.14	46.74	3.29	0.61	15.47	5.85	735.0
9/18/98	3:30	A	7295	33.97	26.96	23.66	15.54	0.16	42.84	3.07	0.55	14.18	5.38	738.1
	3:25	B	7141	33.25	26.01	25.62	15.24	0.16	41.65	3.00	0.54	13.79	5.24	734.1
9/30/98	4:50	B	7265	33.66	27.17	26.36	12.90	0.16	42.81	3.04	0.55	14.17	5.37	739.5
11/1/98	13:13	B	7339	34.17	27.67	27.04	11.22	0.14	43.54	3.08	0.56	14.41	5.46	744.1
	13:17	A	7420	34.22	27.96	26.86	11.04	0.14	43.80	3.09	0.57	14.50	5.49	739.8
	15:15	A	7442	34.48	28.05	27.07	10.48	0.13	44.05	3.11	0.57	14.58	5.52	742.0
	15:17	B	7398	34.25	27.50	27.35	11.00	0.14	43.47	3.09	0.56	14.39	5.46	737.5
	16:20	B	7336	34.21	27.53	27.19	11.15	0.14	43.48	3.09	0.56	14.39	5.46	743.7
	16:25	A	7251	34.17	27.17	26.79	11.98	0.14	43.16	3.08	0.56	14.29	5.42	747.8
	17:26	A	7477	34.43	28.14	26.96	10.55	0.14	44.08	3.11	0.57	14.59	5.52	738.7
	17:28	B	7475	34.82	28.48	27.00	9.78	0.15	44.59	3.14	0.58	14.76	5.59	747.5
	18:30	B	7475	34.76	28.01	26.85	10.39	0.14	44.26	3.14	0.57	14.65	5.55	742.7
	18:33	A	7425	34.68	27.87	27.22	10.28	0.15	44.06	3.13	0.57	14.59	5.53	744.8
	21:40	A	7418	34.21	27.94	27.05	10.89	0.15	43.77	3.09	0.57	14.49	5.49	739.5
	21:45	B	7343	34.11	27.62	26.56	11.81	0.14	43.46	3.08	0.56	14.39	5.45	742.4
	0:06	B	7496	34.81	28.25	26.86	10.17	0.13	44.42	3.14	0.58	14.70	5.57	743.0
	0:09	A	7251	34.02	27.17	26.92	11.99	0.13	43.07	3.07	0.56	14.26	5.41	746.0
	1:26	A	7355	34.18	27.60	26.98	11.33	0.14	43.50	3.09	0.56	14.40	5.46	742.0
	2:16	B	7322	34.34	27.36	27.20	11.18	0.13	43.44	3.10	0.56	14.38	5.46	745.2
11/3/98	8:34	B	7388	34.42	27.18	26.57	11.93	0.13	43.35	3.11	0.56	14.35	5.45	737.6
	8:40	A	7202	33.44	26.79	26.93	12.94	0.13	42.40	3.02	0.55	14.04	5.32	739.1
11/6/98	7:34	A	7326	34.44	27.73	28.69	9.21	0.12	43.80	3.11	0.57	14.50	5.50	750.1
	7:38	B	7480	34.35	28.22	28.03	9.48	0.13	44.09	3.10	0.57	14.60	5.52	738.3
11/8/98	16:12	B	7141	35.38	26.70	27.85	10.14	0.15	43.65	3.19	0.57	14.45	5.51	771.6
	16:12	B	7136	35.59	26.65	26.94	10.92	0.15	43.73	3.21	0.57	14.48	5.52	774.2
	16:12	B	7094	35.40	26.38	28.04	10.32	0.15	43.37	3.19	0.56	14.36	5.48	772.9
11/10/98	13:55	B	6912	34.27	25.77	28.23	11.85	0.15	42.17	3.09	0.55	13.96	5.33	770.6
11/11/98	15:30	B	6821	34.52	25.46	28.73	11.39	0.15	42.12	3.12	0.55	13.95	5.33	781.3
11/13/99	11:48	A	6575	33.16	24.24	28.38	14.33	0.14	40.30	2.99	0.52	13.34	5.10	776.0
	11:46	B	7037	34.07	25.87	27.90	12.26	0.13	42.14	3.08	0.55	13.95	5.32	755.5
11/20/98	18:43	A	7026	34.63	26.17	28.23	11.07	0.14	42.73	3.13	0.55	14.15	5.39	767.7
	18:40	B	6871	33.96	25.14	28.22	12.79	0.14	41.51	3.07	0.54	13.74	5.25	764.0
12/11/98	?	A	7205	34.46	26.71	26.97	11.96	0.18	42.99	3.11	0.56	14.23	5.42	751.7
	?	B	7275	34.65	32.50	27.14	11.42	0.19	43.25	3.13	0.56	14.32	5.45	748.8
12/19/98	16:30	A	7136	34.94	26.18	28.87	10.10	0.20	42.92	3.15	0.56	14.21	5.42	760.0
	16:30	B	7589	36.79	27.96	25.70	9.63	0.21	45.49	3.32	0.59	15.06	5.74	756.5
1/31/99	1:35	A	7439	35.64	27.09	27.67	9.67	0.28	44.03	3.21	0.57	14.57	5.56	747.3
	1:35	B	7611	36.28	27.96	27.49	8.34	0.27	45.11	3.27	0.58	14.93	5.69	747.4
3/11/99	10:55	A	7433	36.11	24.70	22.56	14.16	0.26	44.47	3.25	0.58	14.72	5.62	755.8
	10:50	B	7110	34.00	23.90	28.00	11.81	0.27	42.30	3.06	0.55	14.01	5.33	750.3
	14:55	A	6088	33.49	20.37	22.33	21.30	0.36	39.43	3.01	0.51	13.05	5.03	826.3
	14:50	B	5546	31.68	17.85	22.18	25.69	0.37	36.39	2.85	0.47	12.05	4.67	841.6
3/13/99	12:20	A	7284	34.90	24.97	26.88	10.96	0.17	43.78	3.15	0.57	14.49	5.51	756.3
	12:30	B	7232	35.27	24.69	28.15	9.45	0.15	43.95	3.18	0.57	14.55	5.54	765.6
4/14/99	13:55	A	7559	36.81	23.91	26.02	10.85	0.20	44.35	3.32	0.57	14.68	5.63	744.4
	13:50	B	7261	35.46	22.88	26.51	12.76	0.22	42.64	3.20	0.55	14.12	5.41	745.4
4/23/99	3:50	A	7532	37.98	26.00	24.74	11.29	0.26	44.86	3.42	0.58	14.85	5.72	758.8
	3:44	B	7297	37.01	25.48	26.57	10.94	0.26	43.82	3.33	0.57	14.51	5.58	764.8
6/6/99	12:00	A	7003	35.67	24.16	25.82	14.25	0.18	42.06	3.22	0.54	13.93	5.36	765.3
	12:00	B	7226	36.39	24.86	26.00	12.74	0.18	43.00	3.28	0.56	14.24	5.48	757.9
	16:00	A	7637	37.54	26.68	25.68	10.11	0.15	45.14	3.39	0.58	14.94	5.73	750.0
	16:00	B	7581	37.54	26.56	26.16	9.73	0.21	45.03	3.39	0.58	14.91	5.72	754.2
6/9/99	8:00	A	7271	36.36	24.92	25.66	13.06	0.18	43.02	3.28	0.56	14.24	5.48	753.3
	8:00	B	7196	36.16	24.52	25.14	14.23	0.17	42.56	3.26	0.55	14.09	5.42	753.8
	13:00	A	7859	38.29	27.67	25.32	8.72	0.15	46.39	3.46	0.60	15.36	5.88	747.9
	13:00	B	7513	36.56	26.57	25.44	11.43	0.17	44.39	3.30	0.57	14.70	5.62	748.3
	18:00	A	7397	36.46	25.91	25.70	11.93	0.21	43.80	3.29	0.57	14.50	5.56	751.7
	18:00	B	7478	36.50	25.82	26.25	11.43	0.19	43.78	3.29	0.57	14.49	5.56	743.3
	21:30	A	7204	35.79	25.20	25.97	13.04	0.19	42.84	3.23	0.55	14.18	5.44	755.3
	21:30	B	7249	37.48	26.95	26.29	9.28	0.16	45.30	3.38	0.59	15.00	5.74	792.2
6/10/99	8:00	A	7513	37.13	26.27	26.86	9.74	0.15	44.57	3.35	0.58	14.75	5.66	753.0
	8:00	B	7565	37.21	26.59	26.66	9.54	0.15	44.86	3.36	0.58	14.85	5.69	752.0
	13:00	A	7443	36.90	26.05	26.88	10.17	0.15	44.25	3.33	0.57	14.65	5.62	754.7
	13:00	B	7401	36.75	25.68	26.67	10.91	0.16	43.86	3.32	0.57	14.52	5.57	753.1
	18:00	A	7602	37.05	26.55	26.52	9.89	0.13	44.73	3.35	0.58	14.81	5.67	745.9
	18:00	B	7660	37.34	26.66	25.95	10.05	0.16	44.99	3.37	0.58	14.90	5.71	745.0
6/11/99	8:00	A	7344	36.19	25.55	25.96	12.29	0.16	43.40	3.27	0.56	14.37	5.51	750.2
	8:00	B	7273	35.66	25.61	26.24	12.49	0.17	43.07	3.22	0.56	14.26	5.46	750.8
	13:00	A	7620	37.09	26.68	26.22	10.02	0.15	44.84	3.35	0.58	14.84	5.68	745.8
	13:00	B	7365	36.44	25.88	26.33	11.35	0.17	43.80	3.29	0.57	14.50	5.56	754.7
	18:00	A	7485	36.48	26.24	26.58	10.70	0.17	44.09	3.29	0.57	14.60	5.59	746.7
	18:00	B	7389	36.38	25.76	26.41	11.46	0.15	43.67	3.28	0.57	14.46	5.54	750.2
avg			7369	35.49	26.72	26.48	11.19	0.17	43.87	3.20	0.57	14.52	5.54	752
std %			5	3.82	7.95	4.92	24.05	28.23	3.92	3.83	3.92	3.92	3.71	2

HCCP Slag and Flyash Properties - Analysis Performed by Commercial Testing and Engineering

Ultimate Analysis

Date	Time	Sample	HHV (Btu/Lb)	Moisture (%)	Carbon (%)	Nitrogen (%)	Sulfur (%)	Ash (%)	Oxygen (%)
11/08/98	1350	Slag Ash/Pyrites	3347	14.99	23.25	0.31	0.31	52.75	6.84
12/19/98	1845	Slag Ash	168	6.07	1.14	0.5	0.01	92.26	0.01
5/26/99	16:15	Molten Slag Ash	89	3.8	0.25	0.01	0.01	95.88	0
4/13/99		Slope Ash	NA	NA	0.026	NA	NA	NA	NA
11/08/98	1345	FCM Flyash	253	0.88	0.27	0.08	2.65	96.09	0.01
3/13/99	10:40	FCM Flyash	<100	2.08	0.76	0.07	2.56	92.41	1.98
4/14/99		FCM Flyash	60	1.09	0.26	0.03	2.53	95.85	0.01
6/9/99	15:00	Flyash	NA	NA	NA	NA	NA	NA	NA
6/10/99	13:00	Flyash	NA	NA	NA	NA	NA	NA	NA
3/13/99	1050	Boiler Ash	<100	0.01	0.23	0.02	0.88	98.77	0.04
4/14/99	900	Boiler Ash	NA	NA	NA	NA	NA	NA	NA
12/18/98	1200	Pyrites B	4921	7.96	29.8	0.38	0.16	47.48	12.19

Mineral Ash Analysis

Date	Time	Sample	SiO2 (%)	AlO (%)	TiO2 (%)	FeO (%)	CaO (%)	MgO (%)	K2O (%)	NaO (%)	SO3 (%)	PO5 (%)	StO (%)	BaO (%)	MnO (%)	Undertermined (%)	T250 (F)
11/08/98	1350	Slag Ash/Pyrites	74.40	9.42	0.40	4.46	6.49	1.30	1.09	0.90	0.50	0.11	0.02	0.23	0.07	0.61	2900
12/19/98	1845	Slag Ash	52.40	14.04	0.73	7.56	18.95	2.44	1.31	0.36	0.32	0.20	0.21	0.45	0.18	0.85	2350
5/26/99	16:15	Molten Slag Ash	56.2	17.06	0.74	5.26	15.47	2.22	1.38	0.83	0.03	0.22	0.14	0.42	0.03	0	2493
4/13/99		Slope Ash	31.44	10.45	0.59	4.99	45.85	2.31	0.53	0.1	0.21	0.08	0.2	0.25	0.08	2.92	24.98
11/08/98	1345	FCM Flyash	44.70	16.51	0.62	5.34	18.61	3.52	1.67	1.29	6.80	0.20	0.17	0.48	0.09	0.00	2317
3/13/99	10:40	FCM Flyash	32.64	13.27	0.60	5.28	35.06	3.90	1.20	0.47	6.66	0.32	0.15	0.41	0.04	0.00	2343
4/14/99		FCM Flyash	40.34	18.22	0.67	5.69	24.4	2.69	1.26	0.28	5.55	0.32	0.12	0.39	0.4	0	2257
6/9/99	15:00	Flyash	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6/10/99	13:00	Flyash	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3/13/99	1050	Boiler Ash	38.26	14.59	0.68	5.85	31.62	4.38	1.20	0.39	1.53	0.30	0.14	0.38	0.09	0.59	2237
4/14/99	900	Boiler Ash	35.40	10.61	0.49	4.58	43.39	2.84	0.68	0.38	0.14	0.33	0.13	0.29	0.03	0.71	2447
12/18/98	1200	Pyrites B	87.88	3.64	0.21	2.53	2.75	0.49	1.03	0.39	0.72	0.07	0.00	0.16	0.13	0.00	2900

Calcium Analysis

Date	Time	Sample	CaCO3 (%)	CaSO4 (%)	CaO (%)	MgCO3 (%)	MgSO4 (%)	MgO (%)	Calcination Eff (%)
11/08/98	1350	Slag Ash/Pyrites	NA	NA	NA	NA	NA	NA	NA
12/19/98	1845	Slag Ash	NA	NA	NA	NA	NA	NA	NA
5/26/99	16:15	Molten Slag Ash	NA	NA	NA	NA	NA	NA	NA
4/13/99		Slope Ash	NA	NA	NA	NA	NA	NA	NA
11/08/98	1345	FCM Flyash	2.25	11.56	12.61	0.5	0.5	3.52	93.2
3/13/99	10:40	FCM Flyash	6.50	10.26	24.79	NA	NA	NA	88.9
4/14/99		FCM Flyash	2.17	9.44	18.77	NA	NA	NA	94.9
6/9/99	15:00	Flyash	4.22	12.06	26.21	NA	NA	NA	93.0
6/10/99	13:00	Flyash	4.15	11.29	26.49	NA	NA	NA	93.1
3/13/99	1050	Boiler Ash	2.32	2.30	28.93	NA	NA	NA	95.8
4/14/99	900	Boiler Ash	NA	NA	NA	NA	NA	NA	NA
12/18/98	1200	Pyrites B	NA	NA	NA	NA	NA	NA	NA

1998		
Percent Carbon Loss to Slag	0.27	%
Percent Carbon Loss to Flyash	0.02	%
Total Carbon Loss	0.28	%
Carbon Burnout	99.7	%
Assumes Slag Recovery of ….	80	%

1999		
Percent Carbon Loss to Slag	0.06	%
Percent Carbon Loss to Flyash	0.03	%
Total Carbon Loss	0.09	%
Carbon Burnout	99.9	%
Assumes Slag Recovery of ….	80	%

APPENDIX D – PRELIMINARY PLANT AVAILABILITY DATA

1998 Summary

Description	Test Period	Coal Burn-A (Hrs)	Coal Burn-B (Hrs)	Coal Burn (A or B) (Hrs)	Resulting Down Time in Hours (Power Island)	Planned Shutdown Time	Balance of Plant Not Available	Boiler Island Not Available (excludes comb)	Precombustor A Inspection and Work Time	Precombustor B Inspection and Repair Time	Misc. Combustor Inspection and Repairs
Hours	4/23/98 12:00	1009	1009	1009	1018	273	514	20	516	557	184
Total Elapsed Time	through	2027	2027	2027	2027	2027	2027	2027	2027	2027	2027
Availability, %	7/16/98 22:30	49.8	49.8	49.8	49.8	86.6	74.7	99.0	74.5	72.5	90.9
Hours	7/16/98 22:30	1002	1438	1551	846	356	165	191	544	657	72
Total Elapsed Time	through	2397	2397	2397	2397	2397	2397	2397	2397	2397	2397
Availability, %	10/24/98 19:00	41.8	60.0	64.7	64.7	85.2	93.1	92.1	77.3	72.6	97.0
Hours	10/24/98 19:00	885	983	1031	605	256	182	65	332	332	102
Total Elapsed Time	through	1637	1637	1637	1637	1637	1637	1637	1637	1637	1637
Availability, %	12/31/98 23:59	54.1	60.0	63.0	63.0	84.4	88.9	96.0	79.7	79.7	93.8
Hours	4/23/98 12:00	2896	3430	3590	2469	884	860	276	1392	1546	358
Total Elapsed Time	through	6060	6060	6060	6060	6060	6060	6060	6060	6060	6060
Availability, %	12/31/98 23:59	47.8	56.6	59.2	59.3	85.4	85.8	95.4	77.0	74.5	94.1

1999 Summary

Description	Test Period	Coal Burn-A (Hrs)	Coal Burn-B (Hrs)	Coal Burn (A or B) (Hrs)	Resulting Down Time in Hours (Power Island)	Planned Shutdown Time	Balance of Plant Not Available	Boiler Island Not Available (excludes comb)	Precombustor A Inspection and Work Time	Precombustor B Inspection and Repair Time	Misc. Combustor Inspection and Repairs
Hours	1/18/99 23:15	1967	2004	2008	2335	1244	529	602	116	112	353
Total Elapsed Time	through	4344	4344	4344	4344	4344	4344	4344	4344	4344	4344
Availability, %	6/12/99 21:48	45.3	46.1	46.2	46.3	71.4	87.8	86.1	97.3	97.4	91.9

Healy Test Summary and Reasons for Test Termination - Baseline Precombustor Configuration

Test Matrix Designation	Start Date	End Date	Coal Burn-A (Hrs)	Coal Burn-B (Hrs)	Coal Burn (A or B) (Hrs)	Operating Conditions and Configuration	Reason for Test Termination	Resulting Down Time in Hours (Power Island)	Planned Shutdown Time	Balance of Plant Not Available	Boiler Island Not Available (excludes comb)	Precombustor A Inspection and Work Time	Precombustor B Inspection and Repair Time	Misc. Combustor Inspection and Repairs	Combustor Work Performed
ROM-S4-Trial	4/23/98 12:00	4/27/98 3:30	87.5	87.5	87.5	A PC, B PC Baseline Mix Annulus PC Phi 0.65-0.76, Coal split 38-40% Last 45 Hours on ROM/Waste Blend	Trip due to River Inlet Blockage Resulting in Loss of Pump Suction	95.5		95.5		48	48	12	Combustor Inspection Precombustor clean-out Six way splitter inspection
PERF-S4-2	5/1/98 3:00	5/1/98 21:00	18	18	18	A PC, B PC Baseline Mix Annulus PC Phi 0.75-0.77, Coal split 38-43% ROM/Waste Blend Seam 4	Trip due to Turbine/Boiler Control Problems	14			14	0	0	0	No combustor work
PERF-S4-2 PERF-S4-3	5/2/98 11:00	5/5/98 8:30	69.5	69.5	69.5	A PC, B PC Baseline Mix Annulus PC Phi 0.75-0.77, Coal split 38-43% ROM/Waste Blend Seam 4	Trip During Attempt to Implement Turbine Follow Logic (Drum Level Trip)	211.5		211.5		48	48	12	Combustor inspection Precombustor clean-out Cleaned B- six way splitter elbow
PERF-S4-4-1 PERF-S4-7 PERF-S4-3	5/14/98 4:00	5/18/98 4:30	96.5	96.5	96.5	A PC, B PC Baseline Mix Annulus PC Phi 0.95-1.0, Coal split 38-43% ROM/Waste Blend Seam 4	High Furnace Pressure Trip	86.5		86.5		48	48	24	Combustor inspection Precombustor clean-out Repaired limestone injector
PERF-S4-1	5/21/98 19:00	5/22/98 11:19	16.3	16.3	16.3	A PC, B PC Baseline Mix Annulus PC Phi 0.7, Coal split 32% ROM/Waste Blend Seam 4	High Furnace Pressure Trip	6.45			6.45	0	0	0	No combustor work
PERF-S4-3	5/22/98 17:45	5/24/98 0:00	30.25	30.25	30.25	A PC, B PC Baseline Mix Annulus PC Phi 0.7, Coal split 32% ROM/Waste Blend Seam 4	Planned Shut Down	64.5	64.5			64	64	64	Combustor inspection (only B-side) Inspected and patched dipper skirt crack Repaired PC mill air ports Cleaned out Precombustor
PERF-S4-9	5/26/98 16:30	5/28/98 11:45	43.25	43.25	43.25	A PC, B PC Baseline Mix Annulus PC Phi 0.6, Coal split 32% PC Vel 250 Ft/s, Dampers in 8" on E,W ROM/Waste Blend Seam 4	Accidental Trip of feedwater pump	3.75		3.75		0	0	0	No combustor work
PERF-S4-9	5/28/98 15:30	5/31/98 2:00	58.5	58.5	58.5	A PC, B PC Baseline Mix Annulus PC Phi 0.6, Coal split 32% PC Vel 250 Ft/s, Dampers in 8" on E,W ROM/Waste Blend Seam 4	Planned Shut Down	208	208			48	48	0	Combustor inspection Precombustor clean-out ?? (Nabil present)
ROM-S4-1	6/8/98 18:00	6/26/98 17:17	431.25	431.25	431.25	A PC, B PC Baseline Mix Annulus PC Phi 0.6, Coal split 32% 48 Hrs ROM/Waste Blend Seam 4	High Furnace Pressure Trip	116.3		116.3		48	48	72	Combustor Inspection Dipper skirt coupon;mitre joint repair;rewelded clamps Installed refractory on dipper skirt shield Cleaned-out PC's; plugged B-SC 1:00 injector
PERF-S4-1A	7/1/98 13:40	7/6/98 10:00	116.3	116.3	116.3	A PC, B PC Baseline Mix Annulus PC Phi 0.59, Coal split 32% 48 Hrs ROM/Waste Blend Seam 4	TRW decision to install mix annulus blank off plates	101.6				102	102	0	Combustor Inspection (PC-B windbox damage) Installed blank-off plates in A Cleaned-out PC's
PERF-S3-1-7000	7/10/98 15:40	7/12/98 9:00	41.3	41.3	41.3	A PC - 45 deg. Openings on each side of mix annulus B Combustor Offline PC Phi 0.58, Coal split 32% ROM/Waste Blend Seam 3	TRW decision to install mix elbows	109.5				110	110 41	0	Combustor inspection (A only) Installed PC-A mix elbows
SUBTOTAL			1009	1009	1009		SUBTOTAL	1018	273	514	20	516	557	184	
TOTAL ELAPSED TIME			2027	2027	2027		TOTAL ELAPSED TIME	2027	2027	2027	2027	2027	2027	2027	
AVAILABILITY, %			49.8	49.8	49.8		AVAILABILITY, %	49.8	86.6	74.7	99.0	74.5	72.5	90.9	

Healy Test Summary and Reasons for Test Termination - Precombustor Mixing Tests

Test	Start Date	End Date	Coal Burn-A (Hrs)	Coal Burn-B (Hrs)		Operating Conditions and Configuration	Reason for Test Termination	Resulting Down Time in Hours	Planned Shutdown Time	Balance of Plant Not Available	Boiler Island Not Available (excludes comb)	Precombustor A Inspection and Work Time	Precombustor B Inspection and Repair Time	Misc. Combustor Inspection and Repairs	Combustor Work Performed
PERF-S3-1-7000	7/16/98 22:30	7/18/98 1:00	26.5	0	26.5	A PC - 14 ports B Combustor Offline PC Phi 0.58-0.85, Coal split 32-41% ROM/Waste Blend Seam 3	TRW decision to reconfigure mix elbows	39.2				39	39 27	0	Combustor Inspection Clean-out precombustor:blocked off top two elbows
PERF-S3-2-7000	7/19/98 16:10	7/23/98 6:00	85.8	0	85.8	A PC - 12-13 ports B Combustor Offline PC Phi 0.85-1.0, Coal split 41-43% ROM/Waste Blend Seam 3	Planned plant outage	287.5	287.5			96	96 86	72	Combustor inspection; baffle bore close inspection Blocked off PC-A NOx ports; replugged top two elbows Installed 12 elbows in PC-B Repaired PC-B mix annulus Dipper skirt refractory work
PERF-S3-3	8/4/98 5:30	8/4/98 16:15	10.75	10.75	10.75	A PC - 12 ports, No NOX ports B PC - 8 ports, All NOX ports open PC Phi 1.0, Coal split 43% ROM/Waste Blend Seam 3	Turbine checkout test	6.25		6.25		0	0	0	No combustor work
	8/4/98 22:31	8/5/98 13:10	14.7	14.7	14.7	A PC - 12 ports, No NOX ports B PC - 8 ports, All NOX ports open PC Phi 1.0, Coal split 43% ROM/Waste Blend	Operator error, opening both seal air lines to both pulverizers during cleaning	2.83		2.83		0	0	0	No combustor work
	8/5/98 16:00	8/9/98 12:38	92.6	92.6	92.6	A PC - 12 ports, No NOX ports B PC - 8 ports, All NOX ports open PC Phi 1.0, Coal split 43% ROM/Waste Blend	Loss of main plant power	7.33		7.33		0	0	0	No combustor work
	8/9/98 20:00	8/11/98 2:30	30.5	30.5	30.5	A PC - 12 ports, No NOX ports B PC - 8 ports, All NOX ports open PC Phi 1.0, Coal split 43% ROM/Waste Blend	Problems with coal loading equipment, running out of coal	51.5		51.5		52	52	0	Combustor inspection Removed PC NOx port plugs;Plugged two elbows PC-A Cleaned-out precombustors
ROM-S3-1	8/13/98 6:00	8/19/98 11:50	149.8	149.8	149.8	A PC - 8 ports B PC - 8 ports All PC NOX ports open ROM Seam 3	Pulverizer oil skid trip	4.5			4.5	0	0	0	No combustor work
	8/19/98 16:00	8/30/98 0:00	248	248	248	A PC - 8 ports B PC - 8 ports All PC NOX ports open ROM Seam 3	Coal plug in line - A combustor Operators did not clean out NOX ports after they were intention-ally blocked on the previous test	57		57		57	57	0	Combustor inspection Cleaned out coal in PC-A NOx ports
	9/1/98 9:00	9/6/98 12:00	123	123	123	A PC - 8 ports B PC - 8 ports All PC NOX ports open 66 Hrs. ROM/Waste Blend, Rest ROM Only	TRW decision to reconfigure mix elbows	96				96	96	0	Combustor inspection Cleaned out PC's Blocked off more elbows on A+B
BLEND-1	9/10/98 12:00	9/13/98 16:00	76	76	76	A PC - 5 ports B PC - 6 ports All PC NOX ports open ROM/Waste Blend	Over load slag ash drag chain	40		40		40	40	0	Combustor inspection Cleaned-out both PC's Plugged SC-A 11:00 injector
	9/15/98 8:00	9/20/98 0:00	112	112	112	Waste Coal (6700 Btu/#) A PC - 5 ports B PC - 6 ports All PC NOX ports open ROM/Waste Blend	Internal boiler leak	186			186	96	96	0	Combustor inspection Cleaned-out PC's Plugged additional PC mix elbows Installed new LFS gear Repaired PC NOX ports
BLEND-2	9/27/98 18:00	A - 9/29/98 2:30 B - 10/21/98 23:00	32.5	581	581	A PC - 4 ports B PC - 5 ports All PC NOX ports open ROM/Waste Blend	A - Excessive mill exhauster fan vibrations B - Planned shut down	68	68			68	68	0	Combustor inspection Installed hot air lines to SC-A head end Plugged remaining elbows in PC-A Cleaned-out PC's
SUBTOTAL			1002	1438	1551		SUBTOTAL	846	356	165	191	544	657	72	
TOTAL ELAPSED TIME			2397	2397	2397		TOTAL ELAPSED TIME	2397	2397	2397	2397	2397	2397	2397	
AVAILABILITY, %			41.8	60.0	64.7		AVAILABILITY, %	64.7	85.2	93.1	92.1	77.3	72.6	97.0	

Healy Test Summary and Reasons for Test Termination - Secondary Air Injection in Slagging Stage

Test	Start Date	End Date	Coal Burn-A (Hrs)	Coal Burn-B (Hrs)		Operating Conditions and Configuration	Reason for Test Termination	Resulting Down Time in Hours	Planned Shutdown Time	Balance of Plant Not Available	Boiler Island Not Available (excludes comb)	Precombustor A Inspection and Work Time	Precombustor B Inspection and Repair Time	Misc. Combustor Inspection and Repairs	Combustor Work Performed
BLEND-3	10/24/98 19:00	A - 10/25/98 14:00 B - Not Operated	19	0	19	A PC - Mix Annulus Blocked Off A PC Mix Elbows Packed with refractory All PC NOX ports open ROM/Waste Blend	A - Coal fire in silo	90		90		90	90	0	Combustor inspection Did not clean PC's Installed hot air lines to SC-B head end Plugged remaining elbows in PC-B
BLEND-4	A - 10/29/98 8:00	A - 11/7/98 12:54	220.9		20	PC Mix Annulus Blocked Off PC Mix Elbows Packed with Refractory Combustion Air to SC Head End (4 ports) All PC NOX ports open ROM/Waste Blend	A - Coal silo liner debond								Combustor inspection Removed mix elbows and installed blank-off plates Repaired PC-A swirl damper Repaired dipper skirt Installed more refractory in dipper skirt
	A - 11/7/98 20:04	A - 11/8/98 21:15	25				A - Coal silo liner debond								
	A - 11/9/98 3:00	A - 11/9/98 19:40	16.6				A - AIDEA decision to fix silo liner								
	A - 11/13/98 2:00	A - 11/15/98 9:00	55				A - TRW decision to remove precombustor mix elbows	102.5				102	102	102	
	B - 10/30/98 4:30	B - 11/15/98 9:00		388.5	388.5		B - TRW decision to remove precombustor mix elbows								
BLEND-5	A - 11/19/98 15:30	A - 11/24/98 17:56	122.4		122.4	PC Mix Annulus Blocked Off, Elbows Removed Combustion Air to SC Head End (4 ports) All PC NOX ports open ROM/Waste Blend	High furnace pressure	37.13			37.13	0	0	0	No combustor work
	B - 11/19/98 15:30	B - 11/24/98 17:56		122.4											
	A - 11/26/98 7:05	A - 11/28/98 10:15	51.2			PC Mix Annulus Blocked Off, Elbows Removed Combustion Air to SC Head End (4 ports) All PC NOX ports open ROM/Waste Blend	A - Exhauster fan leak								Blanked off PC NOx ports Installed two additional hot air lines to SC head end
	A - 11/29/98 17:45	A - 12/2/98 17:25	71.7				A - Exhauster fan leak	91.75		91.75		92	92	0	
	B - 11/26/98 7:05	B - 12/3/98 12:45		173.7	173.7		B - Bucket elevator problem								
BLEND-6	A - 12/7/98 12:36	A - 12/19/98 9:30	284.9		284.9	PC Mix Annulus Blocked Off, No Elbows Combustion Air to SC Head End (6 ports) A - No PC NOX ports B - PC NOX ports open	A - Fire in A-exhauster motor								Combustor inspection
	A - 12/19/98 16:30	A - 12/19/98 19:45	3.25		3.25		A - Tripped when B was shutdown								
	A - 12/20/98 17:00	A - 12/21/98 8:00	15		15		A - Planned shutdown								
	B - 12/7/98 8:35	B - 12/15/98 5:30		188.9	4		B - Coal freezing in hopper								
	B - 12/15/98 13:00	B - 12/16/98 7:00		18			B - Coal freezing in hopper								
	B - 12/16/98 8:30	B - 12/19/98 9:30		73			B - Tripped when A was shutdown	7			7				
	B - 12/19/98 16:30	B - 12/19/98 19:45		3.25			B - Coal freezing in hopper	21			21				
	B - 12/20/98 17:00	B - 12/21/98 8:00		15			B - Planned shutdown	256	256			48	48	0	
SUBTOTAL			885	983	1031		SUBTOTAL	605	256	182	65	332	332	102	
TOTAL ELAPSED TIME			1637	1637	1637		TOTAL ELAPSED TIME	1637	1637	1637	1637	1637	1637	1637	
AVAILABILITY, %			54.1	60.0	63.0		AVAILABILITY, %	63.0	84.4	88.9	96.0	79.7	79.7	93.8	
TOTAL (4/23/98 12:00 - 12/31/98 24:00)			2896	3430	3590		TOTAL	2469	884	860	276	1392	1546	358	
TOTAL ELAPSED TIME			6060	6060	6060		TOTAL ELAPSED TIME	6060	6060	6060	6060	6060	6060	6060	
AVAILABILITY, %			47.8	56.6	59.2		AVAILABILITY, %	59.3	85.4	85.8	95.4	77.0	74.5	94.1	

1999 Healy Test Summary and Reasons for Test Termination

Downtime Code - A = Design Problem, B = Fab Problem, C = Operational Problem, D = Maintenance Problem, E = Installation Problem, F = Control System or Instrumentation Problem, G - Weather or Environmental Problem, H - Consumable or equip supply problem

Test	Start Date	End Date	Coal Burn-A (Hrs)	Coal Burn-B (Hrs)	Coal Burn (A or B) (Hrs)	Operating Conditions and Configuration	Reason for Test Termination	Downtime Code	Resulting Down Time in Hours	Planned Shutdown Time	Balance of Plant Not Available	Boiler Island Not Available (excludes comb)	Precombustor A Inspection and Work Time	Precombustor B Inspection and Repair Time	Misc. Combustor Inspection and Repairs	Combustor Work Performed
									431.3							
BLEND-7	A - 1/19/99 0:30	A - 1/19/99 7:00	6.5				A - Frozen Coal - trip, no coal on belt									Exhauster fan rotors, blades, and tiles installed Closeup small gaps in mix annulus blank off
	A - 1/21/99 9:00	A - 1/21/99 19:45	10.8			PC Mix Annulus Blocked Off, No Elbows Combustion Air to SC Head End (6 ports)	A - Trip - carrier air calc problem									Larger support clamp supports added to dipper skirt shield Dipper skirt vent line leaks repaired
	A - 1/22/99 10:25	A - 1/25/99 5:00	67.4			A - No PC NOX ports B - PC NOX ports open	A - Trip on turbine throttle valve									
est	A - 1/31/99	A - 2/1/99	48.0				A - Turbine chkout, out of limestone									
	B - 1/18/99 23:15	B - 1/19/99 7:00		7.8	7.8		B - Frozen coal - Trip, no coal on belt	G,C	35.8		35.8					
	B - 1/20/99 18:45	B - 1/21/99 19:45		25.0	25.0		B - Trip - carrier air calc problem	F	6.1		6.1					
	B - 1/22/99 1:50	B - 1/25/99 5:00		75.2	75.2		B - Trip on turbine throttle valve	D	139.0		139.0					
est	B - 1/31/99	B - 2/1/99		48.0	48.0		B - Turbine chkout, out of limestone	H	399.0	399.0	339.0					
BLEND-8	A - 2/18/99 15:00	A - 2/23/99 4:00	109.0		109.0	same as BLEND-7	A - Dipper skirt drain valve open	C	55.0						20.0	Combustor inspection Repair swirl damper leak - weld overlay Vent line sockolet weld repair
	B - 2/18/99 18:00	B - 2/23/99 4:00		106.0			B - Dipper skirt drain valve open	C								
BLEND-9	A - 2/25/99 11:00	A - 2/26/99 13:30	26.5				A - High Silicate in boiler feed water									Combustor inspection Cleaned-out PC's Fabricated/installed swirler/flame holder in inner burner
	A - 3/3/99 3:00	A - 3/3/99 4:30	1.5				A - Coal feed system puff									
	A - 3/5/99 3:00	A - 3/6/99 13:00	34.0			same as BLEND-7, except moved FWEC Burner inner sleeve back 1"	A - Trip on bad Bailey board									
	A - 3/6/99 18:00	A - 3/8/99 22:07	52.1				A - Trip on high furnace pressure									
	A - 3/9/99 18:00	A - 3/14/99 22:00	124.0				A - Hot gas leak from A PC aspirating door									
	B - 2/25/99 11:00	B - 2/27/99 1:30		38.5	38.5		B - High Silicate in boiler feed water	C	97.5			145.5				
	B - 3/3/99 3:00	B - 3/3/99 4:30		1.5	1.5		B - Coal feed system puff	C	46.5						46.5	
	B - 3/5/99 3:00	B - 3/6/99 13:00		34.0	34.0		B - Trip on bad Bailey board	F	5.0		5.0					
	B - 3/6/99 18:00	B - 3/8/99 22:07		52.1	52.1		B - Trip on high furnace pressure	A	19.9			19.9				
	B - 3/9/99 18:00	B - 3/14/99 22:00		124.0	124.0		B - Hot gas leak from A PC aspirating door	C	90.8				16.0	16.0	90.8	
BLEND-10	A - 3/18/99 17:55	A - 3/30/99 12:20	282.4				A - Trip on high furnace pressure									Combustor inspection Cleaned-out PC's
						same as BLEND-9, except Swirler Added to Inner Passage of Coal Burner										Mix annulus ducts plugged off A PC NOX port blank off plates removed
	B - 3/18/99 16:48	B - 3/19/99 14:00		21.2	21.2		B - Trip on coal feeder	G	1.0		1.0					Installed 7th SC HE air port Modified mill air curve to control mill air temperature outlet
	B - 3/19/99 15:00	B - 3/30/99 12:20		261.3	261.3		B - Trip on high furnace pressure	A	190.9			190.9	24.0	24.0	48.0	
BLEND-11	A - 4/7/99 11:14	A - 4/17/99 21:00	250.0		250.0	same as BLEND-10, except	A - Trip on high furnace pressure	A	14.5			14.5				Combustor inspection Cleaned-out PC's East swirl damper 32", west 14"
	A - 4/18/99 11:30	A - 4/21/99 7:11	67.7		67.7	Mix Annulus air duct plugged off A - PC NOX Ports Opened	A - Trip on PC-A Flame Scanner	C	5.8						5.8	7th SC HE air port valves installed and closed Dipper skirt shield vent line repaired
	A - 4/21/99 13:00	A - 4/24/99 10:40	69.7		69.7	7th SC HE air port installed	A - Trip on high furnace pressure	A	2.3			2.3				Limestone feeder vibrator installed
	A- 4/24/99 13:00	A-4/27/99 18:00	77.0		77.0		A - Shut-down: damage to slag tank	C	220.0			220.0	16.0	12.0	12.0	
	B - 4/7/99 11:50	B - 4/17/99 21:00		249.0			B - Trip on high furnace pressure									
	B - 4/18/99 11:30	B - 4/21/99 7:11		67.7			B - Trip on PC-A Flame Scanner									
	B - 4/21/99 13:00	B - 4/24/99 10:40		69.7			B - Trip on high furnace pressure									
	B-4/24/99 13:00	B-4/27/99 18:00		77.0			B - Shut-down: damage to slag tank									
BLEND-12	A - 5/6/99 22:00	A - 5/14/99 7:00	177.0		177.0	same as BLEND-11, except 7th SC HE air ports closed	A - Water leak in dipper skirt shield	A,D	70.0						70.0	Combustor inspection
	A - 5/17/99 6:00	A - 5/17/99 7:30	1.5		1.5	east swirl damper 32", west 14"	A - Trip on low pressure cooling water	C	3.3		3.3					
	A- 5/17/99 10:45	A - 5/20/99 21:23	82.6		82.6		A - Trip - Hopper slope ash fall	A	4.3			4.3				
	A - 5/21/99 1:40	A - 5/29/99 20:40	211.0		211.0		A - Trip - Hopper slope ash fall	A	4.3			4.3				
	A - 5/30/99 1:00	A - 6/2/99 23:00	94.0		94.0		A - Planned shutdown	D	58.5	58.5						
	B - 5/6/99 22:00	B - 5/14/99 7:00		177.0			B - Water leak in dipper skirt shield									
	B - 5/17/99 6:00	B - 5/17/99 7:30		1.5			B - Trip on low pressure cooling water									
	B - 5/17/99 10:45	B - 5/20/99 21:09		82.4			B - Trip - Hopper slope ash fall									
	B - 5/21/99 1:40	B -5/29/99 20:40		211.0			B - Trip - Hopper slope ash fall									
	B - 5/30/99 1:00	B - 6/2/99 23:00		94.0			B - Planned shutdown									
BLEND -13	A - 6/5/99 11:40	A - 6/12/99 18:23	174.7			same as BLEND-12	A - Planned shutdown									Combustor inspection Permanent mix annulus blank off plate installed Replace old SC hot air injectors with new ones
	B - 6/5/99 9:30	B - 6/12/99 21:48		180.3	180.3		B - Planned shutdown	D	434.2	786.1			60.0	60.0	60.0	Swirl damper weld overlays applied Larger dipper skirt clamps installed
SUBTOTAL			1967.4	2004.2	2008.4		SUBTOTAL		2334.8	1243.6	529.2	601.7	116.0	112.0	353.1	
TOTAL ELAPSED TIME			4344.0	4344.0	4344.0		TOTAL ELAPSED TIME		4344.0	4344.0	4344.0	4344.0	4344.0	4344.0	4344.0	
AVAILABILITY, %			45.3	46.1	46.2		AVAILABILITY, %		46.3	71.4	87.8	86.1	97.3	97.4	91.9	