EVALUATION AND TESTING OF A LOW-VOLATILE BITUMINOUS COAL AT NEW ENGLAND POWER

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INTRODUCTION

Steam coals used by eastern United States electric utilities are traditionally high volatile, moderate to high sulfur, high ash content bituminous coals. Increasingly stringent regulations on sulfur emissions have caused an emphasis on beneficiated coals. Recent changes in the economics of steel-making and the decline of steel plants has released large quantities of metallurgical or coking coals to the open market. This is low volatile, low sulfur, low ash bituminous coal and is commonly beneficiated prior to sale. The decline in the market for coking coals has caused them to be priced competitively with steam coals.

Plant operators, however, have been reluctant to substitute low volatile coals, even though they are generally compliance coals from a standpoint of sulfur emissions. There are at least three reasons why coking coals have not found ready acceptance as substitutes for steam coals. The first is that most existing pulverized coal utility boilers have been designed for medium to high volatile coals and operators have wisely been hesitant about switching to out-of- specification coal stocks. Secondly, it has been generally understood that the flame stability of pulverized coal flames is a function of volatility. It has been demonstrated by the authors that volatility is not the only key parameter, but the heating value of the volatiles plays a significant role in the combustion stability of a coal. Finally, these coals are more friable, which does improve their pulverization characteristics, but also results in a higher percentage of fines. These fines, depending on the surface moisture and extraneous mineral matter, may cause handling concerns.

The potential use of low volatile, bituminous coal has been evaluated over the past two years by New England Power (NEP) at both its Salem Harbor and Brayton Point Stations. Phase I of the evaluation consisted of informational presentations to plant operations personnel; in Phase II, laboratory investigations of low volatile coal flowability and combustion characteristics were performed for the existing equipment at Salem Harbor and Brayton Point.

The results of the Phase II study showed no "red flags" which would prevent a full scale test burn at Salem Harbor or Brayton Point. A test burn of low volatile coal could be performed by incorporating a Safety Assurance Plan into the normal plant operating procedures without making any plant equipment modifications. The Safety Assurance Plan allows the anticipation or quick detection of any abnormal conditions, providing for technical guidance to assure safe operation of the boiler at all times. An in-furnace video system was incorporated into the Safety Assurance Plan to provide control room engineers with a visual indication of flame stability.

The authors have been involved in a series of laboratory studies and full scale utility boiler demonstration test burns which have shown conclusively that these coking coals can be successfully substituted for conventional medium and high volatile coals in existing pulverized, coal-fired utility boilers. These coals can be used with no changes in plant operating procedures and with no changes in equipment settings. This work has led to the development of a coal specification model that NEP used to further develop their coal specifications when procuring coals of this type. The coal specification model parameters are: the higher heating value of the volatiles on a pound of coal basis (HHV_{vol}) derived from coal calorimetry; the Bimaceral Reflectance Index (BRI) derived from the petrographic analysis (coal fingerprint) and the Coal Stability Index (CSI) derived from the HHV_{vol} and the BRI.

Based on the successful results of the laboratory investigation, NEP decided to proceed to Phase III of the low volatile coal evaluation. A full scale test burn was conducted on Unit 1 at Salem Harbor in May 1990. Energy Systems Associates (ESA) was contracted by New England Power and Island Creek (the coal company selected to supply coal for the test burn) to conduct the test program. A total of 16,000 tons of low volatile coal were burned in Unit 1 from May 13 to June 5. The test program started with combustion tests on the baseline coal beginning on May 2 and continued until the low volatile coal was exhausted.

A number of tests were conducted on Unit 1 to determine the trends and sensitivities of flue gas combustion products (CO, O_2, NO, SO_2) to changes in the boiler combustion parameters. These tests were documented by an 18 point gaseous emissions matrix at the economizer outlet, boiler control room settings, isokinetic fly ash samples entering the electrostatic precipitator (ESP) for carbon analysis, coal analyses and mill fineness, furnace exit gas temperatures, and flame and slag observations. The flame observations included 35mm photographs and VHS videotaping, both real time and time lapse. Tests were conducted at full load with four and three mills in service, and at minimum load with two mills in service.

Tests with the baseline coal began on May 2, 1990. Low volatile coal was first burned in mill 1-1 on May 13 and mil 1-2 on May 14. A few days were spent documenting 50% low volatile coal operation. Because of the initial success without any problems on low volatile coal, it was decided to proceed to 100% low volatile coal operation. All four mills were operating on low volatile coal by May 17.

The results of these tests demonstrated the capability of burning low volatile coal (down to 18.7% volatility on a dry basis) on Unit 1. Tests were conducted at full load (three and four mill operation) and minimum load (two mill operation with and without oil support) while utilizing the existing operational configuration.

As a result of this successful, logically sequenced engineering evaluation, all three Salem Harbor coal fired units have been operating on 100% Alpine, low volatile coal beginning in September 1990.

This success has allowed NEP to open the door to a new coal market, one which could include the use of low volatile coals as part of NEP's overall sulfur compliance strategies.

Due to these factors, NEP was able to take advantage of an opportunity to evaluate a low volatile <u>compliance coal</u> that met their fuel specifications with the exception of the ash fusion temperature (2370°F vs. 2450°F specification).

The objective of this second diagnostic engineering program was to determine the impact on the slagging and fouling characteristics of this coal in the Salem Harbor boilers. Boiler 3 was selected for this investigation due to its higher heat input per plan area and FEGT compared to units 1 and 2. Island Creek's Virginia Pocahontas coal was introduced into boiler 3 in November 1990 and utilized in all boilers for approximately three months.

The results of these tests demonstrated that the Pocahontas #3 seam coal could be fired in the Salem Harbor boilers following normal plant operating procedures.

The key to this project has been the fact that the engineering team has shown that understanding the technology of low volatile coals has led to its successful use as a fuel in existing pulverized coal utility boilers. The potential benefit is that reserves of this low sulfur coal from Pennsylvania to Alabama (including WV, MA, VA, KY, TN) could have a significant impact on the domestic supply and availability of compliance coals in the eastern United States.

<u>PEDA Study (Phase I and II)</u>

NEP participated in a detailed program sponsored by the Pennsylvania Energy Development Authority (PEDA) designed to investigate the feasibility of using low volatile coals in pulverized coal (PC) boilers. The program consisted of a "paper study" to evaluate performance characteristics of the subject coals, concentrating on handling, combustion, and emissions, as well as laboratory/engineering investigations to corroborate the predicted results. This included site specific evaluations of the candidate boilers of participating utilities. In addition, a major contribution from this study was the development of coal specification guidelines to address flame stability criteria (based on volatile content, heating value of the volatiles, and coal petrography) for low volatile coals.[1]

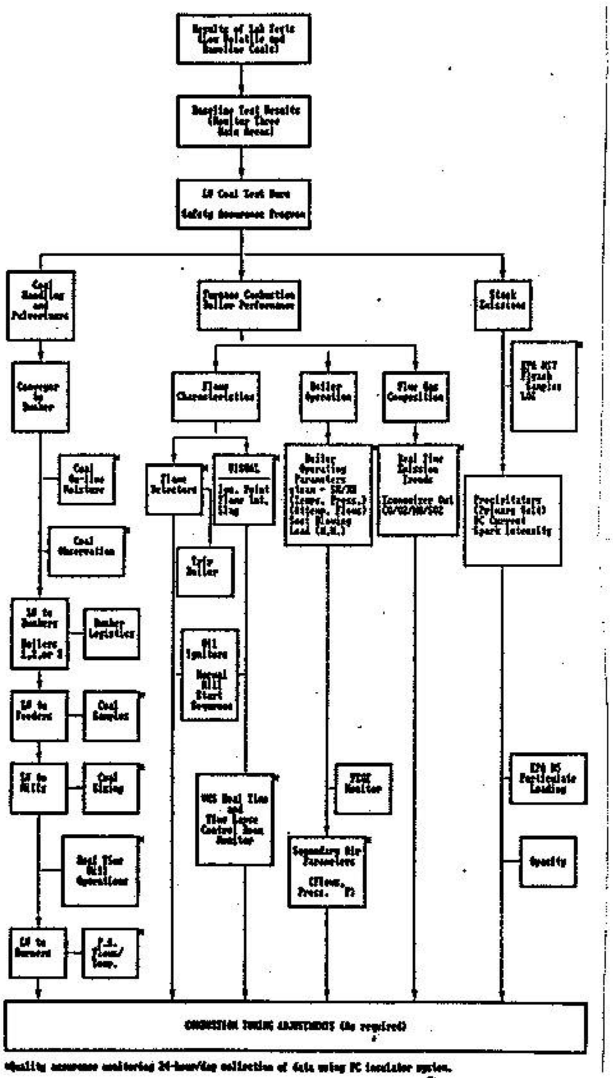
COMBUSTION SAFETY ASSURANCE PROGRAM

The potential problems of the low volatile test burn are related to plant shutdown and the economic penalties that result from the revenue loss and fires or explosions in mills or boilers that could result in human injury or equipment damage. It was imperative that the safety assurance program be properly designed to detect the onset of problems so that corrective action could be taken in time to prevent a possible outage or an incident.

The program was designed for the strict adherence to all start-up, operational and shutdown codes, rules and regulations as promulgated by plant personnel. It was especially important to observe those strictly when operating in a test mode that was unfamiliar, such as the low volatile test burn.

Figure 1 outlines a Safety Assurance Plan which was followed on Salem Harbor 1 during the low volatile coal demonstration burn. This type of safety assurance program encompasses the three main areas which are monitored during baseline testing and monitored on a 24-hour basis during a demonstration test.

Figure 1. Low Volatile Coal Test Burn Safety Assurance Program



Development of a Low Volatile Coal Specification Model

These studies have involved both laboratory testing and full scale demonstration test burns. Results showed that the laboratory data can be used to successfully project the results of full scale demonstration test burns. In order that low volatile coals be acceptable as a steam coal in utility boilers, it must be shown that the use of the low volatile fuel will cause no problems of flame stability, burnout, slagging or fouling, milling operations, coal handling and emissions. The most daunting problem of low volatiles coals, as perceived by power plant operators, is that of flame stability.

A special test apparatus was designed by B. Breen and W. Rohrer to measure relative flame stability of pulverized coals.[2,3] During the investigations referred to above, the results from the Breen-Rohrer apparatus were correlated with the results from petrographic analysis, thermal gravimetric analysis, differential thermal gravimetric analysis, and gas chromatography/ mass spectroscopy, and those from the full scale demonstration test burns. A coal specification model has been derived which is useful in projecting coal performance in pulverized coal fired utility plants, and for use by utility companies in establishing coal purchase specifications when switching supplies.

The coal specification model parameters are: Flame Stability Parameter (T^*_{ign}) derived from data taken from the Flame Stability Apparatus; the higher heating value of the volatiles on a pound of coal basis (HHV_{vol}) derived from coal calorimetry; the Bimaceral Reflectance Index (GRI) derived from petrographic analysis; and the Coal Stability Index (CSI) derived from the HHV_{vol} and the BRI.

FLAME SENSITIVITY TESTS

The Breen-Rohrer Pulverized Coal Flame Stability Test Burner is shown in Figure 2 and has been described previously.[2,3] Due to the design of the burner, flame holding is accomplished primarily by the radiation field, while hot gas recirculation is held to a minimum. A vertically downward jet of pulverized coal and air with an equivalency ration of 0.2 rich in fuel is heated by a concentric tubular heater and is ignited by a propane ignitor as it leaves the heater. The stability of the flame is determined from its appearance. Intermittent flames, or flames that shown the ignition point traveling up and down the tube, are judged unstable; those that have stable ignition points but show streaks of unburned or partially burnt fuel moving downstream are judged marginally stable. Stable flames are attached deep within the combustion tube with no evidence of ignition point traveling, fuel streaking, or unburned fuel exiting the flame zone.

In previous studies[2,3] of the stability of pulverized coal and air, the parameter T^*_{ign} representing a measure of coal furnace temperature for stable ignition and stable flame has been presented. The higher the stable flame ignition temperature, the higher the value of T^*_{ign}. Unstable and marginally stable flames at test conditions show very high values of T^*_{ign}. This parameter has been defined as:

$$T^*_{ign} = T_{ign}/(\%VM)^2(C.V. \ \ x \ HHV_{vol})^{1/2}$$

where,

T_{ign} = measured minimum combustion tube temperature to achieve stable ignition, °F

VM = volatile matter as determined using ASTM D3175, (%)

C.V. = higher heating value of the coal, Btu/lb coal

HHV_{vol} = higher heating value of the volatile matter in coal on a unit mass of coal basis, Btu/lb coal

The HHV_{vol} was determined from coal analysis as:

$$HHV_{vol} = C.V. - [(1 - \%VM/100) \ HHV_{char}]$$

where the char is the residue from the ASTM volatile matter test.

Figure 2. Schematic Diagram of Test Apparatus

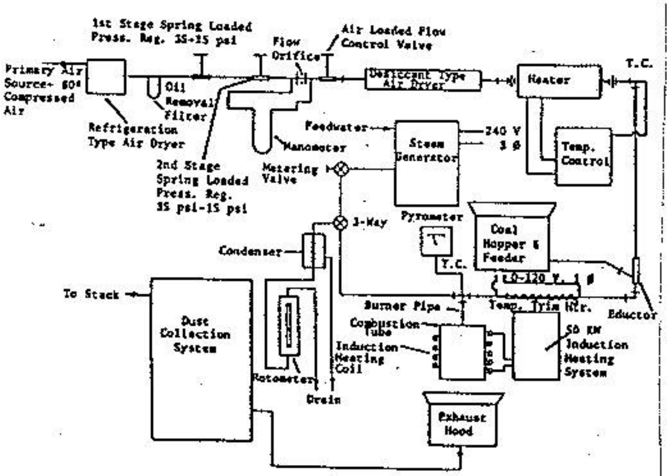
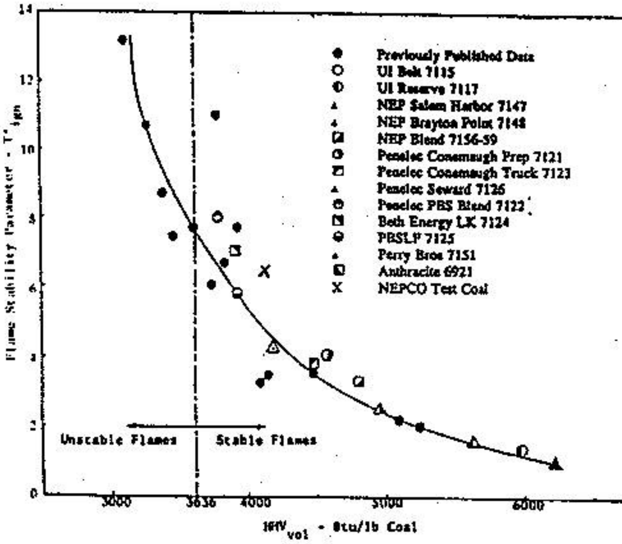


Figure 3 is a graph of T^*_{ign} vs. the HHV of the volatiles for the coal samples tested in the present study and includes the published data for the coals used in previous studies. It is seen that the correlation is valid for coals of varying volatile matter content ranging from 11 to 39 percent. All the coals that have HHV_{vol} values less than 3,636 Btu/lb of coal showed unstable flame characteristics. The Alpine coal selected for the Salem Harbor test burn had a T^*_{ign} = 6.5 and a HHV_{vol} equal to 4,366 Btu/lb of coal, which was well above the minimum stability limit, as shown in Figure 3.

COAL STABILITYINDEX

The heating value of the volatiles per pound of volatiles and the heating value of the volatiles per pound of coal are important parameters which impact on the

Figure 3. Comparison of Flame Stability Data with Previously Published Data T_{ign}* vs. HHV_{vols}



stability of the flame. A correlation has been developed which takes into consideration the petrographic characteristics of the coal and the heating value of the volatiles to indicate the stability of the pulverized coal and air flame. This Coal Stability Index is defined as follows:

$$\text{Coal Stability Index (CSI)} = \frac{HHV_{vol}/\text{lb of coal}}{\text{Bimaceral Reflectance Index}}$$

The methodology for determining the HHV_{vol}/lb of coal has been presented earlier. The BRI is determined from the petrographic reflectance analyses for the coals and is calculated as follows:

1. The volume percentages for each exinoid, resinoid and vitrinoid class are normalized to total 100 percent.
2. The normalized volume percentage values are multiplied by their respective reflectance class numbers, the products are summed and the total is divided by 10.

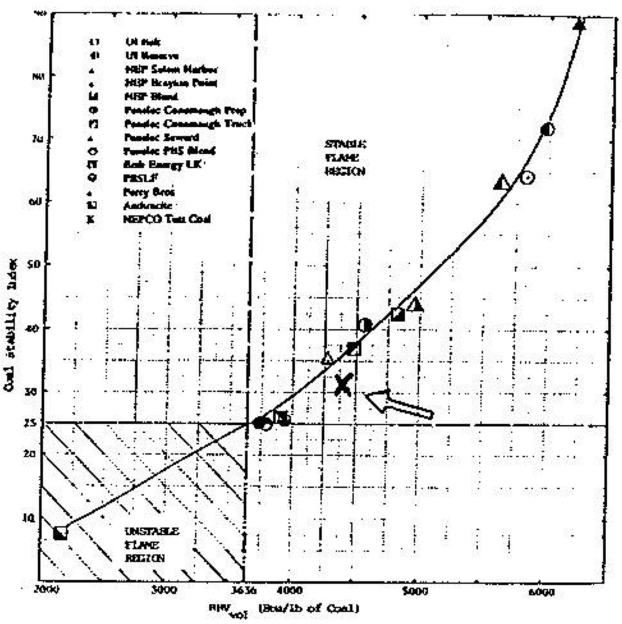
The CSI of the different coals has been plotted against the HHV_{vol}/lb of coal in Figure 4. It has been observed that coals which have a CSI value less than 25 show unstable flame characteristics. Coals with a CSI value equal to or greater than 25 do not show any unstable flame characteristics such as sparklers, streaking or moving of the flame. Earlier it has been shown that coals with an HHV_{vol}/lb of coal < 3,363 Btu/lb showed unstable flame characteristics. Figure 3 clearly shows that pulverized, low-volatile coal should meet two important criteria so as to ensure no unstable flame characteristics, i.e.:

1. CSI value must be equal to or greater than 25,

2. HHV_{vol}/lb of coal value must be > 3,636 Btu/lb.

Figure 4 shows the test coal selected for the Salem Harbor unit 1 test burn (Island Creek Coal Company, Alpine coal) to have a CSI equal to 31, well within the stable range.

Figure 4. Coal Stability Index vs. the HHV_{vols}



Understanding Technology of Low Volatile Coal

Pyrolysis of coal in an inert atmosphere results in the evolution of varying amounts of methane and hydrogen along with other volatiles. Trend plots presented in Figure 5 show that the amount of methane, as indicated by its total Btu content, decreases slightly with the decrease in volatility of the coal. The total heat content of the hydrogen produced from coals of varying volatile matter content is indicated in Figure 6 which shows that the total heat content of the hydrogen Btu/lb of coal increases with the decrease in volatile matter content of the coal to approximately 17 percent. Below 17 percent volatile matter there is a sharp drop in the heat content of the hydrogen.

Figure 7 shows the impact of the increased hydrogen levels on the HHV_{vols} (Btu/lb_{vols}) as the total volatile content of the coal is reduced. It is this increased contribution of the hydrogen content that provides the heating value in the volatiles which results in the continued combustion stability of the pulverized coal flame as the percent volatiles decrease.

Figure 5. Btu's of Methane vs. Volatile Matter

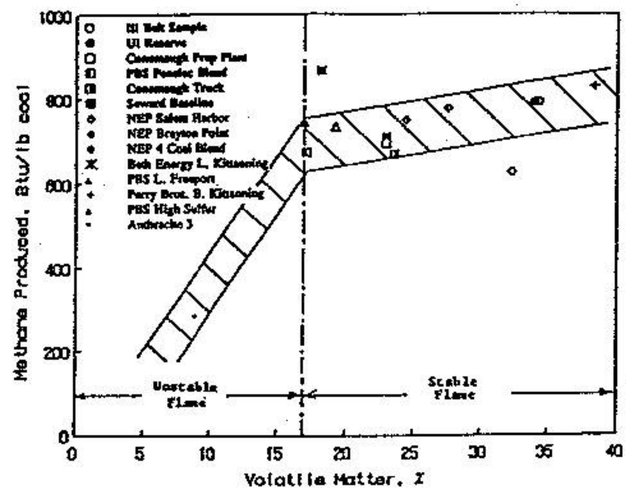


Figure 6. Hydrogen Btu/lb Coal vs. Volatile Matter

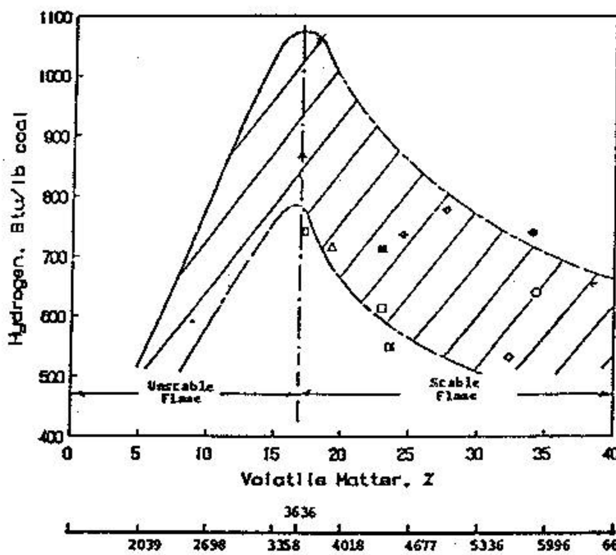
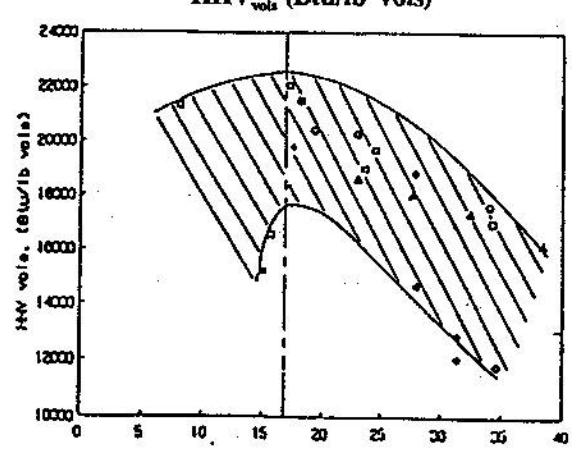


Figure 7. Hows Increased H_2 Levels Impact on HHV_{vols} (Btu/lb vols)



Salem Harbor Unit 1 Test Burn (Phase III)

The results of the PEDA study (Phase I and II) together with the above considerations and several in-house test technical transfer seminars, led to a decision to conduct a full scale test burn at Salem Harbor unit 1. A test protocol was developed to properly and thoroughly address all of the critical issues related to low volatile coals. The coal selected for the test burn was an Island Creek Coal Company, upper Freeport seam, eastern bituminous, low volatile coal from West Virginia. Coal analyses are presented in Table 1. Coal analyses required to show adherence to the flame stability criteria, as well as additional pilot combustion tests to ensure "no surprises" during a full scale test were conducted for the Alpine coal. Again, no problems were identified at this time.

Table 1
Salem Harbor Station Test Coal Analysis

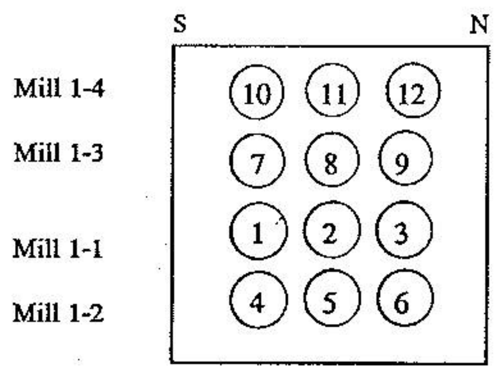
Coal Analysis (as received)	Test Coals	
	Baseline	Low Volatile
Volatile	29.1	18.0
Fixed Carbon	57.0	66.0
Ash	8.0	9.1
Moisture	4.8	6.3
Carbon	74.0	74.0
Hydrogen	4.5	4.0
Nitrogen	1.4	1.37
Sulfur	1.4	1.4
Oxygen	5.3	3.3
HHV (Btu/lb)	13,100	13,050
HGI	65	95
AST (°F)	2,700+	2,700+
T^*_{ign}	1.65	6.5
HHV_{vols} Btu/lb coal	5,625	4,366
CSI	63.4	31

The experience developed during other compliance coal test burns[2,3] mentioned above was instrumental in "tailoring" the test plan to maximize its impact and effectiveness. Particular attention was devoted to a safety assurance plan throughout the test burn. In-furnace video monitoring and an extensive observations/communications network were key elements of this plan. In addition, combustion conditions (O_2, CO, LOI, FEGT, slag deposits) and emissions performance (NO_x, SO_2, particulates) were monitored throughout the test burn.

NEP's Salem Harbor Station, Unit #1 (SH #1) is a B&W single wall-fired, balanced draft unit with a maximum gross load of 87 MW. The boiler is rated at 625,000 lb/hr steam flow with 1000°F superheat and reheat temperatures. The boiler has four levels of three burners each and is equipped with four B&W EL-type mills each feeding one burner level. SH #1 is dual-fuel capable and can be fired on #6 oil or coal up to full load. It uses manual oil start-up and is not equipped with a flame detection system. Particulate emissions are controlled via an Environmental Elements ESP with an SCA of 475.

The test plan called for two test series: first, a characterization of unit operation and performance was conducted for the baseline coal; then, a second test series was performed for the test coal. The test plan was designed such that the low volatile coal was introduced gradually (one mill at a time) and under controlled conditions (oil ignition support) into the boiler. Low volatile coal was introduced to the four mills in the following sequence:

Date	Mills on Low Volatile	Mills on Baseline
May 2	None	All
May 13	1-1	1-3, 1-4 (level 1-2 on oil)
May 14	1-1, 1-2	1-3, 1-4
May 17	All	None



The test burn activities were directed at characterizing the existing boiler combustion performance under normal plant operating conditions, firing both baseline and low volatile coals according to he feed sequence above. The only deviation from normal plant operating procedures was the use of an in-furnace video system to provide the control room engineers the ability to monitor flame stability.

SALEM HARBOR 1
LOW VOLATILECOAL TEST BURN RESULTS

Coal Handling

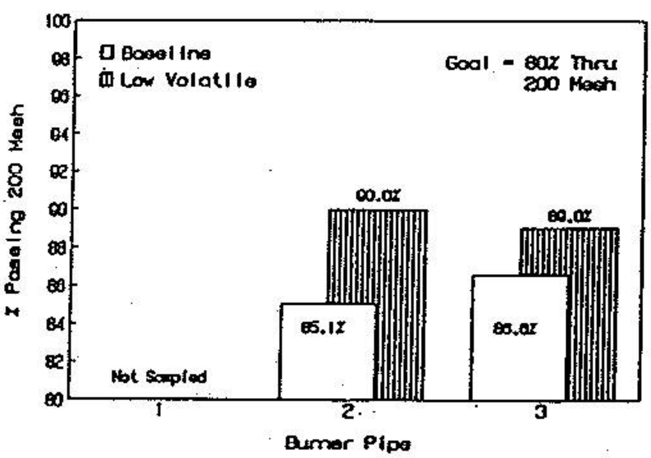
Concerns about coal plugging and/or dusting due to the increase in fines as compared to the baseline coal (87 percent-1/4 in. versus 67 percent-1/4 in.) did not materialize. Even with a high moisture content of about 8 percent due to heavy rain during the test period, no plugging problems were detected during the test (i.e., feeder/mill trips); minor funneling in the bunker was handled with normal vibrator procedures. In addition, coal pile operations proceeded normally without any significant impact. No fugitive emissions were detected during normal coal pile handling operations.[6]

Mill Performance

Mill fineness tests were taken from all accessible coal burner pipes by NEP personnel on both the baseline and low volatile coals.

The low volatile coal had an HGI of 95 compared to an HGI of 60 to 65 for the baseline coal. Naturally, mill performance improved with the softer coal. A 25 percent decrease in mill power requirements was noted, combined with a slight increase in fineness from 85 to 90 percent through 200 mesh (Figure 8). A result of the reduction in power consumption was the capability to maintain full load on three mills with the low volatile coal. These results were achieved without adjusting mill settings. Limited optimization tests varying primary air temperature, and air-to-coal ratio did not indicate major benefits from additional fine tuning.

Figure 8. Mill 1-1 Percent Passing 200 Mesh Baseline and Low Volatile Coals



Combustion Performance

The Salem Harbor unit 1 low volatile coal test burn was conducted by introducing the low volatile coal into the subject boiler over a five day period starting with mill 1-1 and adding an additional mill, (1-2) after 24 hours. Mills 1-3 and 1-4 made the transition to low volatile coal simultaneously following several days of operation on 50% low volatile coal under full load conditions. The low volatile coal boiler combustion parameters were characterized and documented as each mill was placed on low volatile coal.

The safety assurance plan was in place during the entire test burn including 24 hour TV/VHS monitoring of the primary furnace, with a monitor located in the boiler 1 control room. When the low volatile coal was initially introduced to an individual mill, class one oil ignitors were fired simultaneously with the coal until the flame characteristics were monitored and observed by both NEP plant operations personnel and the ESA engineering team. Once the combustion parameters were characterized and documented, a decision was made to remove the ignitors from service one ignitor at a time until the mill was firing 100% low volatile coal without oil support. These individual mill tests included operating the mill throughout its normal operating range, while maintaining the boiler at full load conditions.

This complete test series was successfully accomplished following standard boiler operating procedures.

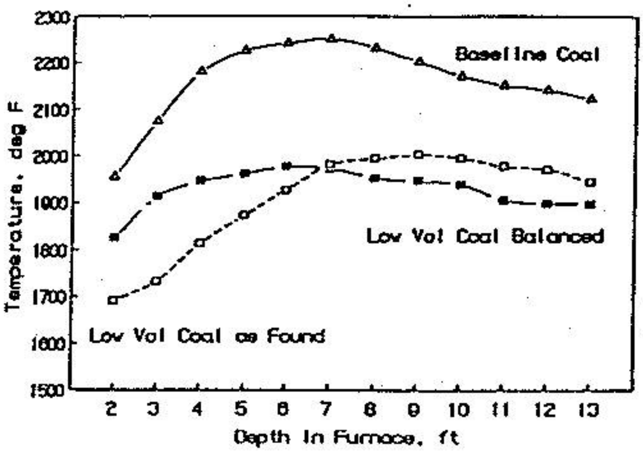
Detailed observations indicated strong, swirl-stabilized flames with ignition points at the burner throat, similar to the baseline coal. Visual observations in the furnace revealed relatively clean (free of slag) walls throughout the test program for both coals. Traditional "eyebrows" were present in both cases, but easily removed using normal procedures. Investigation of convective pass fouling showed no such indication for either coal. A water-cooled deposition probe used in the secondary superheater revealed similar build-up patterns for both coals, especially friable and removable for the low volatile coal.

Furnace Exit Gas Temperature

FEGT profiles were measured with an HVT probe to provide indications of combustion intensity, deposit growth, and/or changes in flame patterns. FEGTs were lower by approximately 250°F for the low volatile coal than the baseline coal. The somewhat more compact low volatile coal flames (due to higher fineness?) may have contributed to the lower FEGT. Consistent with the results was a slight reduction in attemperation sprays (superheat and reheat) to maintain design steam temperatures. In addition, increases in nitric oxide (NO)emissions levels further supports the shorter, more compact, higher primary flame zone peak temperatures with the low volatile coal.

Figure 9 shows that FEGTs ranged from 1955°F near the furnace wall to 2250°F on 100% baseline coal. These results were obtained with the boiler operating in its "as found" condition for excess O_2 level and burner register positions. With the same O_2 level and register positions, the low volatile coal showed a drop in temperature of 250-300°F. The new range was from 1690°F near the furnace wall to 2002°F at the maximum. The shape of the "as found" profile was the same for baseline and low volatile coals.

Figure 9. Unit 1 Furnace Exit Gas Temperature Profile Baseline and Low Volatile Coal



Once 100% low volatile coal operation had been documented, some boiler O_2 balancing was performed by making selective burner register adjustments. When the boiler O_2 was balanced across the duct within the capabilities of the existing controls, the FEGT profile was again documented. The temperatures are again lower than baseline by 150-250°F, but the distribution was much more uniform. The temperatures ranged from 1825°F near the furnace wall to a maximum of 1976°F. This test was done at a slightly lower average O_2 level than the "as found" tests (3.5% vs. 4.1%).

Minimum Load Test

Because the operation of the boiler on 100% low volatile coal was proceeding so smoothly, the decision was made to perform one evening of minimum load testing (two mill operation) on 100% low volatile coal. No data was taken at minimum load on the baseline coal. Minimum load (35 MW) was scheduled for 11 p.m. on May 23 through 3 a.m. on May 24. Two configurations were to be tested for minimum load:

1. Mills 1-1 and 1-3 in operation, with mill 1-1 using class 1 ignitors for flame stability. This was considered the most conservative minimum load operating configuration.
2. Mills 1-1 and 1-4 in operation with no oil support. This was considered the least conservative minimum load operating configuration.

After observations of the flames showed no combustion problems, both low load configurations were operated without oil support. The flame patterns showed strong swirl stabilized flames, with ignition points back near the burner throat for both configurations. Carbon monoxide (CO) levels averaged 28 ppm.

Flue Gas Analysis

In order to quantify changes between baseline and low volatile coal combustion performance characteristics of unit 1, measurements of O_2, CO, NO and SO_2 were taken at the economizer outlet utilizing an eighteen point matrix.

The carbon monoxide emission trends were used as a primary diagnostic tool during the low volatile coal test burn, because CO is a positive indicator of incomplete combustion. The excess oxygen distribution was utilized to determine the balance of the boiler across the furnace, to indicate possible areas of fuel/air maldistributions. Also, balanced O_2 across the boiler allows operation at lower excess air levels than possible with an unbalanced conditions.

The nitric oxide concentrations were also measured on unit 1 for the range of baseline and low volatile coal configurations tested. Nitric oxide is formed in the peak flame temperature regions; therefore, it is an excellent indicator of flame zone intensity and changes in the localized interaction between fuel dynamics and burner aerodynamics.

The CO/O_2 distribution of the baseline coal fired with the boiler operating in its "as found" condition in shown in Figure 10. The point plotted for each sample port is the average of the three depths sampled at each port. The CO levels are very low, with slightly higher levels in the north duct (15 ppm vs. 10 ppm). The O_2 distribution reflects this imbalance more clearly. The north duct excess O_2 level is 1.5% lower than the level in the south duct (3.4% vs. 4.9%), and the average O_2 level overall is 4.15%

The NO distribution is superimposed on the same O_2 distribution for the baseline coal in Figure 11. The north and south duct averages are essentially the same, and the overall average is 685 ppm corrected to 3% O_2. This corresponds to an NO emission rate of 0.98 lb/10^6 Btu, which is in good agreement with the historical rate of 1.0 lb/10^6 Btu.

Figure 12 shows the CO/O_2 distribution for the low volatile coal under the same operating conditions as the baseline coal. The O_2 imbalance is again evident, with the north duct averaging 3.25% and the south duct averaging 4.9%. The overall average of 4.1% is essentially the same as the average for the baseline test (4.15%). The CO levels are once again very low, averaging 4.9%. The overall average of 4.1% is essentially the same as the average for the baseline test (4.15%). The CO levels are once again very low, averaging only 7 ppm. There were no problems with incomplete combustion with the low volatile coal while operating under the same conditions as the baseline coal.

Figure 10. **Unit 1 Carbon Monoxide and Oxygen Distribution Baseline Coal (as found operating conditions)**

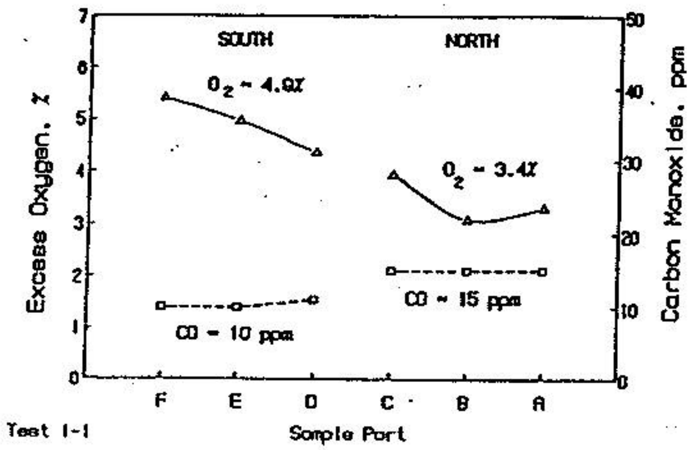


Figure 11. **Unit 1 Nitric Oxide and Oxygen Distribution Baseline Coal (as found operating conditions)**

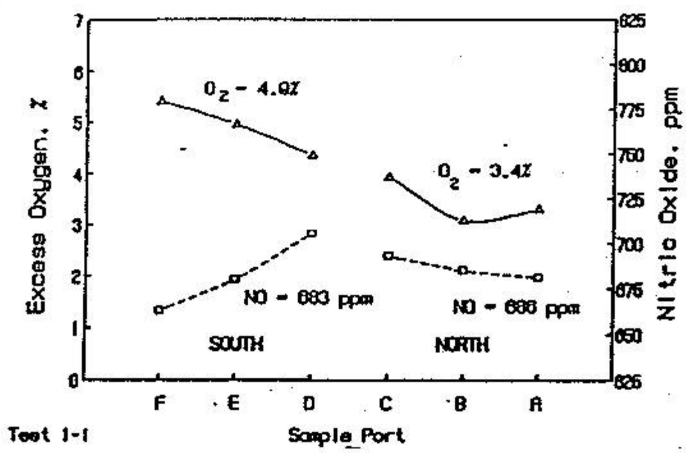


Figure 13 shows the NO/O_2 distribution for the same test. At nearly identical operating conditions and excess O_2 levels as the baseline coal, the NO levels showed a slight increase. The average NO concentration was 758 ppm.

Because the excess O_2 across the boiler varied across such a wide range (3.1% to 5.4%), balancing of the boiler was performed. This was accomplished with burner register adjustments. However, making adjustments to the burner registers on unit 1 has two effects. The secondary air flows can be increased or decreased at an individual burner, but this also impact the air/fuel mixing process by changing the axial to tangential momentum ratio at the burner exit. The degree of O_2 balancing possible is limited by the need to maintain good swirl characteristics (strong ignition points) at each burner.

Figure 12. **Unit 1 Carbon Monoxide and Oxygen Distribution Low Volatile Coal (as found operating conditions)**

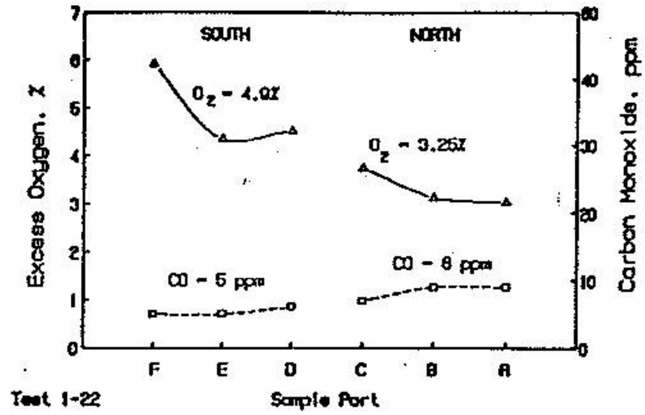
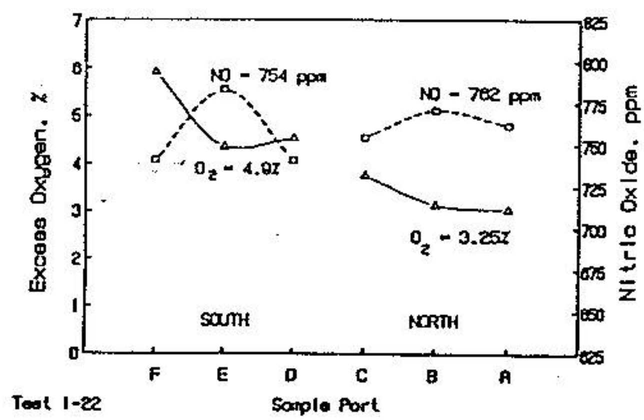


Figure 13. **Unit 1 Nitric Oxide and Oxygen Distribution Low Volatile Coal (as found operating conditions)**

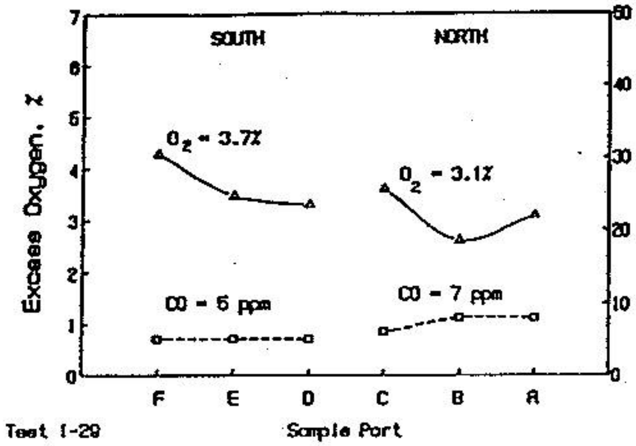


After the boiler O_2 was balanced as well as possible while maintaining strong ignition points at all burners, the excess O_2 level was decreased to determine the sensitivity of low volatile coal NO emissions to boiler O_2 level. The results are shown in Figures 14 and 15.

Figure 14 shows the CO/O_2 distribution for the balanced and reduced O_2 operating conditions on low volatile coal. The O_2 distribution is much more even, with a north duct O_2 average of 3.1% and a south duct average of 3.7%. The overall average O_2 was reduced from 4.1% at the baseline condition to 3.4%. Also, the

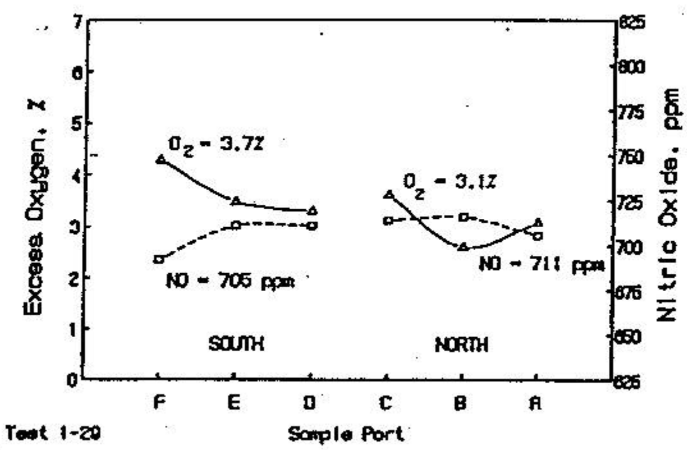
O_2 maldistribution between ducts on low volatile coal was reduced from 1.65% to 0.6%. Because of the better O_2 balance, the CO emissions remained very low while reducing the excess O_2. CO emissions averaged only 6 ppm.

Figure 14. **Unit 1 Carbon Monoxide and Oxygen Distribution Low Volatile Coal, Balanced/Reduced Oxygen Level**



The effect of balancing the air fuel ratios and reducing O_2 on low volatile coal NO emissions is shown in Figure 15. As can be seen, the NO emissions were uniform across the boiler and averaged 708 ppm. This value corresponds to an NO emissions rate of 1.01 lb/10^6 Btu which is in good agreement with the historical value of unit 1.

Figure 15. **Unit 1 Nitric Oxide and Oxygen Distribution Low Volatile Coal, Balanced/Reduced Oxygen Level**



Loss On Ignition

Isokinetic fly ash samples entering the ESP were taken at several different operating conditions for carbon analysis. the conditions shown in Table 2 are the baseline and low volatile coals as found, and the low volatile coal at a balanced, low O_2 condition.

Table 2
Carbon Content in the Fly Ash

	Avg O_2	Avg Carbon
Baseline Coal, Unbalanced	4.1%	8.4%
Low Volatile Coal, Unbalanced	4.0%	14.6%
Low Volatile Coal, Balanced	3.5%	12.4%

The low volatile coal does appear to be more sensitive to boiler balance and local O_2 level than the baseline coal. This is evidenced by the higher carbon content with low volatile coal in an unbalanced condition at the same O_2 level. Also, it does appear that carbon levels in the fly ash increased with low volatile coal, even as the fineness improved. This is counter intuitive to the normal practice of increasing fineness to minimize LOI.

Opacity/Particulate Emissions

During the entire test period, there were no indications of problems with opacity with either the baseline or low volatile coals. The opacity readings were steady and in the same range of 2-4%. There was no evidence of opacity deterioration over time with the low volatile coal.

As an assurance that there would be no particulate emissions problems with low volatile coal, EPA Method 5 tests were done at the final balanced condition. The measured particulate emissions rates average 0.008 lbs/10^6 Btu. This is in the range of baseline rates reported by NEP and well below the regulation.

In summary, the test coal performed well at SH #1, giving assurance to NEP of its viability as a fuel option for the Salem Harbor Station. Further analysis and optimization to fully understand LOI and NO behavior will be conducted on future cargoes of the now "qualified" Alpine coals.

Demonstration Burn of Low Volatile/Low Ash Fusion Coal

The success of the low volatile coal test burn on Salem Harbor unit 1 has allowed NEP to open the door to a new coal market, one which includes the use of low volatile coals as part of NEP's overall sulfur compliance strategies.

Due to these factors, NEP was able to take advantage of the opportunity to evaluate a low volatile compliance coal that met their fuel specifications with one exception, the ash fusion temperature of 2370°F was below their specification.

The objective of this diagnostic engineering program was to determine the impact on the slagging and fouling characteristics of this coal in the Salem Harbor boilers. Boiler 3 was selected for this investigation and the Pocahontas coal was introduced into boiler 3 in November 1990.

The results of these tests demonstrated that the Pocahontas coal could be fired in the Salem Harbor boilers following normal plant operating procedures. The primary furnace of unit 3 appeared clean and free of slag, and the ash in the superheater was friable and easily removed by the existing soot blowers. Salem Harbor boilers 1, 2 and 3 have been successfully operating on the Pocahontas low volatile, compliance coal from November 1990 into February 1991. Table 3 shows a summary analysis of the as-received Pocahontas #3 seam coal.

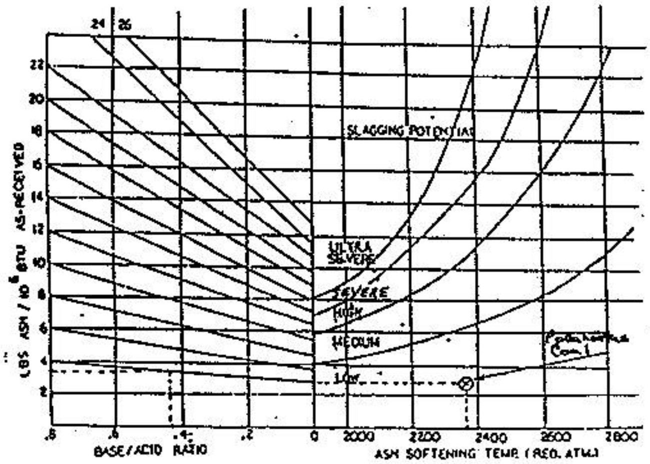
Table 3. Pocahontas #3 Seam Coal Analysis

Base/Acid Ratio	0.42
Initial Deformation Temperature	2370°F
As-Received Ash (%)	4.83
As-Received HHV (Btu/lbm)	14,079
lbs Ash/10^6 Btu (As-Received)	3.43
% Volatiles (Dry)	18.23%

Visual observations of the Salem Harbor unit 3 primary furnace while firing the Pocahontas low volatile coal showed them to be relatively clean and free of slag for the entire test period. The only area where there was a slight indication of plastic slag was on the eyebrow formations over the individual burners. these eyebrows were basically the same size and shape as those experienced on the high volatile coals and the Alpine coal previously tested. The eyebrows were also in a steady state condition, that is, not growing. Samples taken from the furnace walls and eyebrows showed the deposits to be friable and easily removed with the scoop sampler.

Figure 16 shows a slagging potential nomograph developed from full scale utility boiler empirical data as part of a series of slag investigations on a range of coals and boiler types. Using the fuel analysis of the Pocahontas coal provided by NEP, it can be seen that this coal has a very low ash loading of 3.43 lbs/10^6 Btu, with a medium base/acid ratio (0.42) which places it into the flat region of the curve. Taking into account the ash softening temperature, the Pocahontas coal slagging potential falls in the low range. This correlates well with what was experienced and observed on the Salem Harbor unit 3 tests. In addition, this data shows that with the low level of total ash loading of this coal, it would remain in the low slagging potential range even if the ash softening temperature were reduced. Thus, the ash softening temperature for this particular coal is not critical to its potential slagging characteristics as long as the total ash content remains low.

Figure 16. Slagging Potential - Nomograph



CONCLUSIONS

The full scale test burn program proved conclusively that low volatile, eastern bituminous coals (to a percent volatility of approximately 18% dry basis) can be fired safely in the Salem Harbor boilers 1, 2 and 3 using standard station operating procedures. It was specifically shown that:

- At full load and reduced loads, the boilers show stable and consistent flame pattern with strong ignition points near the burner throats.
- The primary furnace remained clean with no evidence of slagging at all conditions tested, including the low ash fusion Pocahontas coal.
- No operational difficulties with mills and feeders were experienced with the low volatile coal tested even under some severe rain conditions that existed during May 1990.
- Low volatile coal is a Btu grade, low ash, low sulfur coal that NEP is now evaluating as part of their various strategies for meeting compliance with regard to sulfur emissions.
- More immediate benefits, however, have been realized as a result of the low volatile test program. The confidence gained through this project has allowed NEP to sign a multi-year contract with Island Creek Coal Company

resulting in fuel cost savings of $10 to $11M over the next four years. In addition, O&M costs associated with reduced pulverizer power consumption and lower maintenance costs due to the high grindability of the low volatile coal, translate into several hundred thousand dollars per year.

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