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DEVELOPMENT AND TESTING OF A HIGH EFFICIENCY ADVANCED COAL COMBUSTOR PHASE III INDUSTRIAL BOILER RETROFIT

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Prepared by:

Mr. R. W. Borio - Program Manager, ABB/C-E

Principal Investigators:

Mr. R. L. Patel, ABB/C-E
Mr. D. E. Thornock, ABB/C-E
Prof. A. W. Scaroni, Penn State
Mr. B. G. Miller, Penn State
Prof. J. G. McGowan, University of Massachusetts

ABB/Combustion Engineering
Power Plant Laboratories
1000 Prospect Hill Road
Windsor, Connecticut 06095

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PETC Project Manager: Mr. Douglas F. Gyorke

Pittsburgh Energy Technology Center
U.S. Department of Energy
P.O. Box 10940
Pittsburgh, Pennsylvania 15236

TECHNICAL STATUS

This technical report is being transmitted in advance of DOE review and no further dissemination or publication shall be made of the report without prior approval of the DOE Project/Program Manager. This report is being transmitted as a draft for review by the DOE Project/Program Manager. If no revisions are received within 30 days, this draft report will become the final report.

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Executive Summary

The objective of this project is to retrofit a burner, capable of firing microfine coal, to a standard gas/oil designed industrial boiler to assess the technical and economic viability of displacing premium fuels with microfine coal. This report documents the technical aspects of this project during the sixteenth quarter (July '95 through September '95) of the program.

The overall program has consisted of five major tasks:

1.0 A review of current state-of-the-art coal firing system components.
2.0 Design and experimental testing of a prototype HEACC (High Efficiency Advanced Coal Combustor) burner.
3.0 Installation and testing of a prototype HEACC system in a commercial retrofit application.
4.0 Economics evaluation of the HEACC concept for retrofit applications.
5.0 Long term demonstration under commercial user demand conditions.

Work under Task 5 of this program continued during this reporting period. Activities at Penn State focused on completing the installation of a new soot blower in the convective pass which extends to convective pass entrance; installation of the new ABB's RSFC-based burner and quarl; shaking down the new coal handling system; and firing micronized coal. Starting from July 10 '95 new RSFC-based burner was installed and demonstration testing is in progress. Initial testing with this new burner has demonstrated, as expected, significantly improved performance (i.e., excellent flame shape/stability, lower NOx and higher combustion efficiency) on both gas and coal firing compared to the HEACC burner. Therefore, ABB CE and Penn State have decided to continue this demonstration phase testing with ABB's new RSFC-based micronized coal burner. The detailed test plan (Attachment A) was prepared and submitted to DOE-PETC for their review /approval. Approximately 105, 15, and 115 hours have been accumulated firing natural gas, cofiring gas and micronized coal, and 100% micronized coal, respectively, through end of September '95. A meeting with DOE PETC was held on September 21, 1995, at Penn State to review /discuss the overall progress made to date on the Task 5 1000 hr demonstration testing and to discuss with DOE PETC the possibility of using the same RSFC-based burner for Penn State's CWS demonstration project.

Results with the RSFC-based burner while firing both 100% natural gas and 100% coal show significant improvement over those obtained for the HEACC burner during the previous Task 3 testing. For natural gas firing, when the boiler was perfectly clean (i.e., without any ash deposits), NOx values were on the order of ~45 to 55 ppm (calculated @ 3% O2) and CO on the order of ~40 to 60 ppm (calculated @ 3% O2). After coal had been burned in the furnace and residual ash deposits were present, operation on natural gas resulted in NOx values on the order of 70 ppm. The NOx values for the HEACC were ~140 to 190 ppm (@ 3% O2) and the CO was on the order of 10 to 30 ppm (@ 3% O2), and boiler cleanliness (ash deposition) did not show any significant sensitivity on NOx emissions. Results, with the RSFC-based burner, while firing 100% coal on a continuous basis show that NOx emissions can be maintained around ~360 - 420 ppm (which is lower than the project target of 443 ppm (0.6

lb/MBtu)) with combustion efficiencies of ~96 - 97% (somewhat below ~98% project target). Excellent flame shape/stability can be maintained with this ABB's RSFC-based burner. At the higher NOx (~550 ppm) emissions, ~98-99% combustion efficiency can also be achieved in this very small boiler with the bulk gas residence time of ~0.75 second. Long-term coal firing testing is in progress to generate the information/data on management of ash and its impact on boiler performance.

A technical paper "Microfine Coal Firing Results from a Retrofit Gas/Oil-Designed Industrial Boiler" was presented at the Eleventh Annual Coal Preparation, Utilization and Environmental Control Contractors Review Meeting, held in Pittsburgh, during July 12-14, 1995.

During the next quarter we plan to continue and complete Task 5 demonstration testing per Demonstration Test Plan, log ~1000 hrs with various typical industrial gas/oil-designed boiler operational conditions while firing micronized coal to demonstrate the technical viability of the complete system (microfine coal firing in gas/oil-designed boiler). Long-term round the clock testing and generating data /information on management of ash will be one of the key elements of this demonstration testing.

1.0 Introduction

The objective of this project is to retrofit a burner capable of firing microfine coal to a standard gas/oil designed industrial boiler to assess the technical and economic viability of displacing premium fuels with microfine coal. A complete microfine pulverized coal milling and firing system will be retrofitted to an existing 15,000 lb/hr package boiler located in the East Campus Steam Plant of the Pennsylvania State University.

Following a brief burner confirmation test at ABB/CE's Power Plant Laboratories, the complete retrofit milling and firing system at Penn State will be run for a total of 400 hours on microfine coal to obtain performance and economic data for comparison against a base fuel (natural gas) case. Pending acceptable technical and economic results, a 1000 hour test will then be run under normal user demands to evaluate the system's capability to perform acceptably under field conditions. It is expected that a successful outcome of this program will help facilitate the acceptance of clean coal technology by American industry. The technical approach chosen for this program, namely direct firing of dry microfine pulverized, low ash coal is the fastest track technology available to displace significant quantities of oil and natural gas in industrial equipment.

2.0 Task 1 Design, Fabricate and Integrate Components

Complete

3.0 Task 2 Preliminary System Tests at ABB Combustion Engineering

Complete

4.0 Task 3 Proof-of-Concept-Tests at Penn State

Complete

5.0 Task 4 Economic Evaluation and Commercialization Plan

No work was scheduled or performed during this quarter.

6.0 Task 5 Site Demonstration

6.1 Summary of Quarterly Activities

Task 5 work continued during this reporting period. Activities during this reporting period focused on installing the burner, characterizing the burner on natural gas, conducting baseline natural gas tests, performing cold flow tests in the boiler, and firing the burner on micronized coal. A summary of monthly activities is presented followed by discussions of the burner/system operability, burner characterization firing natural gas and micronized coal, and combustion and boiler performance when firing natural gas and micronized coal. Approximately 105, 15, and 115 hours have been accumulated firing natural gas, cofiring gas and micronized coal, and 100%

micronized coal, respectively, through end of September '95. A meeting with DOE PETC was held on September 21, 1995, at Penn State to review /discuss the overall progress made to date on the Task 5 1000 hr demonstration testing and to discuss with DOE PETC the possibility of using the same RSFC-based burner for Penn State's CWS demonstration project. Hard copies of all the slides/ view graphs that were presented during this review meeting are attached (Attachment B) with this quarterly report.

Results with the RSFC-based burner while firing both 100% natural gas and 100% coal show significant improvement over those obtained for the HEACC burner during the previous Task 3 testing. For natural gas firing, when the boiler was perfectly clean (i.e., without any ash deposits), NOx values were on the order of ~45 to 55 ppm (calculated @ 3% O2) and CO on the order of ~40 to 60 ppm (calculated @ 3% O2). After coal had been burned in the furnace and residual ash deposits were present, operation on natural gas resulted in NOx values on the order of 70 ppm. The NOx values for the HEACC were ~140 to 190 ppm (@ 3% O2) and the CO was on the order of 10 to 30 ppm (@ 3% O2), and boiler cleanliness (ash deposition) did not show any significant sensitivity on NOx emissions. Results, with the RSFC-based burner, while firing 100% coal on a continuous basis show that NOx emissions can be maintained around ~360 - 420 ppm (which is lower than the project target of 443 ppm (0.6 lb/MBtu)) with combustion efficiencies of ~96 - 97% (somewhat below ~98% project target). Excellent flame shape/stability can be maintained with this ABB's RSFC-based burner. At the higher NOx (~550 ppm) emissions, ~98-99% combustion efficiency can also be achieved in this very small boiler with the bulk gas residence time of ~0.75 second. Long-term coal firing testing is in progress to generate the information/data on management of ash and its impact on boiler performance.

6.2 Summary of Monthly Activities

This section contains a summary of the activities conducted at Penn State from July through September 1995. Detailed results of the activities are contained in sections 6.3 through 6.6.

July '95

During July, activities focused on installation of the new ABB's RSFC-based burner, characterizing the burner on natural gas, conducting baseline natural gas tests, and characterizing the burner on coal. A day-by-day synopsis of the Penn State boiler operation for this quarter follows:

- July 3 -- The boiler was cleaned prior to starting the testing with the new burner. In addition, work started on installing a new convective pass sootblower. The new sootblower is longer than the original one and is capable of cleaning up to the convective pass entrance.
- July 4 -- Holiday
- July 5 -- A code welder from Kibbe Boiler Works welded a guide ring for the extended sootblower onto the boiler tubes. Installation of the sootblower was completed.
- July 6 -- The new quarl and new RSFC-based burner was installed.

- July 7 -- Curing the refractory quarl was started. Preliminary natural gas data was obtained.
- July 10 -- Curing the refractory quarl was completed. Burner characterization firing natural gas was conducted. The burner was removed and plates were welded on three of the six tertiary air inlets in order to increase air flow through the primary and secondary zones. The burner was reinstalled.
- July 11 -- Burner characterization firing natural gas was conducted. High burner pressure drop was limiting air through the burner.
- July 12 -- The burner was removed and the plates covering the tertiary air inlets were removed. The burner was reinstalled and burner characterization continued. High burner pressure drop was observed.
- July 13 -- Natural gas and coal cofiring was conducted. Coal was fired to test the new coal feed system and burner.
- July 14 -- Natural gas and coal cofiring was conducted for ~3.5 hours at firing rates of ~12 million Btu/h natural gas. The boiler flamed out when attempting to convert to 100% coal firing.
- July 17 -- The burner was removed and taken to Windsor, Connecticut for modifications. Modifications consisted of removing the primary and secondary air swirlers and installing tangential primary and secondary air inlets. 'Bubbles' were observed on the surface of the refractory quarl.
- July 18 through 20 -- An ash hopper was constructed, a coal sampling pipe was installed in the transition pipe between the weigh-belt feeder and rotary valve, and the quarl was ground to remove the 'bubbles' and pockets.
- July 21 -- The modified burner was installed and fired on natural gas with coal transport air. The windbox pressure was substantially less than prior to the modifications.
- July 24 -- The boiler was operated firing natural gas without coal t transport air.
- July 25 -- The boiler was fired with natural gas without coal transport air. Longer duration tests were conducted at 13.2 million Btu/h (75% load) with 1, 2, and 3% O2. Boiler efficiencies were calculated and summary sheet were prepared.
- July 26 -- The boiler was fired at 17 million Btu/h (full load) at 1.2% O2. A copy of boiler efficiency data is attached. After the natural gas test was completed, 100% coal firing was attempted. The boiler shut down when converting from coal and natural gas cofiring to 100% coal firing. The low atomizing air pressure alarm was observed. Upon closer examination it was noted that part of the atomizing air train (which contains a sensor to ensure that there is sufficient atomizing air prior to switching from natural gas/coal-water slurry fuel cofiring to 100% coal-water slurry fuel) was not replaced after installing the burner. Although atomizing air is not used during dry, micronized coal firing, the boiler interlocks contain this parameter. The train was reinstalled with the sensor located between the atomizing air source and a valve which is closed when firing dry, micronized coal.
- July 27 -- The boiler was fired on 100% coal for burner characterization. Ash and coal samples were collected. Burnout ranged from 81% to 86%.
- July 28 -- The boiler was fired on 100% coal for burner characterization. Burnout ranged from 86% to 87%.
- July 31 -- The floor ash sparge system was installed.

August '95
During August, activities focused on characterizing the burner on natural gas, conducting baseline natural gas tests, and characterizing the burner on coal. A day-by-day synopsis of the Penn State boiler operation for August follows:

- August 1, -- On July 31, a coal test was started but the inverter and rotary valve motor failed. The rotary valve was dismantled to determine the cause of the shutdown. On August 1, the rotary valve was reassembled and the problem identified. The motor and variable speed drive inverter were damaged. A motor was ordered (with next day delivery) and an inverter was obtained from a coal handling/processing construction company. In addition, a natural gas test was conducted firing at 8.6 million Btu/h (50% load). The boiler efficiency was calculated. Copies of the boiler efficiency and summary sheet (which has been added to the July results) are attached.
- August 2 -- The inverter and motor for the rotary valve were installed. The burner was removed and approximately 0.5" from the primary air zone was removed to increase the primary air flow area. The burner was then reinstalled.

  August 3 -- The boiler was fired on 100% coal for ~ 12 hours for burner characterization. Coal and baghouse ash samples were obtained and burnout ranged from 84 to 93%.
- August 7 -- A shipment of Middle Kittaning seam coal was received and unloaded into the 25-ton hopper. All testing conducted during the rest of the month was with Middle Kittaning except for approximately two tons of Upper Freeport seam coal which was in the surge bin. Coal firing was not conducted on this date because the bearing on the transfer fan (located between the TCS mill and burner) failed.
- August 8 -- A new bearing was installed on the transfer fan. A section of the cylindrical extension was removed and the 8" extension was welded into the burner between the secondary and tertiary air zones. The burner was reinstalled and characterized firing natural gas and 100% coal (for two hours). Coal and baghouse ash samples were obtained and burnout ranged from 90 to 92%.
- August 9 -- The boiler was fired on 100% coal for 8 hours for burner characterization. Two 2-hour tests were conducted with coal, baghouse ash, and cyclone (which is located in the duct prior to the baghouse) ash samples were obtained. The first test was to minimize NOx emissions and the second test was to maximize coal combustion efficiency. NOx and coal combustion efficiency (based on the baghouse ash samples ranged from 300 to 390 ppm and from 93 to 95%, respectively for the first test. NOx and coal combustion efficiency ranged from 675 to 700 ppm and from 97 to 98%, respectively for the second test.
- August 10 -- The burner was removed from the boiler and the extension was removed from the burner. Six stainless steel perforated plates with an open area of 50% were installed on the tertiary air scoop inlets to increase the air flow through the primary and secondary air zones. The burner was reinstalled and characterized firing natural gas for three hours and 100% coal for five hours.
- August 11 -- OPP began their annual West Campus Steam Plant maintenance and started up the boilers in the East Campus Steam Plant (ECSP). The demonstration boiler, which is adjacent to the ECSP, was not operated during the maintenance period which lasted through August 18. On August 11, the boiler was drained to

reduce the temperature inside the boiler in order to perform burner air flow testing the following week. In addition, modifications to the ash screw mezzanine (located below the baghouse) were started. The modifications were necessary in order to raise the ash screw sot he fly ash hopper and cover can be placed directly below the screw outlet and form a dust-free fit. Additional activities included performing site and equipment maintenance.

- August 14 -- The burner was removed from the boiler in order to drill and tap holes. the ash was removed from boiler. Modifications to the ash screw and mezzanine, and site and equipment maintenance continued.
- August 15 -- Holes were drilled and tapped in the burner for performing pressure readings during the air flow tests. The burner was reinstalled in the boiler. The ash screw and mezzanine modifications were completed. Ash was removed from the breeching between the boiler and heat pipe combustion air preheater.
- August 16 -- Burner air flow testing was conducted. Installation of the final component (a staircase between the second and third mezzanine levels) to the coal handling modifications was started.

  August 17 -- Burner air flow testing continued. Installation of the staircase continued.
- August 18 -- Burner air flow testing was completed. For the final test, the burner was removed and the perforated plates were removed. The burner was reinstalled. Installation of the furnace ash blowdown system was started. Installation of the staircase was completed.
- August 21 -- Installation of the he furnace ash blowdown system was completed. The boiler was filled with water and burner characterization testing restarted. Natural gas and coal testing was conducted for approximately two hours.
- August 22 -- The boiler was fired on natural gas for six hours for burner characterization.
- August 23 -- The boiler was fired on natural gas for six hours and on 100% coal for five hours for burner characterization. Coal, cyclone ash, and baghouse ash samples were obtained and burnout ranged from 85 to 87% and from 87 to 91% based on the cyclone ash and baghouse ash samples, respectively.
- August 24 -- The boiler was fired on 100% coal for 8.5 hours for burner characterization. Coal, cyclone ash, and baghouse ash samples were obtained and burnout ranged from 89 to 95% based on the cyclone ash sample. The baghouse ash samples are currently being analyzed.
- August 25 -- The boiler was fired on 100% coal for 4.5 hours for burner characterization. Coal, cyclone ash, and baghouse ash samples were obtained and are currently being analyzed.
- August 28 -- The boiler was fired on 100% coal for eight hours for burner characterization. Coal, cyclone ash, and baghouse ash samples were obtained and burnouts ranged from 87 to 96% and from 93 to 96% based on the cyclone ash and baghouse ash samples, respectively.
- August 29 -- The boiler was fired on 100% coal for 6.5 hours for burner characterization. Coal, cyclone ash, and baghouse ash samples were obtained and burnout ranged from 94 to 96% and from 95 to 97% based on the cyclone ash and baghouse ash samples, respectively.

- August 30 -- The boiler was fired on 100% coal for 6.5 hours for burner characterization and suction pyrometery. Coal, cyclone ash, and baghouse ash samples were obtained and burnout ranged from 93 to 96% and from 94 to 97% based on the cyclone ash and baghouse ash samples, respectively.
- August 31 -- The boiler was fired on 100% coal for six hours for burner characterization. Coal, cyclone ash, and baghouse ash samples were obtained and burnout ranged from 94 to 96% and from 95 to 96% based on the cyclone ash and baghouse ash samples, respectively.

September '95

During September, activities focused on characterizing the burner on coal, preparing for and attending a U.S. Department of Energy (DOE)/ABB CE/Penn State project review meeting, repairing the boiler feedwater pump, and performing equipment maintenance and repair. A day-by-day synopsis of the Penn State boiler operation for September follows:

- September 1 -- Work started on replacing the sheave on the TCS, Inc. mill to increase the mill speed from 1,940 to 2,080 rpm in order to reduce the coal particle size.
- September 4 -- Holiday
- September 5 -- Work on replacing sheaves on the mill was completed. Attached is a spreadsheet listing the coal particle size distribution for samples isokinetically collected at the burner inlet before and after increasing the mill speed. A decrease in the particle size was observed.

  A shipment of Middle Kittaning seam coal was received. All testing in September was with Middle Kittaning seam coal.

  The boiler was operated on a two-shift per day basis. Two hours of steady-state boiler operation was conducted after replacing the sheave. The coal combustion efficiency, based on baghouse particulate samples, was 97.5%. A summary of the test is contained in a coal-fired summary sheet which is attached.

  The boiler was then operated for an additional hour after changing the swirler settings. Operational parameters are listed in the burner characterization summary sheet which is attached. This summary sheet contains the burner characterization results for testing conducted from 07/24/95 through 09/07/05.
- September 6 -- The boiler was fired on 100% coal for ~10.5 hours for burner characterization. Coal, baghouse ash, and cyclone ash samples were collected. NO_x and coal combustion efficiency (based on the baghouse samples) ranged from 403 to 600 ppm and 96.2 to 96.9, respectively.
- September 7 -- The boiler was fired on 100% coal for ~10.5 hours for burner characterization. Coal, baghouse ash, and cyclone ash samples were collected. NO_x and coal combustion efficiency (based on the baghouse samples) ranged from 414 to 526 ppm and 95.6 to 96.8, respectively. During boiler shutdown, the feedwater pump failed.
- September 8 -- The feedwater pump was removed and driven to a pump vendor for inspection and repair. It was determined that the pump was not repairable and must be replaced.

- September 11 through 20 -- The boiler was not operated due to feedwater pump, motor, and electrical component procurement. Activities that were conducted during this period include:
  - Identified and ordered the feedwater pump/motor combination and necessary electrical components;
  - Performed data reduction for August and September testing;
  - Completed the analysis of all coal and ash samples collected in August and September;
  - Removed the burner and delivered to ABB CE for cold flow testing;
  - Prepared information for a DOE/ABB CE/Penn State project review meeting;
  - Conducted equipment and instrumentation maintenance and repair which included replacing the bearing on the Redler conveyor, removing, cleaning, and reinstalling the cage mill bearing, inspecting the cage mill internals (with mill serviceman) to identify replacement materials for worn parts, and getting the steam orifice operational; and
- Installed a railing and ladder on the ash screw mezzanine.
- September 21 -- Attended a DOE/ABB CE/Penn State project review meeting. Information that was prepared for the meeting is attached. This includes plots of coal combustion efficiency as a function of time and plots of CO and NO_X emissions as a function of time for testing conducted in August and September, burner characterization results, coal particle size distributions for samples collected at the burner inlet, coal-fired testing summary, and boiler efficiencies for testing conducted in August and September.
- September 22 -- The boiler and ducting connecting the boiler to the heat pipe heat exchanger were cleaned and the ash collected and weighed. Dismantling of the cage mill began in order to install new striking plates on the cage mill bars.
- September 25 -- The cage mill was disassembled and the striking plates were removed.
- September 26 -- New striking plates were installed in the cage mill. Started assembling the floor ash sparge system in the boiler.
- September 27 -- The cage mill was reassembled. Work continued on installing the floor ash sparge system in the boiler.
- September 28 -- The burner was returned to Penn State by ABB who borrowed it during boiler down time. The floor ash sparge system was installed in the boiler. Beitzel Inc., a coal handling/processing construction company, was on site replacing the switchgear in the motor control center and installed conduit and wires for the new feedwater pump (to be delivered October 2, 1995). Electrical components had to be replaced because the new motor is larger (50 hp compared to 20 hp).
- September 29 -- Beitzel Inc. completed the electrical work. The burner was reinstalled.

6.3 Burner/System Operability

The coal handling system was modified (as discussed in last quarterly report), to improve coal flowability from the surge bin to the mill, and to provide an instantaneous and constant coal feed rate to the mill and burner. Prior to the modifications, coal feed rate was determined by using coal curves (coal feed rate as a function of screw speed). The coal curves were generated with each coal shipment or when the coal moisture content varied by drying in the hoppers. The new system (Figure 1) with the weigh-belt feeder provides an instantaneous coal feed rate.

During the testing in Task 3, coal handling problems were attributed to burner instability. Figures 2 and 3 are graphs of O_2 and CO emissions as a function of time during two steady-state tests conducted in December 1993 and April 1994, respectively, in which the coal combustion efficiency was ~95%. The data were plotted in this manner to determine if CO excursions and burner instability were a function of coal slugging and hence, O_2 variability. In Figure 2, O_2 varied from ~2.4 to 3.8% (~1.5%) and CO varied from 100 to 500 ppm with excursions. Figure 3 exhibited similar trends with O_2 varying from 2.5 to 4.5%. However, CO emissions varied significantly ranging from 100 to >1,500 ppm.

Similar plots were prepared from testing conducted after the coal feed system was modified. Figure 4 shows the O_2 and CO emissions for testing conducted on 08/03/95. This was one of the first full-day tests firing coal and burner settings (primary, secondary, and tertiary air damper, coal gun positioning) were constantly changed. This is reflected in the figure as O_2 varied from 1.8 to 4.0% and CO varied from 100 to >1,800 ppm. Testing conducted later in the month, after more optimum burner settings were identified (Figure 5), resulted in fairly constant CO emissions but still exhibited O_2 fluctuations up to 1%. O_2 variations over four separate periods were 3.4-4.4, 2.8-3.8, 2.4-3.0, and 3.4-3.8%. The burner stability during the testing this reporting period was good. Pressure readings in the boiler were constant and the flame shape remained constant when set.

In order to address the O_2 fluctuations, the knife gate, which sets the height of the coal bed on the weigh-belt feeder, was adjusted to decrease the bed height. This was done to produce a more uniform coal bed on the belt. Figures 6 through 9 show the emissions as a function of time for tests conducted on August 25, 28, 30, and September 5, 1995. The knife gate was lowered prior to testing on August 25, and lowered still further prior to testing on August 28. This did not seem to have much of an affect as the O_2 fluctuations were still ~1%. CO emissions were very stable during the testing.

In order to identify the cause of the O_2 fluctuations, the coal transfer air flow and oxygen concentration were plotted as a function of time. Fuctuations in O_2 were not observed when firing natural gas. Figures 10 and 11 are one-hour plots of coal transfer air flow and O_2 concentration as a function of time for testing conducted on August 3 and 30, 1995, respectively. The coal transfer air flow is an instantaneous reading whereas there is a lag of approximately 90 seconds in the O_2 concentration recording. With this in mind, there is not an obvious trend observed between the parameters. At times the O_2 concentration appears to track with the transfer air variations, at other times there appears to be an inverse relationship. Because the mill air flow is approximately 11% of the total air flow, the variations of 10 to 20 acfm (<1% of the total combustion air flow) are not expected to account for the 1% fluctuations in O_2. The inverse relationship may be due to variations in the coal flow delivered to the burner. Coal variations were not suspected to be due to the weigh-belt feeder. The coal fed to the mill is relatively constant as shown in Figure 12. Figure 12 is a plot of coal feed rate and O_2 concentration for the same one-hour period shown in Figure 10. The average coal feed rate was 19.1 lb/m and varied from approximately 19.35 to 18.9 lb/m (~1% deviation from the mean). Coal feed variations may be the result of coal dropping out in the transfer line when the transfer air flow decreases and is then re-entrained when the transfer air flow increases. An amp meter for the mill that is capable of providing a signal that can be integrated into the data acquisition system will be installed to compare transfer air flow and mill amps to determine if the coal is accumulating in the mill and periodically being discharged to the burner.

6.4 Burner Characterization/Combustion and Boiler Performance

Table 1 is a summary of the burner characterization that was conducted during this reporting period. The first two columns contain the date and time when the operational parameters were recorded. Data were recorded either every half hour or whenever operational changes (e.g., burner settings, O_2 concentration, firing rate, etc.) were made. When testing was conducted for an extended period of time without making operational changes, data collected by the data acquisition system was averaged and summarized in Tables 2 and 3 (Summary of Natural Gas Baseline Testing and Summary of Coal-Fired Testing, respectively) rather than listed in Table 1.

A summary of the testing that was conducted during this reporting period is:

- July 24 -- Natural gas firing;
- July 25 -- Natural gas firing and natural gas baseline testing at 75% load and O_2 concentrations of 3, 2, and 1%;
- July 26 -- Natural gas baseline testing at 100% load;
- July 27 -- Micronized coal firing;
- July 28 -- Micronized coal firing;
- July 31 -- Micronized coal firing;
- August 1 -- Natural gas baseline testing at 50% load;
- August 3 -- Micronized coal firing;
- August 8 -- Natural gas testing followed by micronized coal firing;
- August 9 -- Micronized coal firing;
- August 10 -- Natural gas testing followed by micronized coal firing;
- August 21 -- Natural gas firing;
- August 22 -- Natural gas firing;
- August 23 -- Natural gas testing followed by micronized coal firing;
- August 24 -- Micronized coal firing;
- August 25 -- Micronized coal firing;
- August 26 -- Micronized coal firing;
- August 29 -- Micronized coal firing;
- August 30 -- Micronized coal firing;
- September 5 -- Micronized coal firing;
- September 6 -- Micronized coal firing; and
- September 7 -- Micronized coal firing.

6.4.1 Natural Gas Testing

Table 2 is a summary of the natural gas baseline tests conducted with the RSFC-based burner. Five tests were conducted, three at 75% load (13.2 million (MM) Btu/h), one at full load (17.1 MM Btu/h), and one at 50% load (8.6 MM Btu/h) with boiler efficiencies ranging from 82.8 to 83.6%. Copies of the boiler efficiency calculations are contained in Appendix A. Figure 13 shows the boiler efficiencies as a function of O_2 concentration for each load. Included in Figure 13 are the HEACC results when firing at 100 and 75% load. The boiler efficiencies for the tests conducted at 100% load were similar, approximately 83%, for both the HEACC and RSFC-based burner testing. The boiler efficiencies at 75% load, with the HEACC burner were approximately 1% higher than those for the RSFC-based burner. This is due to lower dry flue gas losses during the HEACC tests. The flue gas temperature leaving the air preheater was ~50° higher when performing the RSFC-based burner tests.

6.4.2 Micronized Coal Testing

Summaries of the micronized coal testing that was conducted during this reporting period are given Tables 1 and 3. The majority of the testing was conducted to determine optimum burner settings. The damper settings and gun position are recorded in Table 1, which includes a summary of micronized coal testing. The results from this work were used to develop a test matrix which will be performed during the next reporting period. A test matrix is listed in Section 6.6.

When testing was conducted for an extended period of time without making operational changes, data collected by the data acquisition system was averaged and summarized in Table 3 rather than listed in Table 1. Boiler efficiencies were determined for the extended test periods listed in Table 3 and copies of the calculations are contained in Appendix A. Two coals from Pennsylvania, the Upper Freeport and Middle Kittanning seams, were used in the testing. The analyses of the coals are given in Table 4.

Combustion Performance

Particulate samples were collected at two locations and analyzed for ash content to determine coal combustion efficiency. Samples were collected prior to the baghouse using a cyclone sampler located in the duct, and from the baghouse discharge (ash screw conveyor). These results are shown in Figures 14 through 25, which are plots of the coal combustion efficiency as a function of time when collected. The graphs also show when sootblowing occurred. Sootblowing includes cleaning the boiler convective pass (with a steam sootblower), boiler floor (with a compressed air floor ash blowdown system), and heat-pipe heat exchanger (with compressed air). In Figures 15 through 25, periods identified by the 'blowdown' refer to all sootblowing at all three locations. In Figure 14 (08/03/95), the convective pass sootblow and floor ash blowdown were conducted at two different times.

During this optimization period, coal combustion efficiencies (based on the baghouse samples) ranged from the mid to high 80's to 97.8%. Combustion efficiencies approaching 97% (96.5-96.8%) were routinely achieved.

Emissions

Emissions data, NO_X and CO, as a function of time are also included in Figures 14 through 25 to compare them with combustion efficiency. NO_X and CO emissions varied from 131 to 701 and from 74 to 515 ppm, respectively. Figure 26 shows the relationship between NO_X and CO emissions and coal combustion efficiency for the steady-state testing listed in Table 3. NO_X and CO emissions varied from 0.38 to 0.88 and from 0.10 to 0.22 lb/MM Btu, respectively.

Coal Particle Size Distribution

On September 1, 1995, the TCS mill speed was increased by changing sheaves in order to reduce the coal particle size. Typically the mill is operated at 1,930 rpm. A 12" sheave was replaced with a 13" sheave and the mill speed was increased to 2,080 rpm. Coal particles were sampled near the burner inlet prior to and after changing the sheaves. The coal was collected using ASTM D197-87 (Standard Test Method for Sampling and Fineness of Pulverized Coal). Coal particle sizing was conducted using a Malvern 2600 Particle and Droplet Sizer. The results are listed in Table 5 and indicate a reduction in the particle size with the higher mill speed. A comparison is given in Table 6 with results from the Task 3 work. As can be seen, there is a significant reduction in the coal particle size for the latter testing. This appears to be reflected in the coal combustion efficiency which are consistently near 97% for the testing conducted on September 5, 6, and 7.

6.5 Ash Deposition/Accumulation

Preliminary work on ash deposition and accumulation in the boiler system was started. This included monitoring sootblowing frequency and the quantity of ash retained in the boiler system after consuming a known quantity of coal.

Typically the boiler outlet and baghouse inlet temperatures are monitored and the convective pass steam sootblower operated when the boiler outlet temperature reaches ~600°F. The baghouse inlet temperature approaches 400°F as the boiler outlet temperature reaches 600°F and this is the upper limit set for comfortable operation.

The sootblowing frequency when firing the Middle Kittanning seam coal is similar to that when firing Brookville seam, Kentucky, and Upper Freeport seam coals tested earlier on this and other DOE-PETC funded projects. Approximately 3,000 to 10,000 lb of Middle Kittanning seam coal was consumed between sootblowing events.

On August 14, the boiler and connecting breaching between the boiler and heat-pipe heat exchanger were cleaned. After operating through September 7, the boiler and breaching were cleaned again and 212 and 123 lb of ash were removed from the boiler and breaching, respectively. Approximately 97,500 lb of coal were consumed, and using an average of 5.25% ash, approximately 4,150 lb of ash were introduced into the boiler. This translates into ~8% of the ash being retained in the boiler system during two-shift per day operation. To date, ash accumulation and deposition have not been a problem (i.e., causing a forced shutdown) during two shift/day operation. This is consistent with past operation after the floor ash blowdown system was installed. It is deposition during continuous operation (24 h/day) that must be investigated because past continuous operation (during testing in November 1994) has resulted in 20 to 25% of the ash introduced into the boiler being retained primarily as tube deposits in the furnace. Ash deposition during continuous boiler operation will be investigated during the next reporting period.

6.6 Next Quarter's Plan -

During the next quarter we plan to continue and complete Task 5 demonstration testing per Demonstration Test Plan, log ~1000 hrs with various typical industrial gas/oil-designed boiler operational conditions while firing micronized coal to demonstrate the technical viability of the complete system (microfine coal firing in gas/oil-designed boiler). Long-term round the clock testing and generating data /information on management of ash will be one of the key element of this demonstration testing.

Fine tuning of the burner to maximize the carbon burnout (~98% - project target) and lowest NOx emissions (less than the project target of 0.6 lb/MBtu) will be continued during the next quarter. The following test matrix will be conducted while firing micronized coal. The matrix will be modified as the testing is conducted. There is duplication of testing included in the matrix as a check on reproducibility. If the reproducibility is good, then some tests will be eliminated.

TEST MATRIX

Primary Damper (% Open)	Secondary Damper (% Open)	Tertiary Damper (% Open)	Radial Scoop (% Open)
(1) The effect of closing primary damper on combustion performance and flame characteristics will be determined.			
100%	100%	50%	0%
100%	100%	50%	100%
100%	100%	50%	25%
100%	100%	50%	50%
50%	100%	50%	0%
50%	100%	50%	100%
50%	100%	50%	25%
50%	100%	50%	50%
0%	100%	50%	0%
0%	100%	50%	100%
0%	100%	50%	25%
0%	100%	50%	50%
(2) The effect of secondary damper position on combustion performance and flame characteristics will be determined.			
100%	100%	50%	0%
100%	100%	50%	100%
100%	100%	50%	25%
100%	100%	50%	50%
100%	50%	50%	0%
100%	50%	50%	100%

100%	50%	50%	25%
100%	50%	50%	50%
100%	0%	50%	0%
100%	0%	50%	100%
100%	0%	50%	25%
100%	0%	50%	50%

(3) The effect of reducing tertiary air on combustion performance and flame characteristics will be determined.

100%	0%	100%	0%
100%	0%	100%	100%
100%	0%	100%	25%
100%	0%	100%	50%
100%	0%	75%	0%
100%	0%	75%	100%
100%	0%	75%	25%
100%	0%	75%	50%
100%	0%	25%	0%
100%	0%	25%	100%
100%	0%	25%	25%
100%	0%	25%	50%
100%	0%	0%	0%
100%	0%	0%	100%
100%	0%	0%	25%
100%	0%	0%	50%

(4) At optimum primary, secondary, and tertiary air damper settings determined from testing items 1 through 3, the effect of gas and coal gun positions on combustion performance and flame characteristics will be determined.

(5) The effect of mill air flow (300, 360, and 400 acfm), at optimum conditions for burner settings and gun positions, on combustion performance and flame characteristics will be determined.

(6) The effect of excess air (3-3.5, 3.5-4.0, and 4.0-4.5% O_2) on combustion performance and flame characteristics will be determined.

(7) The effect of turndown ratio, at optimal conditions, on combustion performance and flame characteristics will be determined.

Ash deposition and accumulation during continuous boiler operation will also be investigated. Portions of the matrix testing will be conducted during continuous boiler operation.

7.0 Task 6 Decommission Site

No work was scheduled or performed during this quarter.

8.0 Task 7 Project Management

During this reporting period, work included the preparation of required technical, schedular and financial monthly and quarterly reports. A technical paper "Microfine Coal Firing Results from a Retrofit Gas/Oil-Designed Package Boiler" (Attachment C) was presented at the Eleventh Annual Coal Preparation, Utilization and Environmental Control Contractors Review Meeting, held in Pittsburgh, during July 12-14, 1995.

Attachment - A

Task 5
Penn State 1000 Hour Demonstration Test Plan

DEVELOPMENT AND TESTING OF
AN ADVANCED HIGH EFFICIENCY COAL COMBUSTOR
PHASE III INDUSTRIAL BOILER RETROFIT

DOE CONTRACT NO. DE-AC 22-91PC91160

C-E CONTRACT NO. 33691

Task 5 Penn State 1000 Hour Demonstration Test Plan

September 1995

Prepared For:

Mr. Douglas Gyorke
U.S. Department of Energy
Pittsburgh Energy Technology Center

Prepared by:

Program Manager
Mr. R. W. Borio, ABB/C-E

Principal Investigators:

Mr. R. L. Patel, ABB/C-E
Mr. D. E. Thornock, ABB/C-E
Prof. A. W. Scaroni, Penn State
Mr. B. G. Miller, Penn State
Prof. J. G. McGowan, University of Massachusetts

ABB Power Plant Laboratories
Combustion Engineering, Inc.
1000 Prospect Hill Road
Windsor, Connecticut 06095

Task 5 Penn State 1000 Hour Demonstration Test Plan

Introduction

The objective of this task is to conduct a 1000 hour test under typical industrial boiler load demands to demonstrate the technical viability of the system (microfine coal firing in a gas/oil designed boiler) and refine the economic evaluation. Data shall be collected to evaluate the system's combustion and thermal efficiency, ash deposition tendencies, gaseous and particulate emissions, micronized coal handling characteristics, and operability including turndown. Management of ash and it's impact on boiler performance will be a major focus of the demonstration task.

Combustion and Thermal Efficiency
The combustion performance when firing the microfine coal and the effect of burning it in an oil-designed boiler will be evaluated by firing approximately 600 tons of coal over 1000 hours. Temperature, pressures, fuel flow rates, and flue gas analysis (O2, CO, CO2, SO2 and NOx) will be continuously monitored. Fly ash samples will be collected from the baghouse and analyzed to determine carbon burnout and chemical composition. Material and energy balances will be conducted and heat release rate determined when firing microfine coal to evaluate boiler performance.

Management of Ash
Management of ash is seen as a key element of the demonstration testing. Two primary issues are, (1) the effect of ash deposits on heat transfer in the boiler and (2) the ability to successfully remove ash from the boiler. To provide useful information in both of the above categories it is essential that the boiler be run 24 hours per day for a number of consecutive days. Figure 1 shows that some of the weeks during the demonstration have been designated as 24-hour-per-day segments.

Based on observations from earlier tasks it is seen that ash which accumulates in the radiant section of the boiler can come from two sources: (1) from ash particles which drop to the floor from the flames, and (2) from deposits which slough off the water walls. The effects of each type of ash can be different. Deposits which form on water walls will have a greater impact on heat transfer than material which falls out of suspension to the hearth. If deposits on the walls do slough and fall to the flow, their sintered nature will make resuspension and removal much more difficult than the "dust" which falls directly to the hearth. Material which falls directly to the floor will not have a significant affect on heat transfer and, as noted above, will be easier to resuspend and remove. It will be very important during long term testing to establish whether steady state conditions have been reached. It could be argued, for example, that material which falls directly to the floor might eventually "fill in" relatively stagnant areas and reach a condition where no more material is draped out, but, rather all gets carried out in suspension. It is probably less likely that ash deposits which from on furnace walls would reach a similar steady state condition.

Currently the Penn State boiler is fitted with a soot blower (steam-operated) for cleaning the convective pass; this is a commercially-supplied device. Penn State personnel have designed, fabricated and installed an air sparge system which is located on the hearth of the radiant boiler with the intent that it resuspends floor material and allows it to pass out through the boiler.

The objectives of long-term tests, relative to ash management, are to characterize the impact of ash on long term boiler operation (for two different coals), to assess the performance of the two cleaning devices (convective pass soot blower, and radiant section air sparge), and finally to make recommendations for what would be needed to successfully manage the ash in a commercial situation.

Current Project Status

Based on all the results obtained to date (Task 1 through 4), the ABB/Penn State team and DOE/PETC decided to conduct a 1000 hr demonstration (Task 5) of this program. It was also decided to employ a new burner for this demonstration. The new burner is based on the concept called "Radially Stratified Flame Core (RSFC)", developed by MIT and licensed by ABB. The reason to go with RSFC-based burner in place of the HEACC burner was based on the expectation that improved NOx reduction and carbon conversion would be obtained. Experience at MIT with the RSFC burner being fired at 5 million BTU/hr on coal showed excellent performance. Results indicated that the RSFC-based burner has the potential to produce lower NOx and higher carbon conversion efficiencies than the HEACC burner.

Penn State completed the modifications to the coal storage and handling facilities as planned. ABB has completed design /fabrication of the new RSFC-based microfine coal burner. Starting from July 10 '95 ABB's new RSFC-based burner was installed in the Penn State boiler and demonstration testing is in progress. Initial testing with the new burner has already demonstrated, as expected, better performace (lower NOx and higher combustion efficiency) compared to the HEACC. Therefore, ABB CE and Penn State team have decided to continue this demonstration phase testing with this ABB's new RSFC-based burner.

Two low ash (~3 to 4%) coals, Middle Kittaning and Kentucky, have been selected for the demonstration (Task 5) testing. The rationale for this selection was to get the same or similar coals (Brookville and Kentucky) that were used during the Task 3 -400 hr testing. Since the Brookville Seam has been closed, Middle Kittaning coal was selected which is a very similar coal type and it is also from Pennsylvania.

The following summarizes the ~ 1000 hrs test plan:

Test Period- July 10, 1995 to December 31, 1995	Coal Source	Duration	Test Hours	Shifts
1) System Startup/ Verification	Middle Kittanning	2 Weeks		8 -10 hr/d
2) Burner Optimization	Middle Kittanning	3 Weeks	100	8 -10 hr/d
3) Parametric /Characterization	Middle Kittanning	12 Weeks	450	16 - 24 hr/d
4) Effect of coal type	Kentucky	8 Weeks	500	16 - 24 hr/d

Schedule and test sequences are summarize in Figure 1.

1) System Startup / Verification (2 Weeks)

Objective - Startup and verification of entire system. Operation of all components will be verified, the data acquisition system will be run and data quality will be checked.

2) RSFC-based (modified HEACC) Burner Optimization (3 Weeks - ~100 hrs)

Objective - To determine the final hardware configuration and operational parameters for the 1000 hour test.

-- {This was based, in part, on experience /results from 400 hr testing on the HEACC burner and ABB's experience /results with the RSFC burner (5 MBtu/Hr coal/oil/gas firing at MIT & 70 MBtu/Hr oil/gas firing in an on-going program at ABB PPL) and ABB CE's-supported 2D CFD modeling results on RSFC burner from MIT.}.

3) Parametric / Characterization (7 Weeks, 450 hrs testing, 16-24 hr/day operation) - Coal #1 Middle Kittaning

Objective: - to demonstrate the long term (~1000 hour) performance of firing microfine coal in an oil/gas designed Industrial Boiler. During this portion of the test program burner performance and overall boiler performance will be demonstrated over a range of operating conditions. These conditions will include excess air ranges, load ranges, various burner settings etc. Boiler performance data, emissions data and other data required to update the economic analysis and commercialization plan after demo (to reflect performance of RSFC-based burner) will be obtained during this period (similar to 400 hr testing). Information will be generated on "ash deposit effects and "how to best handle ash removal" during this long term demonstration test.

Coal Quantity Estimates

Coal Quantity Required based on Coal HHV of 13500 Btu/Lb

Startup /Shakedown

Total 1000 hrs at various firing rate

	Lbs/Hr Coal	Lbs Coal
16.0 Mbtu/Hr for 700 hrs of testing	1185	829,500
12.0 Mbtu/Hr for 100 hrs of testing	889	88,900
8.0 Mbtu/Hr for 100 hrs of testing	593	59, 260
6.0 Mbtu/Hr for 100 hrs of testing	444	44,400
Total Coal Requirements		1,022,060 lbs
		511 tons
	10% Contingency	50 tons
	Total ----	561 tons

300 tons of the ~3.5% ash Middle Kittanning coal - (similar to Bookville seam coal tested in Task 3) has been purchased for the demonstration tests. Other 300 tons of Kentucky coal of ~4.0% ash have been identified and will be purchased at the appropriate time.

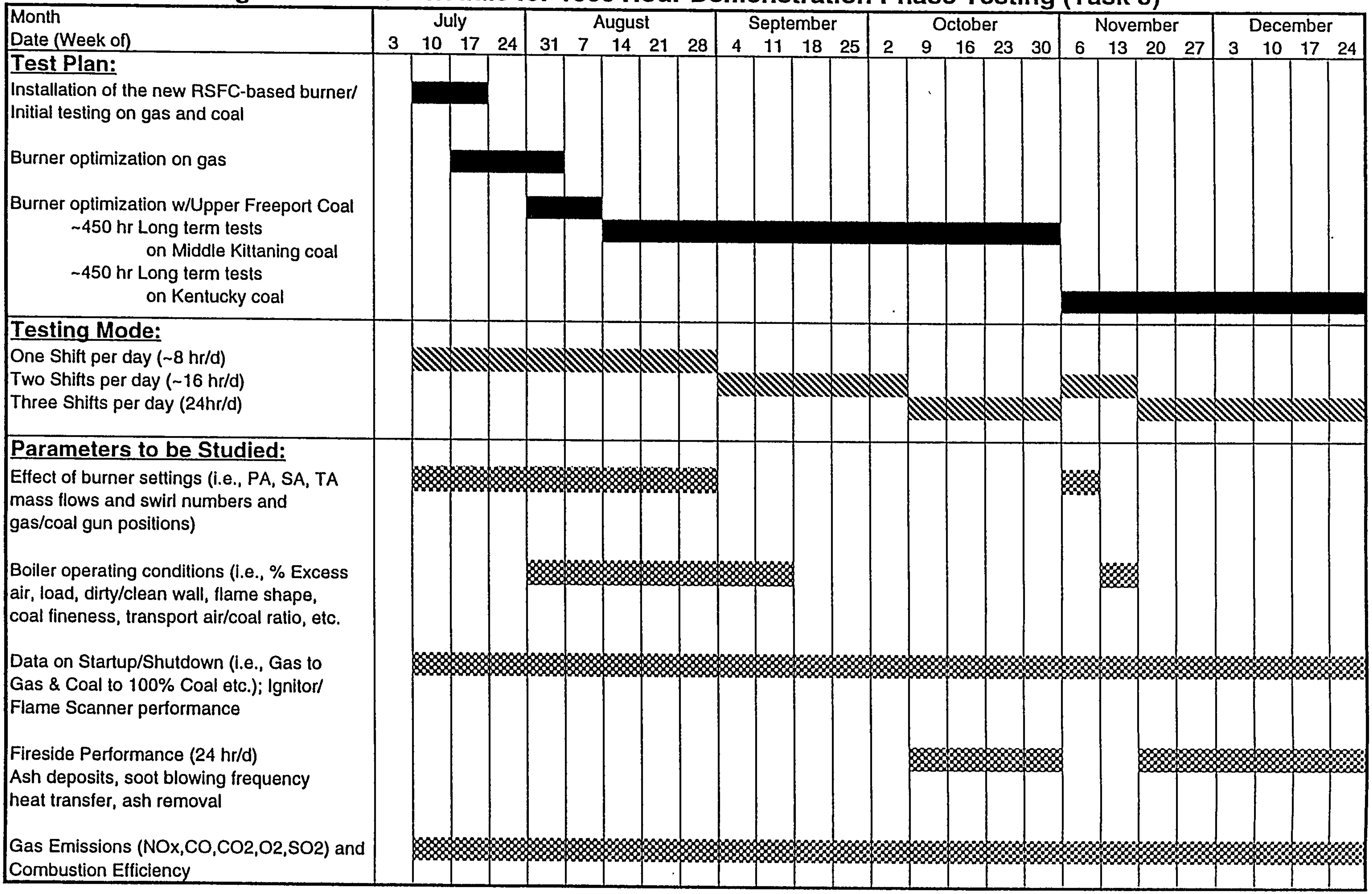
The following key parameters will be varied during the testing:

- Burner configuration - gun position/ air swirl
- Primary, Secondary, and Tertiary Air Splits and Swirl Numbers
- Coal /air ratios
- Overall excess air (15% to 30%)
- Boiler Load

<u>4) Coal #2 Kentucky (6 Weeks, ~500 hrs, 16-24 hr/day operation)</u>

Objective - During this portion of the 1000 hour test, a second coal will be used for evaluating the effects of coal type. Key tests from those conducted during use of the first coal type will be duplicated.

Figure 1 Plan /Schedule for 1000 Hour Demonstration Phase Testing (Task 5)



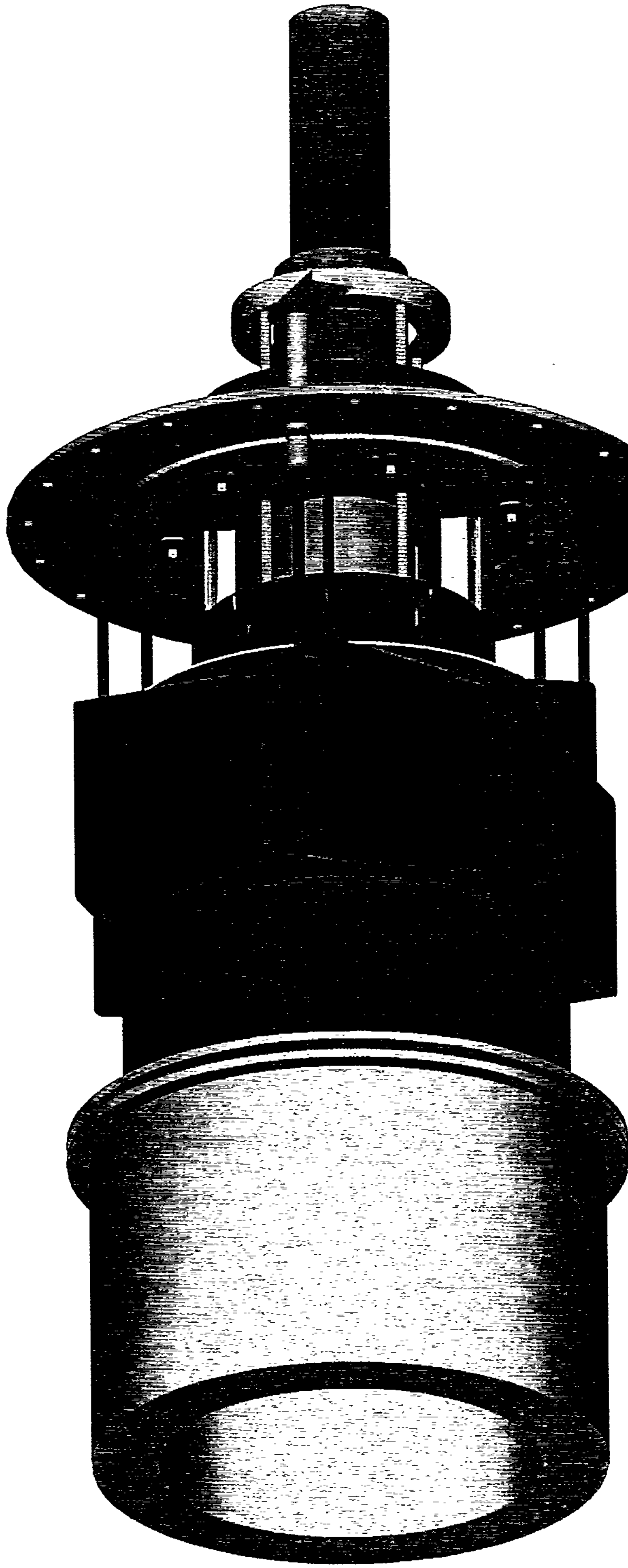
Attachment - B

September 21, 1995
Project Review Meeting with
DOE-PETC

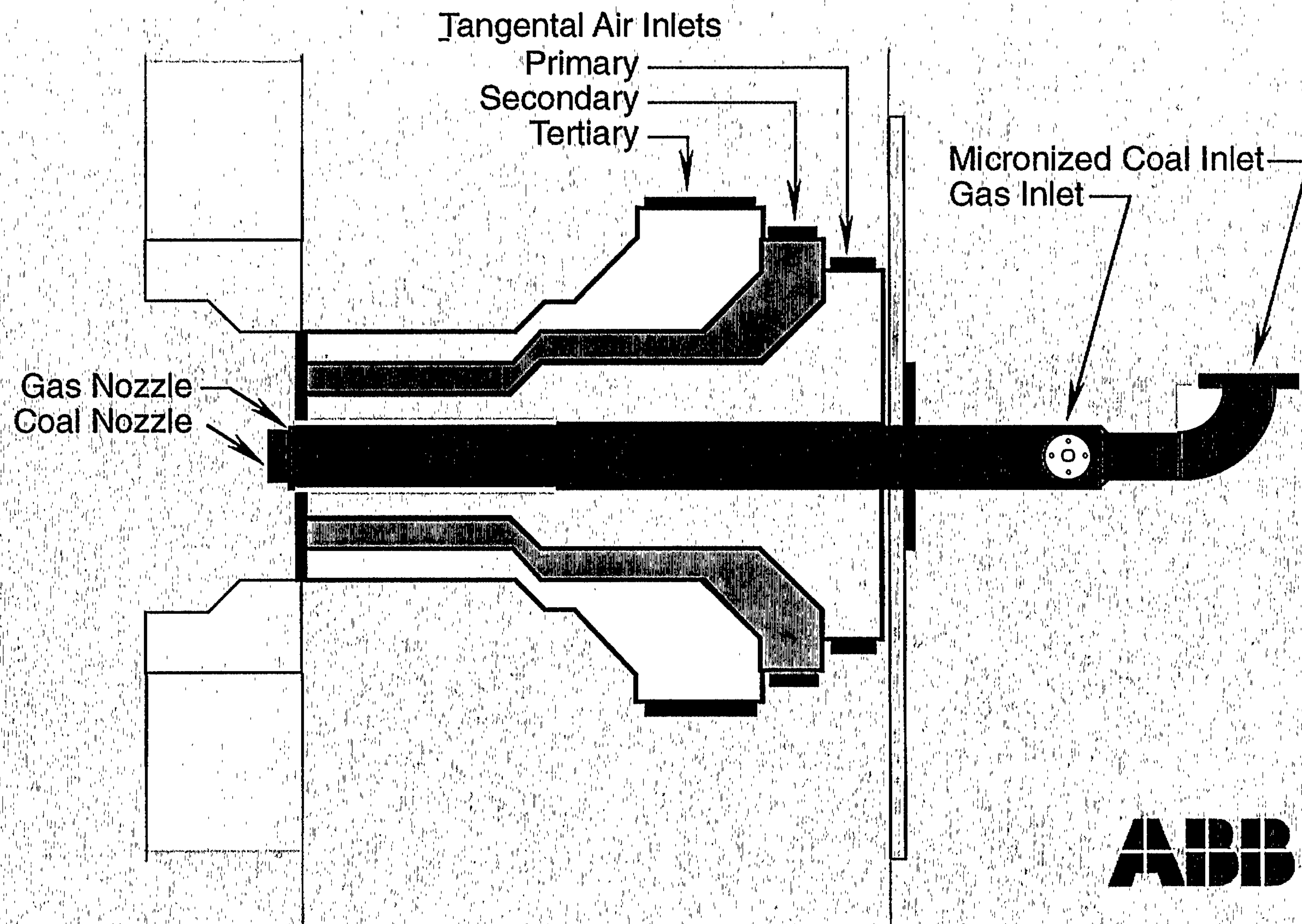
ABB/CE - PSU Combined Review Meeting
Agenda
September 21, 1995

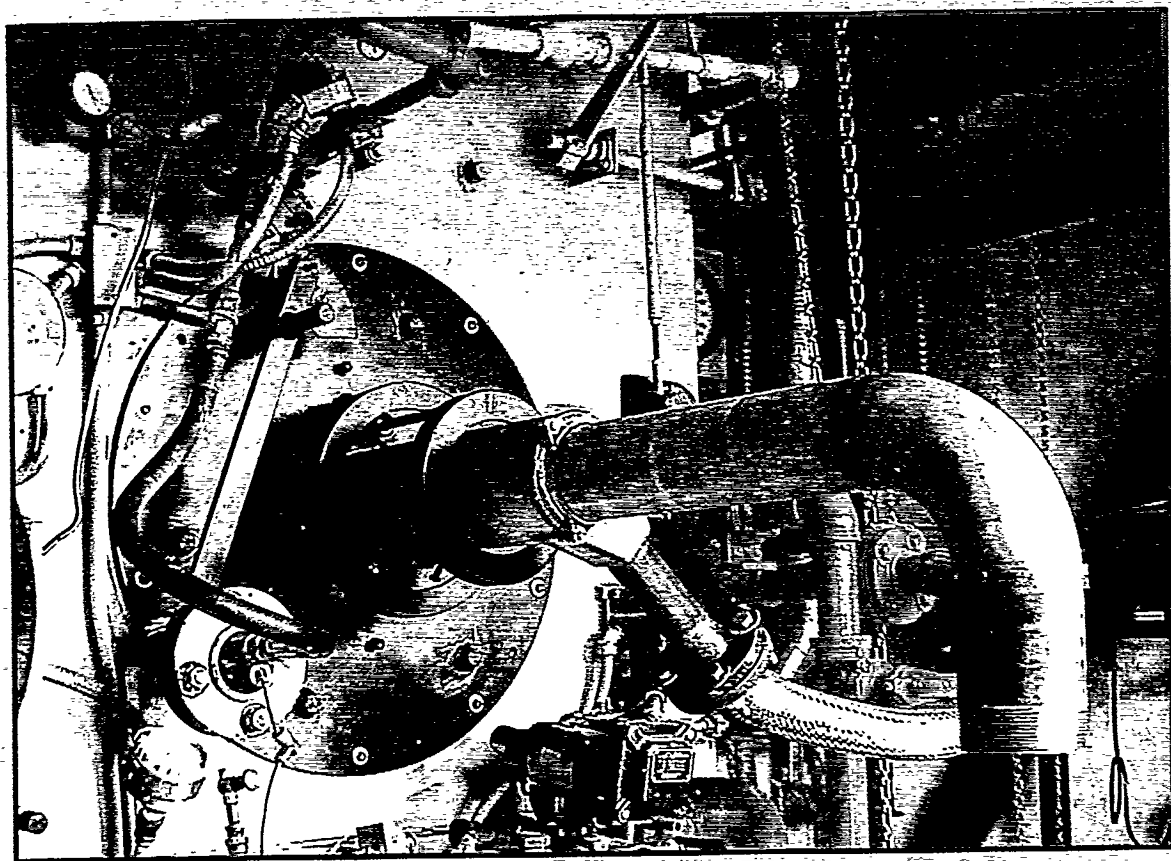
9:00 - 9:30	Review of DOE/PSU program to include the three major projects (For T. Gale)	All
9:30 - 10:00	Final Design of Burner for Demo Tests	R. Borio
	PSU Facility Mods for Demo Tests	B. Miller
10:00 - 10:30	Preliminary Test Results to Date	R. Borio
10:30 - 11:00	Proposed Demo Test Plan	R. Borio
11:00 - 11:30	Discussions*	All
	Lunch	
	Tour of Facilities	All

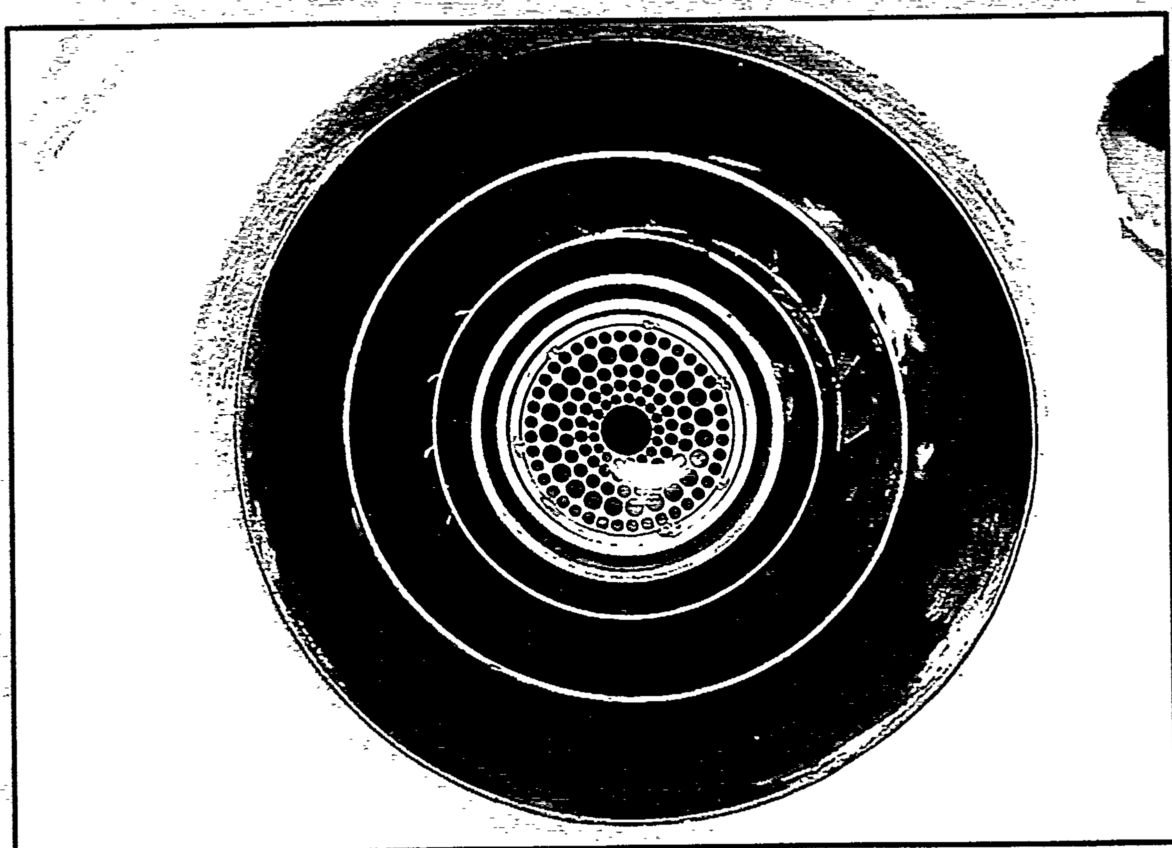
Discussions to include schedule, funding status, approach to completing SCCWS project and thoughts on DOD work (priorities).



ABB/CE's RSFC-Based Micronized Coal Burner

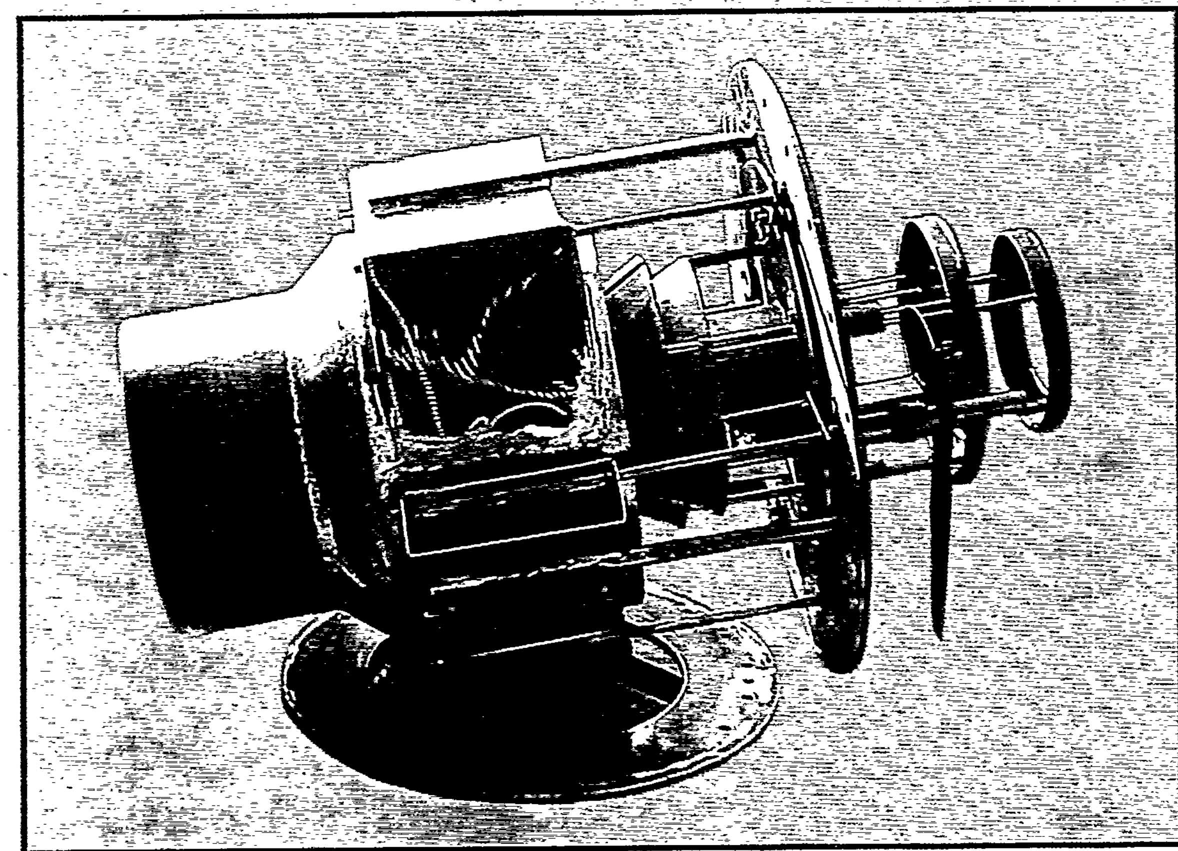


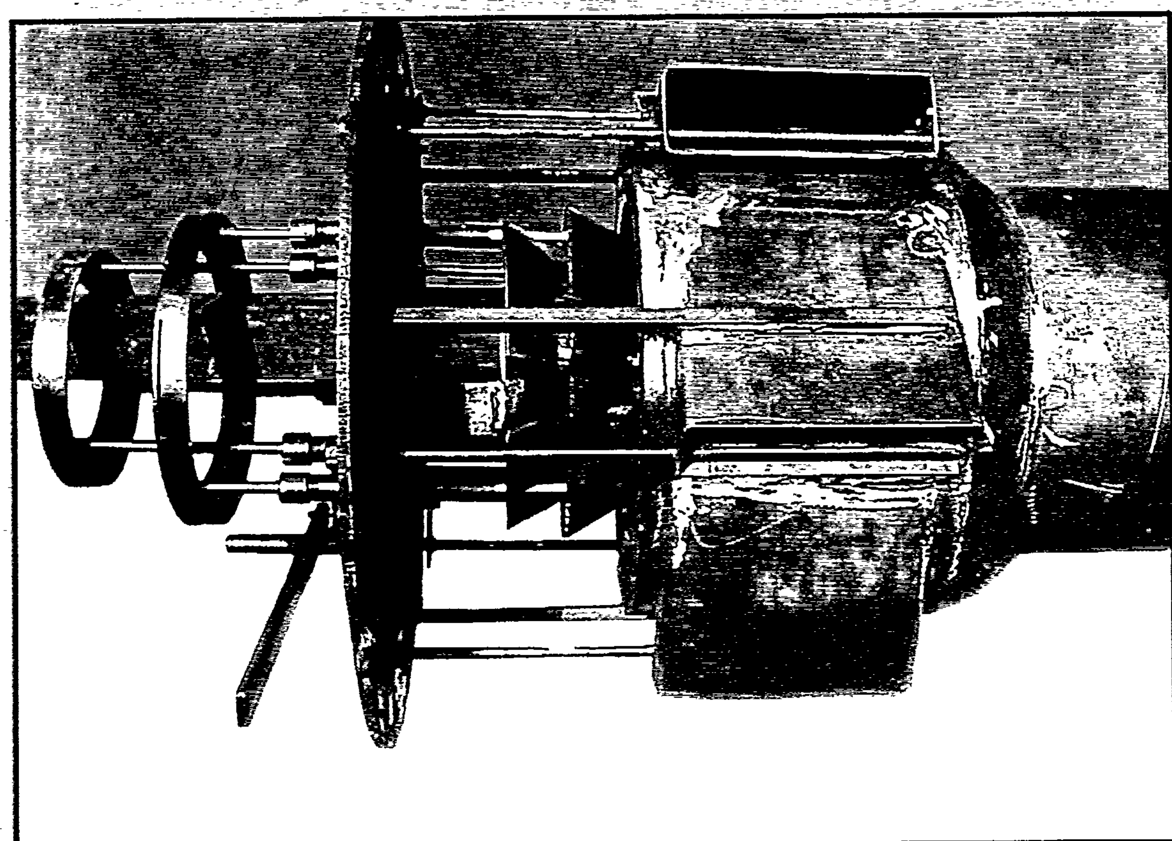




ABB

ABB / CE RSFC - Based Micromized Coal Burner





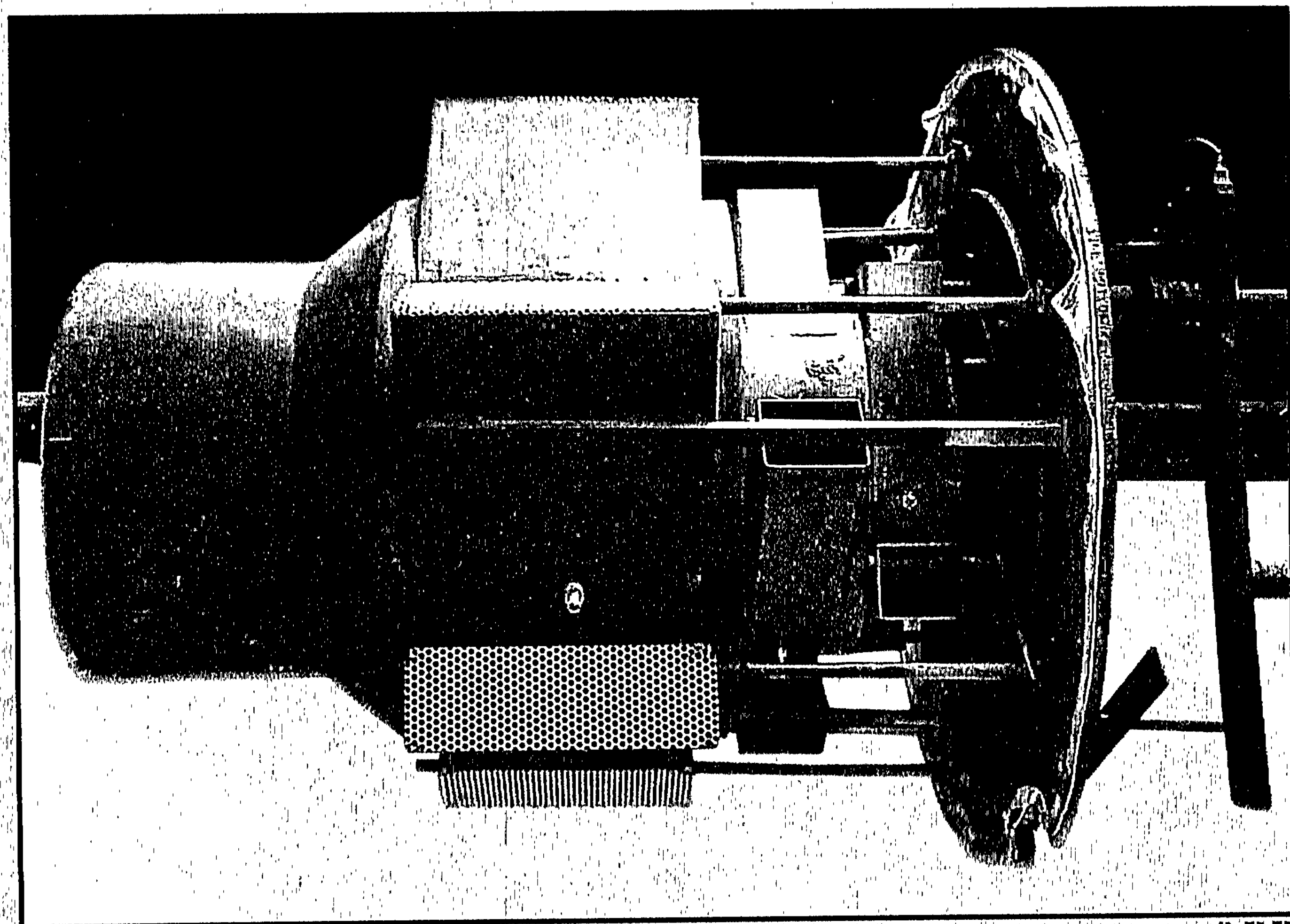


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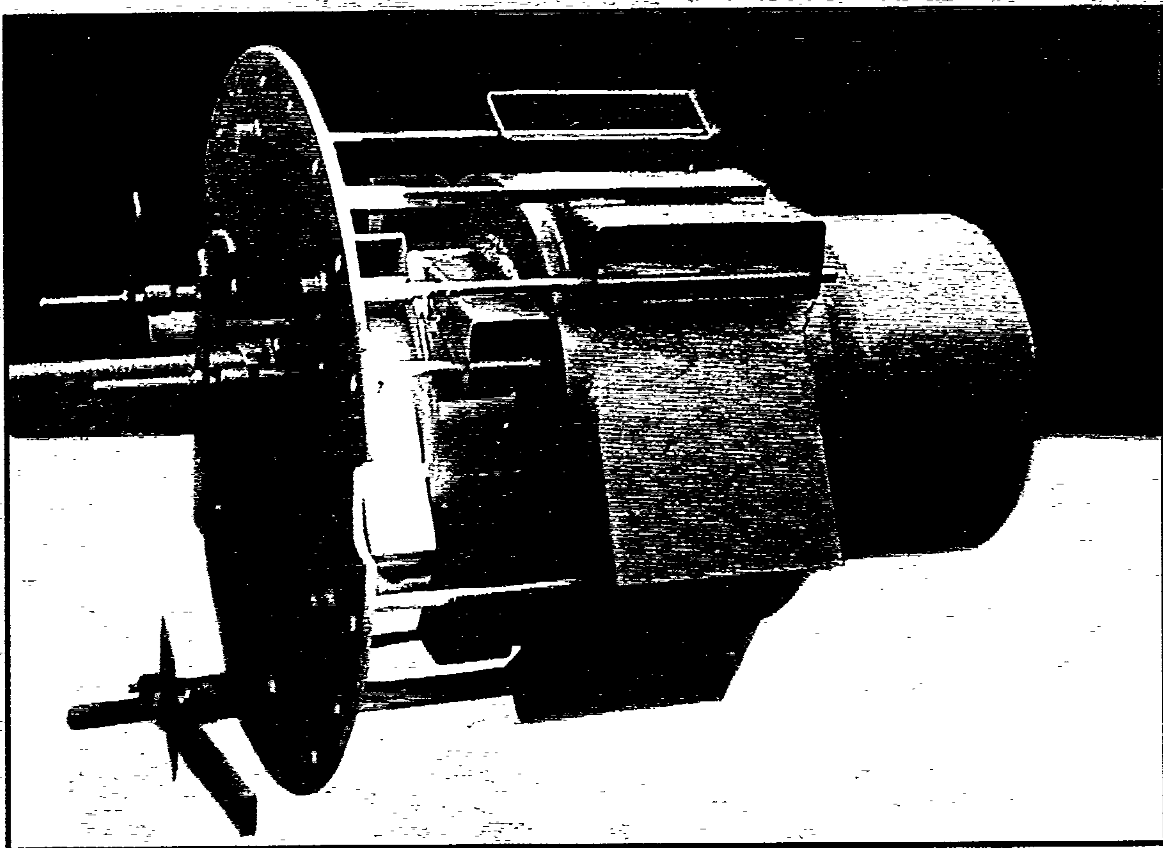
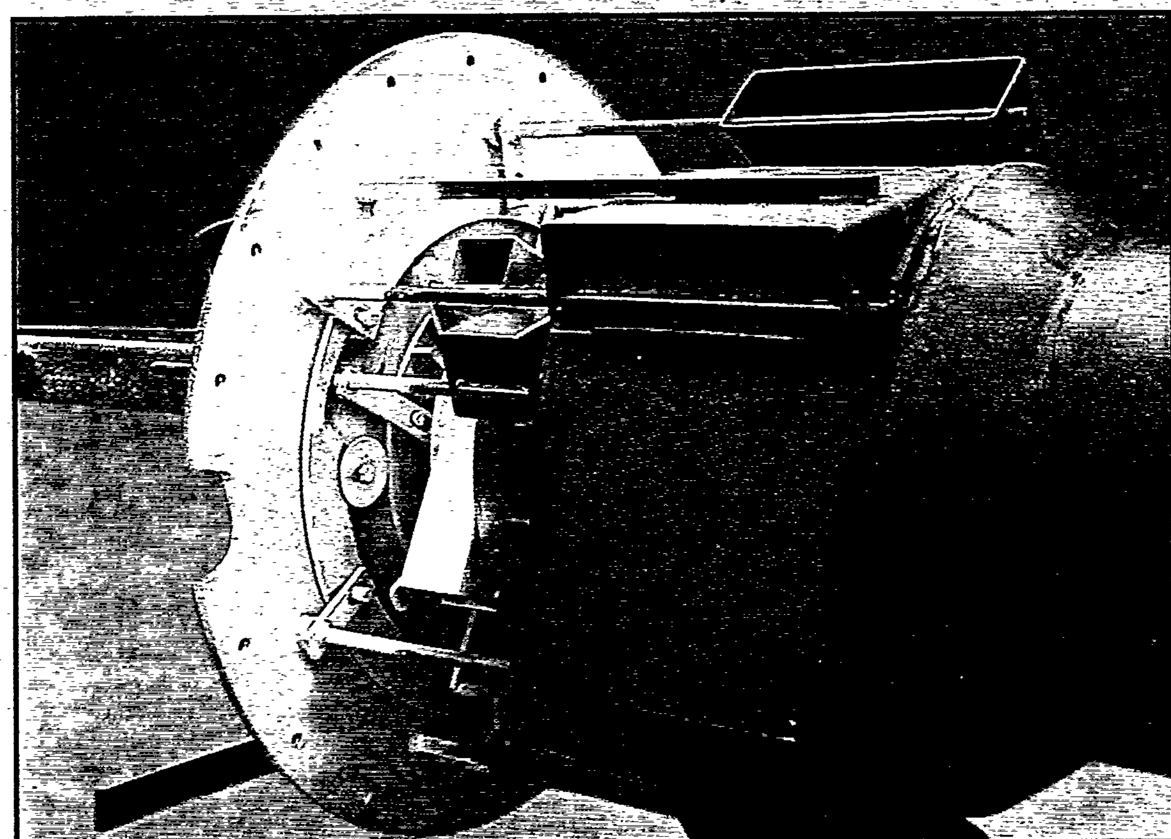
ABB / CE RSFC - Based Micromized Coal Burner





ABB

Task 5

1000 Hour Demonstration Testing in Penn State Boiler

Objective:

The objective of this task is to conduct 1000 hour test under normal load demands to demonstrate the technical viability of the system (microfine coal firing in gas/oil designed boiler) and refine the economic evaluation.

Task 5

1000 Hour Demonstration Testing in Penn State Boiler

Collect data to evaluate:

- micronized coal handling characteristics;
- the system's combustion and thermal efficiency
- deposition and errosion tendencies
- gaseous and particulate emissions; and
- operability including turndown

Selected Analyses of the Coals

	Used During 400 hrs Testing		*Selected for 1,000 hrs Testing*		
Proximate, wt%	Brookville	Kentucky	Upper Freeport	Middle Kittaning	Kentucky
Moisture	8.2	6.8	4.3	3.8	4.9
Volatile Matter	33.1	33.3	30.6	29.8	34.0
Fixed Carbon	55.8	55.4	58.9	62.2	59.6
Ash	2.9	4.5	6.2	4.2	1.5
HHV, Btu/lb	13,260	13,010	13,430	14,010	13,700
Ash Fusion Temp, °F					
IDT	2,820	2,803	–	2,432	2,544
ST	+ 3,000	+ 3,000	–	2,506	+ 2,800
FT	+ 3,000	+ 3,000	–	+ 2,800	+ 2,800

ASEA BROWN BOVERI

Comparison of HEACC vs RSFC-Based Micronized Coal Burner

Test Results	HEACC	RSFC
• Natural Gas Testing		
w/clean Wall		
NOx (ppm)	140 - 200	45 - 55
CO (ppm)	10 - 40	40 - 60
w/dirty (ash deposits)		
NOx (ppm)	140 - 200	60-70
CO (ppm)	10 - 40	45 -60
• Coal Firing Results		
% Comb. Efficiency	~ 95 (Highest ~96)	> 95 (~ 96-97.8)*
NOx (ppm)	~ 413	< 413 (~340 -400)*
Burner Pressue Drop (in H2O)	~ 8	< 8 (~ 4 - 6.5)*

NOx and CO values are calulated @ 3% O2.

* Based on the selected optimized test conditions from the on-going demonstration phase tests.

Comparison of HEACC vs RSFC-Based Micronized Coal Burner

	HEACC	RSFC
• Weight	~ 750 lbs	~ 250 lbs
• Installation/ Dismantle Time on Penn State Boiler	~2.5 hrs.	< 30 min.
• Coal Inlet	Tangential	Axial
• Transport Air	Tangential (Swirl)	Axial
• Primary Air	As Transport Air	Tangential Swirler
• Secondary Air	Fixed Swirler	Tangential Swirler
• Tertiary Air	Tangential Swirler	Tangential Swirler
• Flame Shape	Moderate	Excellent
• Flame Stability	Moderate	Excellent

Typical Test Matrix

Coal Type: Middle Kittaning

Burner settings (opt.): PA = Open, SA = Open, TA = 50% Open, Coal gun position = -10.5" and Gas gun position = -9.5"

			Gun Position		Swirler Settings			Test	
		Excess O2	Gas	Coal	Primary	Secondary	Tertiary	Duration	Mill Air/Coal
Test #	Load	(%)	Inches	Inches	(% open)	(% open)	(% open)	(hrs)	Flow Ratio
1	75	3	-9.5	-10.5	100% Open	100% Open	50% Open	4	~1.2
2	75	3	-9.5	-10.5	100% Open	100% Open	50% Open	8	~1.2
3	75	3	-9.5	-10.5	100% Open	100% Open	50% Open	16	~1.2
4	100	3	-9.5	-10.5	100% Open	100% Open	50% Open	4	~1.2
5	100	3	-9.5	-10.5	100% Open	100% Open	50% Open	8	~1.2
6	100	3	-9.5	-10.5	100% Open	100% Open	50% Open	16	~1.2
7	50	3	-9.5	-10.5	100% Open	100% Open	50% Open	4	~1.2
8	50	3	-9.5	-10.5	100% Open	100% Open	50% Open	8	~1.2
9	50	3	-9.5	-10.5	100% Open	100% Open	50% Open	16	~1.2
10	100	3.5	-9.5	-10.5	100% Open	100% Open	50% Open	16	~1.2
11	75	3.5	-9.5	-10.5	100% Open	100% Open	50% Open	16	~1.2
12	50	3.5	-9.5	-10.5	100% Open	100% Open	50% Open	16	~1.2
13	minimum	3.5	-9.5	-10.5	100% Open	100% Open	50% Open	16	~1.2
14*	100	3	-9.5	-10.5	100% Open	100% Open	50% Open	80	~1.2
15*	50	3	-9.5	-10.5	100% Open	100% Open	50% Open	80	~1.2
16*	minimum	3	-9.5	-10.5	100% Open	100% Open	50% Open	80	~1.2
							Total hrs=	388	

* These tests will be conducted 24 hr/day cotinuous basis