DOE/PC/92159--T17

CeraMem NOx Catalytic Filter
5000 ACFM Field Demonstration Test Plan

for the

United States Department of Energy Project
Engineering Development of a Coal-Fired
Low Emissions Boiler System
Subtask 9.2 Subsystem Test Plan
Contract DEAC-22-92PC92159

June 18, 1996

DISCLAIMER

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0. Revisions

Revision	Modifications
1	Added section including specific description of process design, process flow and equipment description to II. Added section including specific description of engineering activities and tasks to IV.
2	Changes made to reflect deletion of PSC-Commanche as host site to generic site.
3	Changes made to reflect schedule and scope of work for responsible parties: ABBES will now be responsible for site agreements and operation/construction permits. Also, references to Plant Miller location changed to generic site.
4	Site changed to Richmond Power & Light Whitewater Valley Station. Process operating parameters and start/stop/operating instructions updated from Task 7 data. Schedule updated to reflect delays in Task 7.

1. Summary

As a deliverable of the project, ABB Environmental Systems has written this subsystem test plan to outline and detail activities to be undertaken in Tasks 10 and 11 of the Low Emissions Boiler System project.

This subsystem test plan includes the budget and schedule for the construction, modification and operation of the subsystem test unit. This subsystem test plan also discusses securing of all applicable construction and operating permits, completing all necessary agreements with any host facilities, management procedures for monitoring and controlling all procurement and construction activities, implementation of Quality Assurance/Quality Control (QA/QC) measures, data acquisition during operations, data analysis, and the startup and shutdown procedures of the test unit.

The subsystem test plan is part of the updated Phase II RD&T Plan.

2. Background

After the development and feasibility testing of bench scale system (Task 7), a larger demonstration of the CeraMem NOx Catalytic Filter system (hereinafter referred to as CeraNOx) is to take place. The approach to this demonstration test will be to modify CeraMem's flue gas (300°F) filtration pilot plant located at the Public Service Company of Colorado's Commanche Station. The pilot plant was designed, fabricated, and tested as part of CeraMem's DOE (PETC) SBIR Phase II project, with assistance from the Electric Power Research Institute, for developing compact ceramic filters for particulate removal from flue gas. The system presently has the capability to test 36 six inch square cross section filters that are twelve inches long. The system has remote control capabilities and remote data acquisition via modem. The plant also contains a hot air backpulse system with very flexible control, flow control working with a low temperature ID fan, and an automatic ash handling system. It is anticipated that the modified pilot plant will operate at 4000-5000 ACFM.

2.1 Process Design and Capacity

The pilot plant, with 36 full-size 6"x6"x12" filter elements installed, is designed to process 4500 ACFM of coal generated flue gas at 775°F. The flow rate is based on maintaining approximately 4 ft/min face velocity across the filters. This is a typical operating point for flue gas applications. Gas flow is typical of 0.5 MWe at process operating conditions. Each of the elements has 25 sq. ft of filtration surface area resulting in a total unit area of 900 sq. ft.

The plant includes a venturi flow meter with control loop to maintain constant flow, an ash removal system (sized for 60 lb/hr ash flow) and a backpulse air filter cleaning system.

Inlet conditions for process design are:

Dust loading:	2 gr/scf
Temperature:	775°F
Inlet Pressure:	-20 in. water
Flow:	4500 ACFM

2.2 Process Flow and Equipment Description

2.2.1 Main Process

Dirty flue gas from the main plant's flue gas duct enters the unit via an 18" round duct through a manual isolation damper valve and an air operated inlet damper valve. Ammonia is injected into the flue gas stream to provide the necessary reagent for NOx reduction. Flue gas is then drawn into the top inlet of a specially designed carbon steel filter housing which distributes the flow to the inlet side of the 36 horizontal filter elements. Four elements are "canned" in a flanged mounted steel can containing ceramic fiber mat to hold and seal the filters. Each of 9 1"x4" element cans are bolted and gasketed to a vertically mounted tubesheet arrangement within the housing.

Filtered gas exiting the filters is drawn out of the housing through the flow control valve and into the 20" diameter flow measuring venturi and 18" outlet damper control valve. This cleaned gas flow is then routed to the main plant's flue gas duct through a manual return isolation damper valve.

2.2.2 Filter Backpulsing

The filter housing is equipped with an adjustable pressure air supply system to dislodge ash from the filters. This system consists of 9 rows of 2" blow pipes with ¾" nozzles, delivering cleaning air to the backpulse venturis on each of 4 filter elements. Nine 2" Goyen pulse valves control the volume of air delivered during the filter cleaning sequence operation. Pulse cleaning operation initiates on a pre-set filter pressure drop signal from tubesheet differential pressure transmitter.

Manual pulse initiation can also be accomplished from a panel mounted push button. Pulse air is filtered, dried, regulated and stored in a pulse air tank and header system on the inlet side of the pulse valves.

The PLC controls the pulse cleaning cycle with a pre-selected program. Header pressure is manually adjustable between 50 and 100 psig at the makeup air regulator valve. The optimum cleaning cycle will be determined during field testing.

2.2.3 Ash Pickup

A 4" line drawing ambient air provides an ash pickup stream. This line picks up the discharge from a continuously running rotary airlock feeder valve and dumps back into the clean gas flow on the discharge side of the blower. This line returns flue gas and ash into the main plant's dirty flue gas duct.

The hopper is equipped with ash zone heaters to keep the sloped hopper walls warm and ash free flowing. The ash containing portion of the pick up line is also heat traced to prevent ash buildup.

2.2.4 System Control and Instrumentation Description

The system is controlled and monitored by a remote control panel, local instrument box and local heater controllers.

The panel contains a programmable logic controller (PLC) which performs system control, alarm and upset shutdown logic control. Flow through the system is controlled by a flow control loop. The FIC modulates a flow control valve to maintain the pre-set flow rate. The PLC monitors pressure drop across the filter elements. As the filters build to a pre-set "dirty" pressure drop level, the PLC then initiates the pre-programmed pulse cleaning cycle to dislodge the ash and return the pressure drop to normal "clean" levels across the filters. The PLC also monitors valve positions, motor conditions, temperatures, pressures, flow, and level signals and is programmed to control startup, backpulse cleaning, alarm and shutdown procedures.

A local instrument box houses the motor control equipment, level and particulate monitor electronics, pulse valve solenoids, flow and pressure drop transmitters.

Transmitter sensing lines contain 3-way solenoid valves operated on an automatic cycle to periodically blow back air to clear condensation from the sensing lines.

Ash zone thermostatically controlled by a sensing bulb located on the hopper wall. Once manually activated this local controller operates independent of any other controls or signals. Ash line heat tracing is also locally powered and left on to prevent ash buildup.

The panel also contains a data logging and acquisition system to periodically read, store, and output a set of data taken at pre-set intervals during operation.

3. Technical Objectives

ABBES wishes to develop a better understanding of how the CeraNOx system would operate in the field. After determining the effect of various process parameters in the Task 7 testing, this larger demonstration will be used to determine how the process works at selected baseline process conditions over a reasonable period of time. The modified Commanche unit would function as a single filtration compartment demonstration from which ABBES could design a larger, multi-compartment demonstration plant as required as part of the LEBS program.

Specific technical objectives for the testing are as follows:

1. Particulate removal of greater than 99.5 %.
2. NOx reduction of at least 80% but preferably greater than 90%
3. Filter face velocity of at least 4 ft/sec
4. Operating temperature of 775°F, minimum 675°F.
5. Ammonia slip of less than about 10-15 ppm

4. Project Tasks

The specific tasks to be undertaken in the project and a brief description of each are below.

4.1 Subtask 9.1 - Subsystem Test Unit Design

4.1.1 Material Balance

Flow, lb/hr	Gas Comp wt %	Air Heater Outlet	System Inlet	Ammonia Injection	Filter Inlet	Filter Outlet	Cooling Air	Fan Inlet	Fan Outlet
CO2	12.50%	73,813	1,043.97	0.00	1,043.97	1,043.97	0.00	1,043.97	1,043.97
N2	73.88%	436,258	6,170.19	0.00	6,170.19	6,501.85	1,113.41	7,615.26	7,615.26
O2	7.00%	41,335	584.62	0.00	584.62	671.57	338.24	1,009.81	1,009.81
SO2	0.62%	3,661	51.78	0.00	51.78	51.78	0.00	51.78	51.78
SO3	0.00%	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H2SO4	0.00%	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HCl	0.00%	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NOx (as NO)	0.03%	184	2.599	0.00	2.599	0.260	0.000	0.260	0.260
NH3	0.00%	0	0.00	1.460	1.460	0.133	0.000	0.133	0.133
H2O	5.97%	35,253	498.60	0.00	498.60	501.25	1.89	503.14	503.14
Flyash		3,859	54.58	0.00	54.58	0.01	0.00	0.01	0.01
Total, lb/hr	100.00%	594,363	8,406	1.460	8,408	8,771	1,454	10,224	10,224
Air Leakage, lb/hr					418			0	
Temp, F		640	576	70	775	750	70	650	660
Pressure, in H2O		-10	-10	2,768	-11.5	-23.5	0	-25.5	-0.5
Cp, Btu/lb F		0.261	0.260	0.799	0.262	0.261	0.240	0.262	0.262
			1,263,170	82	1,696,121	1,716,786	24,419	1,741,205	1,767,994
Heat of Rxtn, Btu/hr						13,649			
Volume, ACFM		282,235	3,760	0.07	4,500	4,774	325	5,129	4,857
Volume, SCFM		130,141	1,841	0.54	1,841	1,933	319	2,252	2,252

4.1.2 Engineering and Equipment Procurement

The system was modified to meet the ABBES test conditions. The characteristics of the modified system is as follows:

- Stainless steel construction
- Remote control and data acquisition through use of the Commanche control system
- Thirty-six horizontal filters
- Face velocity of 2-6 ft/sec
- Temperature capability of 800°F
- Flexible backpulse sequence
- Capability of both on-line and off-line cleaning
- Ammonia injection system with feedback control to produce NH_3/NOx ratios of 0.85- 1.1
- On-line NOx and NH_3 downstream monitors

- Unit lifetime of at least two months

A process flow diagram of the system is shown in Figure 1.

It is envisioned that the housing will be modified for CeraMem's new venturi and filter can designs as well as reinforcements for the high-temperature operation. The system was modified to include a new rotary airlock for the ash handling system, trim heater with temperature control, high temperature blower, feedback-controlled ammonia injection system, downstream NOx and NH_3 detectors, and miscellaneous valving, seals, and expansion joints.

Specific activities required to modify the 5000 ACFM pilot plant to perform NOx SCR testing are discussed in Section 4.2.

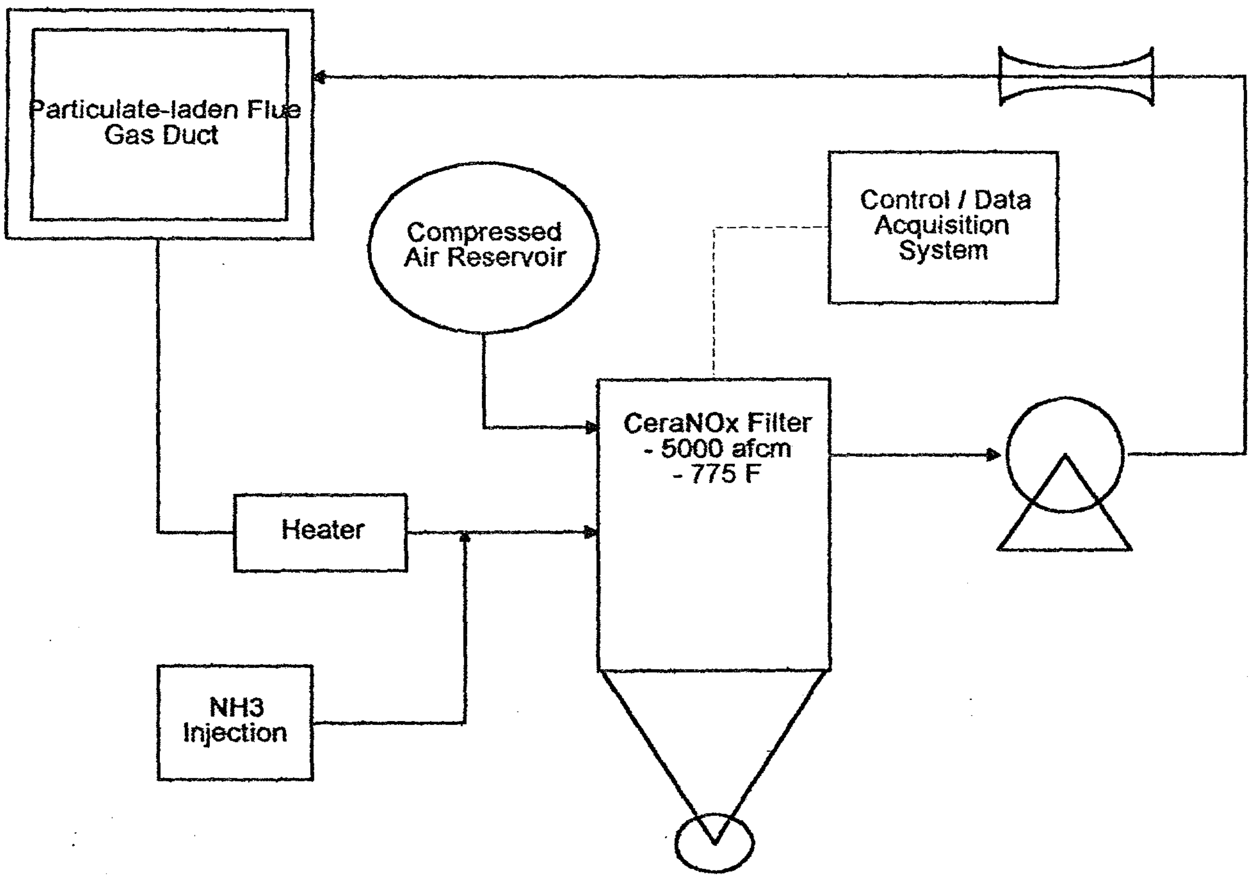

Figure 1. Process Flow Diagram of 5000 ACFM Test Unit.

4.1.3 Securing Of Applicable Construction And Operating Permits

Since the system is a pilot unit of such a small size and will not significantly affect the emissions from the power plant, construction and operation permits were not needed.

4.1.4 Necessary Agreements With Any Host Facilities

The host site felt that a written site agreement was not necessary as both ABB ES and the host site, RP&L, were both members of the LEBS project team.

4.1.5 Management Procedures for Monitoring and Controlling All Procurement and Construction Activities and Implementation of Quality Assurance/Quality Control (QA/QC) Measures

Management procedures for monitoring and controlling all procurement and construction activities and implementation of quality assurance/quality control (QA/QC) measures are outlined in a separate document, ABB Environmental System's Quality Assurance/Quality Control Plan for the Low Emissions Boiler Project.

4.2 Task 10 - Subsystem Test Unit Construction

4.2.1 Modify Filter Housing

Based on the initial engineering analysis, the carbon steel housing was modified by a local fabricator. The filters, cans, and venturis were removed from the unit before shipping and were replaced with new items. The internal hardware, such as thermocouples, sensing lines, and expansion joints were checked for ability to perform properly in high-temperature service. Where inadequate service could not be assured with existing equipment, the equipment was replaced with the proper piece. Heating strips were added to the compartment walls to reduce heat loss from the system. In all, the following tasks were performed in the modification of the system:

- Identification and specification of new and changed equipment
- Select blower and blower cooling system
- Select heater system
- Select high-temperature rotary airlock
- Redesign control system, allowing manual overrides, ammonia control, and temperature control
- Determine compressed air requirements
- Remove filter, cans, and venturis and ship back to CeraMem
- Remove housing from pad/ductwork and ship to fabricator
- Modify unit to withstand high-temperature operation
- Replace expansion joints, sensing lines, other low temperature parts as required
- Remove sightglasses and blank flush

- Replace aluminum baffle supports
- Add sufficient wall heaters to maintain temperature
- Add wall heaters to compressed air receiver
- Install high-temperature rotary airlock
- Skid mount blower and cooling system

4.2.2 Fabricate Catalytic Filters

Based on the results from the Engelhard laboratory and Task 7 tests, a catalytic filter was selected for fabrication. CeraMem manufactured the ceramic filters with Engelhard applying the catalyst. In all, approximately 40 filters were prepared for the test. In addition, CeraMem fabricated steel cans into which the filters were stuffed and sealed with fiber mat. Redesigned venturis were attached to the cans.

4.2.3 Modify Test Site and Install Equipment

After the housing was returned to the site, the equipment was installed and ducting was erected. Installed equipment is as described in Section 4.1.1. New insulated ducting leading from a tap before the air preheater to the pilot plant inlet will be installed. Work will be performed under the supervision of ABBES. In all, the following tasks were identified and undertaken to install the test equipment.

- Install housing at site
- Install new filters, cans, and venturis in housing
- Insulate air receiver
- Insulate housing to maintain temperature
- Install connections, blanking plates, and dampers to allow extraction of flue gas
- Install and insulate outlet and inlet ductwork from hot gas source
- Installation of the ammonia injection system
- Installation of the NOx analytical equipment

4.3 Subtask 11.1 - Subsystem Test Operations

After the new equipment is installed and the site is refurbished, the pilot plant will be started up. CeraMem has included the cost of ammonia for three months and a field engineer for one month It is anticipated that the plant will operate well after one month of debugging and that ABBES will be responsible for on-site monitoring during the two month test period. CeraMem will monitor the system operation remotely and help with data analysis.

4.3.1 Process Operation

From the tests performed during Task 7, optimum parameter combinations are expected to be determined. The testing during this subtask is to obtain some operating experience with those parameter combinations over an extended and preferably uninterrupted period of time.

Key parameter settings for this subtask are:

- Face velocity: 4 ft/min
- Cleaning Cycle:
  - Pressure: min 50 psig, max 100 psig
  - Pulse Length: 200 milliseconds
  - Frequency: 2 per hour
- NH_3/NOx ratio: 0.8 maximum inlet NOx basis, ammonia slip less than 25 ppm
- NOx in: 400 ppm (or available NOx under full load)
- Flue Gas Temp.: 775°F (410°C)

The following parameters will be monitored: total particulate removal, inlet/outlet particulate size distribution, draft loss, inlet/outlet NOx concentration, and inlet/outlet ammonia concentration. Tentatively, a fly ash sample will be taken and retained for later analysis.

Once the flue gas testing is completed, one or more filter modules shall be inspected regarding residual particulate and catalyst activity.

4.3.2 Data Acquisition During Operations and Data Analysis

4.3.2.1 Flue Gas Analysis

Inlet Analysis - Particulate, NO/NOx, NH_3, SO_2, O_2.

Outlet Analysis - Particulate, NO/NOx, NH_3, SO_2, SO_3, N_2O (tentative), and O_2.

4.3.2.1.1 On-line Analysis Methods

4.3.2.1.1.1 Gas Composition

Flue gas samples for gas composition analysis will be collected from the centroid of the duct using a single point sampling technique. Flue gas is drawn through a stainless steel probe and a peristaltic pump to a conditioning system, where water vapor and particulate matter is collected and removed. The conditioned sample is then delivered to the analyzers. The output from the monitors is recorded by the computerized data acquisition system (DAS). The operation of the analyzers is described below.

Oxygen A ServaMax analyzer will be used to determine the concentration of O_2 in the flue gas stream. This current is then amplified and provides a signal output which corresponds to full scale measurement ranges of 0 to 25 % O_2.

4.3.2.1.1.2 Nitrogen Oxides

Although the concentration of nitrogen oxides (as NO) in the inlet flue gas stream will be measured on a continuous basis by the Thermo Electron Model 10AR Chemiluminescent NOx Analyzer, independent manual measurements of these gases will be conducted using the EPA

Reference Method 7A: Determination of Nitrogen Oxide Emissions From Stationary Sources - Ion Chromatographic Method. In this method, a grab sample is collected in an evacuated flask containing a diluted sulfuric acid-hydrogen peroxide absorbing solution. The nitrogen oxides, except nitrous oxide, are oxidized to nitrate and measured by ion chromatography. Alternatively, the nitrogen oxides concentration will be measured colorimetrically using the phenolsulfonic acid (PDS) procedure. Manual measurements of the NOx concentration in the outlet flue gas stream will be made.

The ABB OPSYS system is not be suitable for this testing because of the small duct diameter (path length) available for the light beam, in addition to other constraints (transmitter cleaning air ratio too high).

4.3.2.1.2 Manual Analysis

4.3.2.1.2.1 Gas Composition

Flue gas samples for gas composition analysis will be collected from the centroid of the duct using a single point sampling technique. Flue gas is drawn isokinetically through a stainless steel probe. Particulate is removed by means of quartz wool and a particulate filter. A peristaltic pump provides the draft suction. Moisture is removed by means of a knockout jar located prior to the pump. The gas sampled is collected in a Tedlar™ bag and analyzed for carbon dioxide and oxygen using an Orsat apparatus.

4.3.2.1.2.2 Mass Concentration

Mass concentration is measured using a sampling train incorporating an in-stack filter and nozzle for isokinetic sampling. The train consists of a filter holder and nozzle that is designed to operate in the flue gas stream, followed by a heated sampling probe, a condenser, a drying column, a gas meter, a pump, and finally a flow control mechanism, usually a calibrated orifice. An S-type pitot and thermocouple located near the nozzle provide a means for sampling isokinetically during each test. Depending on the expected mass concentration at the point of sampling, either glass fiber thimbles or flat quartz fiber filter disks are used. The filters are desiccated before and after sampling and then weighed on an electronic microbalance.

4.3.2.1.2.3 Particulate Size Distribution

Particulate size distributions will be measured on the fly ash samples collected from the test facility inlet and outlet flue gases during mass concentration measurements. The instrument used to determine the particle size distribution of the fly ash will be a Shimadzu Model SA-CP4 Centrifugal Particle Size Analyzer. This instrument is capable of sizing particles into approximately 25 size intervals between 0.056 and 56.2 micrometers physical diameter (or Stokes diameter, assuming spherical shape and true (actual) particle density).

4.3.2.1.2.4 Ammonia

Ammonia will be sampled downstream of the injection point where adequate mixing will have occurred to verify injection quantity and at the outlet to determine slip. Each measurement of ammonia concentration will be an average of three tests. Single point sampling will occur with the probe nozzle situated in the center of the duct.

The flue gas is drawn through a glass-lined probed containing a plug of glass wool to remove particulate. The gas sample passes through a length of PTFE tubing to a set of three impingers in an ice bath. The third impinger serves as a trap to prevent the solution from accidentally being drawn into the pump. A second glass wool plug is placed in the line between the last two impingers to collect any ammonia aerosols that may escape the second impinger. The remainder of the train consists of a silica gel column to remove the last traces of water from flue gas sample, a leak-free pump, and a dry gas meter to measure the volume of the sample.

Gas sampling impingers (100 ml), each containing about 50 ml of solution, will be used for ammonia testing to reduce the detection limit to less than 1 ppm(v) for a typical sample volume, about 3 cu.ft. of gas for inlet ammonia concentrations and 4.5 cu.ft for slip (outlet) ammonia concentrations. A lower detection limit (0.5 to 0.6 ppm(v)) will be required for the slip ammonia testing due to the very low ammonia concentrations that may occur at the filter exit if the facility operates with NH_3/NOx ratios below 0.8.

The impinger solutions following sampling are made alkaline in the laboratory (converting the NH_4^+ ion to free NH_3 in solution). The concentration of ammonia is then determined with an ammonia ion specific electrode, Orion Model 920A. Three independent measurements of ammonia concentration will be made for each test condition. Two independent determinations of the ammonia concentration are then conducted on each sample.

4.3.2.1.2.5 Sulfur Dioxide and Sulfur Trioxide

Sulfur dioxide (SO_2) and sulfur trioxide (SO_3) will be collected (if the optional testing is selected) in a controlled condensation sampling train. All tests will be conducted using single-point sampling at the mid-point in the duct.

The flue gas sample is drawn through a heated, quartz-lined probe maintained at 550°F. The sample then passes through a quartz filter housed in a heated quartz filter holder, also maintained at 550°F. The next element in the train is the SO_3 condenser. The condenser is a length of quartz tubing packed with quartz wool and maintained between 120° and 130°F in a heated water bath. The sample next passes through a length of PTFE tubing to a set of three impingers in an ice bath. The first two impingers contain a 3 % solution of hydrogen peroxide to oxidize SO_2. The third impinger serves as a trap to prevent the solutions from accidentally being drawn into the pump. The remainder of the train consists of a silica gel column to remove the last traces of water from the sample, a leak-fee pump, and a dry gas meter to measure the volume of the sample.

While the SO_3 is removed in the condensing element, the SO_2 is removed in the bubbles by oxidation of H_2SO_4. In the condenser the SO_3 present begins a hydration reaction with the water vapor present making H_2SO_4. The excess water vapor also condenses to produce a condensate of concentrated aqueous H_2SO_4. Thus, two solutions of H_2SO_4 are collected; one a very concentrated solution of limited amount containing the original SO_3 and the other a relatively weak solution in far greater amount containing the original SO_2. The concentrations of the sulfate ion are determined by ion chromatography using a DIONEX Model DX-100 Ion Chromatograph.

Sulfur trioxide concentration at Plant Miller is typically around 1-2 ppm. Measurements would be performed at the beginning, to quantify the impact of the SCR catalyst on sulfur dioxide oxidation. After that, periodic checks should suffice.

4.3.2.1.2.6 Nitrous Oxide

The concentration of nitrous oxide will be measured using a sample train to extract and condition a sample that is collected in a Tedlar™ gas sample bag. The nitrous oxide concentration in each sample is determined directly by gas chromatography. A Varian Star 3400 gas chromatograph with an electron capture detector will be used for these analyses.

The flue gas sample is drawn through a glass-lined probe containing a glass wool plug in its tip to remove the particulate in the sample. The sample then passes through two 500 ml modified Greenburg-Smith impingers, each containing 200 ml of 3 % hydrogen peroxide solution. A third impinger serves as a moisture trap. Following the impingers, the gas passes through a desiccant column to remove any residual water vapor. The remainder of the sampling train consists of a diaphragm pump and a diverter valve used to fill the sample bags.

The sample conditioning (scrubbing) is needed to prevent the formation of a nitrous oxide artifact in the sample by means of a reaction between water vapor, sulfur dioxide, and NOx. The removal of water vapor and SO_2 was shown to prevent artifact formation by Muzio et al.[1]

A measurement at the beginning of the test program should be performed to quantify amount, if any, nitrous oxide (N_2O) present. If the amount is negligible compared to NOx concentration, further analysis will not be conducted.

4.3.2.1.3 Sampling Quality Assurance

The measures adopted to ensure that meaningful results are obtained during the various testing procedures can be divided into three categories: equipment maintenance and calibrations, operating techniques, and analytical techniques. State of the art equipment will be used in this test program and preventive maintenance and calibrations are performed at regular intervals.

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[1] L.J. Muzio, M.E. Teague, J.C. Kramlich, J.A. Cole, J.M. McCarthy, and R.K. Lyon. "Errors in Grab Sample Measurements of N_2O from Combustion Sources." JAPCA Vol. 39, No. 3, March 1989.

Due to the dynamic nature of the process, each measurement requires three replicate samples. The replicates are averaged to yield a representative value. Variability gives a means to discern any anomalies not revealed by other quality control checks. For further details of the quality assurance program, please refer to the project quality plan.[2]

4.3.2.1.4 Frequency and Repetition

Sampling and analysis is scheduled in the following matrix.

	On-Line Analysis											
	Inlet Analysis					Outlet Analysis						
Week No.	Particulate	NO/NOx	NH3	SO2	ORSAT	Particulate	NO/NOx	NH3	SO2	SO3	N2O	ORSAT
1		Yes			O2		Yes					O2
2		Yes			O2		Yes					O2
3		Yes			O2		Yes					O2
4		Yes			O2		Yes					O2
5		Yes			O2		Yes					O2
6		Yes			O2		Yes					O2
7		Yes			O2		Yes					O2
8		Yes			O2		Yes					O2
9		Yes			O2		Yes					O2
	Manual Analysis											
1												
2	3 days	3 days	3 days	3 days	3 days	3 days	3 days	3 days	3 days	3 days	3 days	3 days
3												
4												
5												
6												
7												
8												
9	3 days	3 days	3 days	3 days	3 days	3 days	3 days	3 days	3 days	3 days	3 days	3 days

Daily sampling will consist of three samples if sampling duration is one hour or less, two samples if sampling duration is three hours or less, and one sample if sampling duration exceeds three hours. Sampling repetition may be reduced in the remaining test blocks depending on the variability of early results.

4.3.2.2 Process Data

Process variables that will be monitored directly and logged continuously through an automated data acquisition system are listed below.

- Pulse Air Pressure, psi
- Filter Inlet Pressure, inches w.c.
- Filter Tubesheet Differential Pressure, inches w.c.
- Inlet NOx concentration, ppm
- Inlet O_2 concentration, wt %

[2] ABB Environmental System, Quality Assurance/Quality Control Plan for the United States Department of Energy's Engineering Development of a Coal-Fired Low Emissions Boiler System (Contract DE-AC22-92PC92159)

- Duct Surface Temperature, °F
- Filter Inlet Temperature, °F
- Filter Casing Temperature, °F
- Filter Outlet Temperature, °F
- Fan Outlet Temperature, °F
- Fan Outlet Pressure, inches w.c.
- Fan Outlet Flow, cfm
- Outlet NOx concentration, ppm
- Outlet O_2 concentration, %
- Ammonia Flow, lb/hr

Process variables that will be derived from measured process variables are listed below. Equations and derivations of the following can be found in the program quality manual.

- Filter Volumetric Gas Flow, cfm
- Filter Face Velocity, ft/min
- Volumetric Gas Flow, cfm, corrected for air in-leakage through system by oxygen balance.
- Mass Gas Flow, lb/hr, corrected for air in-leakage through system by oxygen balance.
- Inlet NOx Loading, lb/hr
- Outlet NOx Loading, lb/hr
- NOx Reduction Efficiency, %
- NOx/NH_3 Stoichiometric Ratio
- SO_2 Oxidation Efficiency, %
- Particulate Removal Efficiency, %
- Filter Drag or Permeance, inches w.g.-s/ft
- Pulse Air Consumption, scf/ft^2/pulse
- Dust Cake Differential Pressure, inches w.g.
- Dust Cake Resistance, inches w.g.-s/ft
- Residual Filter Resistance, inches w.g.-s/ft

4.3.3 Procedures for Start-up, Shut-down, Outages/Stand-stills

4.3.3.1 General

The catalyst can only be operated within a defined temperature window of 570-800°F (300-425°C) during any time, including startup, shutdown and normal operation. Operation outside of this temperature range should be avoid to prevent precipitation of ammonia salts or damage to the catalyst structure itself. The particulate filter can be operated at temperatures below that range as long as ammonia is not injected.

At all times the formation of water condensate should be avoided by isolation of the filter modules and sealing them from the atmosphere. A dryer might have to be employed (RH < 50-60 %) for longer outages to avoid dissolution of sodium and potassium salts from the dust on the

20. If ammonia is to be injected into the system, start ammonia injection only after reaching operating temperature. Open Ammonia Feed Ball Valve and open Ammonia Tank Valve. Adjust Ammonia Pressure Regulator to 40 psi.
21. At Analog Instrument Panel, adjust "Ammonia Controller" to maintain ammonia flow set point, initially at a stoichiometry of 1.1.

4.3.3.3 Start-up with flue gas only

It cases where it is not possible to preheat the catalyst with clean air to a temperature above 400°F (200°C), the following procedure should be followed.

1. Turn on power to the Analog Instrument Panel, Electrical Panel, Duct Heater Panel, Hopper Heater Panel, Magnehelic Panel, and Continuous Monitoring System.
2. Close ball valves to Gas Conditioner. Open purge valves for 2 minutes. Close purge valves and open ball valves to Gas Conditioner. Start Gas Conditioner.
3. Verify that compressed air header is at pressure.
4. Start the Hopper Heater system 24 hours prior to placing system on-line. Set-point temperature control is 350°F. Verify Hopper Heater system is operating.
5. At the Magnehelic Panel, verify the Photohelic gauge low pressure setpoint is set at 10 in w.g., high pressure setpoint is set at 30 in w.g, and selector switch is set to "Timer".
6. At the Electric Panel, verify that the Pulse Clean System is "ON". Verify that the Timer Set1 parameter reads "9000", Set2 parameter reads "9000", and Set3 parameter reads "0002".
7. Manually activate the Pulse Clean System to dislodge any ash that may have been left on the filter surface by pressing Pulse System "START" button.
8. Open System Bypass Valve.
9. Open manual Skid Inlet Valve and Skid Outlet Valve.
10. Start Flyash Rotary Valve. Verify that rotary valve is operating.
11. Open manual Boiler Inlet Valve and manual Boiler Outlet Valve.
12. Start Booster Fan 1. Verify that fan is operating.
13. Slowly close System Bypass Valve.
14. Start Duct Heater system. Verify that temperature setpoint is 775°F and system is operating.
15. Start Cooling Air Fan if Fan Outlet Temperature is above 500°F. Verify that fan is operating.
16. Verify that the Pulse Clean System is "ON" and operating.
17. At Analog Instrument Panel, adjust "Gas Flow Controller" to maintain gas flow set point, initially 4500 ACFM at process conditions.
18. If ammonia is to be injected into the system, start ammonia injection only after reaching operating temperature. Open Ammonia Feed Ball Valve and open Ammonia Tank Valve. Adjust Ammonia Pressure Regulator to 40 psi.
19. At Analog Instrument Panel, adjust "Ammonia Controller" to maintain ammonia flow set point, initially at a stoichiometry of 1.1.

filter in order to prevent catalyst poisoning. Alkali metals such as sodium and potassium can poison the catalyst by reaction with active sites. Condensation could provide the mechanism for dissolution and transfer of these metals through the membrane to the catalyst.

4.3.3.2 Start-up with ambient air prior to flue gas

It would be beneficial to preheat the catalyst with clean air to a temperature above 400°F (200°C), before flue gas is admitted. The filter elements certainly will not be a limiting factor regarding maximum possible warm-up rate.

1. Turn on power to the Analog Instrument Panel, Electrical Panel, Duct Heater Panel, Hopper Heater Panel, Magnehelic Panel, and Continuous Monitoring System.
2. Verify that compressed air header is at pressure.
3. Start the Hopper Heater system 24 hours prior to placing system on-line. Set-point temperature control is 350°F. Verify Hopper Heater system is operating.
4. At the Magnehelic Panel, verify the Photohelic gauge low pressure setpoint is set at 10 in w.g., high pressure setpoint is set at 30 in w.g, and selector switch is set to "TIMER". At the Electric Panel, verify that the Pulse Clean System is "ON". Verify that the Timer Set1 parameter reads "9000", Set2 parameter reads "9000", and Set3 parameter reads "0002".
5. Manually activate the Pulse Clean System to dislodge any ash that may have been left on the filter surface by pressing Pulse System "START" button.
6. Open the Inlet Particulate Test Port Valve. Verify that Outlet Particulate Test Port Valve is closed.
7. Verify that the manual Boiler Inlet Valve and manual Boiler Outlet Valve are closed.
8. Open manual Skid Inlet Valve, Skid Outlet Valve and Skid Bypass Valve.

   WARNING: Booster Fan 1 and 2 must not be started with the Skid Inlet Valves closed as the duct and filter enclosure will be crushed. However, Outlet Particulate Test Port Valve must be closed to prevent motor overload.

9. Start Booster Fan 1. Verify that fan is operating.
10. Start Flyash Rotary Valve. Verify that rotary valve is operating.
11. Start Cooling Air Fan. Verify that fan is operating.
12. Start Duct Heater system. Verify that temperature setpoint is 200°F and system is operating.
13. Slowly open Outlet Particulate Test Port Valve to allow air into the system.
14. Start Booster Fan 2, if needed. Verify that fan is operating.
15. Monitor air/gas temperature into the filter. Raise setpoint as required to reach a minimum air temperature of 400°F.
16. Open Boiler Inlet Valve and Boiler Outlet Valve.
17. Close Inlet Particulate Test Port Valve and Outlet Particulate Test Port Valve.
18. Verify that the Pulse Clean System is "ON" and operating.
19. At Analog Instrument Panel, adjust "Gas Flow Controller" to maintain gas flow set point, initially 4500 ACFM at process conditions.

4.3.3.4 Shut-down with ambient air circulation

Shutdown procedure uses introduction of ambient air into system to provide for gradual cooling of systems, lessening risks associated with heat shocks and dewpoint cycles.

1. Manually activate the pulse system to dislodge any ash that may have been left on the filter surface. Verify that the pulse system is "ON" and in "TIMER" mode.
2. Turn off ammonia injection system, if in use. Close Ammonia Feed Ball Valve and Ammonia Tank Valve. Turn off ammonia supply at Ammonia Regulator.
3. Verify System Bypass Valve is closed.
4. Turn off Duct Heating system. Verify that Duct Heater system has stopped operating.
5. Before Filter Inlet temperature reaches calculated dewpoint, open Inlet Particulate Test Port Valve to introduce ambient air into the system and close Boiler Inlet Valve.
6. At the Electric Panel, change Timer Set1 parameter to read "1500", Set2 parameter to read "1500", and Set3 parameter to read "0002".
7. Immediately manually actuate the Pulse Clean System to dislodge any ash on the filter. Turn off Pulse Cleaning System.
8. When filter inlet temperatures have stopped falling, stop air flow through system by shutting down Booster Fans 1 and 2. Verify that the fans have stopped.
9. Close Skid Inlet Valve and Skid Outlet Valve.
10. Manually actuate the Pulse Clean System again to dislodge any residual ash.
11. Turn the Cooling Air Fan off. Verify that Cooling Air Fan has stopped operating.
12. Manually actuate the Pulse Clean System again to dislodge any residual ash.
13. Turn off Rotary Ash Valve. Verify that it has stopped operating.
14. Remove Flyash Drum from system and empty.
15. Verify Hopper Heating system is on and set to 350°F.
16. Shut down Gas Conditioner. Close valves to Gas Conditioner and open purge valves for 2 minutes. Close purge valves.

4.3.3.5 Shut-down without ambient air.

1. Manually activate the pulse system to dislodge any ash that may have been left on the filter surface. Verify that the pulse system is "ON" and ready to clean filter in "TIMER" mode.
2. Turn off Ammonia Injection System, if in use. Close Ammonia Feed Ball Valve and Ammonia Tank Valve. Turn off ammonia supply at Ammonia Regulator.
3. Verify System Bypass Valve is closed.
4. Turn off Duct Heating system. Verify that Duct Heater system has stopped operating.
5. Before Filter Inlet temperature reaches calculated dewpoint, stop flow through system by shutting down Booster Fans 1 and 2. Verify that both fans have stopped.
6. Close Boiler Inlet Valve and Boiler Outlet Valve.
7. Close the Skid Inlet Valve and Skid Outlet Valve.
8. At the Electric Panel, change Timer Set1 parameter to read "1500", Set2 parameter to read "1500", and Set3 parameter to read "0002".
9. Immediately manually actuate the Pulse Clean System to dislodge any ash on the filter.
10. Turn the Cooling Air Fan off. Verify that Cooling Air Fan has stopped operating.

11. Manually actuate the Pulse Clean System again to dislodge any residual ash.
12. Verify that Rotary Ash Valve is operating.
13. Remove Flyash Drum from system and empty.
14. Shut down Gas Conditioner. Close valves to Gas Conditioner and open purge valves for 2 minutes. Close purge valves.

4.3.3.6 Outages/Stand-stills

For extended periods of stand-still the CeraNOx filter system should be isolated and either be inertisized or vented to avoid the formation of water condensate and subsequent dissolution of sodium and potassium salts from the residual fly ash on the filter modules.

4.3.3.7 Initial Operation

After initial startup of the test unit, the filter should only be operated in the filtration mode without injection of ammonia to allow elimination of the major initial problems related to particulate removal. This suggested "one problem at a time" approach is meant to protect the filter module from possible permanent damage caused by the presence of ammonia while still experimenting particulate removal in a broad range. Once the major operating difficulties have been resolved, ammonia injection can be added to the testing as long as the catalyst is within the allowable temperature range.

4.4 Subtask 11.2 - Subsystem Test Evaluation

ABBES will critically evaluate the results of all tests performed in Subtask 11.1. The evaluation will include the following:

- A summary of all the primary experimental data, engineering analyses, and computations.
- A summary and analysis of all results.
- A comparison of the results and the objectives of the RD&T Plan to determine the extent to which research needs were successfully addressed, and a residual needs analysis which highlights remaining or incompletely resolved research needs.
- A critical reevaluation of the subsystem option to assess whether it is ready for further development, scale-up, and inclusion in the final design for the POC Test Facility.
- Revision of the RD&T Plan, including schedule and resources required for continued subsystem development, if it were to be continued by DOE. The revised RD&T Plan should highlight the residual research needs and the detailed plans for their resolution.

4.5 Subtask 11.3 - Subsystem Design Evaluation

ABBES will evaluate design and technology options for each subsystem and recommend specific options for incorporation into the final design of the POC Test Facility. The following issues will be addressed in making design recommendations:

- Has sufficient technical and scientific information been developed to produce an improved subsystem design?
- Will the subsystem meet the desired performance specifications and is the subsystem amenable to scale-up, as required by the Commercial Generating Unit Design (Task 5) and the Preliminary POC Test Facility Design (Task 8)?
- What are the residual scientific and technical uncertainties and obstacles? How and when should they be resolved?
- Is the subsystem sufficiently developed to support an accurate estimate of its capital and operating costs in an integrated Low Emission Boiler System?

5. Project Schedule

The project schedule and milestones to be achieved are given below.

Date	Action
By 10/20/95	Complete Subsystem Unit Design and Engineering
By 3/31/96	Complete Subsystem Fabrication
By 10/18/96	Subsystem Equipment to Arrive at Site
By 10/21/96	Start Subsystem Unit Installation.
By 11/15/96	Complete Subsystem Unit Installation
By 11/22/96	Complete Analytical System Installation.
By 11/26/96	Complete System Test and Start Demonstration.
By 2/5/97	Complete Demonstration and Start Demolition.
By 2/18/97	Complete Demolition.
By 2/5/97	Complete Subsystem Design Data Analysis
By 2/11/97	Complete Test Evaluation Data Analysis.
By 2/18/97	Submit Subsystem Design Data Analysis Report.
By 2/25/97	Submit Test Evaluation Data Analysis Report.

6. Deliverables

ABBES will deliver a final report for inclusion into the Task 12 - Phase II Final Report. The report will include design information, raw data, data reduction and analysis, and conclusions. The final report will address individually each bullet item discussed above in the description of work for Subtasks 11.2 and 11.3.

7. Budget

ABBES has estimated the costs of the separate tasks of the project using DOE-approved rates and no fee. The approximate costs of the tasks are as follows:

Subtask 9.1	$182,981
Task 10	$182,440
Subtask 11.1	$99,334
Subtask 11.2	$18,107
Subtask 11.3	$9,009
Total	$491,781

Two additional months of testing support, as described above, will be available at a rate of $15,000 per month.

CeraMem Filter
5000 ACFM Field Demonstration Test Plan

for the

United States Department of Energy Project
Engineering Development of a Coal-Fired
Low Emissions Boiler System
Subtask 9.2 Subsystem Test Plan
Contract DEAC-22-92PC92159

June 19, 1996

Table of Contents

0. Revisions

Revision	Modifications
1	Added section including specific description of process design, process flow and equipment description to II. Added section including specific description of engineering activities and tasks to IV.
2	Changes made to reflect deletion of PSC-Commanche as host site to generic site.
3	Changes made to reflect schedule and scope of work for responsible parties: ABBES will now be responsible for site agreements and operation/construction permits. Also, references to Plant Miller location changed to generic site.
4	Site changed to Richmond Power & Light Whitewater Valley Station. Process operating parameters and start/stop/operating instructions updated from Task 7 data. Schedule updated to reflect delays in Task 7.
4.1	Revision 4, with scope of work reduced to demonstration of non-catalytic filtration

1. Summary

As a deliverable of the project, ABB Environmental Systems has written this subsystem test plan to outline and detail activities to be undertaken in Tasks 10 and 11 of the Low Emissions Boiler System project.

This subsystem test plan includes the budget and schedule for the construction, modification and operation of the subsystem test unit. This subsystem test plan also discusses securing of all applicable construction and operating permits, completing all necessary agreements with any host facilities, management procedures for monitoring and controlling all procurement and construction activities, implementation of Quality Assurance/Quality Control (QA/QC) measures, data acquisition during operations, data analysis, and the startup and shutdown procedures of the test unit.

The subsystem test plan is part of the updated Phase II RD&T Plan.

2. Background

After the development and feasibility testing of bench scale system (Task 7), a larger demonstration of the CeraMem Filter system is to take place. The approach to this demonstration test will be to modify CeraMem's flue gas (300°F) filtration pilot plant located at the Public Service Company of Colorado's Commanche Station. The pilot plant was designed, fabricated, and tested as part of CeraMem's DOE (PETC) SBIR Phase II project, with assistance from the Electric Power Research Institute, for developing compact ceramic filters for particulate removal from flue gas. The system presently has the capability to test 36 six inch square cross section filters that are twelve inches long. The system has remote control capabilities and remote data acquisition via modem. The plant also contains a hot air backpulse system with very flexible control, flow control working with a low temperature ID fan, and an automatic ash handling system. It is anticipated that the modified pilot plant will operate at 4000-5000 ACFM.

2.1 Process Design and Capacity

The pilot plant, with 36 full-size 6"x6"x12" filter elements installed, is designed to process 4500 ACFM of coal generated flue gas at 775°F. The flow rate is based on maintaining approximately 4 ft/min face velocity across the filters. This is a typical operating point for flue gas applications. Gas flow is typical of 0.5 MWe at process operating conditions. Each of the elements has 25 sq. ft of filtration surface area resulting in a total unit area of 900 sq. ft.

The plant includes a venturi flow meter with control loop to maintain constant flow, an ash removal system (sized for 60 lb/hr ash flow) and a backpulse air filter cleaning system.

Inlet conditions for process design are:

Dust loading:	2 gr/scf
Temperature:	775°F
Inlet Pressure:	-20 in. water
Flow:	4500 ACFM

2.2 Process Flow and Equipment Description

2.2.1 Main Process

Dirty flue gas from the main plant's flue gas duct enters the unit via an 18" round duct through a manual isolation damper valve and an air operated inlet damper valve. Flue gas is then drawn into the top inlet of a specially designed carbon steel filter housing which distributes the flow to the inlet side of the 36 horizontal filter elements. Four elements are "canned" in a flanged mounted steel can containing ceramic fiber mat to hold and seal the filters. Each of 9 1"x4" element cans are bolted and gasketed to a vertically mounted tubesheet arrangement within the housing.

Filtered gas exiting the filters is drawn out of the housing through the flow control valve and into the 20" diameter flow measuring venturi and 18" outlet damper control valve. This cleaned gas flow is then routed to the main plant's flue gas duct through a manual return isolation damper valve.

2.2.2 Filter Backpulsing

The filter housing is equipped with an adjustable pressure air supply system to dislodge ash from the filters. This system consists of 9 rows of 2" blow pipes with ¾" nozzles, delivering cleaning air to the backpulse venturis on each of 4 filter elements. Nine 2" Goyen pulse valves control the volume of air delivered during the filter cleaning sequence operation. Pulse cleaning operation initiates on a pre-set filter pressure drop signal from tubesheet differential pressure transmitter.

Manual pulse initiation can also be accomplished from a panel mounted push button. Pulse air is filtered, dried, regulated and stored in a pulse air tank and header system on the inlet side of the pulse valves.

The PLC controls the pulse cleaning cycle with a pre-selected program. Header pressure is manually adjustable between 50 and 100 psig at the makeup air regulator valve. The optimum cleaning cycle will be determined during field testing.

2.2.3 Ash Pickup

A 4" line drawing ambient air provides an ash pickup stream. This line picks up the discharge from a continuously running rotary airlock feeder valve and dumps back into the clean gas flow on the discharge side of the blower. This line returns flue gas and ash into the main plant's dirty flue gas duct.

The hopper is equipped with ash zone heaters to keep the sloped hopper walls warm and ash free flowing. The ash containing portion of the pick up line is also heat traced to prevent ash buildup.

2.2.4 System Control and Instrumentation Description

The system is controlled and monitored by a remote control panel, local instrument box and local heater controllers.

The panel contains a programmable logic controller (PLC) which performs system control, alarm and upset shutdown logic control. Flow through the system is controlled by a flow control loop. The FIC modulates a flow control valve to maintain the pre-set flow rate. The PLC monitors pressure drop across the filter elements. As the filters build to a pre-set "dirty" pressure drop level, the PLC then initiates the pre-programmed pulse cleaning cycle to dislodge the ash and return the pressure drop to normal "clean" levels across the filters. The PLC also monitors valve positions, motor conditions, temperatures, pressures, flow, and level signals and is programmed to control startup, backpulse cleaning, alarm and shutdown procedures.

A local instrument box houses the motor control equipment, level and particulate monitor electronics, pulse valve solenoids, flow and pressure drop transmitters.

Transmitter sensing lines contain 3-way solenoid valves operated on an automatic cycle to periodically blow back air to clear condensation from the sensing lines.

Ash zone thermostatically controlled by a sensing bulb located on the hopper wall. Once manually activated this local controller operates independent of any other controls or signals. Ash line heat tracing is also locally powered and left on to prevent ash buildup.

The panel also contains a data logging and acquisition system to periodically read, store, and output a set of data taken at pre-set intervals during operation.

3. Technical Objectives

ABBES wishes to develop a better understanding of how the CeraMem Filter would operate in the field. After determining the effect of various process parameters in the Task 7 testing, this larger demonstration will be used to determine how the process works at selected baseline process conditions over a reasonable period of time. The modified Commanche unit would function as a single filtration compartment demonstration from which ABBES could design a larger, multi-compartment demonstration plant as required as part of the LEBS program.

Specific technical objectives for the testing are as follows:

1. Particulate removal of greater than 99.5 %.
2. Filter face velocity of at least 4 ft/sec
3. Operating temperature of 775°F, minimum 275°F.

4. Project Tasks

The specific tasks to be undertaken in the project and a brief description of each are below.

4.1 Subtask 9.1 - Subsystem Test Unit Design

4.1.1 Material Balance

Flow, lb/hr	Gas Comp wt %	Air Heater Outlet	System Inlet	Ammonia Injection	Filter Inlet	Filter Outlet	Cooling Air	Fan Inlet	Fan Outlet
CO2	12.50%	73,813	1,043.97	0.00	1,043.97	1,043.97	0.00	1,043.97	1,043.97
N2	73.88%	436,258	6,170.19	0.00	6,170.19	6,501.85	1,113.41	7,615.26	7,615.26
O2	7.00%	41,335	584.62	0.00	584.62	671.57	338.24	1,009.81	1,009.81
SO2	0.62%	3,661	51.78	0.00	51.78	51.78	0.00	51.78	51.78
SO3	0.00%	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H2SO4	0.00%	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HCl	0.00%	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NOx (as NO)	0.03%	184	2.599	0.00	2.599	0.260	0.000	0.260	0.260
NH3	0.00%	0	0.00	0.000	0.000	-1.328	0.000	-1.328	-1.328
H2O	5.97%	35,253	498.60	0.00	498.60	501.25	1.89	503.14	503.14
Flyash		3,859	54.58	0.00	54.58	0.01	0.00	0.01	0.01
Total, lb/hr	100.00%	594,363	8,406	0.000	8,406	8,769	1,454	10,223	10,223
Air Leakage, lb/hr					418			0	
Temp, F		640	576	70	775	750	70	650	660
Pressure, in H2O		-10	-10	2,768	-11.5	-23.5	0	-25.5	-0.5
Cp, Btu/lb F		0.261	0.260	0.799	0.262	0.261	0.240	0.262	0.262
			1,263,170	0	1,695,825	1,716,489	24,419	1,740,909	1,767,694
Heat of Rxtn, Btu/hr						13,649			
Volume, ACFM		282,235	3,760	0.00	4,499	4,773	325	5,128	4,856
Volume, SCFM		130,141	1,841	0.00	1,841	1,933	319	2,252	2,252

4.1.2 Engineering and Equipment Procurement

The system was modified to meet the ABBES test conditions. The characteristics of the modified system is as follows:

- Stainless steel construction
- Remote control and data acquisition through use of the Commanche control system
- Thirty-six horizontal filters
- Face velocity of 2-6 ft/sec
- Temperature capability of 800°F
- Flexible backpulse sequence
- Capability of both on-line and off-line cleaning
- Unit lifetime of at least two months

A process flow diagram of the system is shown in Figure 1.

It is envisioned that the housing will be modified for CeraMem's new venturi and filter can designs as well as reinforcements for the high-temperature operation. The system was modified to include a new rotary airlock for the ash handling system, trim heater with temperature control, high temperature blower, and miscellaneous valving, seals, and expansion joints.

Specific activities required to modify the 5000 ACFM pilot plant to perform testing are discussed in Section 4.2.

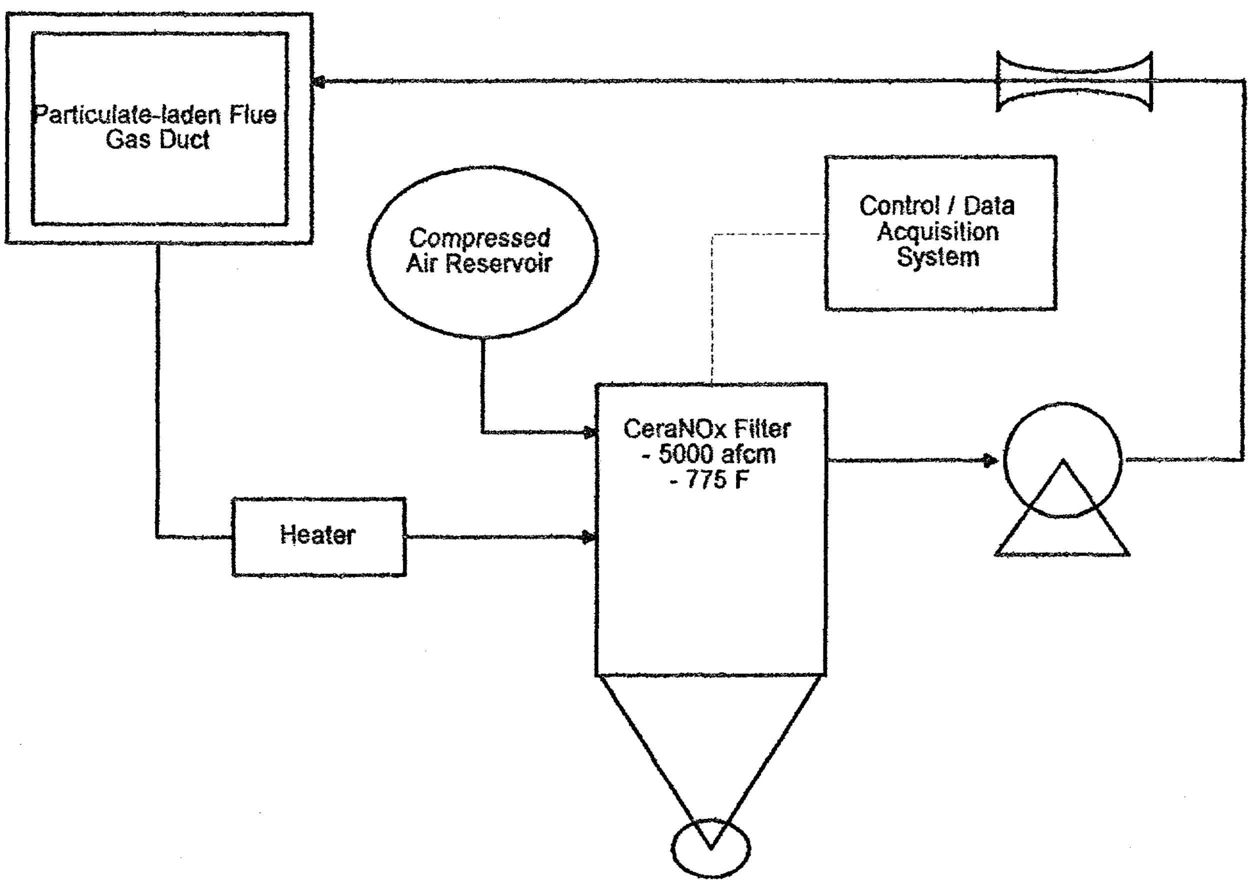

Figure 1. Process Flow Diagram of 5000 ACFM Test Unit.

4.1.3 Securing Of Applicable Construction And Operating Permits

Since the system is a pilot unit of such a small size and will not significantly affect the emissions from the power plant, construction and operation permits were not needed.

4.1.4 Necessary Agreements With Any Host Facilities

The host site felt that a written site agreement was not necessary as both ABB ES and the host site, RP&L, were both members of the LEBS project team.

4.1.5 Management Procedures for Monitoring and Controlling All Procurement and Construction Activities and Implementation of Quality Assurance/Quality Control (QA/QC) Measures

Management procedures for monitoring and controlling all procurement and construction activities and implementation of quality assurance/quality control (QA/QC) measures are outlined in a separate document, ABB Environmental System's Quality Assurance/Quality Control Plan for the Low Emissions Boiler Project.

4.2 Task 10 - Subsystem Test Unit Construction

4.2.1 Modify Filter Housing

Based on the initial engineering analysis, the carbon steel housing was modified by a local fabricator. The filters, cans, and venturis were removed from the unit before shipping and were replaced with new items. The internal hardware, such as thermocouples, sensing lines, and expansion joints were checked for ability to perform properly in high-temperature service. Where inadequate service could not be assured with existing equipment, the equipment was replaced with the proper piece. Heating strips were added to the compartment walls to reduce heat loss from the system. In all, the following tasks were performed in the modification of the system:

- Identification and specification of new and changed equipment
- Select blower and blower cooling system
- Select heater system
- Select high-temperature rotary airlock
- Redesign control system, allowing manual overrides, and temperature control
- Determine compressed air requirements
- Remove filter, cans, and venturis and ship back to CeraMem
- Remove housing from pad/ductwork and ship to fabricator
- Modify unit to withstand high-temperature operation
- Replace expansion joints, sensing lines, other low temperature parts as required
- Remove sightglasses and blank flush
- Replace aluminum baffle supports

- Add sufficient wall heaters to maintain temperature
- Add wall heaters to compressed air receiver
- Install high-temperature rotary airlock
- Skid mount blower and cooling system

4.2.2 Fabricate Filters

CeraMem will manufacture the ceramic filters. In all, approximately 40 filters were be prepared for the test. In addition, CeraMem fabricated steel cans into which the filters were stuffed and sealed with fiber mat. Redesigned venturis were attached to the cans.

4.2.3 Modify Test Site and Install Equipment

After the housing was returned to the site, the equipment was installed and ducting was erected. Installed equipment is as described in Section 4.1.1. New insulated ducting leading from a tap before the air preheater to the pilot plant inlet will be installed. Work will be performed under the supervision of ABBES. In all, the following tasks were identified and undertaken to install the test equipment.

- Install housing at site
- Install new filters, cans, and venturis in housing
- Insulate air receiver
- Insulate housing to maintain temperature
- Install connections, blanking plates, and dampers to allow extraction of flue gas
- Install and insulate outlet and inlet ductwork from hot gas source

4.3 Subtask 11.1 - Subsystem Test Operations

After the new equipment is installed and the site is refurbished, the pilot plant will be started up. CeraMem has included the cost of a field engineer for one month It is anticipated that the plant will operate well after one month of debugging and that ABBES will be responsible for on-site monitoring during the two month test period. CeraMem will monitor the system operation remotely and help with data analysis.

4.3.1 Process Operation

From the tests performed during Task 7, optimum parameter combinations are expected to be determined. The testing during this subtask is to obtain some operating experience with those parameter combinations over an extended and preferably uninterrupted period of time.

Key parameter settings for this subtask are:

- Face velocity: 4 ft/min
- Cleaning Cycle:
  - Pressure min 50 psig, max 100 psig
  - Pulse Length 200 milliseconds

- Frequency 2 per hour
- Flue Gas Temp. 775°F (410°C)

The following parameters will be monitored: total particulate removal, inlet/outlet particulate size distribution, and tubesheet draft loss. Tentatively, a fly ash sample will be taken and retained for later analysis.

Once the flue gas testing is completed, one or more filter modules shall be inspected for residual particulate.

4.3.2 Data Acquisition During Operations and Data Analysis

4.3.2.1 Flue Gas Analysis

Inlet Analysis - Particulate, O_2

Outlet Analysis - Particulate, O_2

4.3.2.1.1 On-line Analysis Methods

4.3.2.1.1.1 Gas Composition

Flue gas samples for gas composition analysis will be collected from the centroid of the duct using a single point sampling technique. Flue gas is drawn through a stainless steel probe and a peristaltic pump to a conditioning system, where water vapor and particulate matter is collected and removed. The conditioned sample is then delivered to the analyzers. The output from the monitors is recorded by the computerized data acquisition system (DAS). The operation of the analyzers is described below.

Oxygen A ServaMax analyzer will be used to determine the concentration of O_2 in the flue gas stream. This current is then amplified and provides a signal output which corresponds to full scale measurement ranges of 0 to 25 % O_2

4.3.2.1.2 Manual Analysis

4.3.2.1.2.1 Gas Composition

Flue gas samples for gas composition analysis will be collected from the centroid of the duct using a single point sampling technique. Flue gas is drawn isokinetically through a stainless steel probe. Particulate is removed by means of quartz wool and a particulate filter. A peristaltic pump provides the draft suction. Moisture is removed by means of a knockout jar located prior to the pump. The gas sampled is collected in a Tedlar™ bag and analyzed for carbon dioxide and oxygen using an Orsat apparatus.

4.3.2.1.2.2 Mass Concentration

Mass concentration is measured using a sampling train incorporating an in-stack filter and nozzle for isokinetic sampling. The train consists of a filter holder and nozzle that is designed to operate in the flue gas stream, followed by a heated sampling probe, a condenser, a drying column, a gas meter, a pump, and finally a flow control mechanism, usually a calibrated orifice. An S-type pitot and thermocouple located near the nozzle provide a means for sampling isokinetically during each test. Depending on the expected mass concentration at the point of sampling, either glass fiber thimbles or flat quartz fiber filter disks are used. The filters are desiccated before and after sampling and then weighed on an electronic microbalance.

4.3.2.1.2.3 Particulate Size Distribution

Particulate size distributions will be measured on the fly ash samples collected from the test facility inlet and outlet flue gases during mass concentration measurements. The instrument used to determine the particle size distribution of the fly ash will be a Shimadzu Model SA-CP4 Centrifugal Particle Size Analyzer. This instrument is capable of sizing particles into approximately 25 size intervals between 0.056 and 56.2 micrometers physical diameter (or Stokes diameter, assuming spherical shape and true (actual) particle density).

4.3.2.1.3 Sampling Quality Assurance

The measures adopted to ensure that meaningful results are obtained during the various testing procedures can be divided into three categories: equipment maintenance and calibrations, operating techniques, and analytical techniques. State of the art equipment will be used in this test program and preventive maintenance and calibrations are performed at regular intervals. Due to the dynamic nature of the process, each measurement requires three replicate samples. The replicates are averaged to yield a representative value. Variability gives a means to discern any anomalies not revealed by other quality control checks. For further details of the quality assurance program, please refer to the project quality plan.[1]

4.3.2.1.4 Frequency and Repetition

[1] ABB Environmental System, Quality Assurance/Quality Control Plan for the United States Department of Energy's Engineering Development of a Coal-Fired Low Emissions Boiler System (Contract DE-AC22-92PC92159)

Sampling and analysis is scheduled in the following matrix.

On-Line Analysis

	Inlet Analysis		Outlet Analysis	
Week No.	Particulate	ORSAT	Particulate	ORSAT
1		O2		O2
2		O2		O2
3		O2		O2
4		O2		O2
5		O2		O2
6		O2		O2
7		O2		O2
8		O2		O2
9		O2		O2

Manual Analysis

1				
2	3 days	3 days	3 days	3 days
3				
4				
5				
6				
7				
8				
9	3 days	3 days	3 days	3 days

Daily sampling will consist of three samples if sampling duration is one hour or less, two samples if sampling duration is three hours or less, and one sample if sampling duration exceeds three hours. Sampling repetition may be reduced in the remaining test blocks depending on the variability of early results.

4.3.2.2 Process Data

Process variables that will be monitored directly and logged continuously through an automated data acquisition system are listed below.

- Pulse Air Pressure, psi
- Filter Inlet Pressure, inches w.c.
- Filter Tubesheet Differential Pressure, inches w.c.
- Inlet O_2 concentration, wt %

- Duct Surface Temperature, °F
- Filter Inlet Temperature, °F
- Filter Casing Temperature, °F
- Filter Outlet Temperature, °F
- Fan Outlet Temperature, °F
- Fan Outlet Pressure, inches w.c.
- Fan Outlet Flow, cfm
- Outlet O_2 concentration, %

Process variables that will be derived from measured process variables are listed below. Equations and derivations of the following can be found in the program quality manual.

- Filter Volumetric Gas Flow, cfm
- Filter Face Velocity, ft/min
- Volumetric Gas Flow, cfm, corrected for air in-leakage through system by oxygen balance.
- Mass Gas Flow, lb/hr, corrected for air in-leakage through system by oxygen balance.
- Particulate Removal Efficiency, %
- Filter Drag or Permeance, inches w.g.-s/ft
- Pulse Air Consumption, scf/ft^2/pulse
- Dust Cake Differential Pressure, inches w.g.
- Dust Cake Resistance, inches w.g.-s/ft
- Residual Filter Resistance, inches w.g.-s/ft

4.3.3 Procedures for Start-up, Shut-down, Outages/Stand-stills

4.3.3.1 Start-up with ambient air prior to flue gas

It would be beneficial to preheat the filter with clean air to a temperature above 400°F (200°C), before flue gas is admitted. The filter elements certainly will not be a limiting factor regarding maximum possible warm-up rate.

1. Turn on power to the Analog Instrument Panel, Electrical Panel, Duct Heater Panel, Hopper Heater Panel, Magnehelic Panel, and Continuous Monitoring System.
2. Verify that compressed air header is at pressure.
3. Start the Hopper Heater system 24 hours prior to placing system on-line. Set-point temperature control is 350°F. Verify Hopper Heater system is operating.
4. At the Magnehelic Panel, verify the Photohelic gauge low pressure setpoint is set at 10 in w.g., high pressure setpoint is set at 30 in w.g, and selector switch is set to "TIMER". At the Electric Panel, verify that the Pulse Clean System is "ON". Verify that the Timer Set1 parameter reads "9000", Set2 parameter reads "9000", and Set3 parameter reads "0002".
5. Manually activate the Pulse Clean System to dislodge any ash that may have been left on the filter surface by pressing Pulse System "START" button.

6. Open the Inlet Particulate Test Port Valve. Verify that Outlet Particulate Test Port Valve is closed.
7. Verify that the manual Boiler Inlet Valve and manual Boiler Outlet Valve are closed.
8. Open manual Skid Inlet Valve, Skid Outlet Valve and Skid Bypass Valve.

   WARNING: Booster Fan 1 and 2 must not be started with the Skid Inlet Valves closed as the duct and filter enclosure will be crushed. However, Outlet Particulate Test Port Valve must be closed to prevent motor overload.

9. Start Booster Fan 1. Verify that fan is operating.
10. Start Flyash Rotary Valve. Verify that rotary valve is operating.
11. Start Cooling Air Fan. Verify that fan is operating.
12. Start Duct Heater system. Verify that temperature setpoint is 200°F and system is operating.
13. Slowly open Outlet Particulate Test Port Valve to allow air into the system.
14. Start Booster Fan 2, if needed. Verify that fan is operating.
15. Monitor air/gas temperature into the filter. Raise setpoint as required to reach a minimum air temperature of 400°F.
16. Open Boiler Inlet Valve and Boiler Outlet Valve.
17. Close Inlet Particulate Test Port Valve and Outlet Particulate Test Port Valve.
18. Verify that the Pulse Clean System is "ON" and operating.
19. At Analog Instrument Panel, adjust "Gas Flow Controller" to maintain gas flow set point, initially 4500 ACFM at process conditions.

4.3.3.2 Start-up with flue gas only

It cases where it is not possible to preheat the filter with clean air to a temperature above 400°F (200°C), the following procedure should be followed.

1. Turn on power to the Analog Instrument Panel, Electrical Panel, Duct Heater Panel, Hopper Heater Panel, Magnehelic Panel, and Continuous Monitoring System.
2. Close ball valves to Gas Conditioner. Open purge valves for 2 minutes. Close purge valves and open ball valves to Gas Conditioner. Start Gas Conditioner.
3. Verify that compressed air header is at pressure.
4. Start the Hopper Heater system 24 hours prior to placing system on-line. Set-point temperature control is 350°F. Verify Hopper Heater system is operating.
5. At the Magnehelic Panel, verify the Photohelic gauge low pressure setpoint is set at 10 in w.g., high pressure setpoint is set at 30 in w.g, and selector switch is set to "Timer".
6. At the Electric Panel, verify that the Pulse Clean System is "ON". Verify that the Timer Set1 parameter reads "9000", Set2 parameter reads "9000", and Set3 parameter reads "0002".
7. Manually activate the Pulse Clean System to dislodge any ash that may have been left on the filter surface by pressing Pulse System "START" button.
8. Open System Bypass Valve.
9. Open manual Skid Inlet Valve and Skid Outlet Valve.
10. Start Flyash Rotary Valve. Verify that rotary valve is operating.

11. Open manual Boiler Inlet Valve and manual Boiler Outlet Valve.
12. Start Booster Fan 1. Verify that fan is operating.
13. Slowly close System Bypass Valve.
14. Start Duct Heater system. Verify that temperature setpoint is 775°F and system is operating.
15. Start Cooling Air Fan if Fan Outlet Temperature is above 500°F. Verify that fan is operating.
16. Verify that the Pulse Clean System is "ON" and operating.
17. At Analog Instrument Panel, adjust "Gas Flow Controller" to maintain gas flow set point, initially 4500 ACFM at process conditions.

4.3.3.3 Shut-down with ambient air circulation

Shutdown procedure uses introduction of ambient air into system to provide for gradual cooling of systems, lessening risks associated with heat shocks and dewpoint cycles.

1. Manually activate the pulse system to dislodge any ash that may have been left on the filter surface. Verify that the pulse system is "ON" and in "TIMER" mode.
2. Verify System Bypass Valve is closed.
3. Turn off Duct Heating system. Verify that Duct Heater system has stopped operating.
4. Before Filter Inlet temperature reaches calculated dewpoint, open Inlet Particulate Test Port Valve to introduce ambient air into the system and close Boiler Inlet Valve.
5. At the Electric Panel, change Timer Set1 parameter to read "1500", Set2 parameter to read "1500", and Set3 parameter to read "0002".
6. Immediately manually actuate the Pulse Clean System to dislodge any ash on the filter. Turn off Pulse Cleaning System.
7. When filter inlet temperatures have stopped falling, stop air flow through system by shutting down Booster Fans 1 and 2. Verify that the fans have stopped.
8. Close Skid Inlet Valve and Skid Outlet Valve.
9. Manually actuate the Pulse Clean System again to dislodge any residual ash.
10. Turn the Cooling Air Fan off. Verify that Cooling Air Fan has stopped operating.
11. Manually actuate the Pulse Clean System again to dislodge any residual ash.
12. Turn off Rotary Ash Valve. Verify that it has stopped operating.
13. Remove Flyash Drum from system and empty.
14. Verify Hopper Heating system is on and set to 350°F.
15. Shut down Gas Conditioner. Close valves to Gas Conditioner and open purge valves for 2 minutes. Close purge valves.

4.3.3.4 Shut-down without ambient air.

1. Manually activate the pulse system to dislodge any ash that may have been left on the filter surface. Verify that the pulse system is "ON" and ready to clean filter in "TIMER" mode.
2. Verify System Bypass Valve is closed.
3. Turn off Duct Heating system. Verify that Duct Heater system has stopped operating.
4. Before Filter Inlet temperature reaches calculated dewpoint, stop flow through system by shutting down Booster Fans 1 and 2. Verify that both fans have stopped.
5. Close Boiler Inlet Valve and Boiler Outlet Valve.

6. Close the Skid Inlet Valve and Skid Outlet Valve.
7. At the Electric Panel, change Timer Set1 parameter to read "1500", Set2 parameter to read "1500", and Set3 parameter to read "0002".
8. Immediately manually actuate the Pulse Clean System to dislodge any ash on the filter.
9. Turn the Cooling Air Fan off. Verify that Cooling Air Fan has stopped operating.
10. Manually actuate the Pulse Clean System again to dislodge any residual ash.
11. Verify that Rotary Ash Valve is operating.
12. Remove Flyash Drum from system and empty.
13. Shut down Gas Conditioner. Close valves to Gas Conditioner and open purge valves for 2 minutes. Close purge valves.

4.3.3.5 Outages/Stand-stills

For extended periods of stand-still the CeraMem Filter system should be isolated and either be inertisized or vented to avoid the formation of water condensate on the filter modules.

4.4 Subtask 11.2 - Subsystem Test Evaluation

ABBES will critically evaluate the results of all tests performed in Subtask 11.1. The evaluation will include the following:

- A summary of all the primary experimental data, engineering analyses, and computations.
- A summary and analysis of all results.
- A comparison of the results and the objectives of the RD&T Plan to determine the extent to which research needs were successfully addressed, and a residual needs analysis which highlights remaining or incompletely resolved research needs.
- A critical reevaluation of the subsystem option to assess whether it is ready for further development, scale-up, and inclusion in the final design for the POC Test Facility.
- Revision of the RD&T Plan, including schedule and resources required for continued subsystem development, if it were to be continued by DOE. The revised RD&T Plan should highlight the residual research needs and the detailed plans for their resolution.

4.5 Subtask 11.3 - Subsystem Design Evaluation

ABBES will evaluate design and technology options for each subsystem and recommend specific options for incorporation into the final design of the POC Test Facility. The following issues will be addressed in making design recommendations:

- Has sufficient technical and scientific information been developed to produce an improved subsystem design?
- Will the subsystem meet the desired performance specifications and is the subsystem amenable to scale-up, as required by the Commercial Generating Unit Design (Task 5) and the Preliminary POC Test Facility Design (Task 8)?
- What are the residual scientific and technical uncertainties and obstacles? How and when should they be resolved?

- Is the subsystem sufficiently developed to support an accurate estimate of its capital and operating costs in an integrated Low Emission Boiler System?

5. Project Schedule

The project schedule and milestones to be achieved are given below.

Date	Action
By 10/20/95	Complete Subsystem Unit Design and Engineering
By 3/31/96	Complete Subsystem Fabrication
By 10/18/96	Subsystem Equipment to Arrive at Site
By 10/21/96	Start Subsystem Unit Installation.
By 11/15/96	Complete Subsystem Unit Installation
By 11/22/96	Complete Analytical System Installation.
By 11/26/96	Complete System Test and Start Demonstration.
By 2/5/97	Complete Demonstration and Start Demolition.
By 2/18/97	Complete Demolition.
By 2/5/97	Complete Subsystem Design Data Analysis
By 2/11/97	Complete Test Evaluation Data Analysis.
By 2/18/97	Submit Subsystem Design Data Analysis Report.
By 2/25/97	Submit Test Evaluation Data Analysis Report.

6. Deliverables

ABBES will deliver a final report for inclusion into the Task 12 - Phase II Final Report. The report will include design information, raw data, data reduction and analysis, and conclusions. The final report will address individually each bullet item discussed above in the description of work for Subtasks 11.2 and 11.3.

7. Budget

ABBES has estimated the costs of the separate tasks of the project using DOE-approved rates and no fee. The approximate costs of the tasks are as follows:

Subtask 9.1	$182,981
Task 10	$182,440
Subtask 11.1	$99,334
Subtask 11.2	$18,107
Subtask 11.3	$9,009
Total	$491,781

Two additional months of testing support, as described above, will be available at a rate of $15,000 per month.