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DEVELOPMENT AND TESTING OF A COMMERCIAL-SCALE COAL-FIRED COMBUSTION SYSTEM – PHASE III

Quarterly Technical Progress Report No. 7
Report Period: April 1, 1992 to June 30, 1992

By A.F. Litka and R.W. Breault

We have no objection from a patent standpoint to the publication or dissemination of this material.

Mark Dvorscak 1-22-96

Mark Dvorscak Date
Intellectual Property Law Dept.
DOE Chicago Operations Office

August 1992

Work Performed Under Contract No. DE-AC22-90PC90156

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1. INTRODUCTION

Coal is the most plentiful energy resource in the United States, and in 1987 it provided approximately one third of the quads of total energy consumed in the United States. Its use, however, has been largely restricted to utility power generation since World War II for environmental and economic reasons.

Within the commercial sector, oil and natural gas are the predominant fuels used to meet the space-heating needs of schools, office buildings, apartment complexes, and other similar structures. In general, these buildings require firing rates of 1 to 10 million Btu/hr. The objective of this program is to demonstrate the technical and economic viability of a coal-fired combustion system for this sector.

The development program includes all aspects of the process, from fuel selection and preparation to pollution control and waste disposal. In attempting to restore coal to small users such as residential and commercial space heating, it is important to recognize that fuel form is an important consideration because of its impact on handling and emissions. Ease of handling is an important criterion at the small sizes since complex equipment will add greatly to the overall system costs. Furthermore, manpower is not available to perform manual functions or keep complex equipment working. Emission levels, if not currently regulated, can be expected to be regulated at low levels in the future. The levels considered acceptable will be reduced over time, following the current environmental trends. Preparation and use of a coal-water slurry (CWS) fuel can aid in meeting these criteria. CWS use eliminates the need for dry pulverized coal with its attendant handling and dusting problems as well as its explosive potential. In addition, CWS is amenable to coal washing since coal cleaning technologies are generally water-based processes requiring fine grinding of the coal. For these reasons, the program objective will be met through the development of a CWS-fired system.

Although the CWS fuel in commercial practice will be manufactured by coal companies or fuel suppliers at regional facilities and transported to the user much as is done today with oil, the program includes the construction of a slurry production facility. In this way, all aspects of the fuel's use – from coal selection to combustion properties – can be evaluated and an economic evaluation of the process can be carried out.

The commercial-scale CWS-fired space heating system will be a scale-up of a CWS-fired residential warm-air heating system developed by Tecogen Inc. under contract to the Department of Energy (DOE), Pittsburgh Energy Technology Center. This system included a patented nonslagging combustor known as IRIS, for Inertial Reactor with Internal Separation. This combustion technology, which has demonstrated high combustion efficiency using CWS fuels at input rates of 100,000 Btu/hr, will be scaled to operate at 2 to 5 million Btu/hr. Along with the necessary fuel storage and delivery, heat recovery, and control equipment, the system will include pollution control devices to meet targeted values of NO_x, SO_2, and particulate emissions. In general, the system will be designed to match the reliability, safety, turndown, and ignition performance of gas or oil-fired systems. Table 1.1 summarizes the performance goals of the system. Figure 1.1 is a process flow diagram for the system.

TABLE 1.1

PERFORMANCE GOALS

• Thermal Input	– 4 million Btu/hr
• Thermal Efficiency	– >80%
• Combustion Efficiency	– >99%
• Emissions	– 1.2 lb SO_2/MMBtu 0.3 lb NO_x/MMBtu 0.03 lb Part./MMBtu
• Turndown	– 3:1
• Ignition	– Fully automatic startup with system purge and ignition verification
• Reliability/Safety	– Comparable to oil-fired commercial boilers
• Ash Removal	– Dust free and automatic or semi-automatic
• Routine Maintenance	– Less than one manhour per day and an additional two manhours per week
• Service Life	– >20 years

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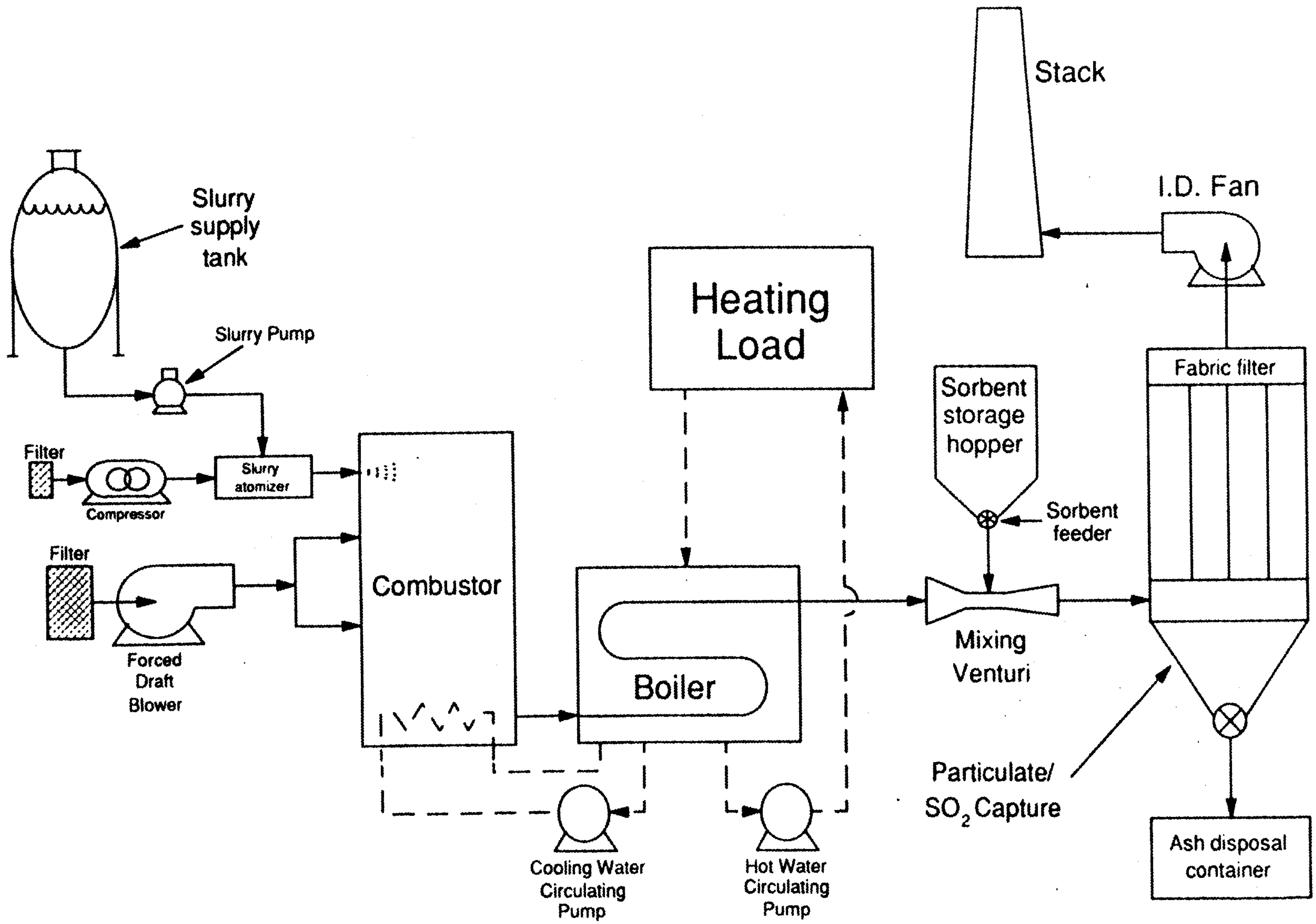

... 1.1 Process Flow Diagram

The successful development and future marketability of the heating system require a strong, dedicated team with expertise in a broad range of areas including CWS preparation, coal combustion, pollution control, component manufacture, and systems integration. Such a team has been assembled and includes the following organizations: Tecogen Inc., Donlee Technologies, AMAX Coal, and Southern Illinois University.

Tecogen Inc. is the prime contractor and is responsible for overall program management, combustor development, and integration of the subsystem components and installation of the system at the field test site. AMAX has extensive experience in CWS preparation and serves as the principal coal supplier. Donlee Technologies is responsible for the boiler/heat exchanger design and manufacture. Donlee has over 70 years experience in the commercial boiler business and is a potential commercializer of the technology. Southern Illinois University (SIU) is the host for the field test portion of the program. The heating system will provide space heating at the SIU Coal Research Center.

The development program has been divided into three stages covering a time span of 39 months. The first stage of the program which covered 16 months focused on component design and manufacture. Once the major components were manufactured, system integration was completed and initial system tests conducted. These tests verified the design and operation of the system components as well as provided a data base for setpoints, process variables and performance for subsequent proof-of-concept testing. Proof-of-concept-testing is currently underway as part of the second stage of the program and will be carried out over an eight month period. The goal of this testing is to demonstrate that the system can operate reliably and that all performance goals can be met. The final stage of the program will cover a 15 month period and will focus on testing the integrated system in an actual installation. Figure 1.2 gives the work breakdown structure for the program.

This report documents the work carried out in the seventh quarter of the program. During this period, proof-of-concept tests aimed at eliminating ash accumulation in the combustor and boiler were conducted. A compressed air soot blower system was installed on the boiler and combustor design changes implemented to reduced direct impingement of slurry on the upper chamber partition. As part of this testing, emission performance goals using Kentucky Hazard Prince Mine coal water slurry were met. Also, during this period, the automatic control system for the system was installed and operation with this system was implemented.

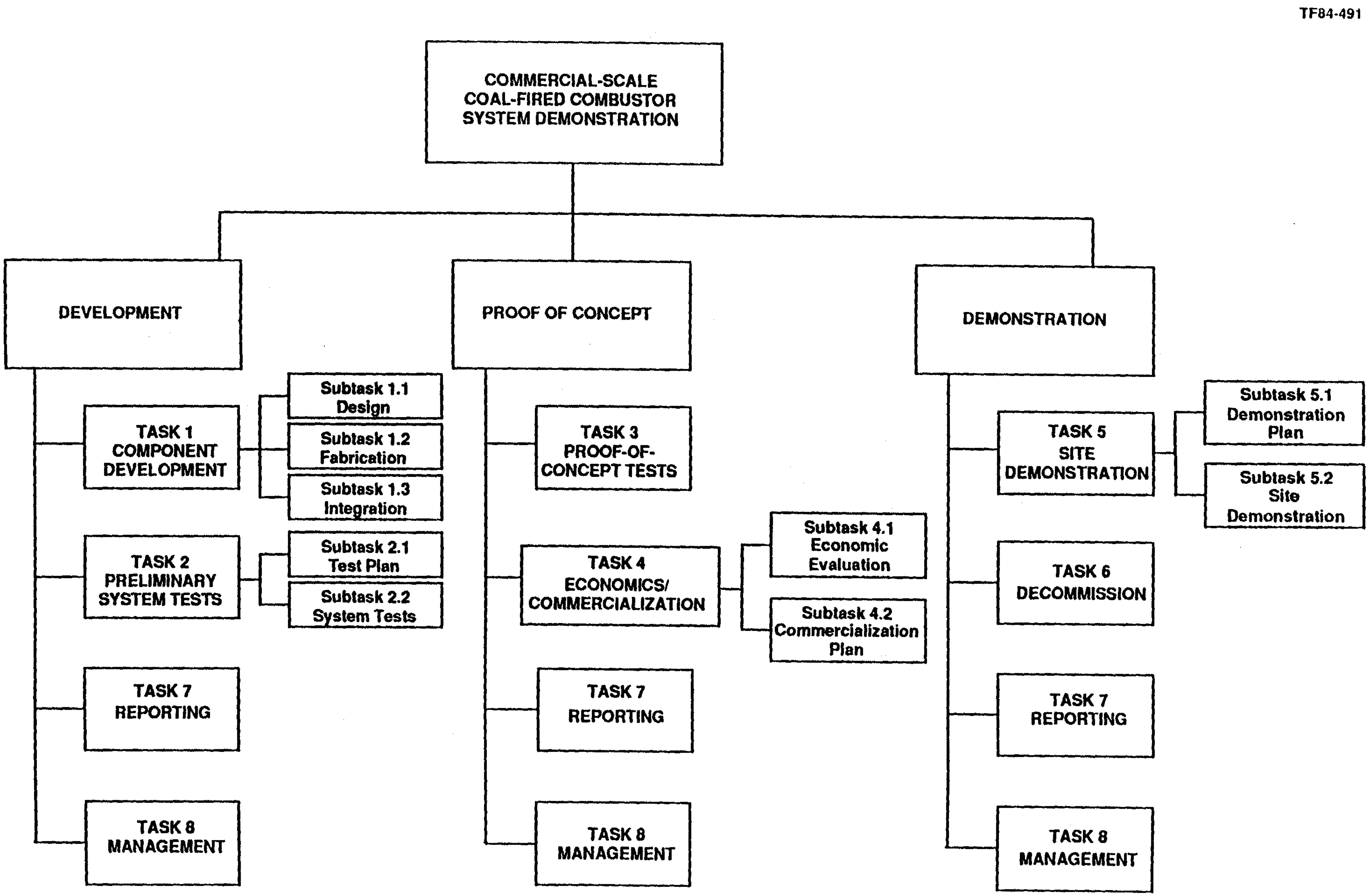

Figure 1.2 Work Breakdown Structure for Entire Project

2. PROJECT STATUS

During the seventh quarter of this program, proof-of-concept testing continued with performance goals attained on Kentucky Hazard Prince Mine coal slurry.

2.1 PROOF-OF-CONCEPT TESTS

Combustor Fouling Evaluation

Several tests were made in a continuing effort to eliminate material accumulation in the combustor and improve overall combustor performance especially as related to NO_x suppression. Tests were made with the water-cooled upper partition located eight inches below the bottom of the primary air inlet. In previous tests, the partition was flush with the bottom of the air inlet. The added distance between the atomizer and partition eliminated direct impingement of slurry droplets onto the partition and increased the time available for slurry droplet heating and vaporization before reaching the partition containment zone. In the first test made with this new partition location, the combustor walls between the bottom of the primary air inlet and the partition were left bare, that is, without refractory or a metal liner to shield the water-cooled combustor shell. Due to excessive heat extraction through this bare wall section and the water-cooled partition, it was difficult to sustain combustion without supplemental fuel oil at low thermal inputs. At intermediate and full load thermal inputs, combustion on slurry alone was achieved but was somewhat unsteady as evidenced by several flameouts when changing load and primary zone stoichiometry. Post run inspection revealed only a small amount of material accumulation in the combustor, primarily on the water-cooled bare wall section.

The remaining tests were performed with a "floating" metal liner extending the length of the primary chamber, from the combustor roof to the top side of the partition, to reduce heat loss from the primary zone and further eliminate material build-up. This configuration is shown in Figure 2.1. The combustor was run for approximately four hours at 3 MMBtu/hr without any material accumulation. Combustor operation was extremely steady.

The compressed air soot blowing system for the fire tube boiler was received from the manufacturer and installed. Figure 2.2 shows the configuration of the system. A hot shakedown test of the soot blower system was made using Kentucky coal slurry. The system operated automatically with sequential pulsing of the four air manifolds every 15 minutes. The combustor was operated at thermal inputs from 2 to 4 MMBtu/hr over a three hour period. Soot blower operation did not adversely effect overall system performance and at the design thermal input of 4 MMBtu/hr boiler outlet temperature was steady at 370°F. Inspection of the boiler tubes after the test revealed that the tubes were relatively free of ash deposits.

Performance Tests

In addition to controlling combustor fouling, the metal liner/water-cooled partition configuration has resulted in a significant reduction in NO_x emissions compared to the refractory lined configuration. This reduction is shown in

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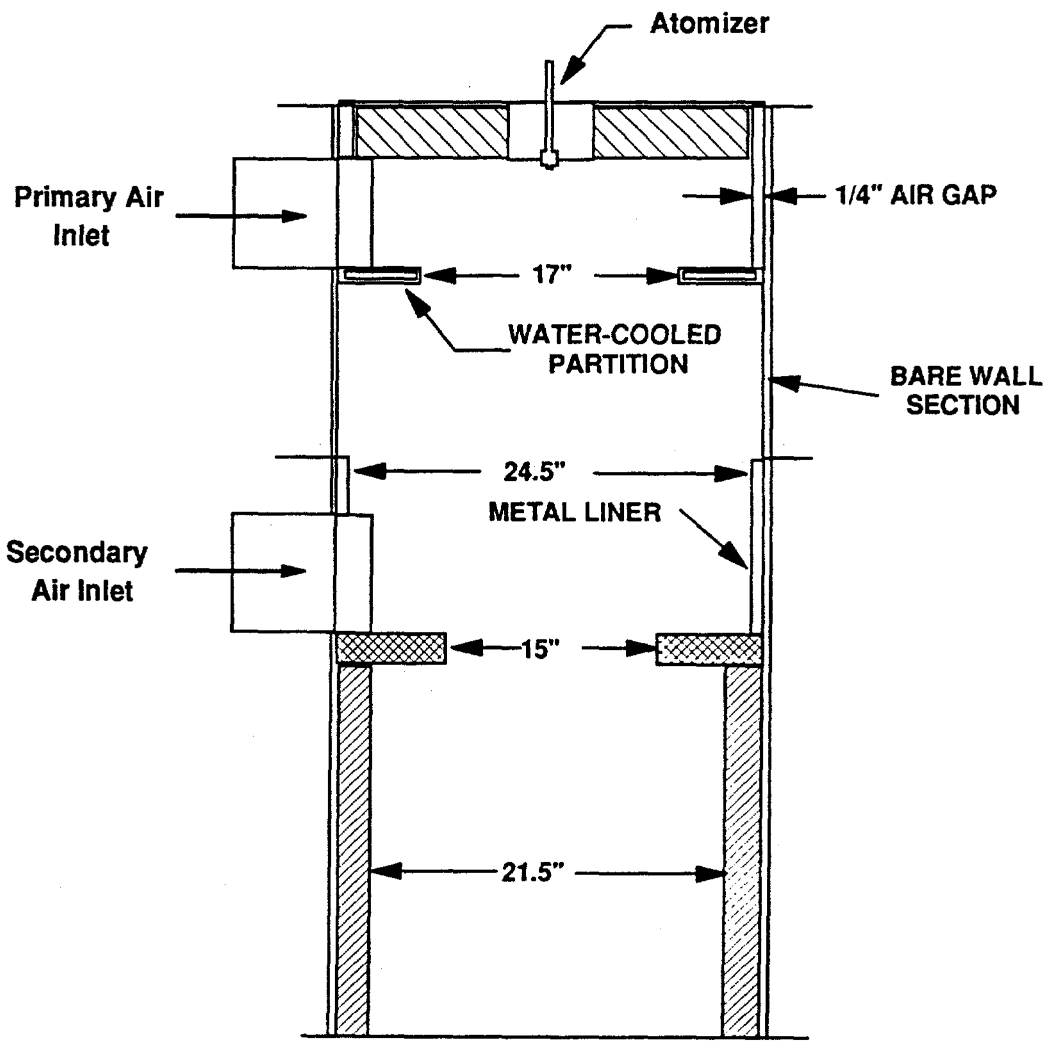

Figure 2.1 Low NO_x Combustor Configuration

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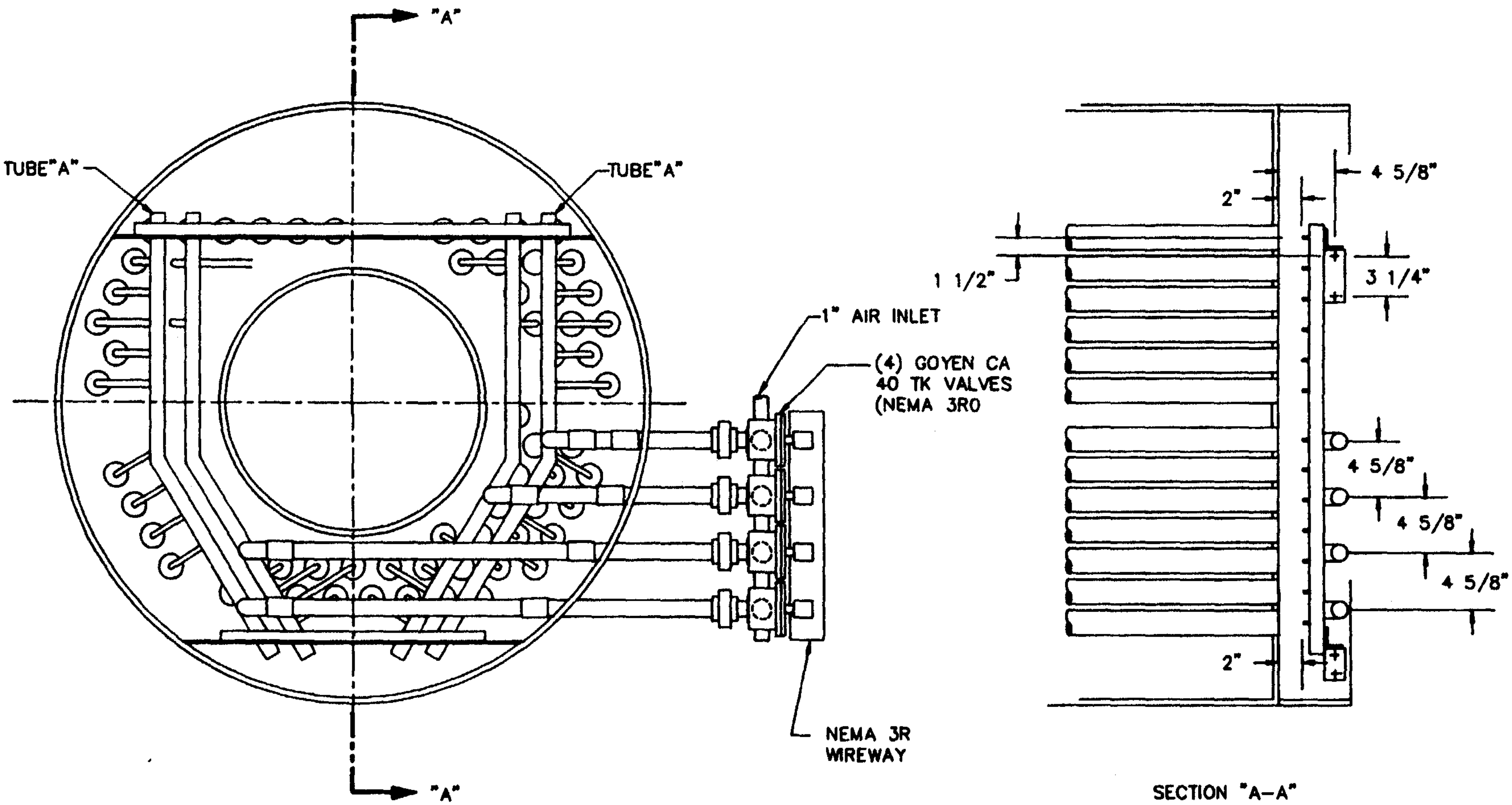

Figure 2.2 Compressed Air Soot Blower System Configuration

Figure 2.3 where NO_x levels are plotted versus combustor thermal input for the different configurations. The NO_x reductions realized with the metal liner/water-cooled partition configuration can be attributed to more uniform devolatilization and burning of the coal particles, a reduction in wall temperatures where the bulk of particle burnout occurs, and a slight reduction in bulk gas temperature resulting from increased heat extraction. As can be seen in Figure 2.3, NO_x emissions goals can be met over the full range of combustor load.

Performance testing with Illinois No. 5 CWS was initiated but subsequent analysis of the coal revealed that an error was made in the type of coal being used. The coal received was the mine's standard product, a partially washed Illinois No. 5 coal having an as-received ash content of 12.4%. For this program, a fully washed coal having an as-received ash content of 6% was to be utilized. This fully washed coal is used for at-the-mine blending to obtain desired heating value levels of the standard product, when necessary. Proximate analysis for these two coals is given in Table 2.1. The fully washed coal's heating value is nearly 10% greater than the partially washed coal on a dry basis.

TABLE 2.1

ILLINOIS NO. 5 WABASH MINE
PROXIMATE ANALYSIS

As Received	Partially Washed	Fully Washed
Moisture	13.1	15.0
Ash	12.4	6.2
Volatile	29.7	33.3
Fixed Carbon	44.8	45.6
Sulfur	1.7	1.4
HHV – Btu/lb	10,685	11,439

Two batches of slurry were produced with the partially washed coal and two test burns were made to evaluate its performance in the system. Figure 2.4 shows the viscosity of the two batches, with coal solids loadings of 57.5% and 53.5%. At the lower loading, the slurry has a heating value approximately 25% lower than the 59% loaded Kentucky coal slurry previously tested.

Self sustained combustion with these fuels could only be maintained at full thermal input and even at this level, combustion was somewhat unstable. At lower thermal inputs, sufficiently high upper chamber temperatures could not be maintained without the introduction of supplemental fuel oil. With 0.5 MMBtu/hr oil co-firing, combustion was steady throughout the load range.

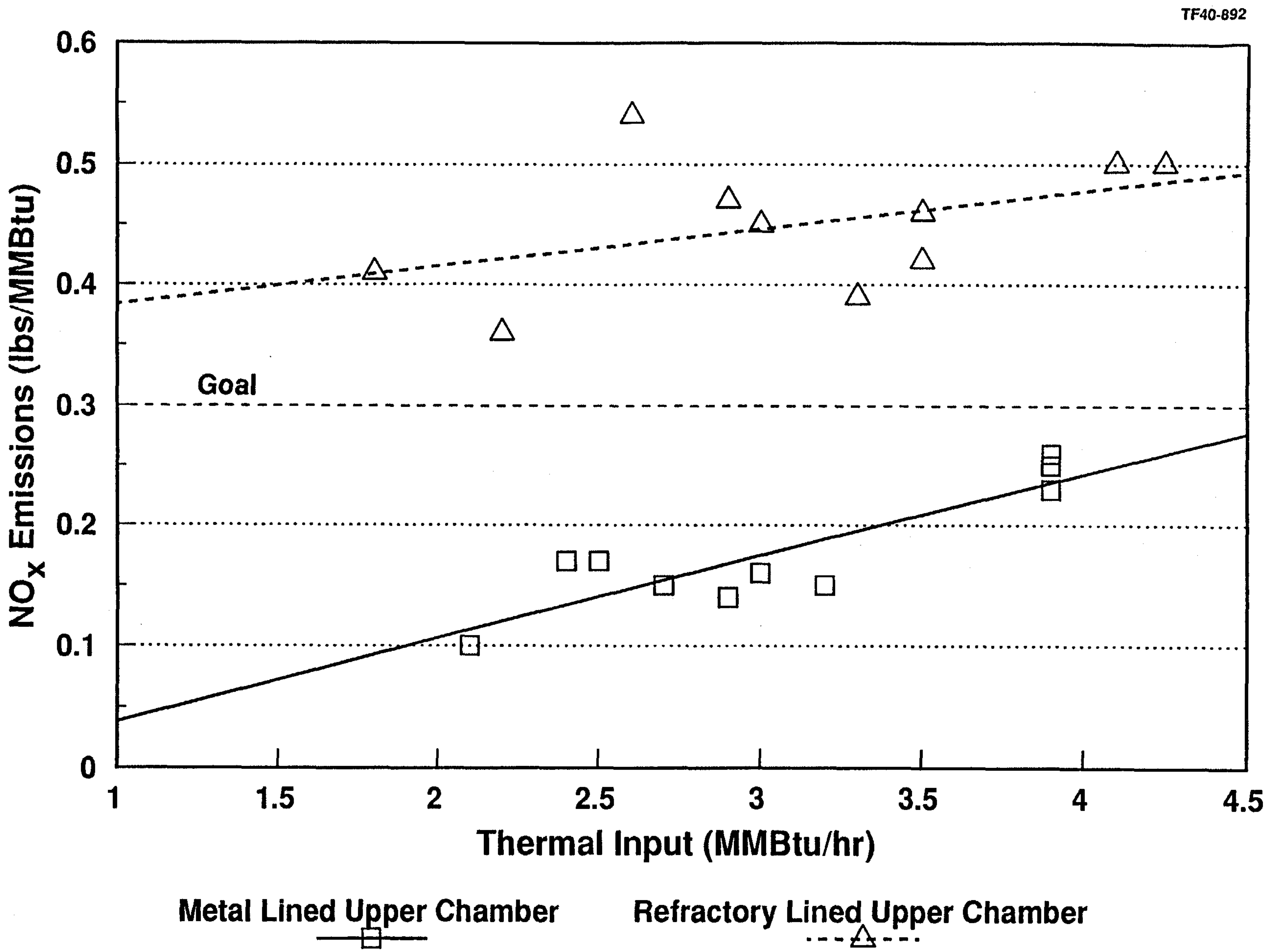

Figure 2.3 NO_x Emissions Versus Combustor Thermal Input

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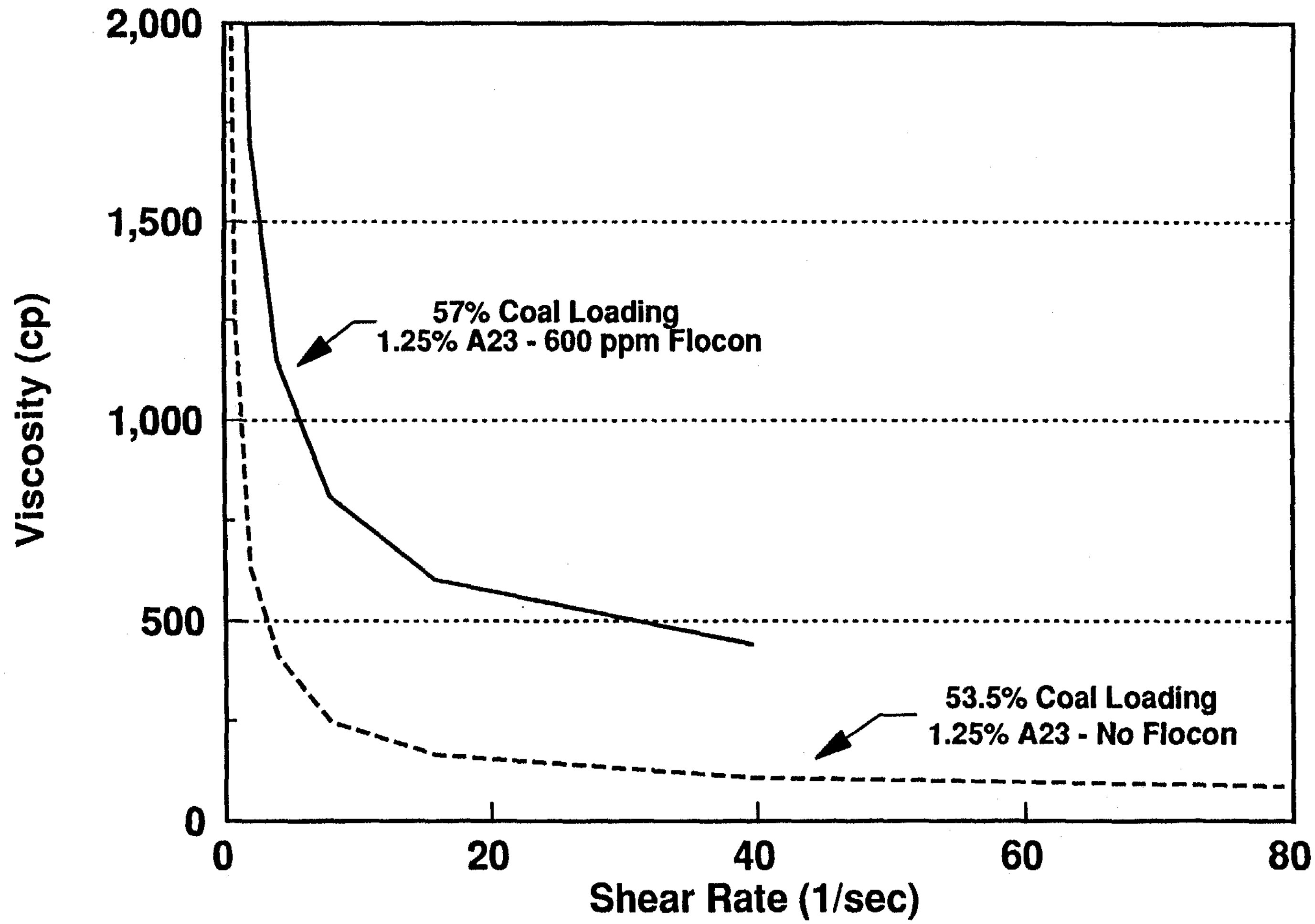

Figure 2.4 Partially Washed Wabash Mine CWS Viscosity

The inability to maintain steady combustion at reduced loads with this lower heating value fuel can be attributed to excessive heat extraction from the combustor primary zone. Operating on Kentucky CWS, the heat extraction from the upper chamber including cover, shell and partition was 300,000 Btu/hr at a thermal input of 2 MMBtu/hr and 450,000 Btu/hr at a thermal input of 3 MMBtu/hr. This represents approximately 15% of the fuel heating value. For the lower heating value fuels, this heat extraction will have to be reduced. Cold flow visualization testing was conducted to evaluate the combustor flow pattern and to determine where a reduction in combustor heat extraction could be most helpful. Injection of particulate material during cold flow simulation revealed that a large inventory of particles was being maintained at the underside of the upper partition in the region where heat extraction is the greatest since this region is bounded by the water-cooled partition and the bare, water-cooled combustor shell.

To reduce the heat extraction in this region, an upper partition with an inner diameter of 20 inches was installed and a metal liner was added directly below this partition to reduce heat loss to the bare, water-cooled combustor shell. Tests were made with slurry made from Kentucky parent coal to evaluate the new geometry. The Kentucky slurry loading was reduced from 59% to 55% to more closely approximate the heating value of the Illinois parent coal slurries. The system was operated for an accumulated 20 hours at 2.75 MMBtu/hr thermal input. After each test, the combustor was inspected. There was virtually no material accumulating in the upper regions of the combustor and the material that did accumulate did not effect slurry atomization or combustor performance and could be removed by turning up the combustion air flow rates to maximum prior to start-up. There was, however, significant accumulation of ash at and below the lower partition and since this material was attached to the refractory surfaces, it could not be swept away prior to system start-up. Although the quantity of this material was not sufficient to effect combustor performance, it may be problematic as operating hours are increased and higher ash coals are utilized. It is conceivable that this section of the combustor will also have to be outfitted with metal liners and a water- cooled partition to eliminate ash deposition as in the combustor upper chamber.

Slurry Preparation

A shipment of the AMAX, fully washed Illinois No. 5 coal was received from the Wabash mine and slurry production using this parent coal has been initiated. Acceptable slurry viscosities (150 cp at 80 inverse seconds) have been obtained at coal loadings of 55% with 1.75% A23 (coal weight basis) added. At 58% coal loading, the slurry viscosity is in excess of 600 cp which is unacceptable from a handling and atomization standpoint. The mass mean diameter for the Illinois No. 5 is 20 microns and the coal size distribution is shown in Figure 2.5. A second rotor was added to the pulverizer to reduce the top size and mean diameter.

2.2 CONTROL SYSTEM IMPLEMENTATION

The development of process control software for automatic control of the system was completed and all controllers, sensors, conduit and wiring were installed. The process and instrumentation diagram for the system is shown in Figure 2.6. The control system consists of a General Electric Fanuc Series 90-30 Programmable Logic Controller. The system provides for complete automatic

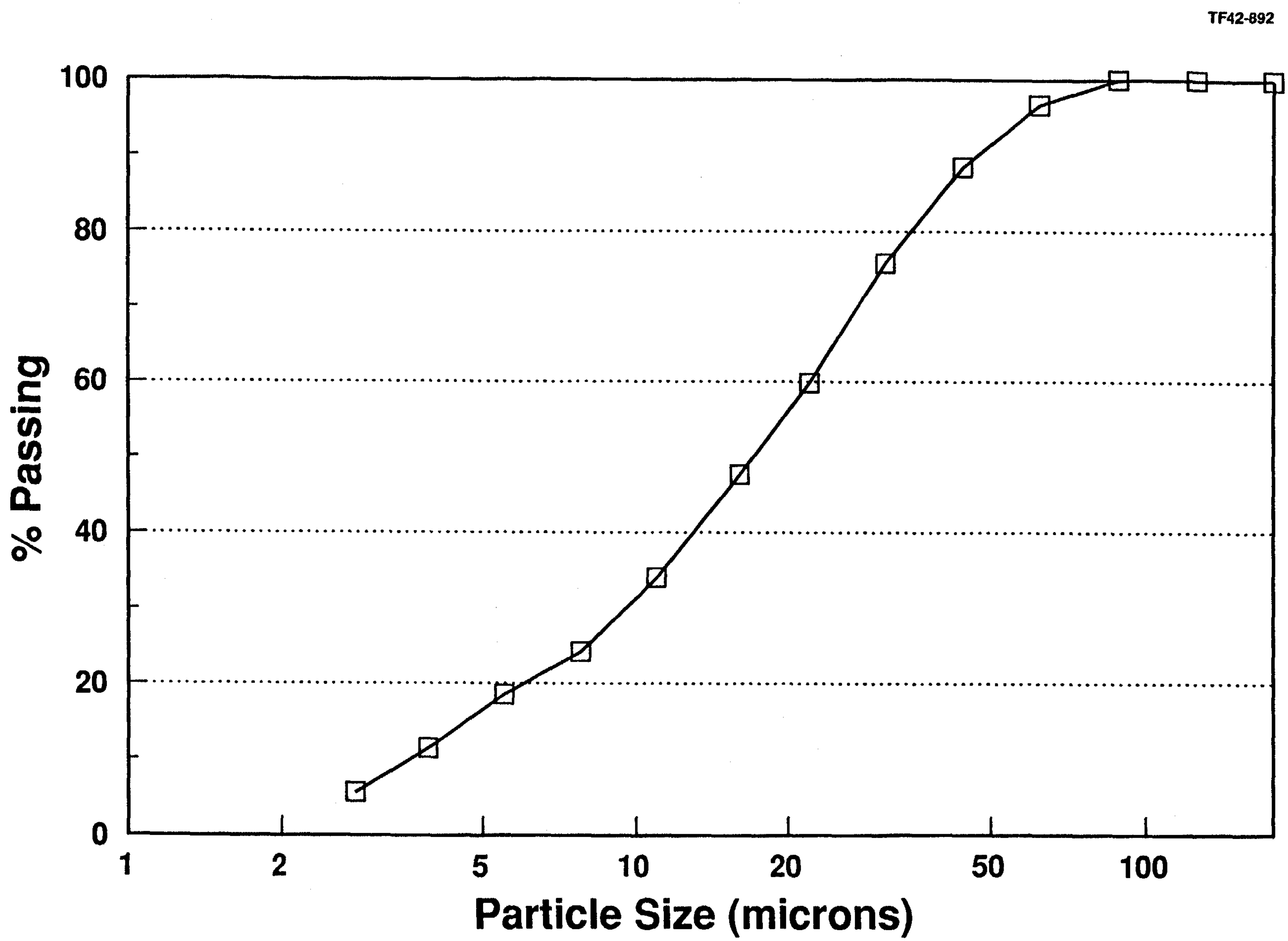

Figure 2.5 Illinois No. 5 Coal Particle Size Distribution

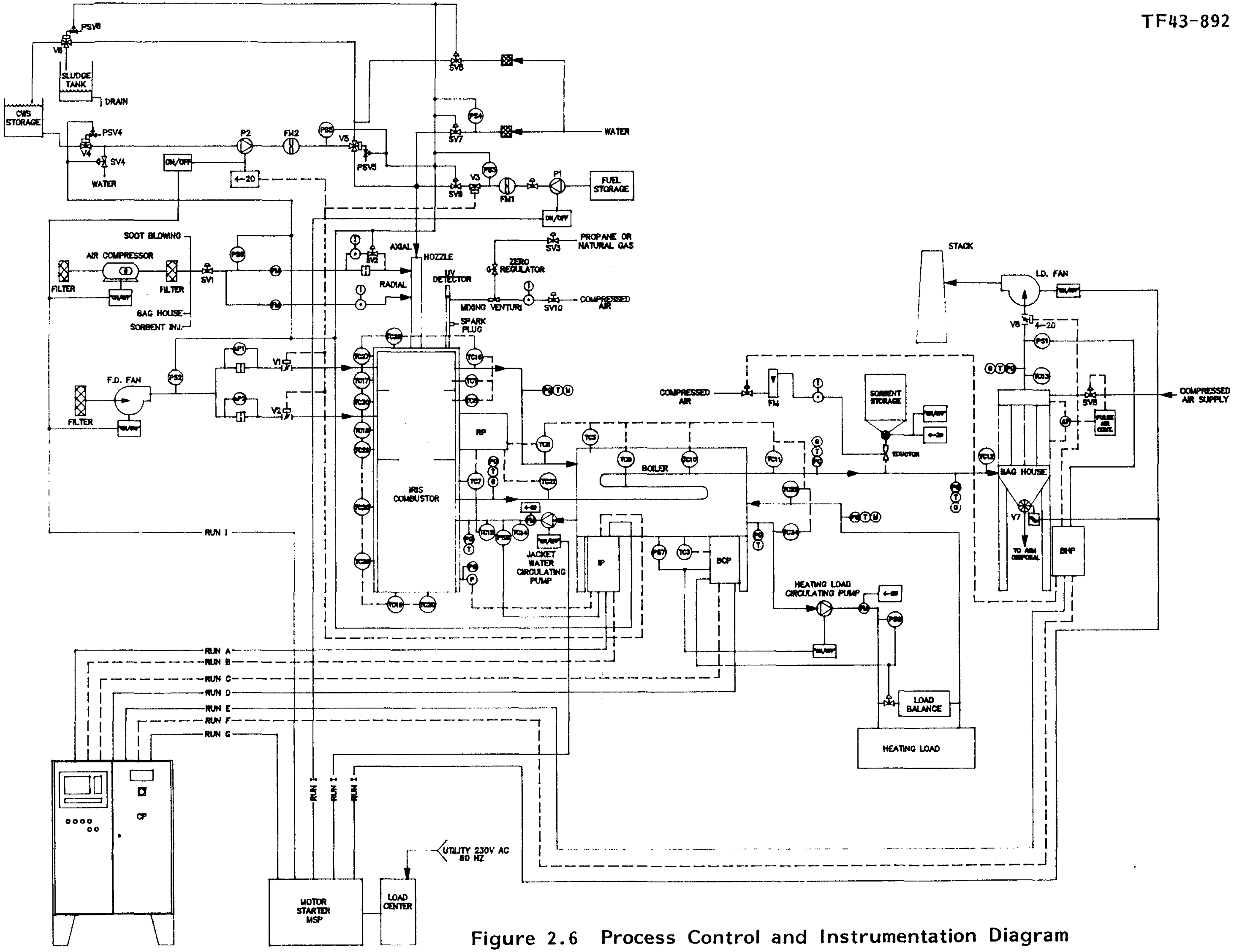

Figure 2.6 Process Control and Instrumentation Diagram

control of the system including pushbutton start and stop, load following, safety interlocks, automatic fuel changeover and alarm messages. The system has six analog output channels, eight analog inputs, four thermocouple channels, 28 discrete output channels and 16 discrete input channels. Operator interface is through a CRT based operator interface terminal. In addition to the PLC system, a personal computer based data logging system has been included to permit monitoring and data reduction of key system variables needed for the development effort.

Along with termination point junction boxes for sensor and controllers, the system has two main electrical enclosures; a main control panel and an instrument panel. Figure 2.7 shows the internals of the instrument enclosure. This enclosure houses the atomizing air controllers and flowmeters, the fuel oil flowmeter and control valve, miscellaneous pressure switches, transducers, and gages. Figure 2.8 is an external view of the main control panel. Control is from an operator interface terminal. This terminal has programmed function keys to allow complete control of the system including selection and manipulation of all proportional control loops in manual mode. Figure 2.9 shows the internal configuration of the control enclosure. Cold shakedown testing and calibration was conducted on each element and subsystem followed by hot shakedown testing of the system.

2.3 ECONOMICS/COMMERCIALIZATION PLAN

Work has begun on evaluating the overall system economics and preparing a commercialization plan for the technology. As a first estimate of the overall system costs, a summary of the developmental system costs have been compiled and are tabulated along with estimated high volume production costs in Table 2.2. As shown in the table, there are several items that have developmental cost but are not required for the production unit. In summary, the cost of the production unit is $57,000. This is a 45% savings from the developmental cost. This cost will be updated as additional information is obtained. These will be included in determining the overall site costs which will include installation costs and site supplied equipment such as the heating system loop.

Simultaneous to developing the system costs, the commercialization plan was initiated. This plan will consist of three parts: a market analysis, an identification of component manufacturers, and finalization of the demonstration site commitment. In addition to developing the market analysis in the United States, it will be important to investigate the potential for an overseas market. Presently, a significant opportunity exists in Eastern Europe for clean burning coal technologies in the residential and commercial markets. To take advantage of the opportunity that exists in these countries because they have primarily coal based economies, a trip was made to Poland and Czechoslovakia to establish contacts, determine market details and system requirements, and promote the technology.

Work has continued on defining the demonstration site configuration, facility requirements, and scheduling. A draft of the EPA permit application was prepared and will be finalized and submitted during the next quarter.

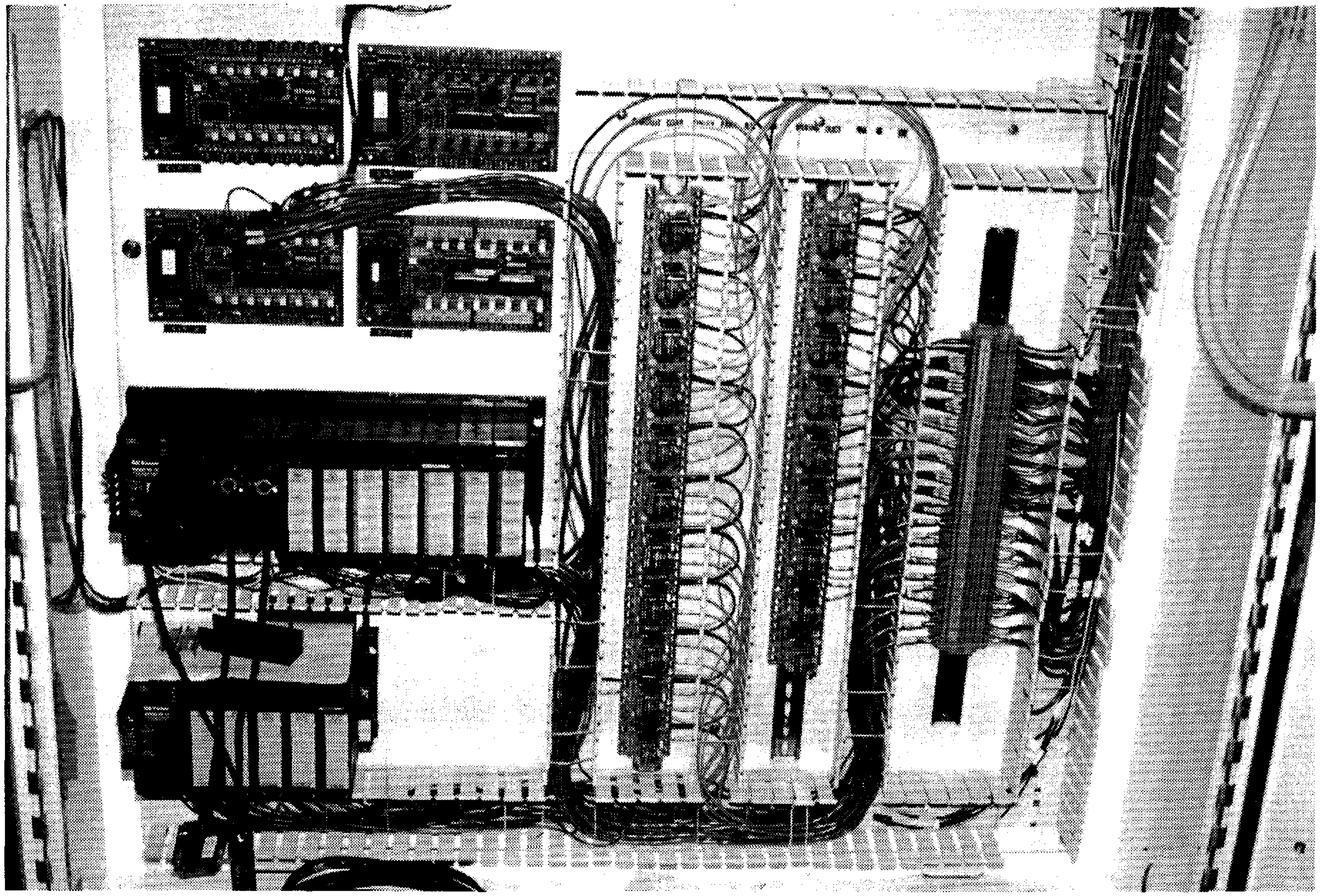

Figure 2.7 Internals of the Instrument Enclosure

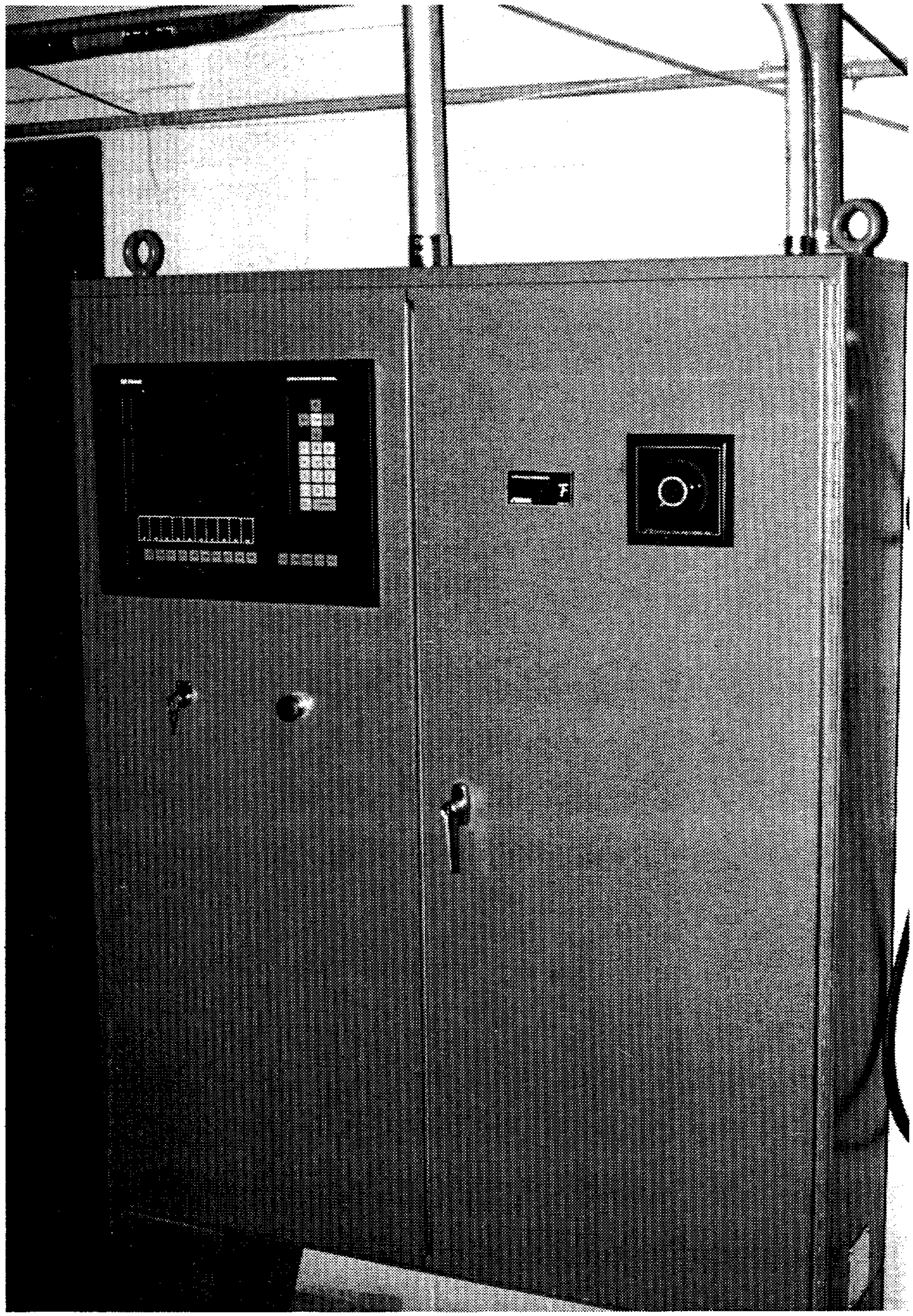

Figure 2.8 External View of the Main Control Panel

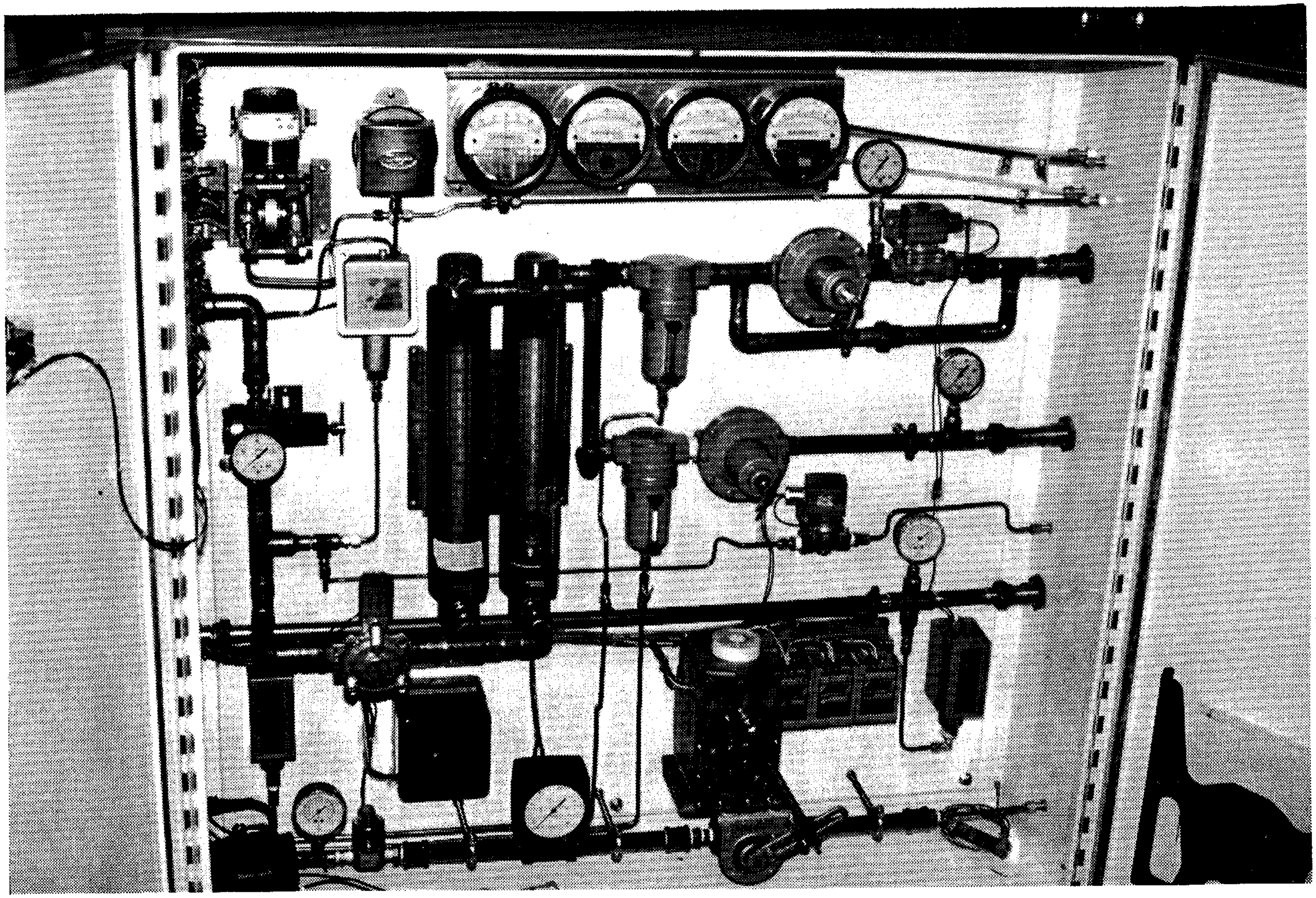

Figure 2.9 Internal Configuration of the Control Enclosure

TABLE 2.2

PACKAGE SYSTEM EQUIPMENT COST ESTIMATE

SYSTEM COMPONENTS	DEVELOPMENT UNIT COST ($)	HIGH VOLUME SYSTEM COST ($)
COMBUSTOR/BOILER		
Combustor/Transition Chamber	20,790	3,500
Expansion Joint	1,075	1,075
Boiler	19,230	19,230
Combustor Cooling Water Pump	679	679
Soot Blower	4,330	3,000
Exhaust Piping	1,909	500
Subtotal	48,013	27,305
COMBUSTION AIR SYSTEM		
FD Fan	2,060	1,500
Air Control Valves	1,896	1,200
Air Piping	500	500
Subtotal	4,456	3,200
EMISSIONS CONTROL SYSTEM		
ID Fan	1,165	800
Exhaust Damper	1,650	NA
Baghouse	7,879	6,000
Sorbent Feeder	3,860	3,000
SO_2 Reactor	3,300	2,000
Sorbent Storage Hopper	2,000	2,000
Subtotal	20,819	13,800
FUEL SYSTEM		
Fuel Oil Pump	321	321
Fuel Oil Flow Meter	720	NA
Fuel Oil Control Valve	969	969
Slurry Pump & Controller	1,456	1,000
Slurry Flow Meter	5,590	NA
Threeway Valves	1,569	520
Atomizer	1,600	2,500
Pilot System & Flame Safety	572	572
Subtotal	12,797	5,882
CONTROLS		
Controller	11,000	2,500
Relays, Breakers & Starters	2,170	2,170
Enclosures	2,037	1,000
Pressure Transmitters	2,595	500
Cooling Water Flow Meter	1,670	NA
Circulation Water Flow Meter	1,670	NA
Combustor Water Flow Meters	990	NA
Subtotal	22,132	6,170
TOTAL	103,887	57,036

3. PLANNED ACTIVITIES

Proof-of-concept testing will continue with Illinois No. 5 CWS. With this higher sulfur coal, sulfur capture with sodium bicarbonate injection will be initiated. A sorbent feed and conveying system will be set up to inject the sorbent into the exhaust pipe between the boiler and baghouse. After completing the Illinois No. 5 tests, the system will be modified with the addition of the SO_2 reaction chamber. This chamber will be installed to provide additional residence time for the removal of the sulfur from the higher sulfur Illinois No. 6 coal. When the reaction chamber has been added, tests will be conducted with the Illinois No. 6 coal.

An EPA operation and construction permit for the demonstration stage of the program will be finalized and submitted.

4. SUMMARY

During the past quarter, significant progress was made in demonstrating the POC system in the laboratory. Combustion was demonstrated on the coals and the control system was shown to work well. Material build-up has been addressed and it is believed that it can be controlled by wall material selection and heat rejection. Tests in the next quarter will demonstrate this.