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

Quarterly Technical Progress Report No. 9
Report Period: October 1, 1992 to December 31, 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

May 1993

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

Tecogen
A division of Thermo Power Corporation, a Thermo Electron company
45 First Avenue
P.O. Box 8995
Waltham, Massachusetts 02254-8995

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

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By
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May 1993

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

Prepared for
PETC Project Manager: Mr. Douglas Gyorke
Pittsburgh Energy Technology Center
U.S. Department of Energy
P.O. Box 10940
Pittsburgh, Pennsylvania 15236-0940

Prepared by
Tecogen
A division of Thermo Power Corporation, a Thermo Electron company
45 First Avenue
P.O. Box 8995
Waltham, Massachusetts 02254-8995

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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 is 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. The combustor concept employs centrifugal forces combined with a staged combustion process to achieve high carbon conversion efficiencies and low nitrogen oxides generation. Along with the necessary fuel storage and delivery, heat recovery, and control equipment, the system includes pollution control devices to meet targeted values of SO_2 and particulate emissions. In general, the system is 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.

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

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

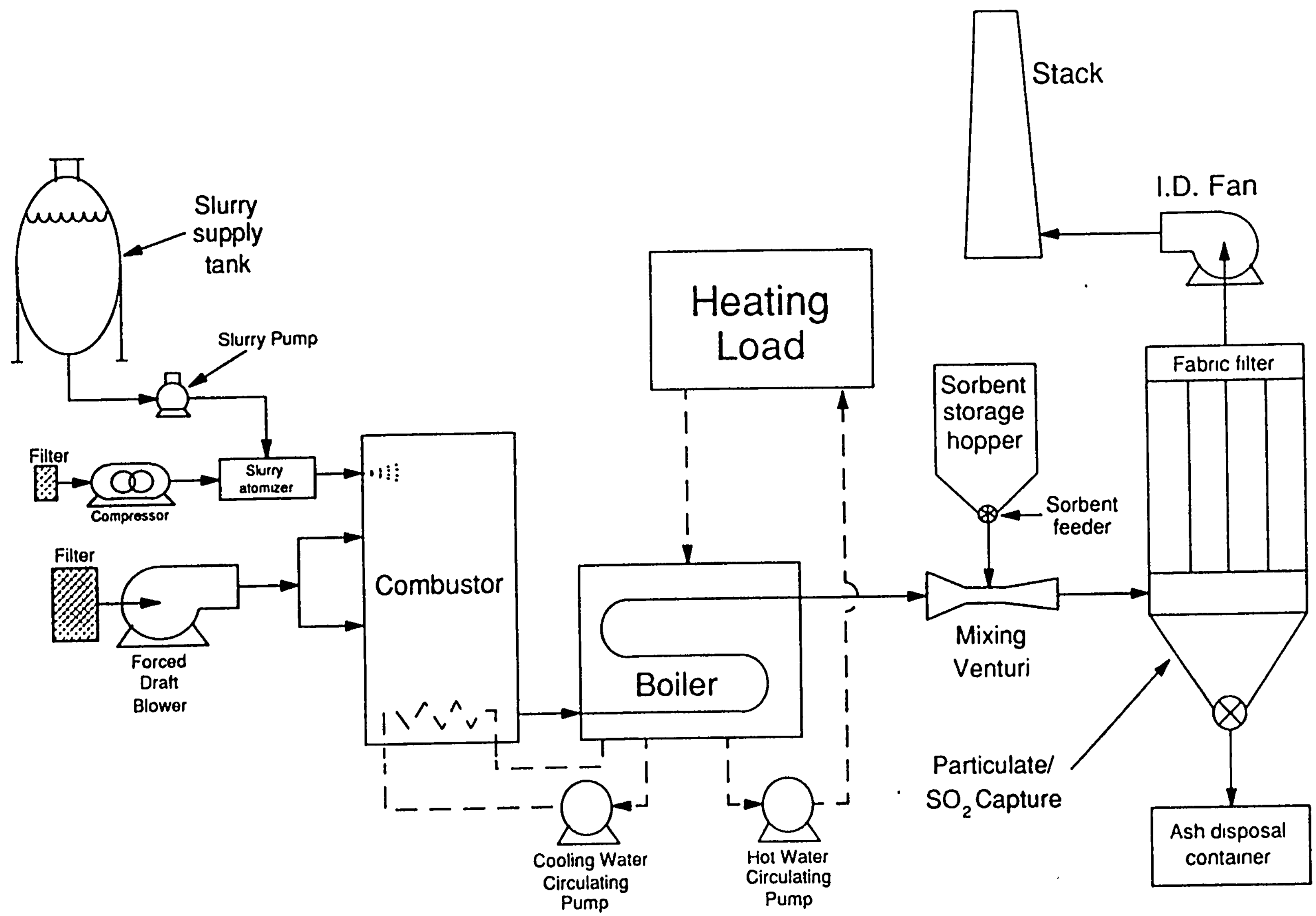


Figure 1.1 Process Flow Diagram

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.

The second stage of the program covered eight months and focused on evaluating the overall performance of the system through Proof-of-Concept Testing. The testing was of sufficient duration to simulate a commercial application with individual tests of up to 48 hours in duration. Combustion and thermal efficiencies; tendencies to slag, foul, erode and corrode; and gaseous and particulate emissions were evaluated.

The final stage of the program which is currently underway will involve integration of the system in an actual installation and operation of the system over the course of a heating season. This demonstration stage is schedule to cover an 18 month period. Figure 1.2 gives the work breakdown structure for the overall program.

This report documents the work carried out in the ninth quarter of the program. During this period, the demonstration stage of the program was initiated. A site demonstration plan was developed which addressed the following items:

- Host site selection and load analysis
- Equipment layout and system interface
- Equipment modifications and/or refurbishments needed to perform the demonstration
- Updated cost estimates
- Demonstration schedule and work plan
- Projected labor and consumable requirements

Also during this period, several equipment upgrades were made to enhance system operation and laboratory testing was performed to evaluate system performance with these improvements.

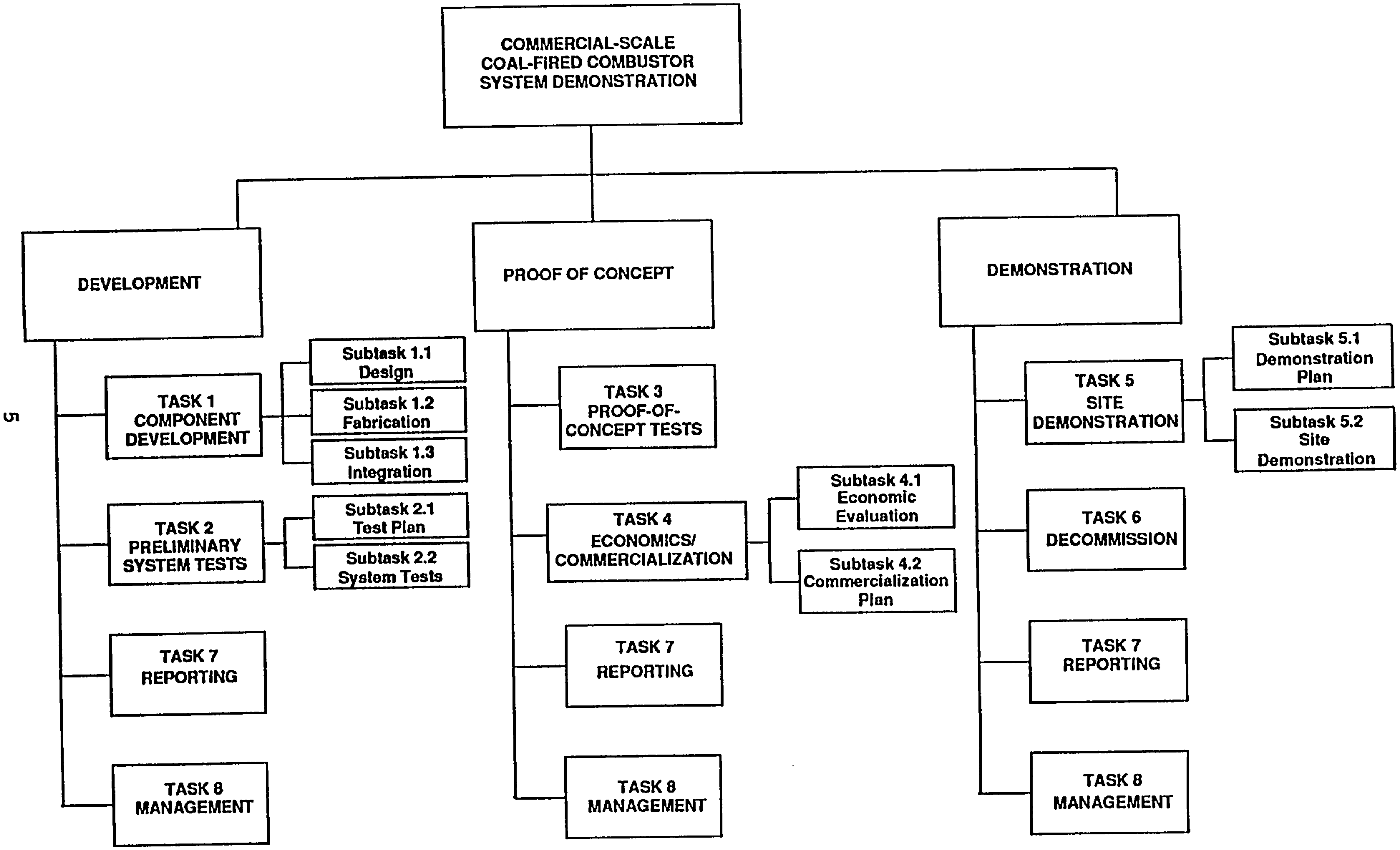


Figure 1.2 Work Breakdown Structure for Entire Project

2. PROJECT STATUS

During the eighth quarter of this program, a demonstration plan was developed for the installation and operation of the space heating system at an actual installation. Also, equipment upgrades were implemented and laboratory testing performed to evaluate the performance of the system with these changes.

2.1 DEMONSTRATION PLAN

Site Description

The space heating system will be installed in the High Bay Building at the Illinois Coal Development Park (ICDP). The ICDP is operated under a cooperative research and development agreement between Southern Illinois University at Carbondale and the Illinois Department of Energy and Natural Resources (IDENR). The objective of the ICDP is to conduct both basic and applied research aimed at the development of technologies to use the abundant coal resources in the state of Illinois in an environmentally sound and cost effective manner. Figure 2.1 shows the location of the ICDP and Figure 2.2 is an aerial view of the facility.

The High Bay Building is a multi-use facility housing classrooms, laboratories, combustion equipment, a grinding facility, and offices. The building has a floor plan of 12,400 square feet and an enclosed volume of approximately 330,000 cubic feet. The high bay area is 36 feet by 122 feet with a 36 foot roof height. It is this area which will be utilized to house the space heating system. Figure 2.3 shows the building layout.

The High Bay Building is currently electrically heated with a combination of electric unit heaters and roof units with ducts. Table 2.1 summarizes the installed heating equipment. The electric unit heaters will be replaced by hot water unit heaters.

System Design

This section provides a brief summary of the space heating design. The system has been designed for a nominal firing rate of 4 million Btu/hr which is approximately the mid-range of the commercial scale market sector. The system has been configured so that commercially available equipment and technologies are utilized wherever practicable. In particular, a fire-tube boiler typically found in installations of the commercial sector size range is used for primary heat extraction. Since only moderate changes are required to the boiler itself, the technology can be utilized to convert existing oil and natural systems to coal firing.

One piece of equipment that is obviously not commercially available is the combustor itself. The commercial-scale space heating system combustor is a scale-up of a combustor technology developed by Tecogen under contract to the Department of Energy, Pittsburgh Energy Technology Center for the residential scale market sector.

The combustor concept (see Figure 2.4) employs centrifugal forces combined with a staged combustion process to achieve high carbon conversion efficiencies and low NO_x emissions. The combustion chamber is divided into multiple zones by

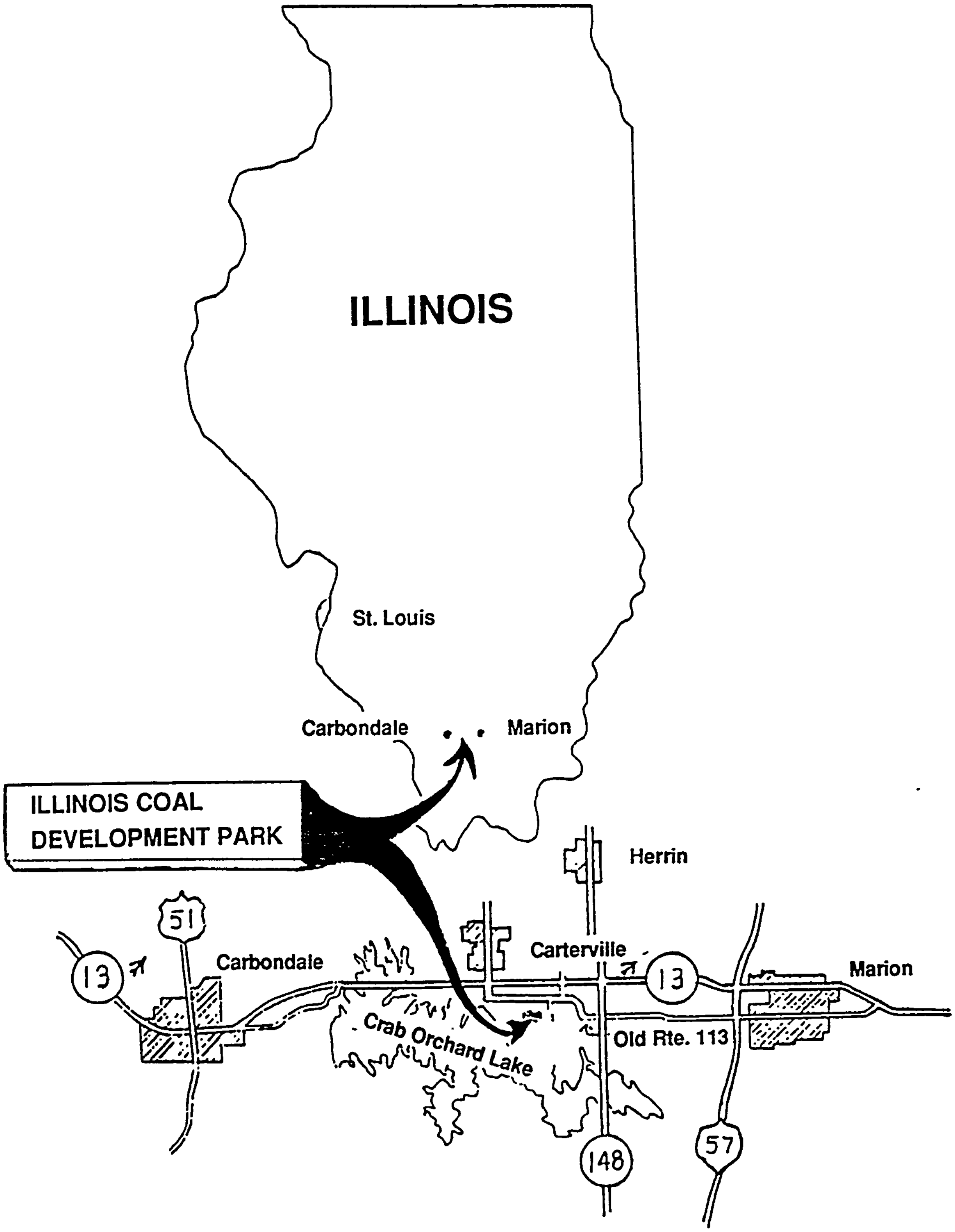


Figure 2.1 Demonstration Site Location

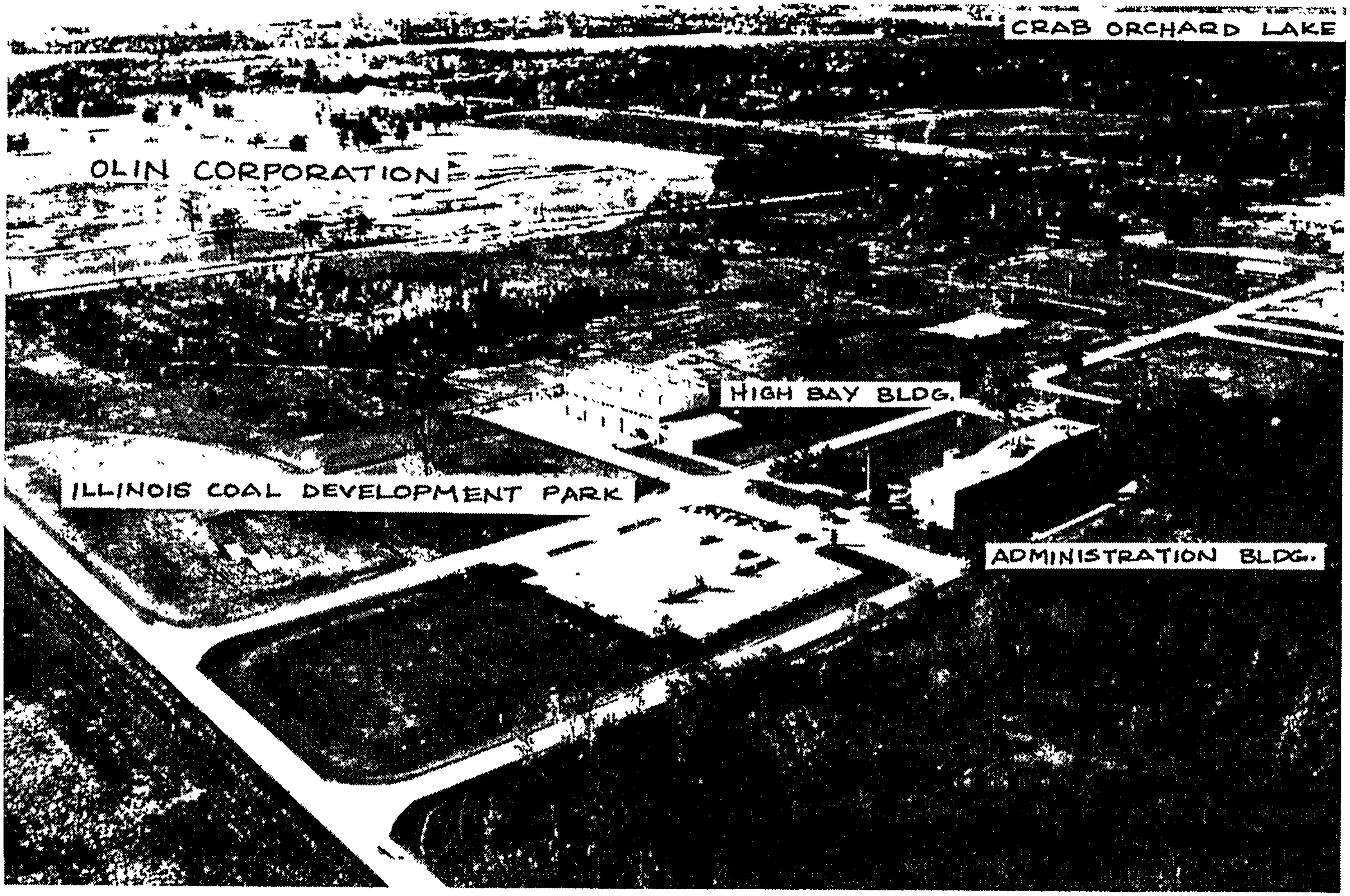


Figure 2.2 Aerial View of Illinois Coal Development Park

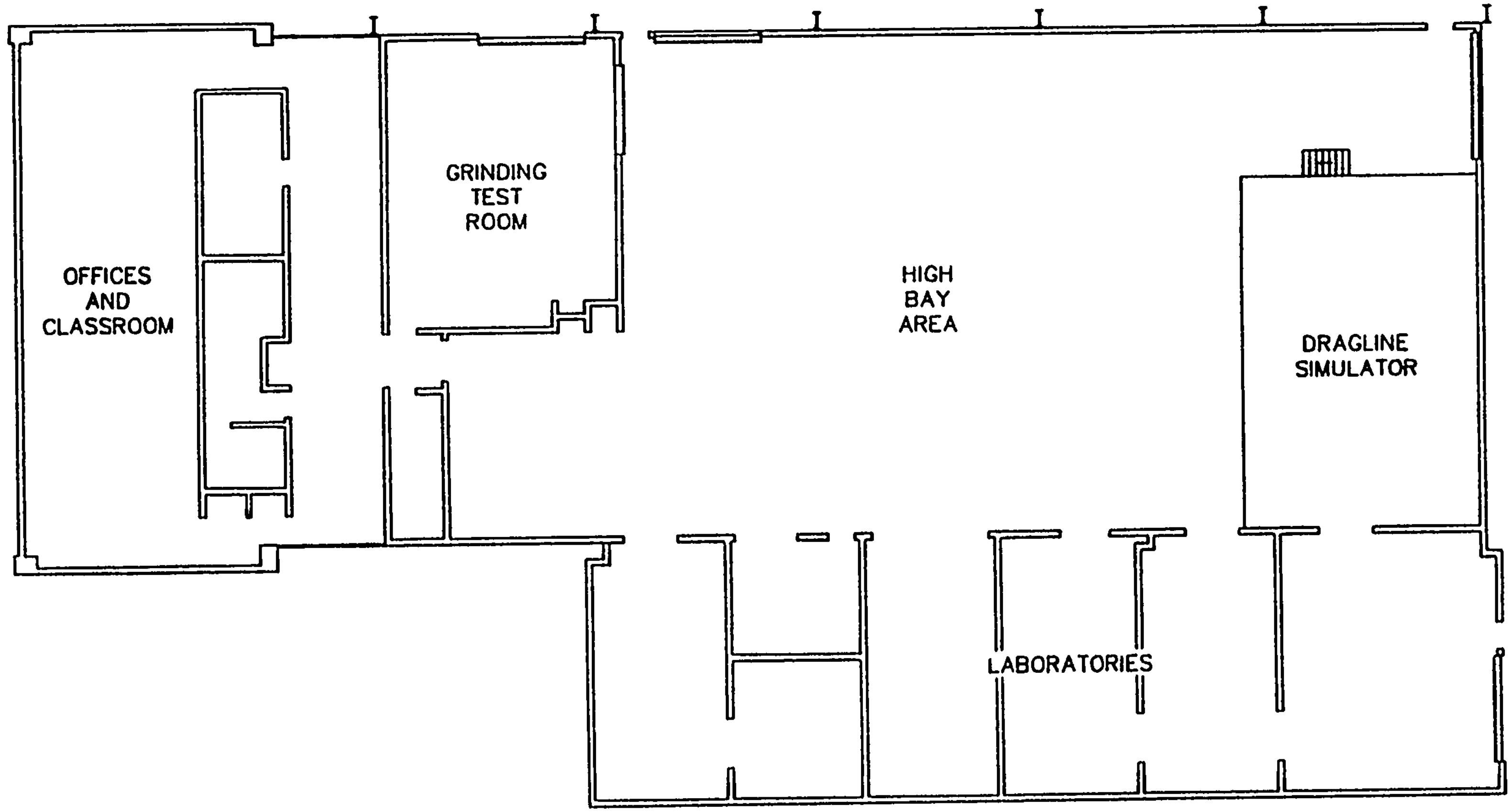


Figure 2.3 High Bay Building Layout

141-17

TABLE 2.1

HIGH BAY BUILDING INSTALLED HEATING CAPACITY

LOCATION	TYPE	QTY	SIZE (kW)	TOTAL HEAT OUTPUT (kW)
High Bay Area	Electric Unit Heater Trane Model E3A256H	5	25	125
Simulator Pit Area	Electric Unit Heater Trane Model E3A056H	1	5	5
Single Lab Room West Side	Electric Unit Heater Trane Model E3A026H	1	2	2
North Classroom Area	Roof Unit with Ducts Carrier Model 50DP006600DC	1	21	21
Labs – West Side	Roof Unit with Ducts Carrier Model 50DP006600DC	1	20	20
Grinding Room	Roof Unit with Ducts Carrier Model 50MH03664DC	1	15	15
Hallways and Restrooms	Roof Unit with Ducts Carrier Model 50DP008800DC	1	28	28
TOTAL				216 (738,000 Btu/hr)

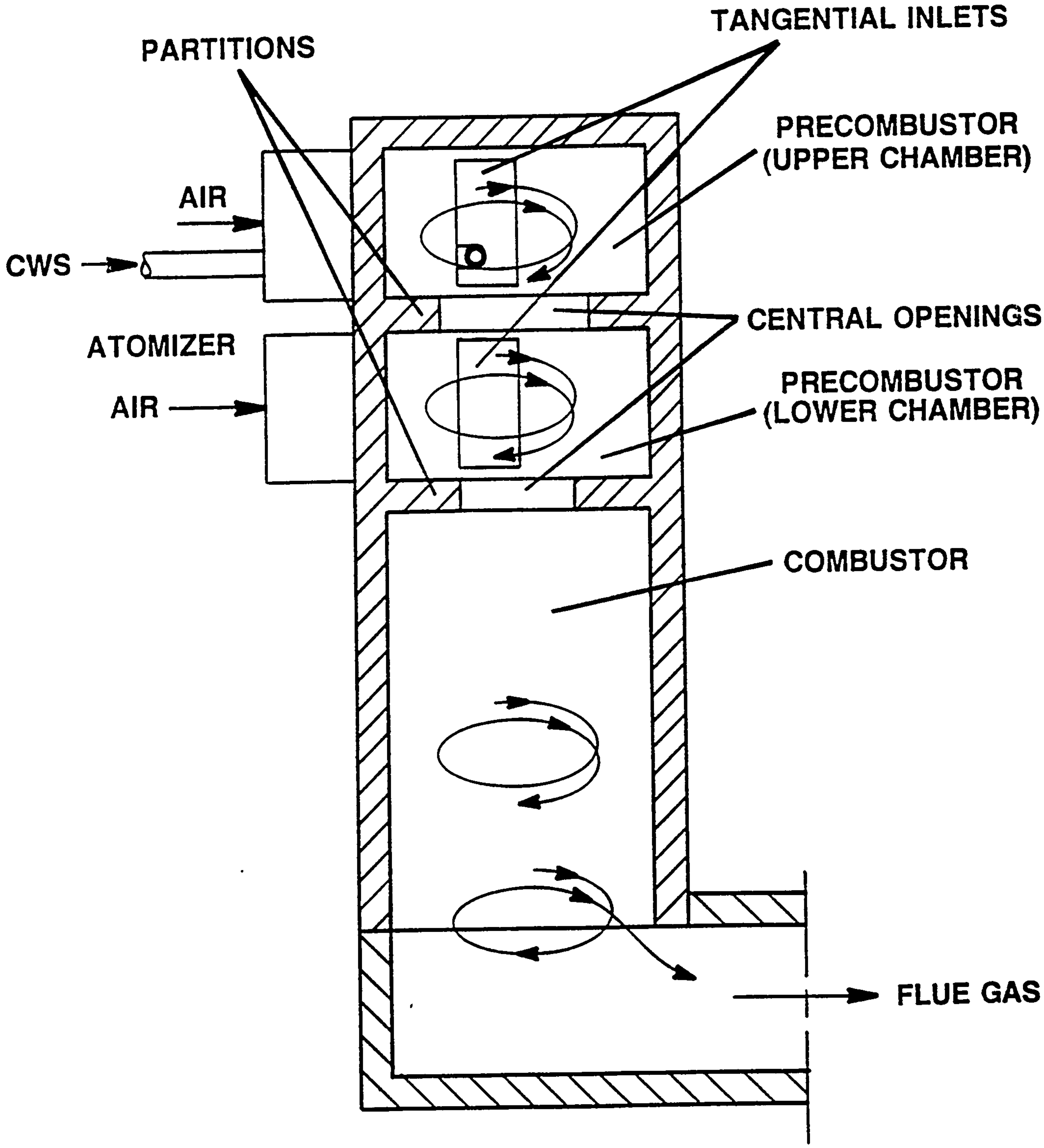


Figure 2.4 Combustor Principle of Operation

partitions to retard the axial flow of unburned coal particles over a given size. In this fashion, the residence time for combustion of the CWS fuel is significantly increased to enable complete carbon conversion for a wide range of particle droplet sizes. Once the particles are small enough to pass through all the partitions, they enter a secondary combustion chamber where burnout of any remaining char is completed.

The combustor is connected to the fire-tube heat recovery boiler through a transition chamber. The transition chamber turns the vertical downward flowing combustion gases and directs them to the horizontal fire tube of the boiler. In addition, the transition chamber serves as a collection vessel for large ash agglomerates which may form in the combustor. A high temperature expansion joint is used to connect the transition chamber outlet with the boiler inlet to allow for alignment flexibility and differential thermal growth of the two assemblies. This arrangement does not require any modification to the inlet of the conventional fire-tube boiler and therefore the combustor can be easily retrofitted into existing oil and gas fired installations.

A conventional fire-tube boiler is used to recover the heat from the combustion gases leaving the transition chamber. To achieve the system performance goal of greater than 80% thermal efficiency, a three-pass configuration was selected. A schematic representation of the boiler configuration is shown in Figure 2.5.

The only changes made to the manufacturer's standard hot water oil and natural gas fired configuration was the addition of particulate drop-out hoppers at each end of the boiler, additional connections for combustor cooling water supply and return, and a compressed air soot blowing system.

Although the use of CWS for the commercial market sector greatly simplifies the fuel delivery system as compared to a dry, pulverized coal system, special attention must be placed on the proper design of the system to ensure proper operation of the combustor. Slurry velocities must be sufficiently high to avoid settling, piping dead-ends must be avoided and proper flushing must be provided to clear the system during prolonged inactivity.

Figure 2.6 is a flow schematic of the fuel delivery system. A key component of the system is the atomizer. The atomizer not only defines the requirements for the handling system, i.e. required pressure and filtration, but also plays a key role in the efficiency and stability of the combustion process. A variable spray angle, externally mixed twin fluid atomizer was developed to meet the needs of the system. The atomizer operating conditions can be set to provide the wide cone angle required of the radial, top center firing configuration of the commercial scale system. This atomizer uses two perpendicular atomizing streams to shear the CWS into a thin, unstable ligament sheet that breaks up into small droplets external to the atomizer.

The external atomization feature of this nozzle prevents erosion and allows for a large CWS passageway which minimizes the head that the CWS pump must produce. In addition to providing fine atomization due to the high shear that is imparted by the two perpendicular atomizing streams, by varying the flow rate of each of these streams, the spray angle can be changed on-line without any mechanical modifications to the atomizer.

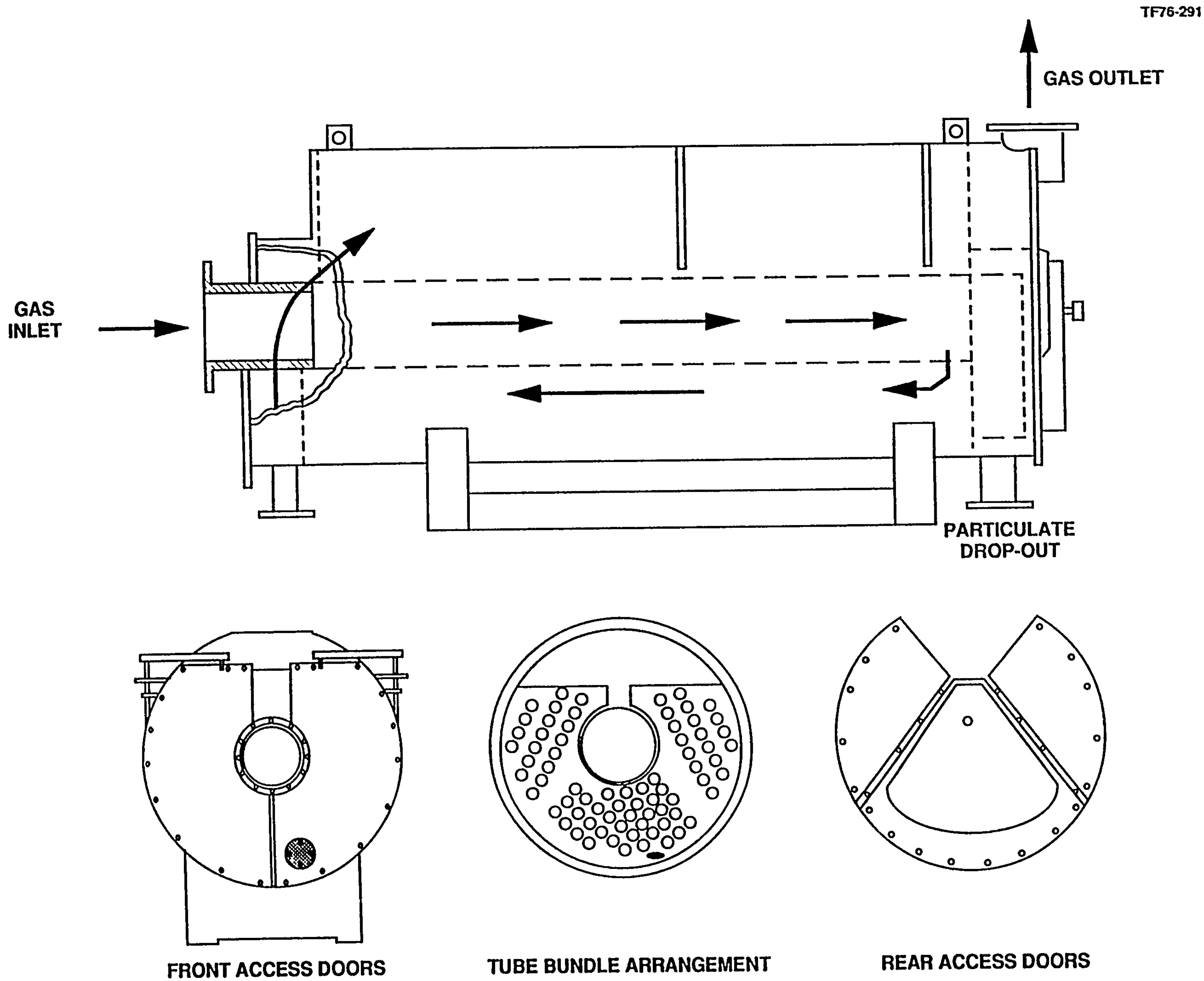


Figure 2.5 York-Shipley Fire-Tube Heat-Recovery Boiler Configuration

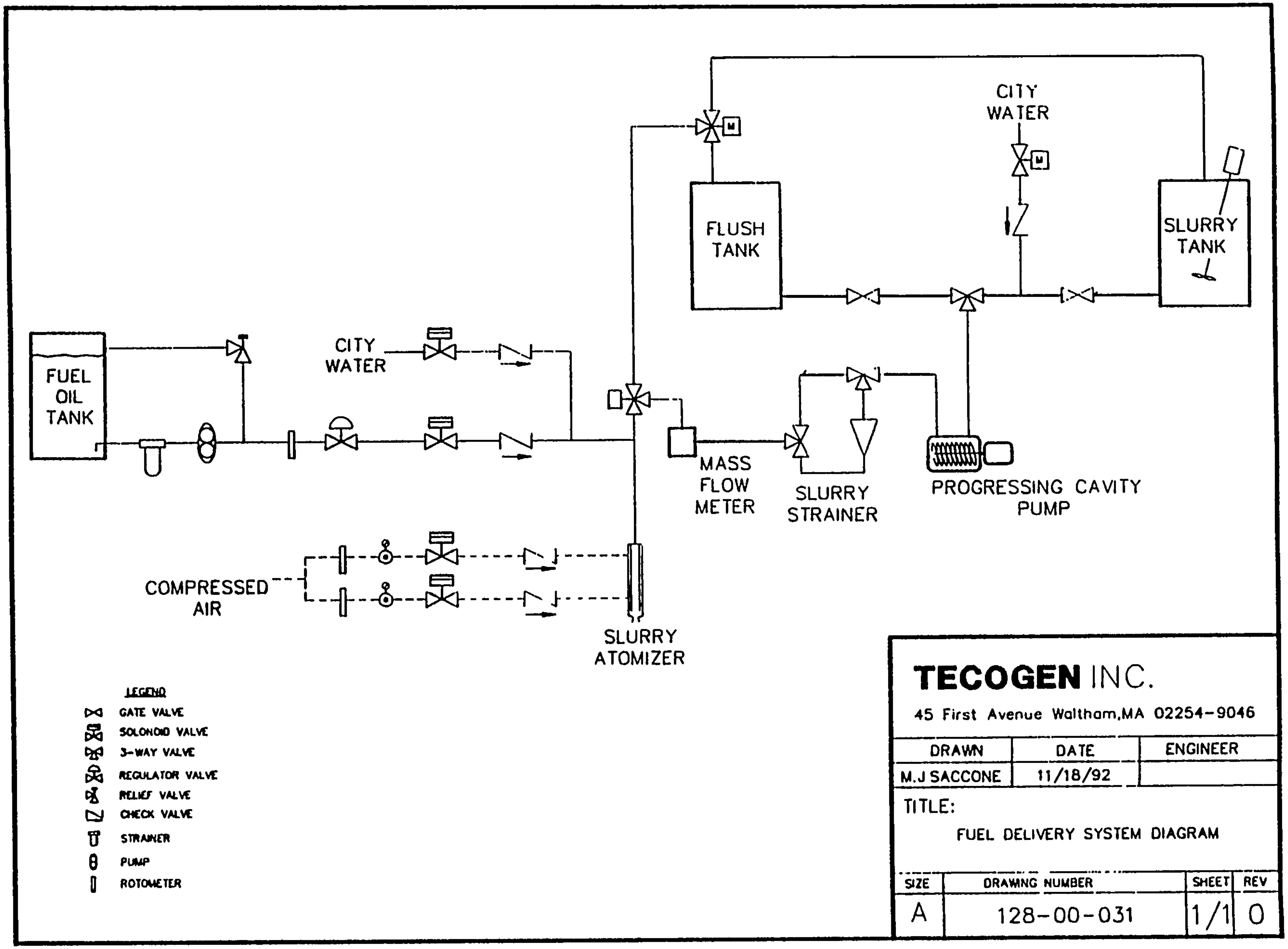


Figure 2.6 Fuel Delivery System Diagram

To meet the targeted emission goals of no more than 1.2 lbs of SO_2 and 0.03 lbs of particulates per million Btu, the CWS fired commercial-scale space heating system must include flue gas pollution control equipment. Uncontrolled, the system will generate emissions of approximately 4 lbs of SO_2 per million Btu and 6.25 lbs of particulates per million Btu, depending on the exact coal composition. As discussed above, the control of nitrogen oxides (NO_x) to targeted levels is achieved through control of the combustion process and therefore the pollution control equipment does not include NO_x reduction capabilities.

To achieve the required goals of 70% reduction of SO_2 and 99.5% particulates capture, dry duct injection of sorbent in conjunction with a fabric filter is utilized. In the duct injection process, a dry, powdered sorbent; namely sodium bicarbonate or trona, is injected directly into the flue gas duct upstream of the particulate-control device. The sorbent undergoes rapid decomposition in the hot flue gas creating a highly porous, reactive particle. SO_2 is absorbed onto the particle initially at the point of injection and further absorption of SO_2 occurs in a baghouse as the sulfur laden gases pass through the filter cake. The baghouse is considered an integral part of the SO_2 removal equipment.

The baghouse is a conventional pulse jet fabric filter design with a cloth surface area of 457 sq. ft. The unit is 4 feet by 4 feet with a height of approximately 13 feet and consists of thirty six 100-inch long bags. The bag material is P84, a nonflammable and thermostable organic fibre with a maximum use temperature of 500°F.

The system has been configured as a low temperature (180°F) hot water system. The circulating portion of the system is a conventional direct return type system. A load dump radiator will be included to permit operation of the system during periods when the building load is low, and to base load the heating system for extended full load operation. Figure 2.7 gives a schematic of the circulating water system. The boiler is equipped with a three way regulating valve to minimize thermal shock to the boiler as heating loads are turned on. This valve is controlled by return water temperature. If the return water temperature drops below the setpoint, the return water is diverted around the boiler thereby reducing drastic boiler water temperature fluctuations.

Operating in conjunction with the main circulating system is a combustor circulating water loop. The double jacketed combustor and transition chambers are cooled with boiler water. Boiler water is pumped from the base of the boiler through these units and returned to the top of the boiler. The temperature rise in the individual sections is controlled to eliminate the possibility of steam generation.

The space heating system has been outfitted with a control system capable of ensuring safe, reliable, and fully automatic system operation. A process and instrumentation diagram for the process is shown in Figure 2.8. The control system consists of a General Electric Fanuc Series 90-30 Programmable Logic Controller. The controller provides for complete automatic or manual 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 input channels, four thermocouple channels, 28 discrete output channels, and 16 discrete input channels. Operator interface is through a CRT-based operator interface terminal. The terminal has selectable flow

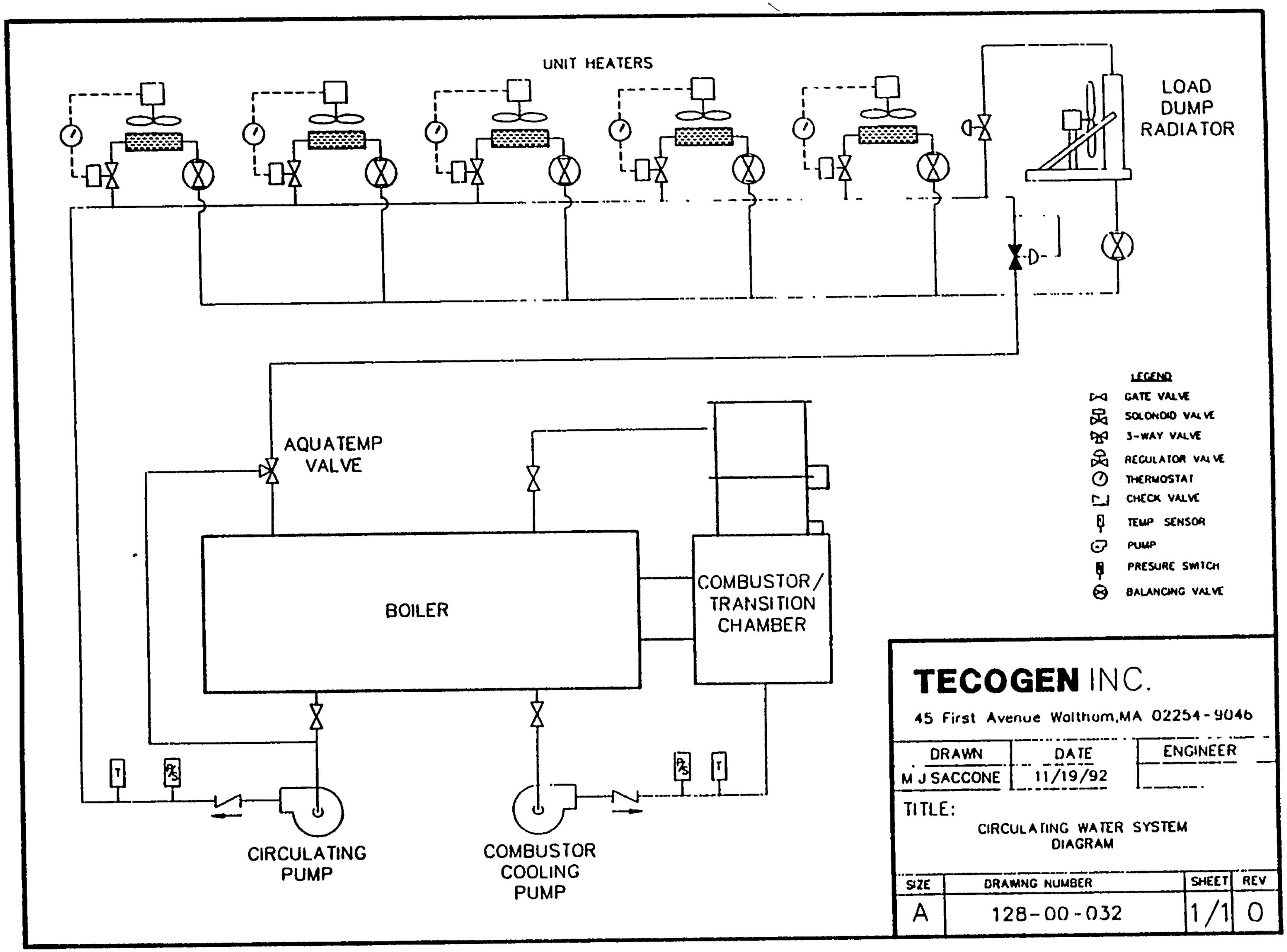


Figure 2.7 Circulating Water System Diagram

schematics which display key process variables and setpoints, and programmed function keys to allow complete control of the system including selection and manipulation of all proportional control loops in manual mode.

Site Design

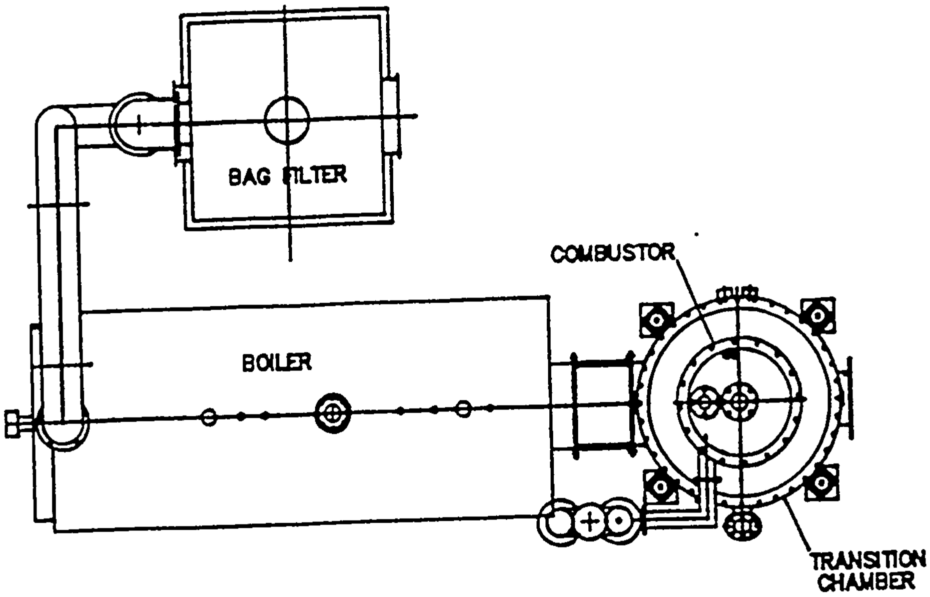
During the component development and proof-of-concept stages of the development program, the prototype space heating system was configured to be compatible with the host site facility. This fact minimizes the amount of engineering and design required to complete the installation of the equipment in the High Bay Building at the ICDP.

Figure 2.9 shows the overall configuration of the major system components as assembled at Tecogen's Waltham facility. The system is made up of three major modules: a combustor module, a boiler module, and a baghouse module. These modules have been designed to contain major piping and electrical connection points to allow for easy disassembly, shipment, and reassembly at the host site. The boiler module contains the bulk of the system auxiliary equipment including: the main instrument panel; fuel oil, circulating and combustor cooling pumps; aquastat valve; and boiler controls. The combustor module consists of the combustor, transition chamber, combustion air control equipment, and combustor instrumentation. The baghouse module consists of the baghouse, the baghouse instrumentation panel, bin and rotary valves, compressed air piping, and baghouse support structure.

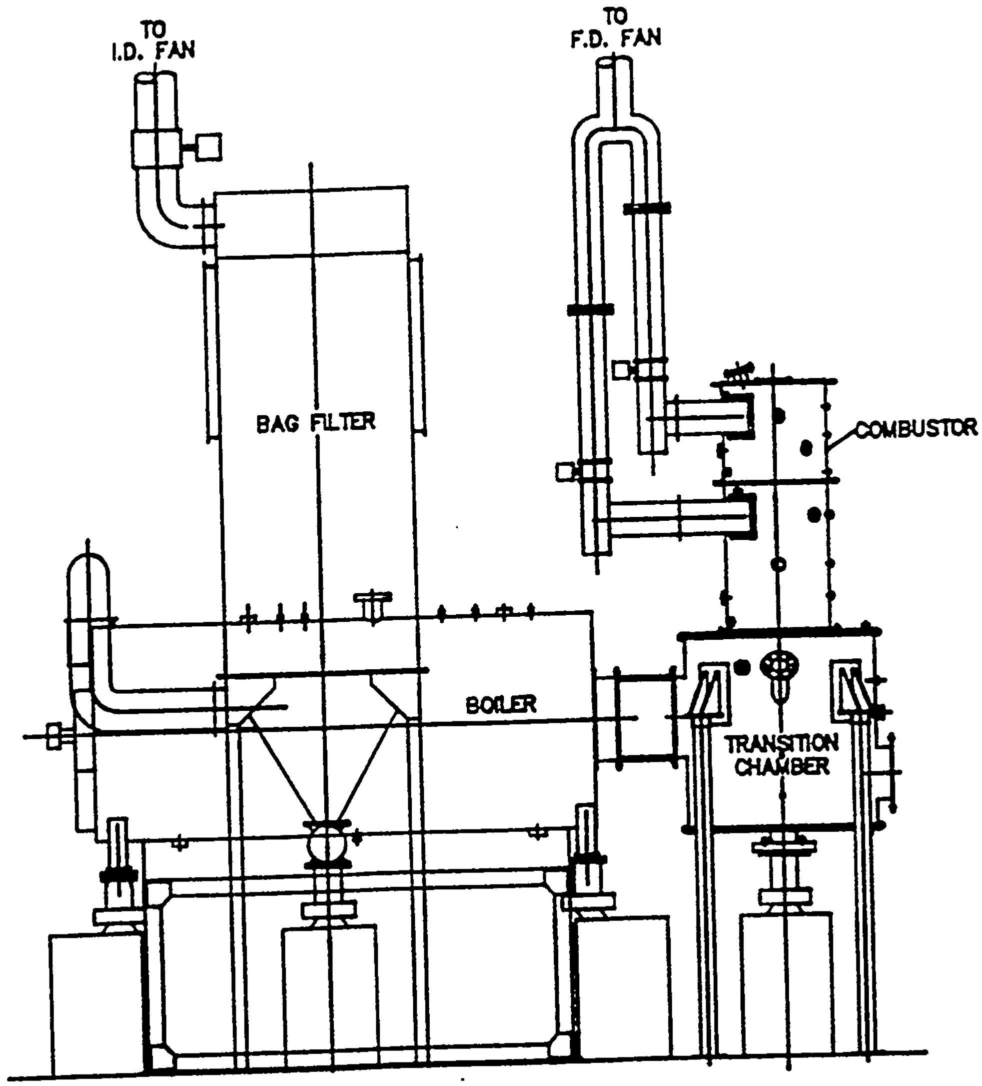
Figures 2.10 thru 2.12 shows the planned equipment layout at SIU. The major system modules will be placed inside the building in the high bay area. Auxiliary equipment such as blowers, compressor, and load management radiator will be placed along the building's east wall.

In addition to the space heating system, the slurry production facility assembled to supply CWS fuel for the program will also be installed at the host site. As with the space heating system, this equipment arrangement was configured to be compatible with the host site facility. A process flow diagram for the slurry production facility is given in Figure 2.13. The system is made up of two modules: a grinding stand and a mixing stand. The grinding stand consists of the coal hopper, feeder, conveying air blower, and pulverizer. Although located inside Tecogen's facility, the grinding stand will be placed outside of the High Bay Building to minimize noise and fugitive dust emissions in the building. The mixing stand which consists of the separation cyclones, rotary valves, mixing tank, transfer pump, and mixers will be placed inside the building in the high bay area. System control will be from the mixing station.

Figures 2.14 and 2.15 show the layout of the equipment including storage tanks at the host site. Five 1,000 gallon tanks will be utilized which will provide a two week supply of fuel at a 50% load factor and ongoing daily (8 hour) slurry production. Round-the-clock operation of the slurry plant is required to accommodate long term operation of the space heating system at full load.

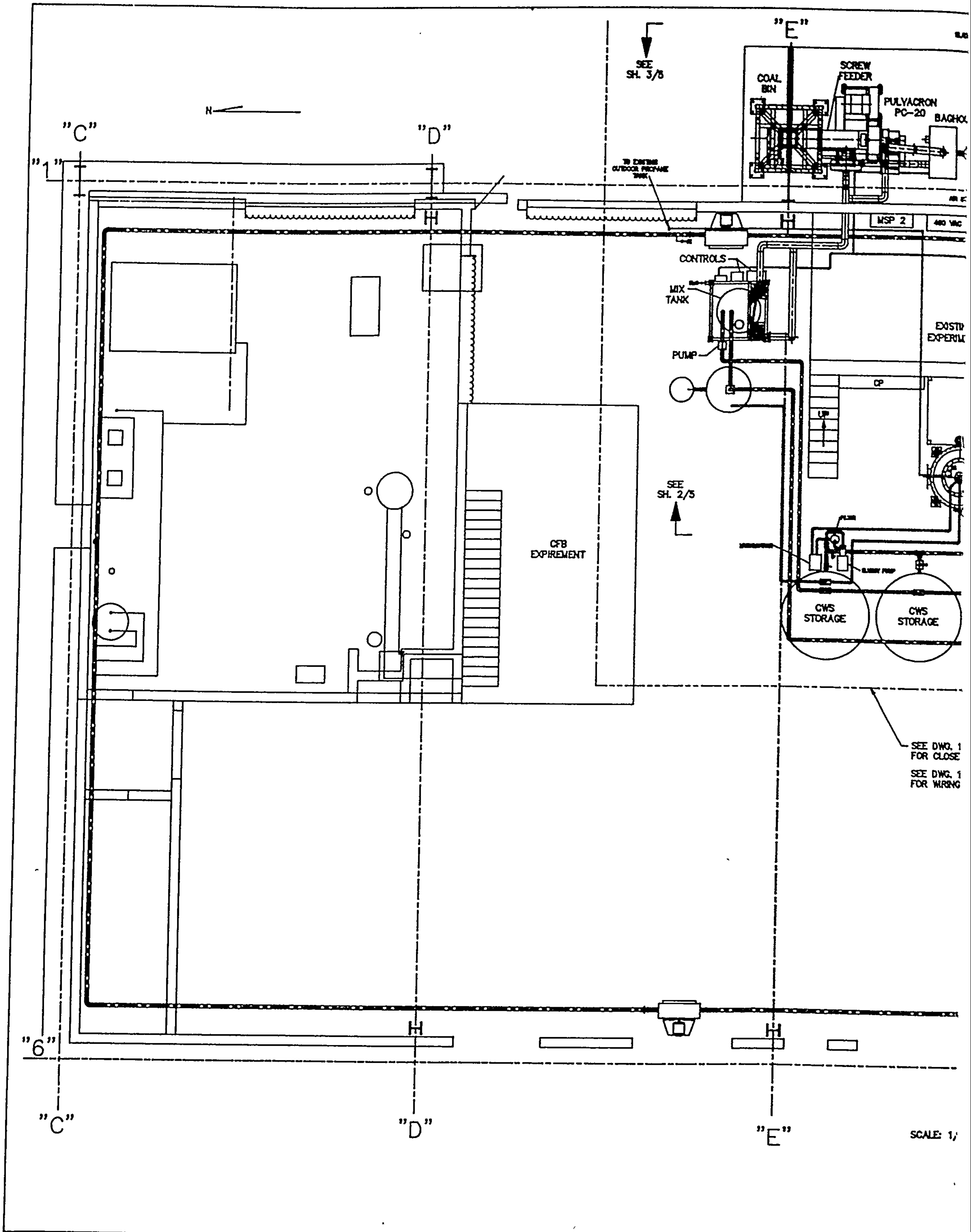


PLAN



ELEVATION

Figure 2.9 Plan and Elevation Views of Major System Components



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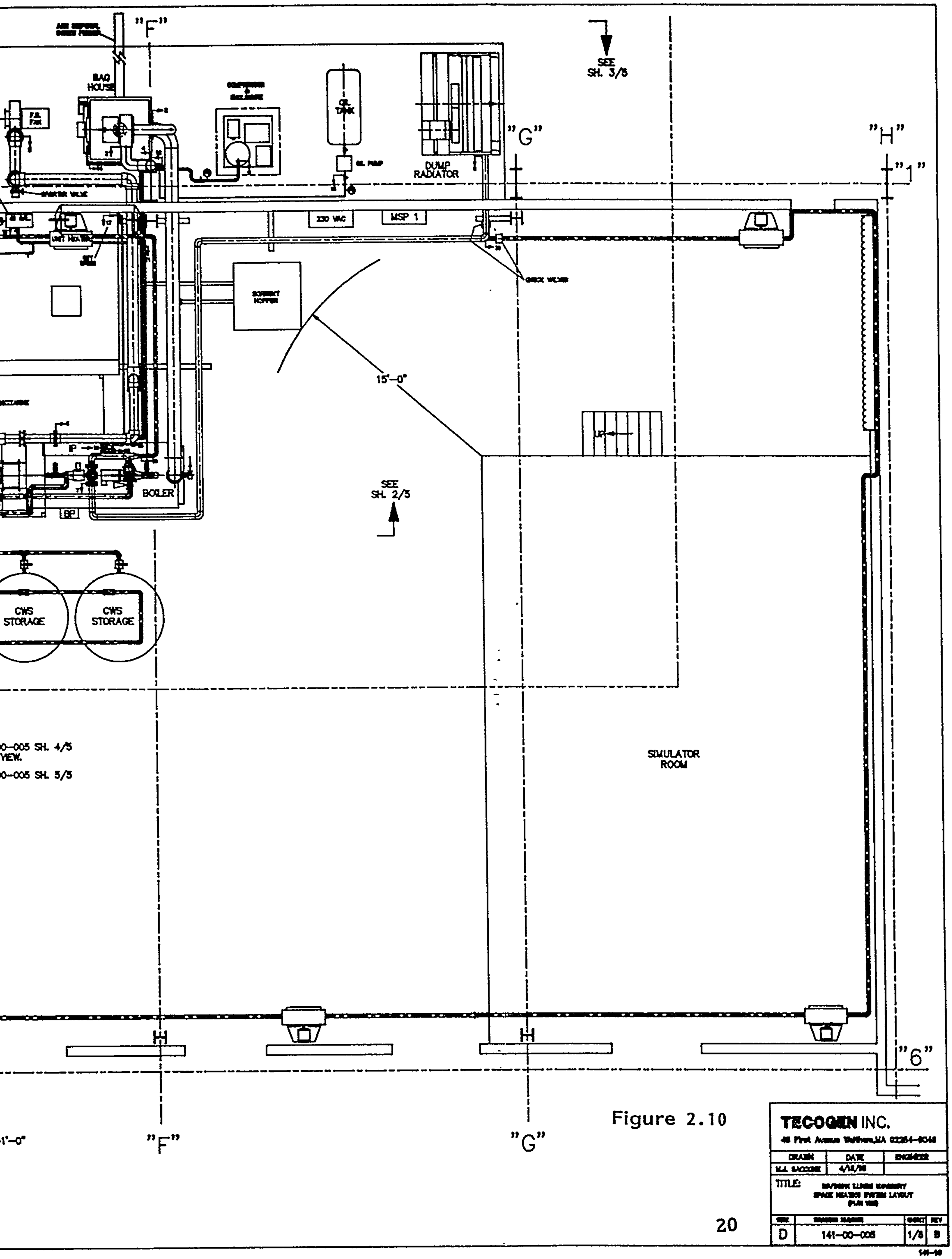
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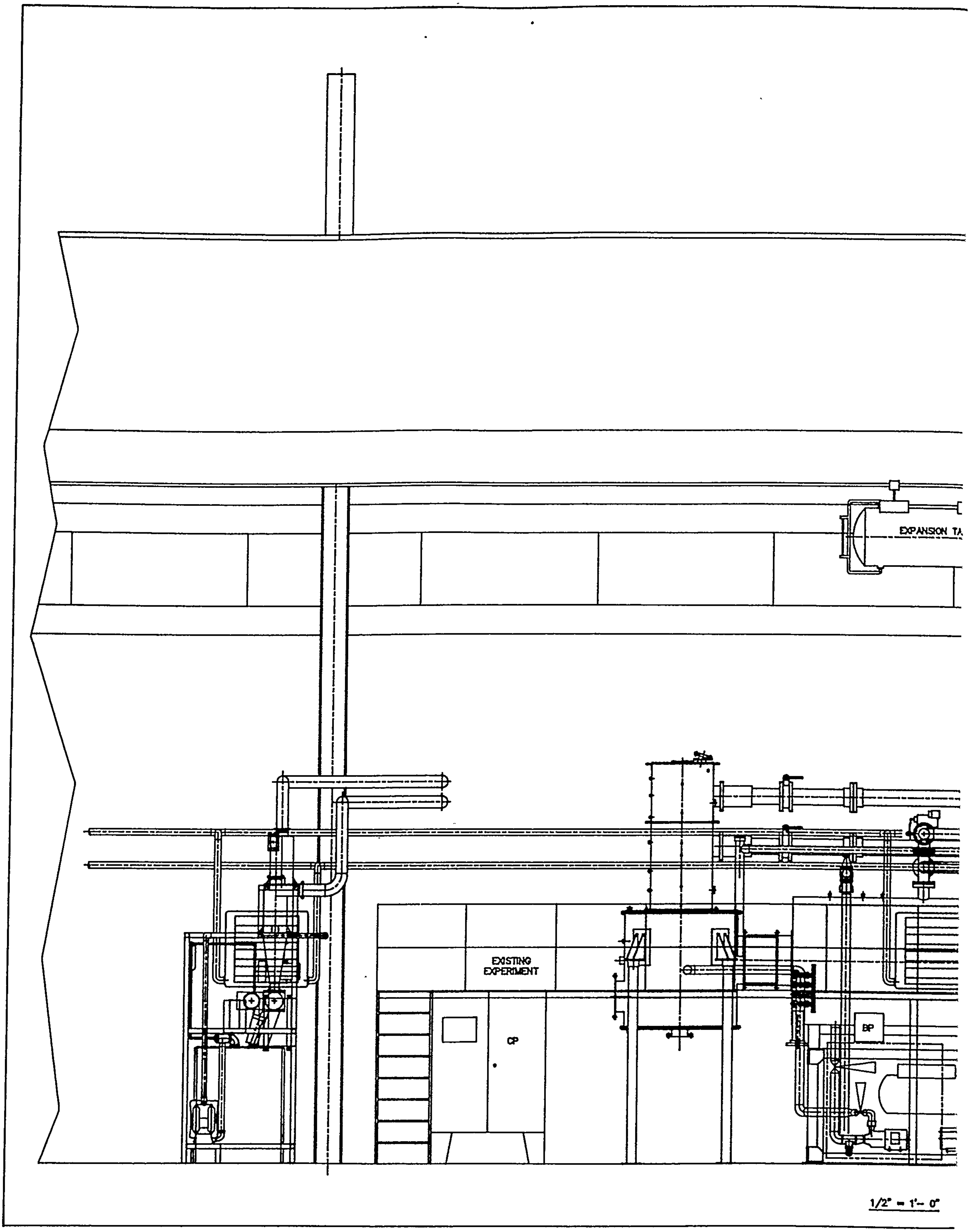
Figure 2.10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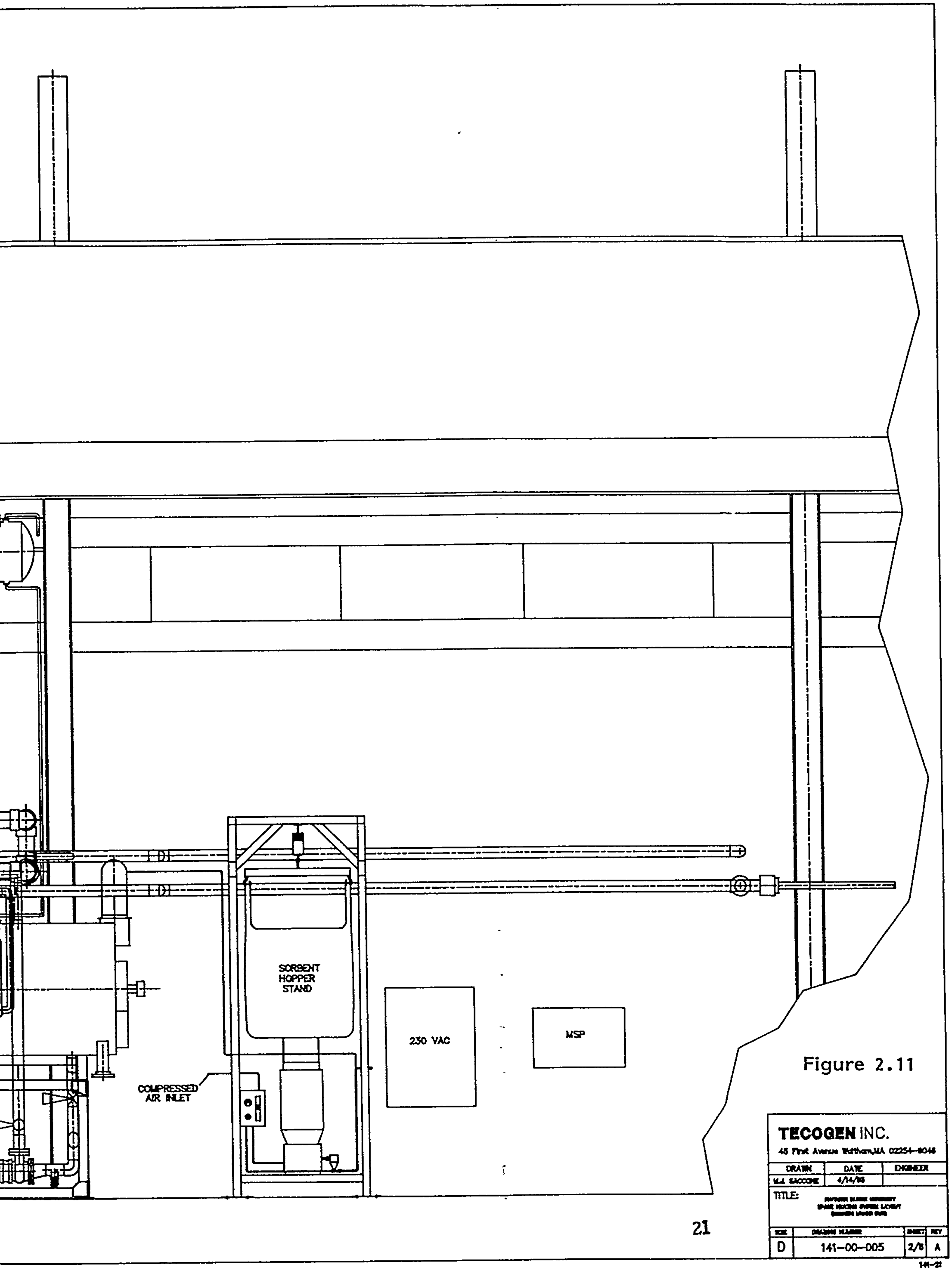
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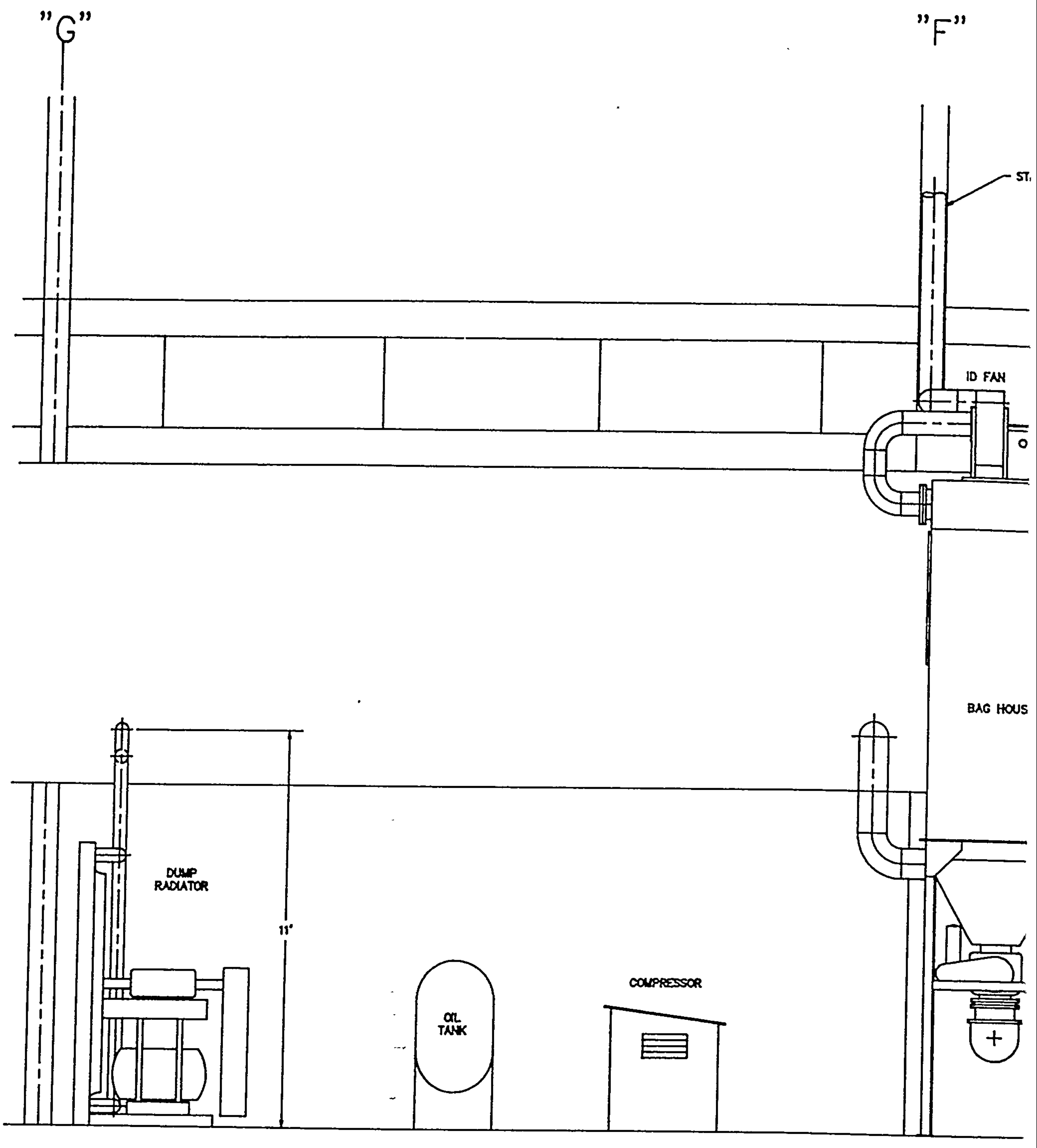
Figure 2.11



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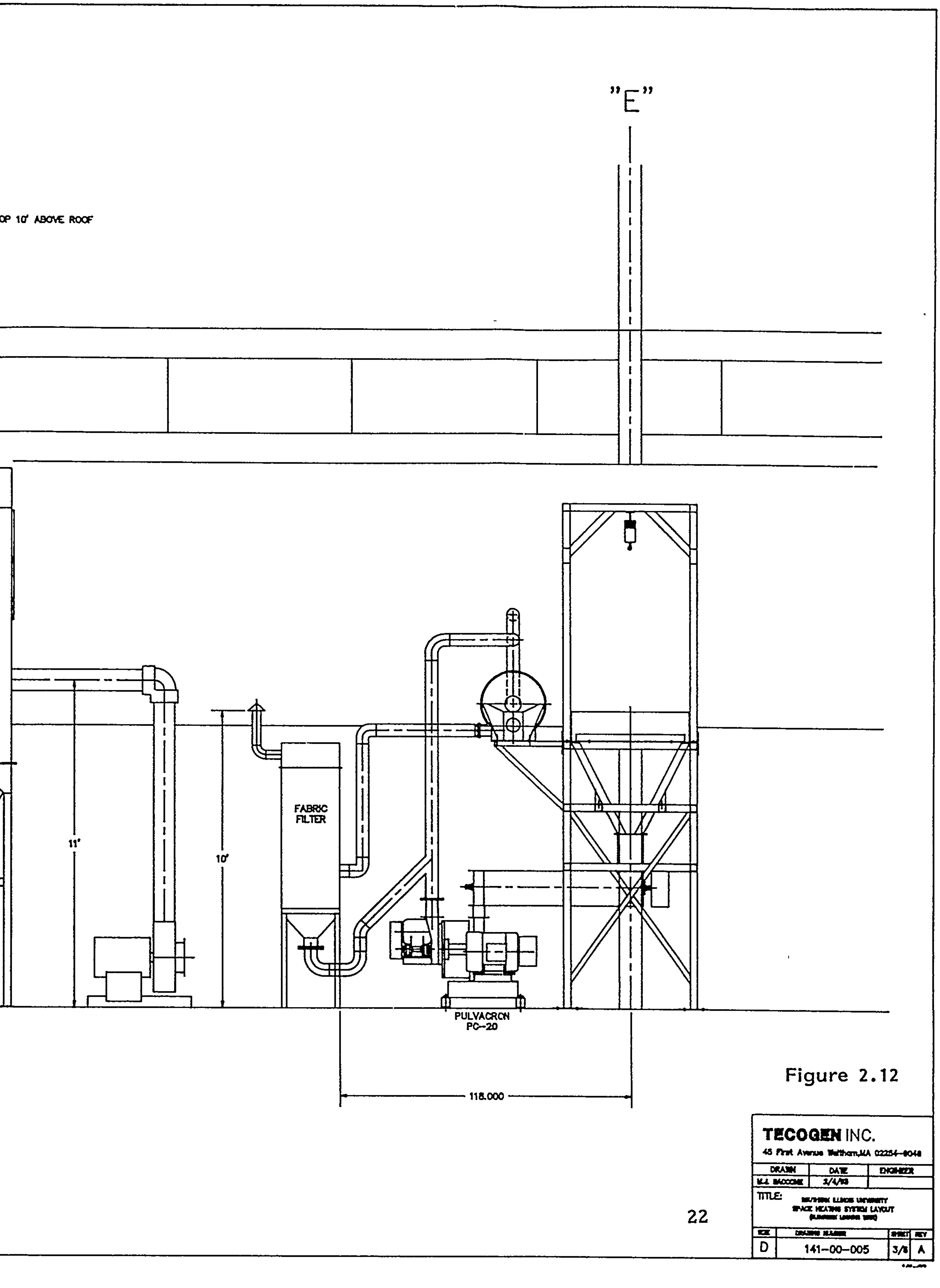
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SPACE HEATING SYSTEM LAYOUT
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Figure 2.12

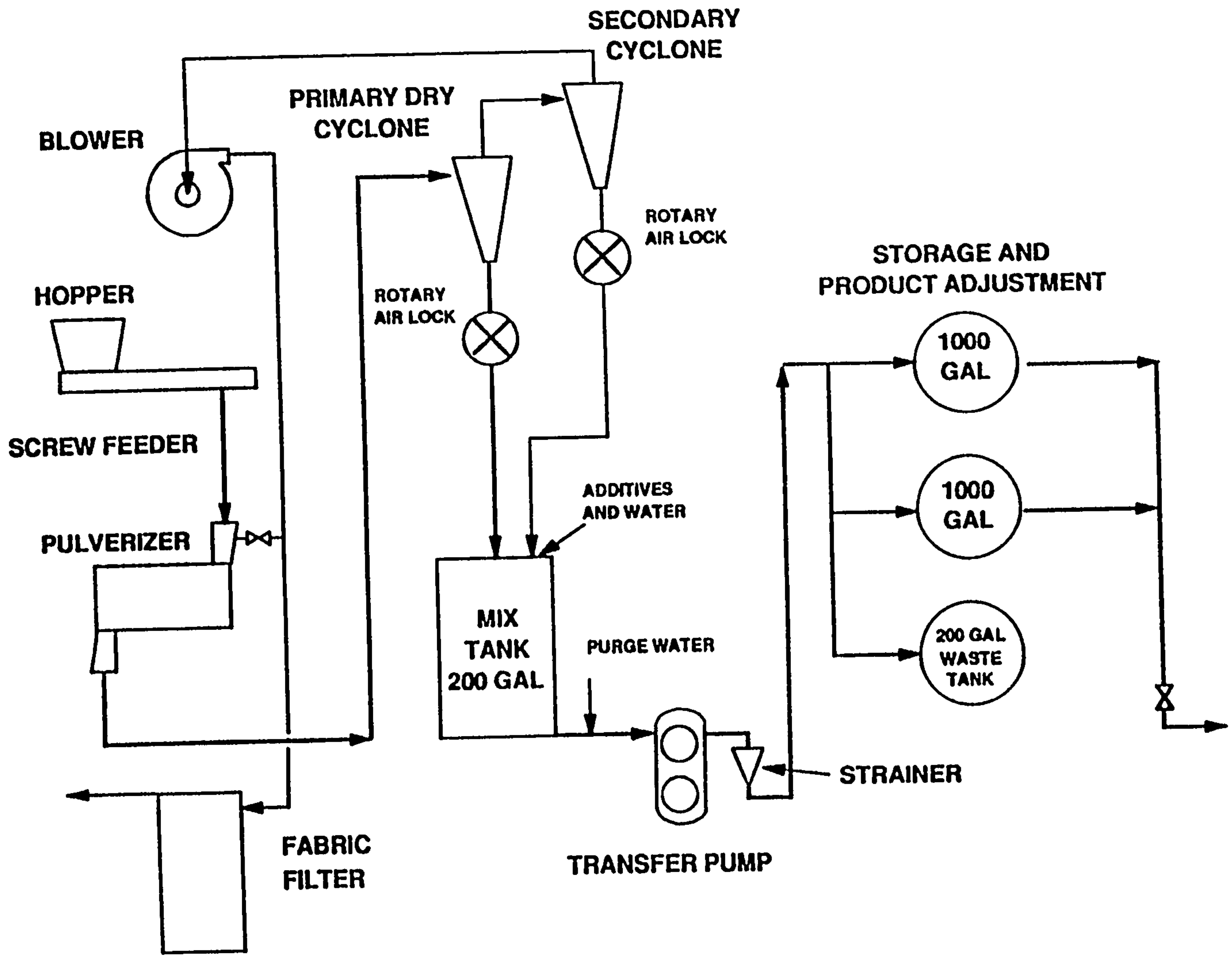
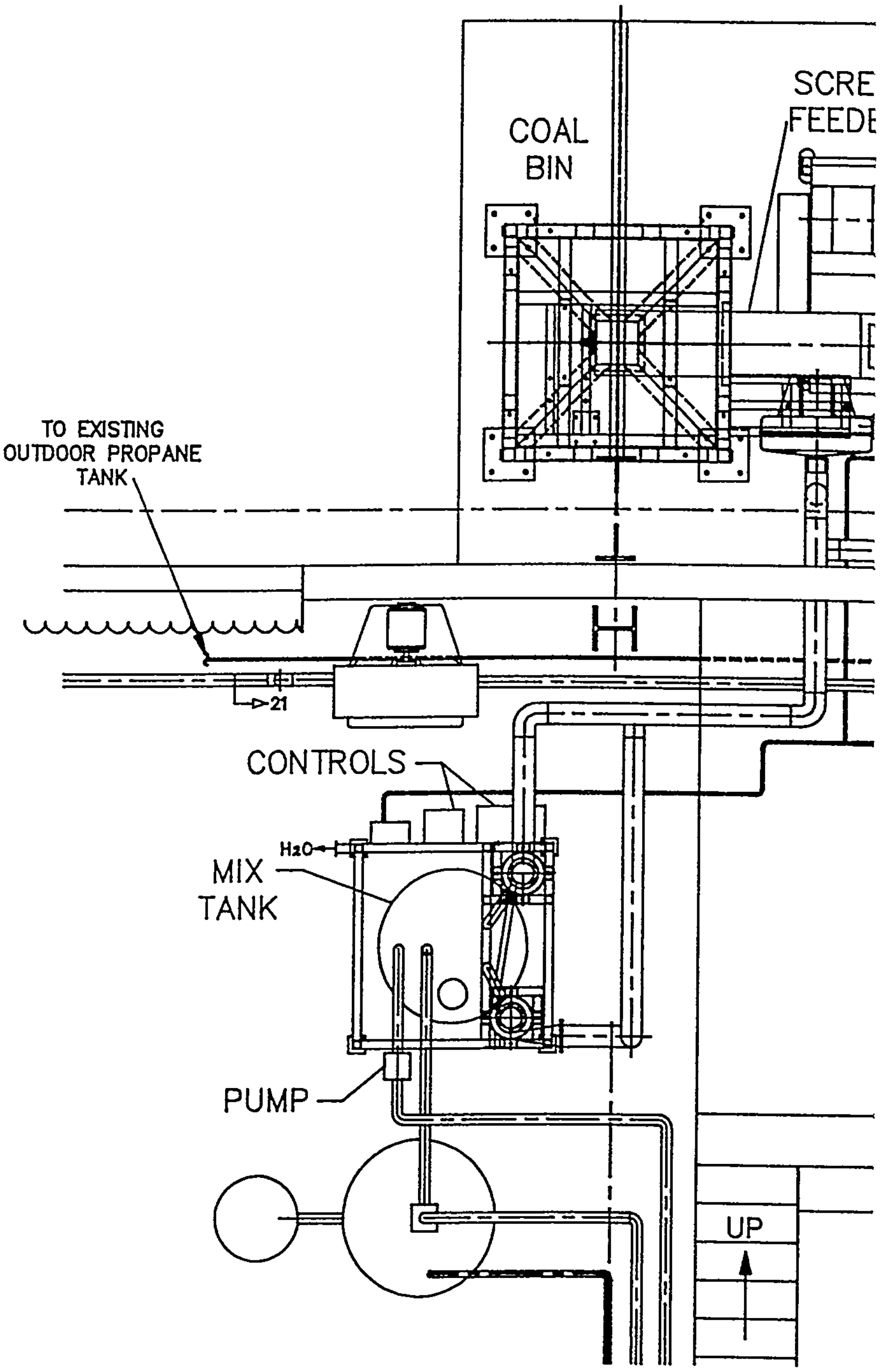


Figure 2.13 Slurry Production Facility Flow Schematic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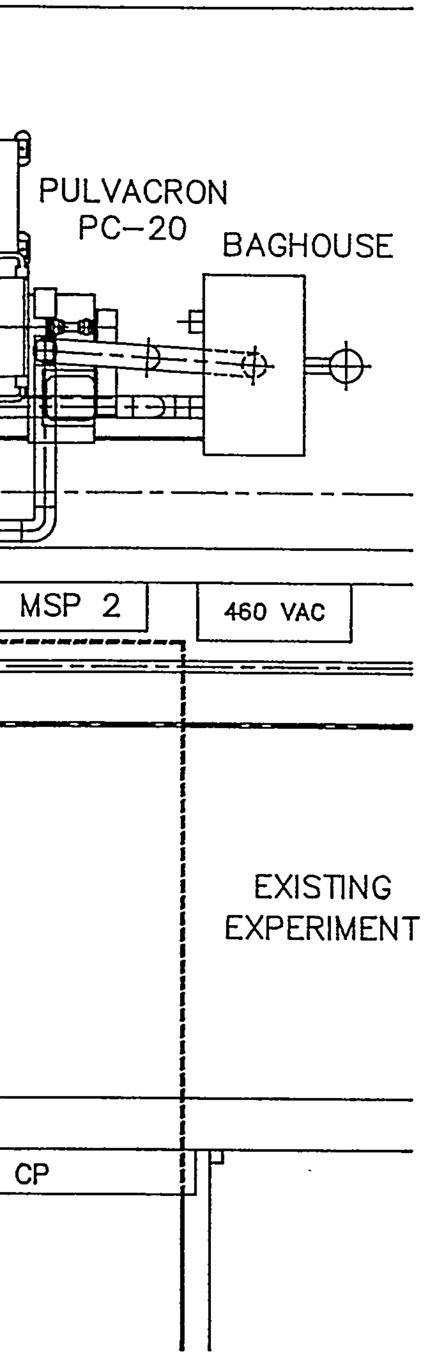

Figure 2.14

TECOGEN INC.

45 First Avenue Waltham,MA 02254-9046

DRAWN	DATE	ENGINEER
M.J. SACCONE	5/25/93	

TITLE:

SLURRY LAYOUT
(PLAN VIEW)

SIZE	DRAWING NUMBER	SHEET	REV
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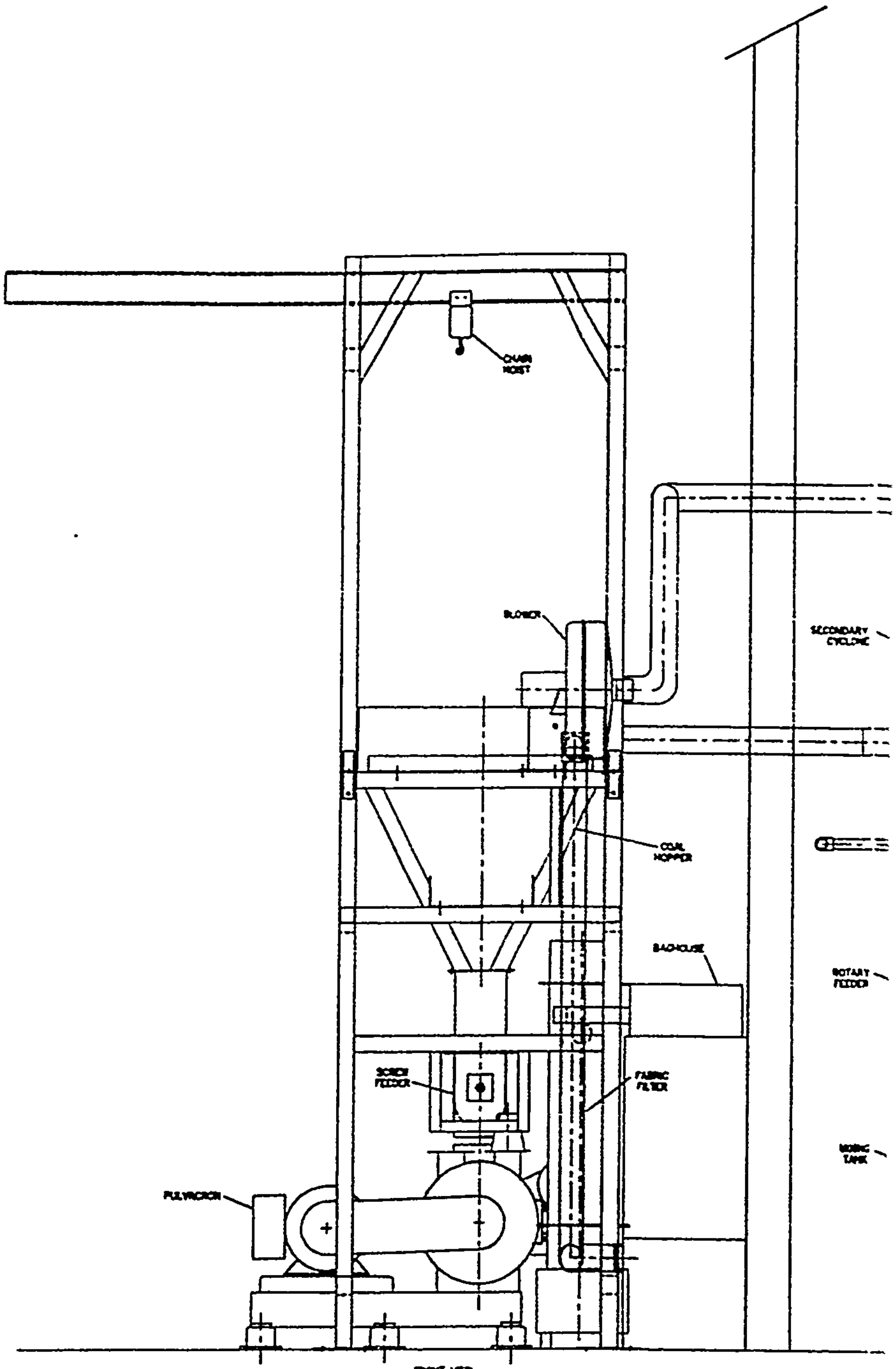

FRONT VIEW
GRINDING STAND

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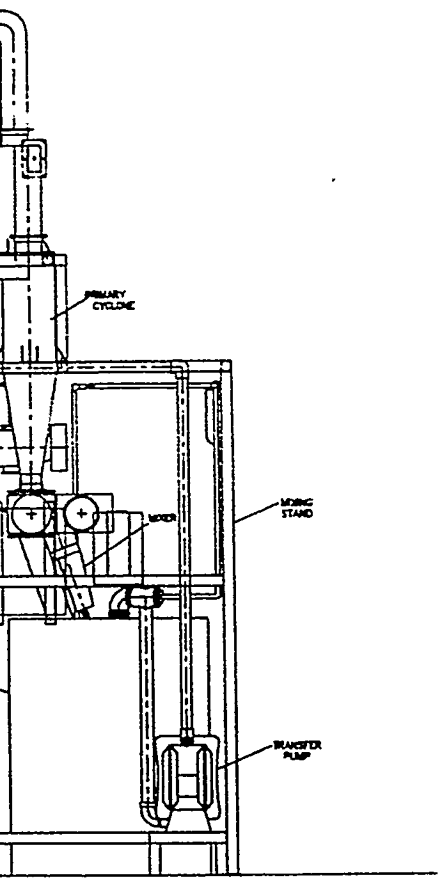

Figure 2.15

TECOGEN INC.

45 First Avenue Waltham,MA 02254-9046

DRAWN	DATE	ENGINEER
M.J. SACCONE	11/20/92	

TITLE:
SLURRY LAYOUT
SUPPORT STRUCTURE & MIXING STAND
ELEVATION LOOKING SOUTH

SIZE	DRAWING NUMBER	SHEET	REV
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141-19

Schedule

The demonstration stage of the commercial scale space heating system development and testing program will cover an eighteen month period. This period includes all aspects of the demonstration phase including site engineering, equipment upgrades, equipment disassembly, shipping and installation, and system shakedown, and operation. Figure 2.16 gives the overall demonstration stage schedule by subtask.

System Operation

The economic and technical viability of the CWS-fired commercial-scale space heating system will be demonstrated at the commercial host site through long term operation over the course of a single heating season. Figure 2.17 shows the planned operating schedule for the shakedown and operation of the system. CWS made from Illinois parent coals (Bledsoe Mine Illinois No. 5 and Wabash Mine Illinois No. 6) will be utilized. This slurry will be produced on-site using the Tecogen supplied slurry production facility.

2.2 DEMONSTRATION STAGE EQUIPMENT UPGRADES

Combustor upgrades were implemented to eliminate material deposition in the combustor and improve overall system performance. The first upgrade involved removal of the combustor roof refractory and installation of a metal liner. To control the liner temperature and at the same time allow for thermal expansion, a stainless steel fiber was sandwiched between the liner and water cooled shell. Several tests with this configuration revealed that material accumulation on the roof surface was totally eliminated.

Once the metal roof configuration was proven, a complete combustor liner change-out was initiated. The liner material was upgraded to a high temperature alloy manufactured by Rolled Alloys, RA85H. This material contains 61% iron, 18.5% chromium, 14.5% nickel, and small percentages of silicon, aluminum, and manganese for high temperature strength, thermal fatigue resistance and resistance to carburization. All liners including the roof liner are 1/4 inch thick for added strength and distortion resistance. Positioning rings were also added to control liner position as well as shape. Figure 2.18 gives a schematic of the combustor configuration. As can be seen in the figure, a liner was reinstalled below the lower partition to reduce combustor heat loss and increase combustion efficiency.

Several tests of up to eight hours duration were made with the new liners. Combustor operation was steady without any degradation from material accumulation. Material visible in the upper combustion chamber during operation was completely removed as a result of the thermal shock imposed by normal combustor cycling. Some material did remain attached to the lower liner, as was experienced previously, but this material did not limit operation. Long duration demonstration operation will be necessary to determine if an ash removal system, such as mechanical rappers, is necessary for this section. A coal carbon conversion of 98% was measured during this testing based on baghouse ash analysis with Illinois No. 6 parent coal slurry.

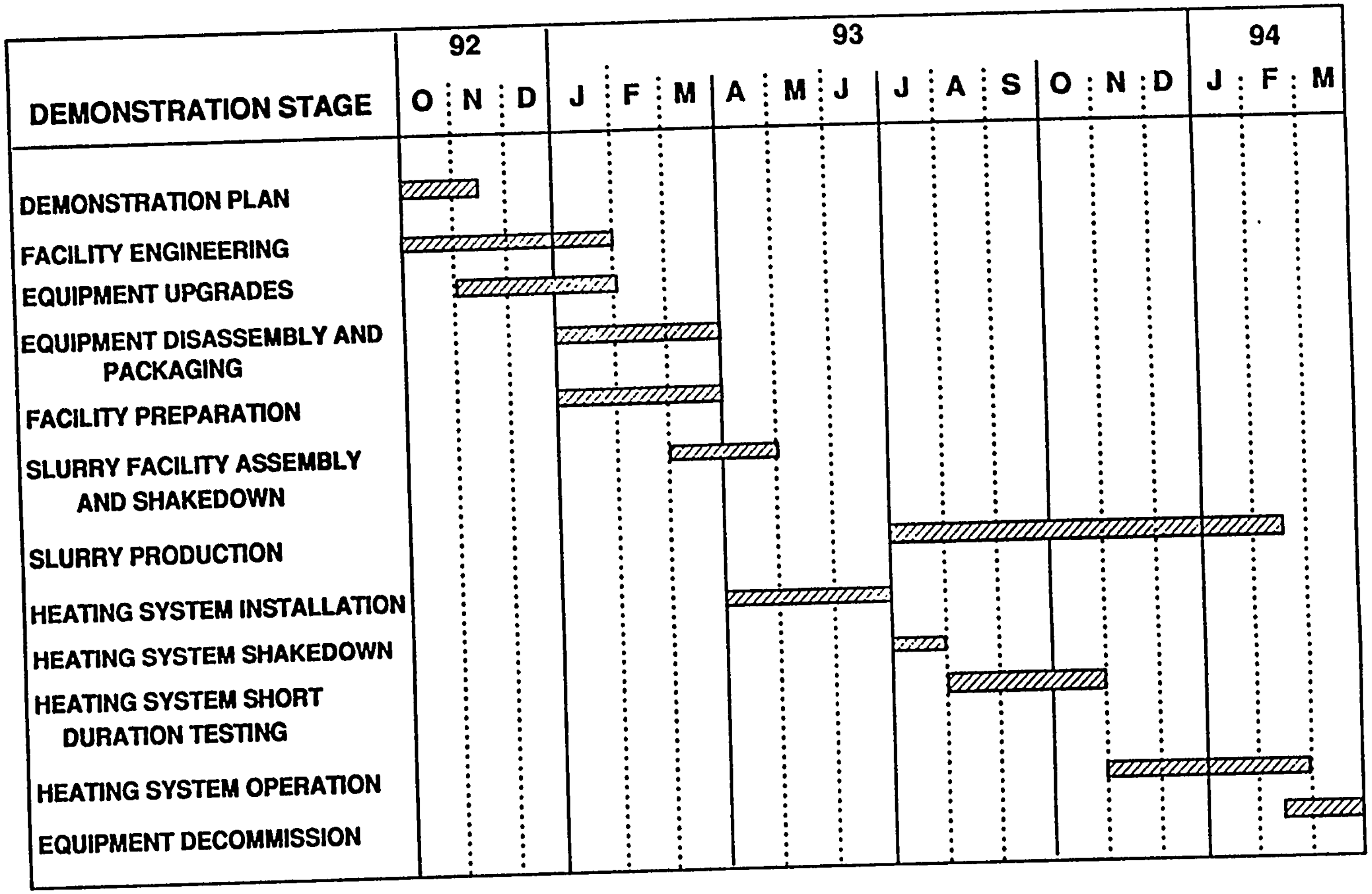

Figure 2.16 Demonstration Schedule

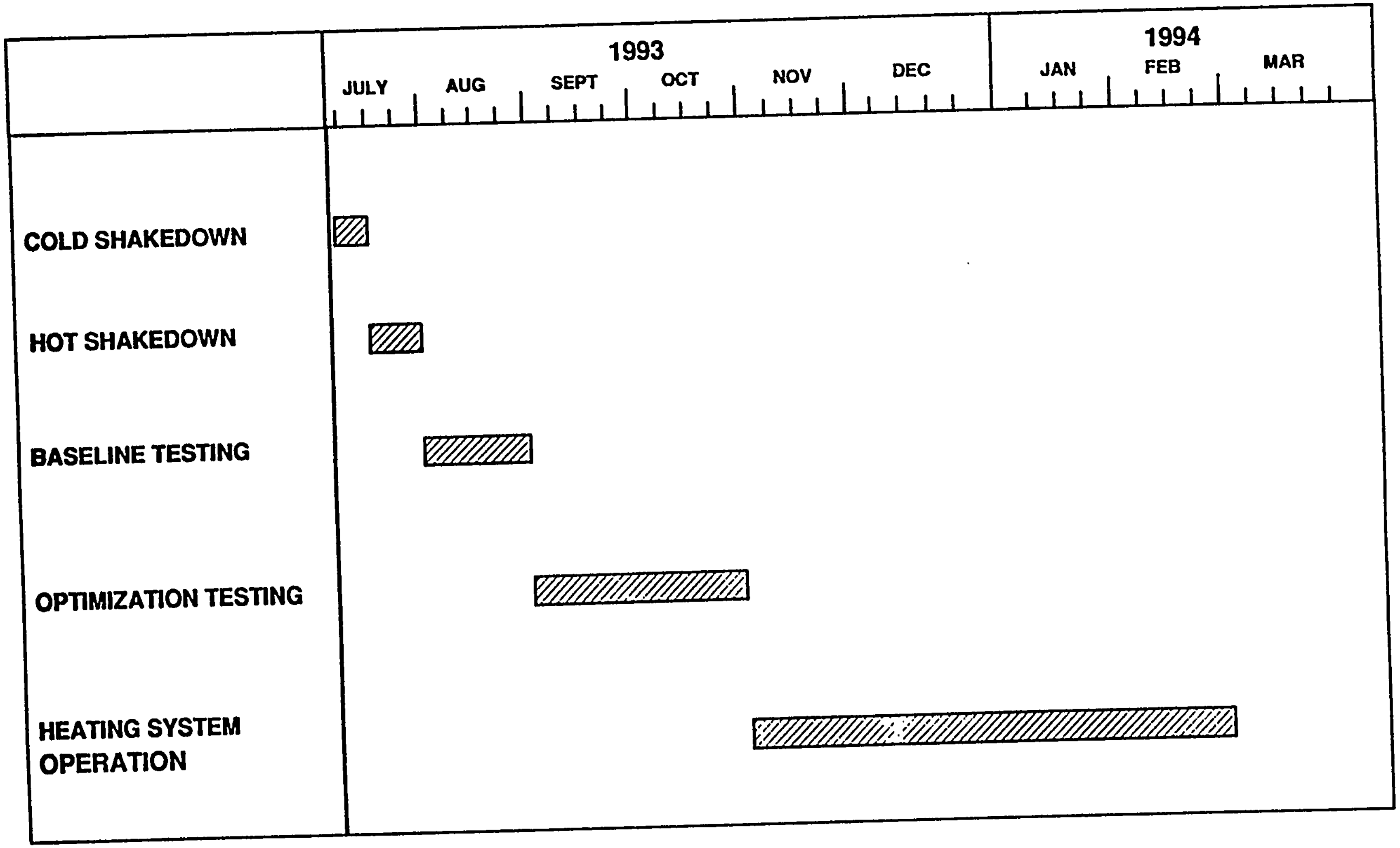

Figure 2.17 System Operation Schedule

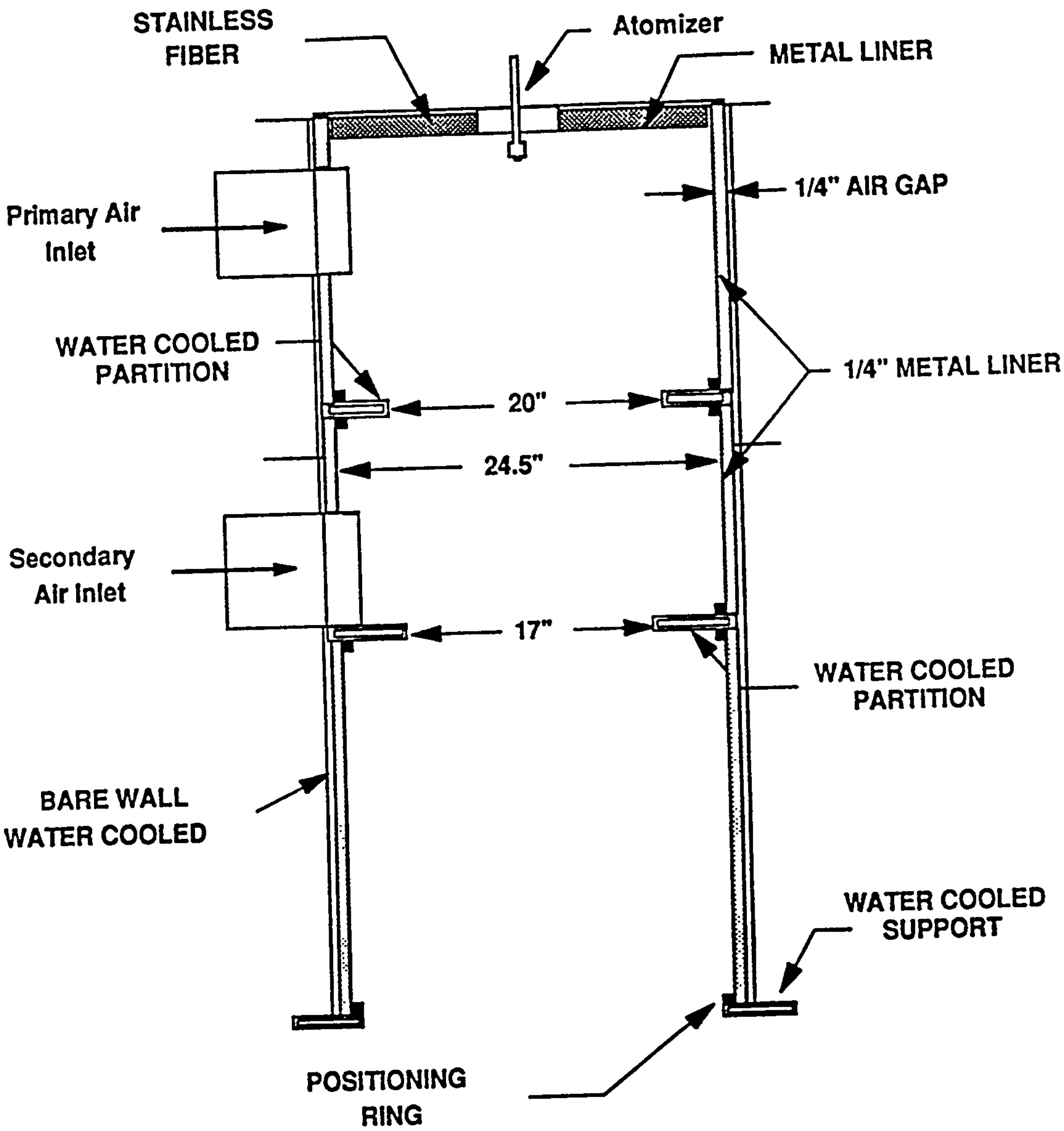

Figure 2.18 Combustor Configuration with Metal Roof Liner

3. PLANNED ACTIVITIES

During the next quarter, program activities will involve preparation of the space heating system and slurry production facility for shipment to the host site. This preparation will include refurbishment and painting of the equipment, and piping and wiring modification necessary to meet the system configuration at the ICDP High Bay Building. Also, site preparations such as installation of an equipment pad and extension of utility services will be made.

4. SUMMARY

During the past quarter, DOE has approved the Demonstration Plan for the Site Demonstration of the commercial-scale combustion at Southern Illinois University and has granted permission to proceed with the site demonstration and the remaining tasks of the project. Demonstration stage engineering and planning has been carried out to ensure a successful and timely completion of the commercial demonstration of the technology. Integration and layout of the equipment into the host site facility has been studied and engineering drawings for the installation prepared.

Combustor modifications aimed at eliminating material accumulation in the combustor and improving overall system performance were implemented and tested. Material build-up in the combustor was significantly reduced. Long duration demonstration operation will be necessary to determine if an additional ash removal system, such as mechanical rappers or pulse jet cleaning, is necessary for the combustor section.