ENGINEERING DEVELOPMENT OF COAL-FIRED HIGH-PERFORMANCE POWER SYSTEMS

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TECHNICAL PROGRESS REPORT 2
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Prepared for
Department of Energy
Pittsburgh Energy Technology Center
Pittsburgh, Pennsylvania

February 1996

FOSTER WHEELER DEVELOPMENT CORPORATION
12 Peach Tree Hill Road, Livingston, New Jersey 07039

MASTER

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INTRODUCTION

In Phase 1 of the project, a conceptual design of a coal-fired high performance power system was developed, and small scale R&D was done in critical areas of the design. The current Phase of the project includes development through the pilot plant stage, and design of a prototype plant that would be built in Phase 3.

Foster Wheeler Development Corporation (FWDC) is leading a team of companies in this effort. These companies are:

- AlliedSignal Aerospace Equipment Systems
- Bechtel Corporation
- TRW, Inc.
- University of Tennessee Space Institute (UTSI)
- Westinghouse Electric Corporation

The power generating system being developed in this project will be an improvement over current coal-fired systems. Goals have been identified that relate to the efficiency, emissions, costs and general operation of the system. These goals are:

- Total station efficiency of at least 47 percent on a higher heating value basis.
- Emissions:
  NOx < 0.06 lb/MMBtu
  SOx < 0.06 lb/MMBtu
  Particulates < 0.003 lb/MMBtu
- All solid wastes must be benign with regard to disposal.
- Over 95 percent of the total heat input is ultimately from coal, with initial systems capable of using coal for at least 65 percent of the heat input.
- Ten percent lower cost of electricity (COE) relative to a modern coal-fired plant conforming to NSPS.

The base case arrangement of the HIPPS cycle is shown in Figure 1. It is a combined cycle plant. This arrangement is referred to as the All Coal HIPPS because it does not require any other fuels for normal operation. A fluidized bed, air blown pyrolyzer converts coal into fuel gas and char. The char is fired in a high temperature advanced furnace (HITAF) which heats both air for a gas turbine and steam for a steam turbine. The air is heated up to 1400°F in the HITAF, and the tube banks for heating the air are constructed of alloy tubes. The fuel gas from the pyrolyzer goes to a topping combustor where it is used to raise the air entering the gas turbine to 2350°F. In addition to the HITAF, steam duty is achieved with a heat recovery steam generator (HRSG) in the gas turbine exhaust stream and economizers in the HITAF flue gas exhaust stream.

An alternative HIPPS cycle is shown in Figure 2. This arrangement uses a ceramic air heater to heat the air to temperatures above what can be achieved with alloy tubes. This arrangement is referred to as the 35 percent natural gas HIPPS, and a schematic is shown in Figure 2. A pyrolyzer is used as in the base case HIPPS, but the fuel gas generated is fired upstream of the ceramic air heater instead of in the topping combustor. Gas turbine air is heated to 1400°F in alloy tubes the same as in the All Coal HIPPS. This air then goes to the ceramic air heater where it is heated further before going to the topping combustor. The temperature of the air leaving the ceramic air heater will depend on technological developments in that component. An air exit temperature of 1800°F will result in 35 percent of the heat input from natural gas.

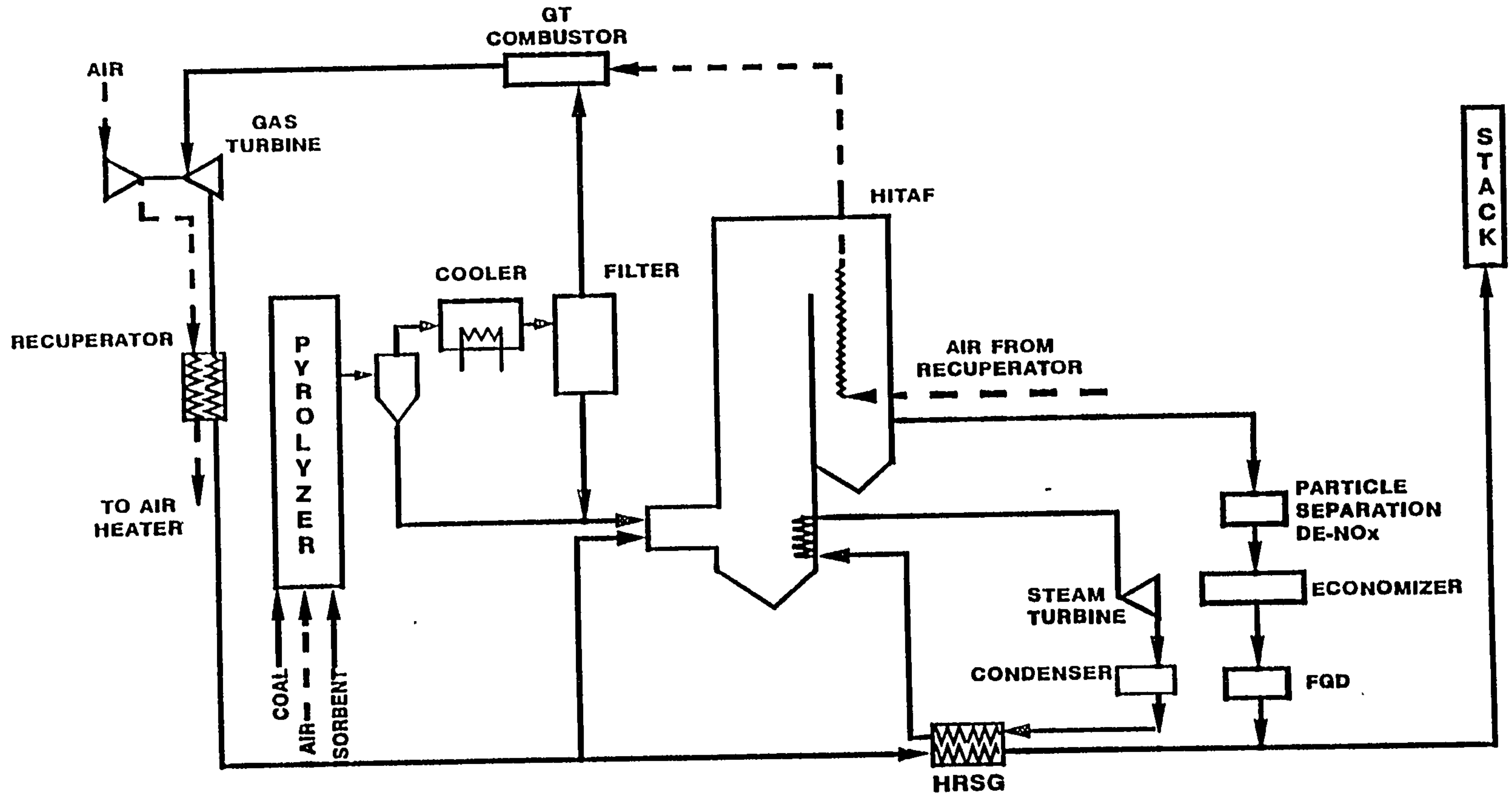


Figure 1 All Coal-Fired HIPPS

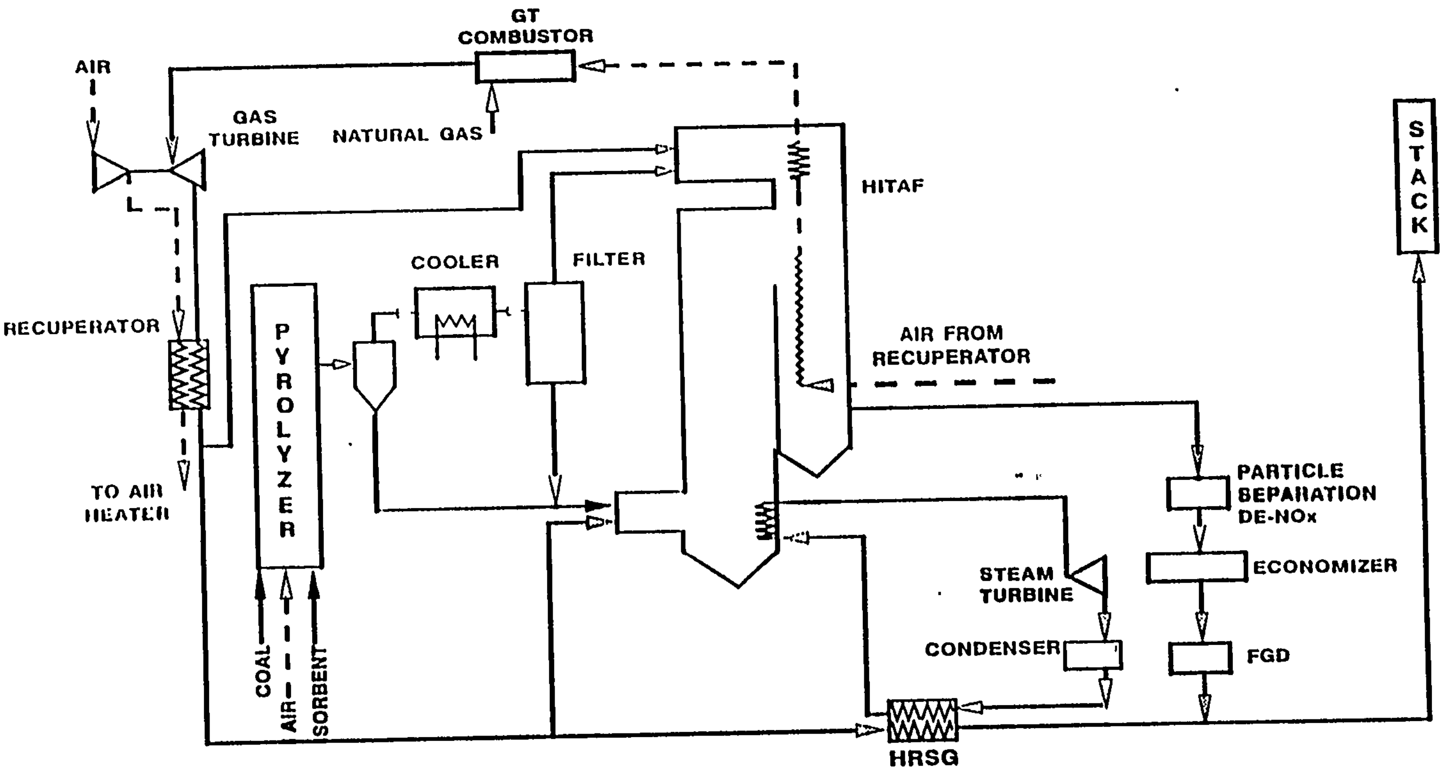


Figure 2 35 Percent Natural Gas HIPPS

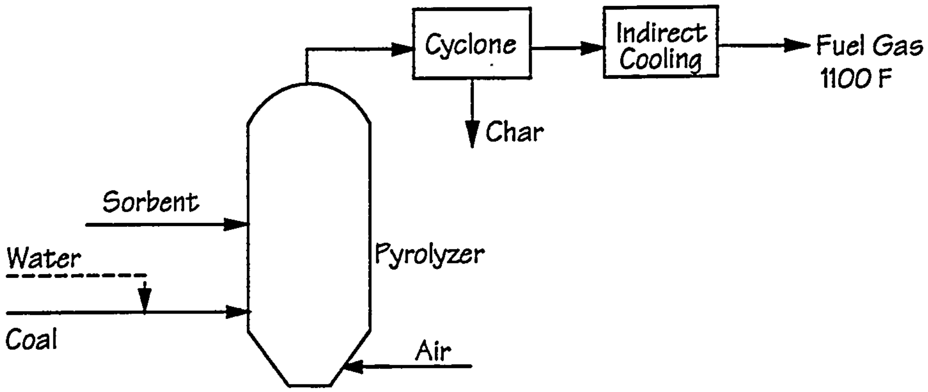
TECHNICAL PROGRESS

Task 1 - Project Planning and Management

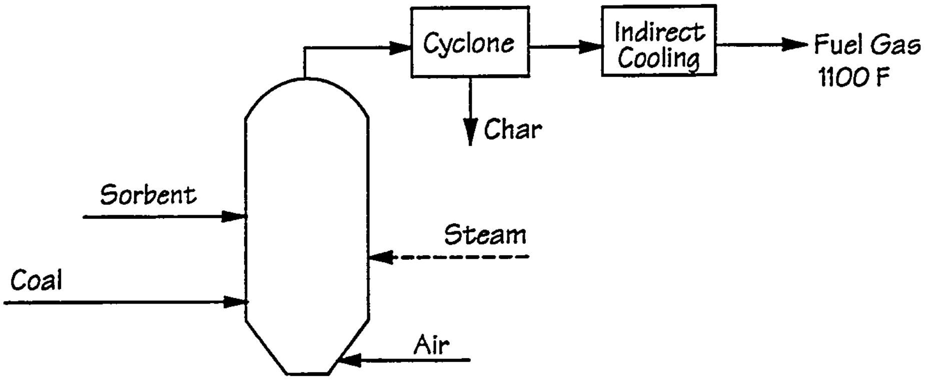
Part of the Phase 2, Task 1 activities is updating the commercial plant design. During this quarter Bechtel's activities focused on evaluating the feasibility of replacing the pyrolyzer wet (paste) feed system that was used in the Phase 1 commercial plant design with a dry coal feed system. The coal preparation and feeding system for the commercial plant should be able to grind the coal enough that no additional grinding/pulverizing of the product char is required ahead of the char combustor. The paste feed system puts more constraints on the coal particle size distribution than a dry feed system because the particle size has to meet the feeding criteria of a pumpable, concentrated paste as well as the particle size distribution (PSD) required for the produced char. A dry feed system, on the other hand, is inherently less restrictive and can be designed to readily meet the char combustor particle size requirements.

As a first step in assessing the feasibility of using to a dry feed system, the impact on overall performance of switching from a wet to a dry feed system was investigated. The pyrolysis performance data generated by Foster Wheeler has shown that the amount of water introduced into the pyrolyzer has a pronounced effect on both the product yield structure, specifically the fuel gas/char ratio, as well as the moisture content and heating value of the fuel gas product. The presence of water in the fuel gas generally enhances the performance of the gas turbine topping cycle because it increases the mass flow to the turbine and raises the turbine exhaust temperature. On the other hand, increasing the moisture content of the fuel gas will lower its heating value until a limit is reached below which the fuel gas cannot support stable combustion in the topping combustor. This heating value limit is somewhat specific to the gas turbine machinery and for the Westinghouse turbine considered for the commercial plant design, this limit falls close to 110 Btu/scf (high heating value basis).

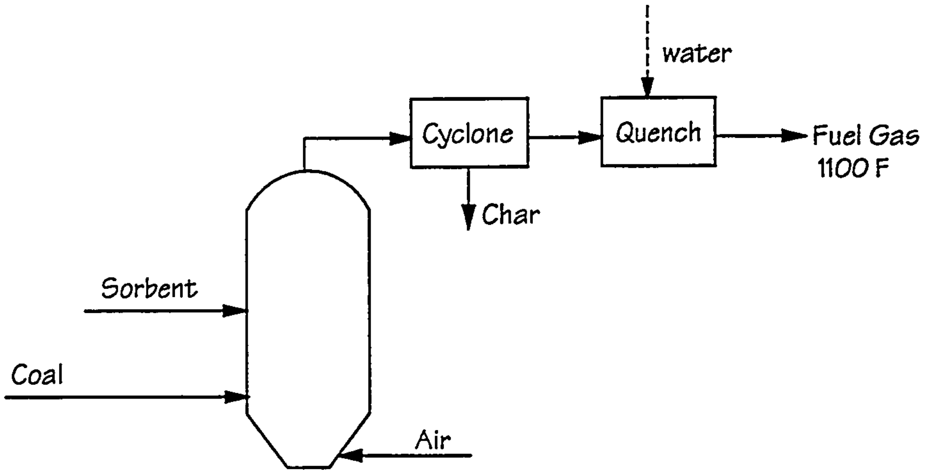
Water can be introduced into the pyrolysis gas in three distinctive ways as Figure 3 shows. Water can be added internal as well as external to the pyrolyzer and in the form of water or steam. For a dry feed, water can be added as steam to the pyrolyzer and/or as quench water downstream of the pyrolyzer. Steam injection adds moisture while chemically altering the fuel gas/char ratio, whereas quench water adds moisture only. Similarly, injecting water into the pyrolyzer, when using a paste feed, adds moisture to the fuel gas and alters the fuel gas/char ratio to an even larger degree than that achieved with steam injection, and that is because more coal is burned just to evaporate the incoming



(a) Paste Feed



(b) Dry Feed



(c) Dry Feed

Figure 3
Three Schemes for Introducing Water in Pyrolysis Gas

water. Steam injection tends to produce a better-quality fuel gas; i.e., a fuel gas with a higher heating content, than that produced with water injection because of its lower carbon dioxide content. On the other hand, steam injection will increase the water treatment cost and, according to our preliminary calculations, may penalize the bottoming cycle performance due to steam extraction.

The above discussion outlines some of the design and performance ramifications of replacing a wet with a dry feed system. To quantify the impact of this change, Bechtel obtained from Foster Wheeler pyrolysis performance data for several dry feed cases differing in the amount of steam being injected to the pyrolyzer. In this reporting period, Bechtel completed the analysis of several plant operating options.

Table 1 summarizes the process and performance results for the two dry feed cases and those obtained earlier in Phase 1 for the paste feed. Some of these results are also graphically shown in Figures 4 through 6. These results show the following:

- As the total water input to the pyrolyzer increases, more of the energy in the feed coal is utilized in the topping cycle as fuel gas and less of it is utilized in the bottoming cycle as char, resulting in a net increase in overall plant efficiency. As shown, the overall plant efficiency for each of the two dry feed cases is lower than that for the paste feed case.

- In the commercial plant design, the topping cycle size is fixed; i.e., the air flow to the turbine compressor is fixed and the topping combustor fuel heat input is fixed. As the water input to the pyrolyzer is decreased, in switching from the paste feed to the dry feed cases, less fuel gas is produced per pound of feed coal. To meet the topping combustor fuel requirement, more coal flow to the pyrolyzer will, therefore, be required. Consequently, more char will be produced and fed to the HITAF/bottoming cycle resulting in increased char combustor, HITAF, an steam turbine sizes and power output. This increase in bottoming cycle size is evident when comparing the process parameters given in Table 1.

- Figure 4 shows the slight gain in gas turbine power output attributed to the increased moisture level in the fuel gas as the water input to the pyrolyzer is increased. It also shows a robust gain in steam turbine power attributed to the increased char production for the drier pyrolyzer feeds.

- Figures 5 and 6 accentuate further what has been discussed in regard to the chemical and physical effects of the pyrolyzer water feed on the fuel gas vs. char yields and the fuel gas heating value.

Table 1

Process & Performance Comparison for Three Pyrolyzer Feed Systems

Plant Area	Dry Feed	Dry Feed & Steam Injection	Paste Feed
<u>Topping Cycle</u>			
Coal flow to pyrolyzer (lb/h)*	195,970	177,152	164,357
Moisture in coal feed to pyrolyzer (wt%)	2.5	2.5	27.0
Total water input to pyrolyzer (lb/1000 lb mf coal)	26	192	370
Fuel gas flow to GT combustor (lb/h)	379,200	436,100	583,490
Moisture in fuel gas to GT combustor (wt%)	2.72	5.51	7.39
Fuel gas high heating value (Btu/scf)	171.6	154	124.5
Inlet coal energy that goes to fuel gas (%)	41.1	46.2	52.4
<u>Bottoming Cycle</u>			
Char flow to slagging combustor (lb/h)	110,106	88,843	67,664
Inlet coal energy that goes to char (%)	58.9	53.8	47.6
Flue gas flow to HITAF economizer (lb/h)	2,164,980	1,663,400	1,192,610
GT exhaust flow to HRSG (lb/h)	1,418,300	1,907,900	2,364,560
Steam to HP steam turbine (lb/h)	1,254,185	1,045,370	840,405
<u>Performance</u>			
Gas turbine generator output (MW)	147.6	149.1	153.6
Steam turbine generator output (MW)	256.2	210.7	173.1
Total auxiliary power (MW)	19.9	17.5	15.7
Net plant power output (MW)	383.9	342.3	311
Net plant efficiency (HHV)	46.34	46.65	47.16

* As-received basis

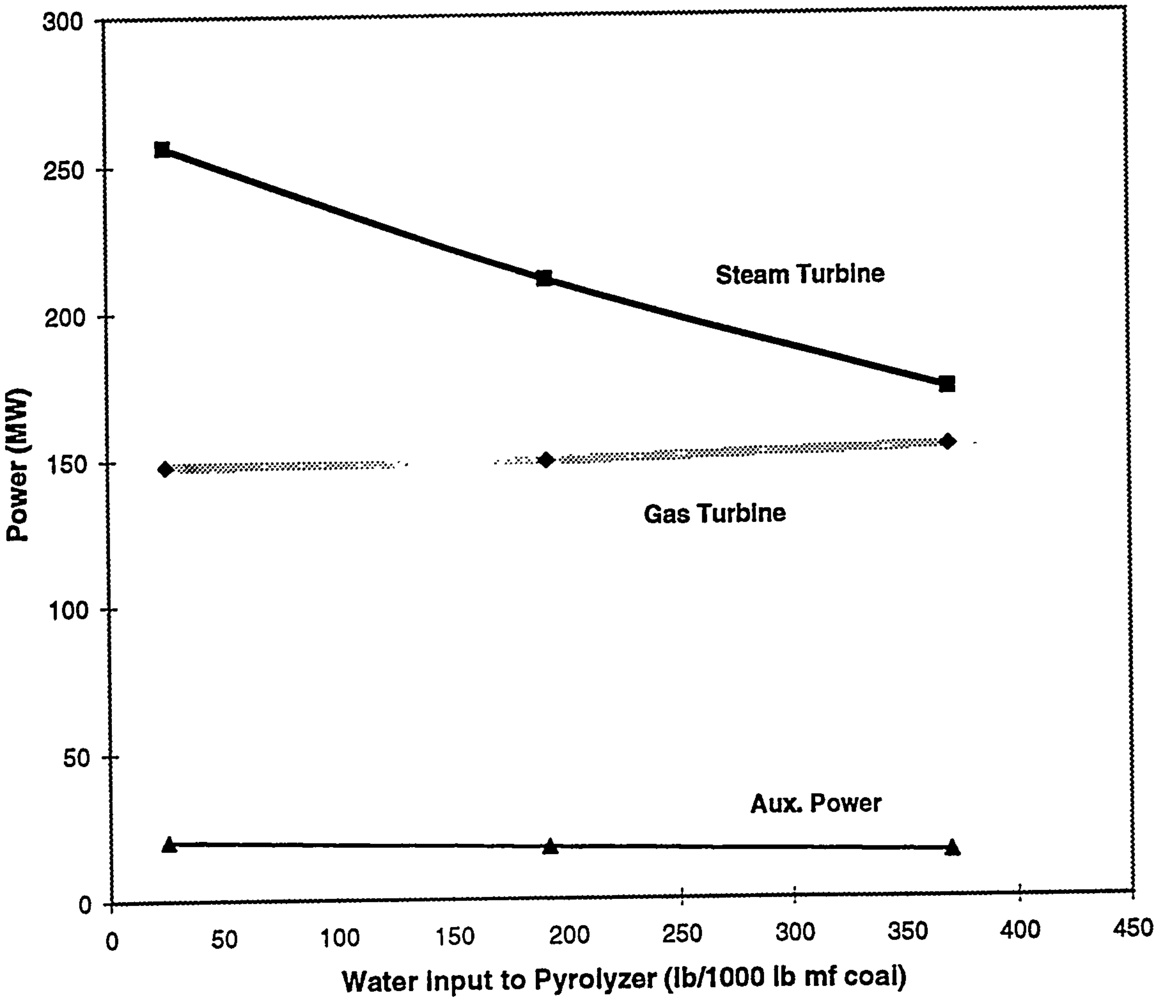


Figure 4 Commercial Plant Power Versus Water Input To Pyrolyzer

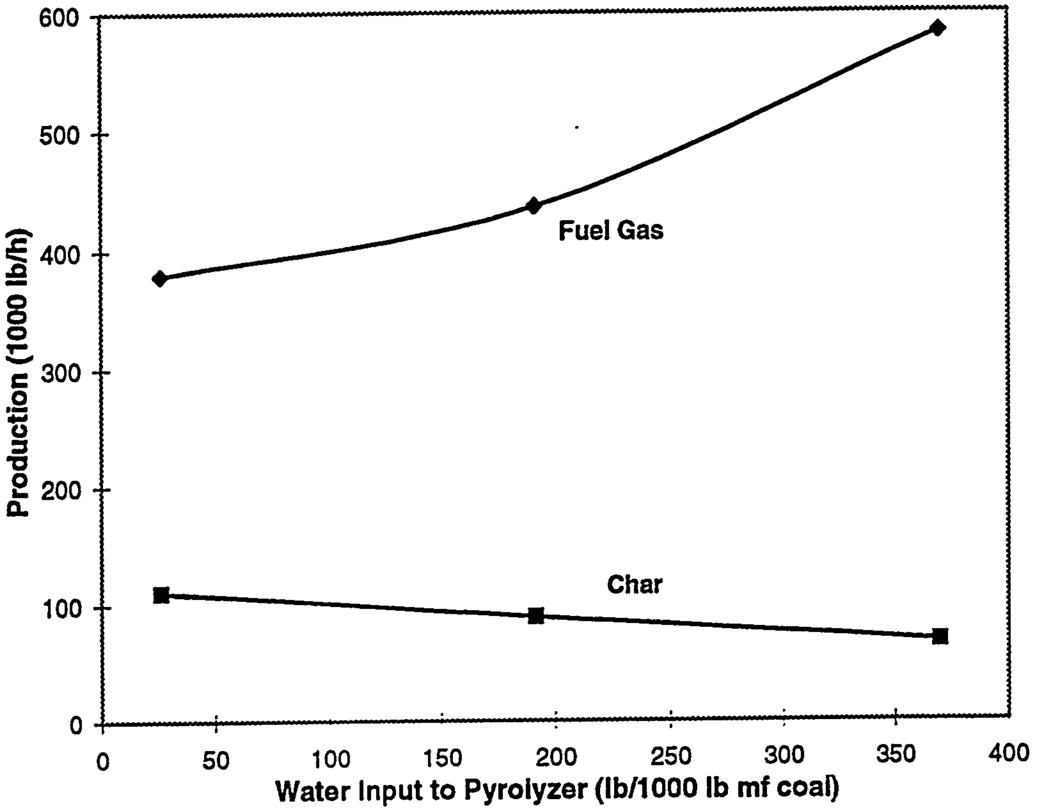


Figure 5 Fuel Gas and Char Production Versus Water Input To Pyrolyzer

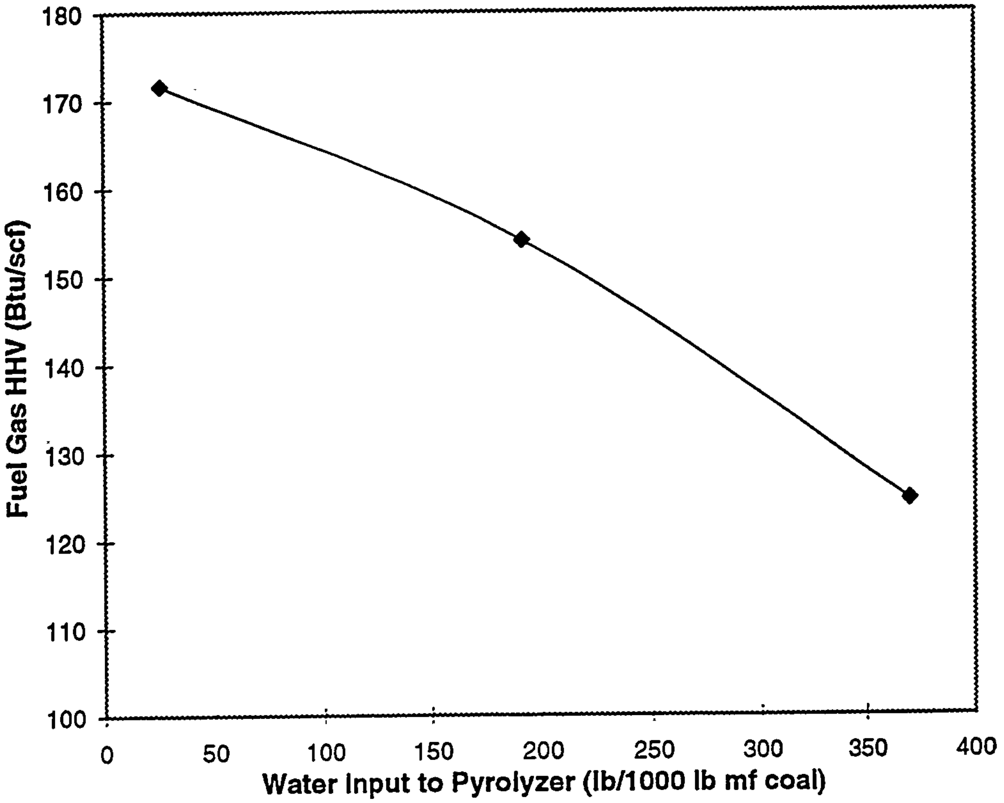


Figure 6 Fuel Gas Heating Value Versus Water Input To Pyrolyzer

- The plant performance analysis also revealed that the sizes of the HITAF economizer (dirty economizer) and gas turbine exhaust HRSG (clean HRSG) tend to change in opposite direction when the char amount increases in going from a wetter to drier pyrolysis feeds. Thus, the HITAF economizer size goes up while the HRSG size goes down, with more of the steam generation duty shifting from the HRSG to the char combustor.

In the next reporting period, we will continue evaluating the dry feed vs. the wet feed options for the pyrolyzer. Our main objective is to identify the most suitable method and process conditions that can achieve an optimum balance among the level of water in the topping cycle, the fuel gas/char ratio, and the fuel gas heating value to achieve the highest overall plant efficiency.

Specifically, we will analyze for the dry feed system the impact on plant performance when increasing the water input to the topping cycle through steam injection and fuel gas quenching as shown in Figure 3.

We will also investigate the feasibility of using a wet feed system that uses a less-concentrated paste feed (in the range of 60 to 65% solids). This paste feed is expected to accept finer coal grind size which would make it more compatible with the particle size distribution requirement for the char combustor. Because of the larger amount of water introduced into the pyrolyzer, this feed system is expected to produce less char and more fuel gas with a high moisture content. We will estimate the impact of this modified paste feed system on the overall plant performance.

Task 2 - Engineering Research and Development

Subtask 2.2 - Restrictive Pipe Discharge (RPD) System Cold Model

A cold test of the RPD system is being done at the Institute of Gas Technology (IGT). The test rig completed. The design is based on the dimensions that will be used in the Pyrolyzer/Char Transport Test (PCTT). The RPD pipe will be 3 inch I.D. x 20 feet long. A schematic diagram of the test rig is shown in Figure 7.

Char/sorbent material from the Second-Generation PFB pilot plant tests has been sent to IGT for use in the cold RPD tests. Quantities sufficient for tests of three different PSD's have been included in the shipment. After receipt at IGT, the PSD analyses were repeated. The results are shown in Figure 8. The middle PSD approximates the PSD that is expected with the base case HIPPS design. This would be the situation where char is generated in the pyrolyzer in the right size range to be fed directly to the TRW char combustor. The coarser size distribution approximates what would be expected if a jetting bed pyrolyzer were used and the char was depressurized, cooled and sent to pulverizers. This type of system is being considered as a near term option for repowering. The

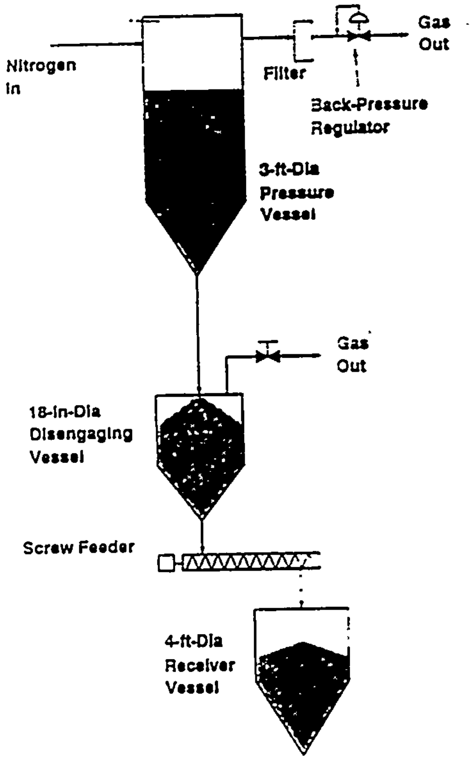


Figure 7 Schematic Drawing of RPD Test Unit

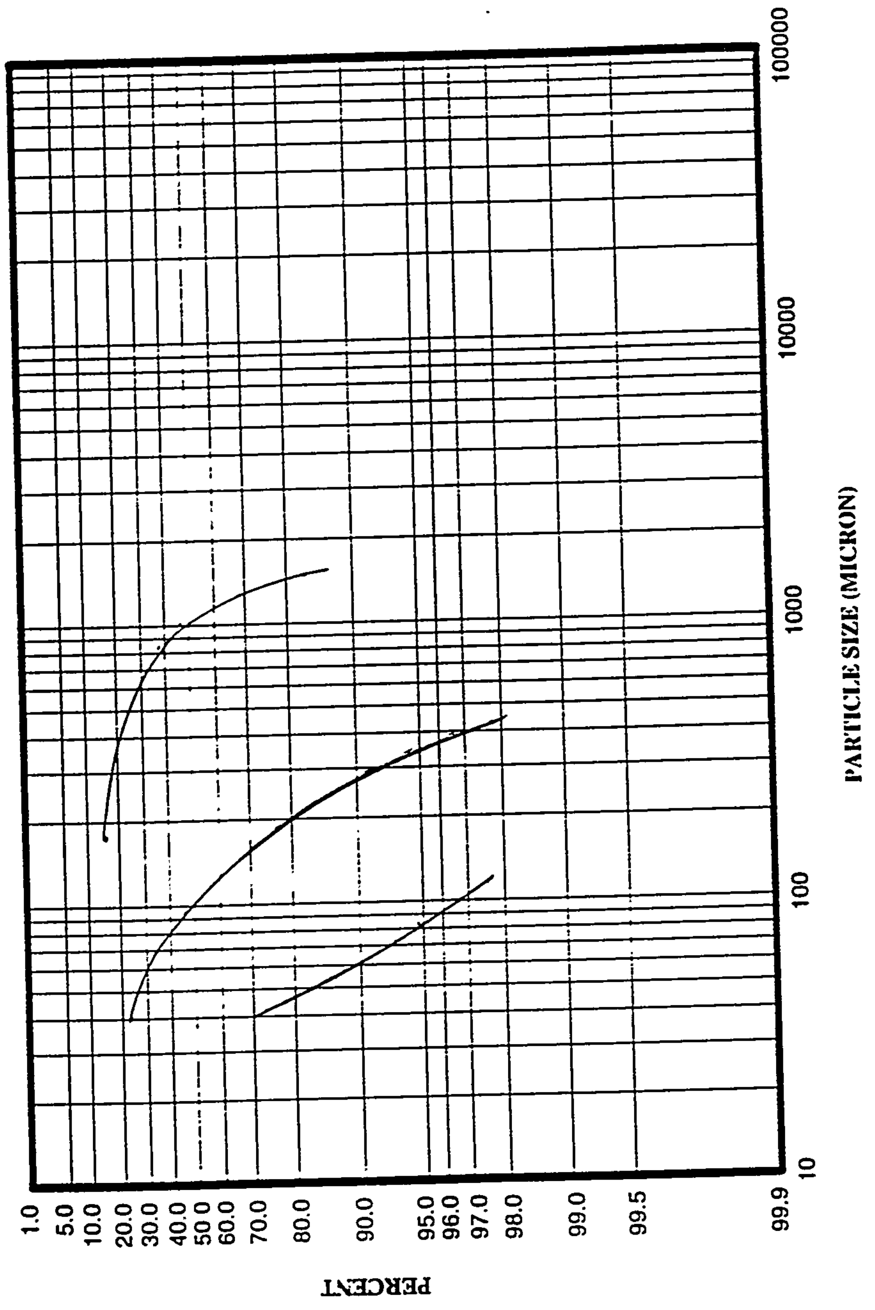


Figure 8 Particle Size Distributions for Cold RPD Test

finest char/sorbent distribution represents the fine end of a range of PSD's that could be used in the TRW combustor.

A test matrix for the cold RPD tests is contained in Table 2. Solids flow rates and pressures correspond to the range that is expected in the PCTT. In addition to general operability information, the following data will be obtained at each operating point:

- Solids flow rate in depressurization pipe
- Gas flow rate from disengaging vessel
- Pressure profile in depressurization pipe
- Pressures in pressure vessel and disengaging vessel

The cold RPD testing will begin in January.

Subtask 2.4 - Char Combustor Analysis and Laboratory Experiments

A laboratory-scale, modular 500,000 Btu/hr char burner was designed, built and tested at TRW during Phase 1 of the HIPPS program for the purpose of providing design information on char combustion kinetics and overall burnout levels. The initial testing during Phase 1 provided an experimental comparison between coal-fired and char-fired operation, and was used to verify analytical model predictions of the char combustion process.

During Phase 2 of the HIPPS program, the laboratory char burner will initially be used to address flame anchoring issues while burning either 100% char, or coal/char blends. The latter case is of particular interest for a HIPPS repowering application. Key parameters to be investigated include char particle size, fuel injector design and injection velocities, precombustor air preheat temperature and stoichiometry, and burner swirl. The data from the testing will be used to help design the precombustor to be used for Subscale Char Combustor Development Testing, which must be capable of operation with either coal, char, or coal/char blends at air preheat temperatures of up to 1150°F.

A schematic of the laboratory char burner test set-up is shown in Figure 9. The test set-up includes a coal/char feed system, a gas-fired vitiator (or direct-fired air heater), a coal/char burner assembly, a refractory-lined combustion chamber, a water tempering chamber, and a high efficiency baghouse for particulate capture. The feed system is capable of providing a solid fuel thermal input of up to 1,000,000 Btu/hr. Air is used to transport the solid fuel to the burner. A splitter is used to divide and feed the solid fuel stream to six individual fuel injectors. During Phase 2, the fuel injectors will be modified to enhance gas-particle mixing and to improve flame anchoring during char-fired operation.

Table 2

RPD Test Matrix

Test No.	Average Particle Size Microns	Pressure psig	Solid Flow Rate lb/h
1	45	225	300
2	45	225	145
3	45	225	80
4	45	225	min
5	45	100	300
6	45	100	145
7	45	100	80
8	45	100	min
9	45	50	300
10	45	50	145
11	45	50	80
12	45	50	min
13	70	225	300
14	70	225	145
15	70	225	80
16	70	225	min
17	70	100	300
18	70	100	145
19	70	100	80
20	70	100	min
21	70	50	300
22	70	50	145
23	70	50	80
24	70	50	min
25	300	225	300
26	300	225	145
27	300	225	80
28	300	225	min
29	300	100	300
30	300	100	145
31	300	100	80
32	300	100	min
33	300	50	300
34	300	50	145
35	300	50	80
36	300	50	min

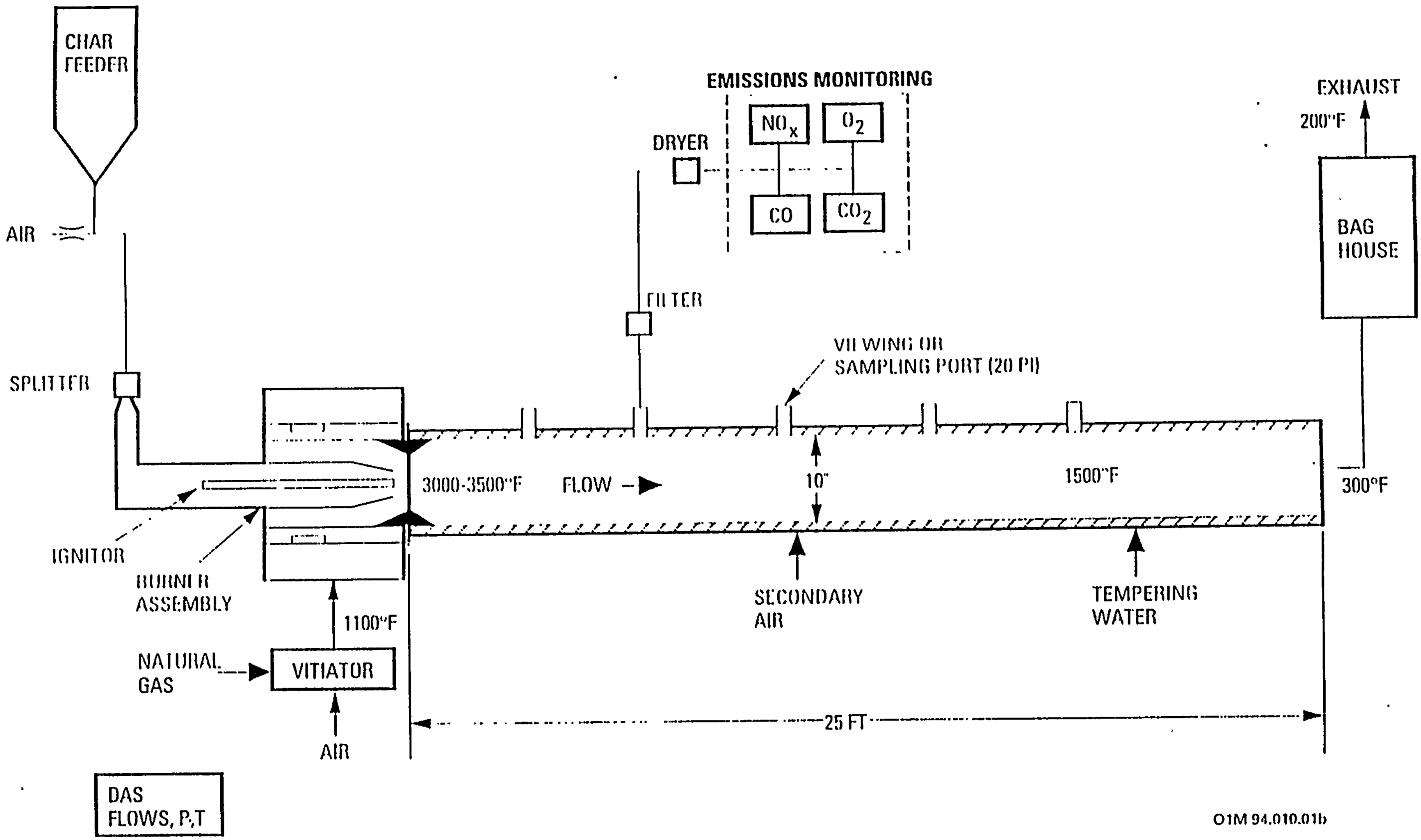


Figure 9 Schematic of Char Combustion Laboratory Test Set-Up

The vitiator is fired with natural gas, and is capable of providing vitiated air temperatures from 700 to 1200°F. The nominal oxygen content of the exhaust stream is 15% (by weight). The vitiator exhaust stream closely simulates the temperature and gas composition of the gas turbine exhaust which will be used as combustion air in an actual HIPPS plant. The vitiator air enters the coal/char burner assembly via an uncooled swirl can, where it is accelerated to a high swirl velocity prior to entering the burner throat region. The burner swirl velocity can be varied by adjusting the swirl vanes located at the gas inlet of the swirl can assembly.

A gas-fired pilot burner is located on the centerline of the coal/char burner assembly. This burner is used to warm up the combustion chamber prior to coal-fired or char-fired operation, and also serves as an ignitor for the coal or char flame. During Phase 2, modifications to the burner may be required to operate at the lower firing rates required for flame anchoring tests. These modifications, if any, will be identified early during the first quarter of 1996, so that changes can be made prior to initiating hot-fire testing.

During coal-fired or char-fired burner operation, flame ignition and anchoring are characterized based both on visual observation and gas composition/temperature measurements. Coal or char combustion profiles are determined based on gas composition and temperature measurements along the length of the combustion chamber. Emissions monitoring equipment measure CO, CO_2, O_2, and NO_x at various locations within the combustion chamber, as well as at the stack. During Phase 2, an additional viewport will be added near the throat of the burner, in order to enhance visual observations of the flame. More detailed gas sampling will also be performed near the burner throat, to better characterize mixing patterns and flame structure in this region.

In addition to the modifications to the fuel injectors and pilot burner, a number of operational changes to the burner are planned for the purpose of improving flame anchoring, including changes in particle size, injection velocity, burner stoichiometry and air preheat temperature, burner swirl, and the relative amounts of combustion air introduced axially and tangentially into the burner.

The char particle size is a key parameter that will be varied during parametric tests. During Phase 2, the particle size tested was approximately 70% passing through 200 mesh. In order to enhance flame anchoring during char-fired operation, finer grind sizes will be tested as well. It should be noted that the optimum particle size typically increases as the burner is scaled to larger sizes. For small burners where the residence time is limited and heat losses are relatively high, a finer particle size is usually required. For larger. commercial-size burners, a larger particle size can be accommodated since more residence time is available.

Additional changes planned for the laboratory char burner operation include a reduction in injection velocity, a reduction in burner stoichiometry, an increase in burner swirl, and a decrease in the amount of primary and secondary air that is introduced on-axis (non-swirling) at room temperature. Once satisfactory burner flame anchoring is achieved, then systematic changes in air preheat temperature will be made to determine the effect of this parameter on overall burner performance.

The current test plan calls for burner modifications and functional checkouts during the first quarter of 1996. Hot-fired testing is also expected to commence towards the end of the first quarter.

Task 3 - Subsystem Test Unit Design

Subtask 3.1 - Pyrolyzer/Char Transport Test Design

System Description. The Second-Generation PFB pilot plant in Livingston, New Jersey is being modified for use as the PCTT. A schematic diagram of the PCTT is shown Figures 10a and 10b.

The existing pyrolyzer will be modified to operate as a circulating fluidized bed. The facility has the capability for both dry and paste feed to the pyrolyzer. It is planned that at least the initial runs will be with dry feed. The primary cyclone is being designed so that it will be easy to modify during the test campaign. Solids will be drained from the bottom of the pyrolyzer bed as required to maintain bed level, but the goal is to have almost all of the char leave the primary cyclone with the fuel gas.

In the initial runs the char/fuel gas stream will go directly to the barrier filter vessel where the solids will be separated from the fuel gas. The barrier filter is part of the existing plant. It is a Westinghouse design using ceramic candle filter elements. The barrier filter will also serve as the upper hopper of an RPD system that will be used to depressurize the char. The barrier filter will be modified to accomodate the additional function. A six foot high spool piece will be added to the vessel to add a surge volume and to keep the solids level safely below the candles. Depending on the operating characteristics of the pyrolyzer/primary cyclone system, a secondary cyclone or classifier may be added later. This device would be located between the primary cyclone and the barrier filter.

An RPD pipe will be added to the bottom of the barrier filter vessel. A combination of nitrogen injection and cooling coils will be used to lower the solids temperature to about 450°F entering the screw feeder. In normal operation the lower RPD hopper will be at low pressure, but the components are being designed for full system pressure through the screw feeder. This approach will give an additional margin of safety. The lower RPD hopper and screw feeder were previously used for other functions in the pilot plant.

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8

7

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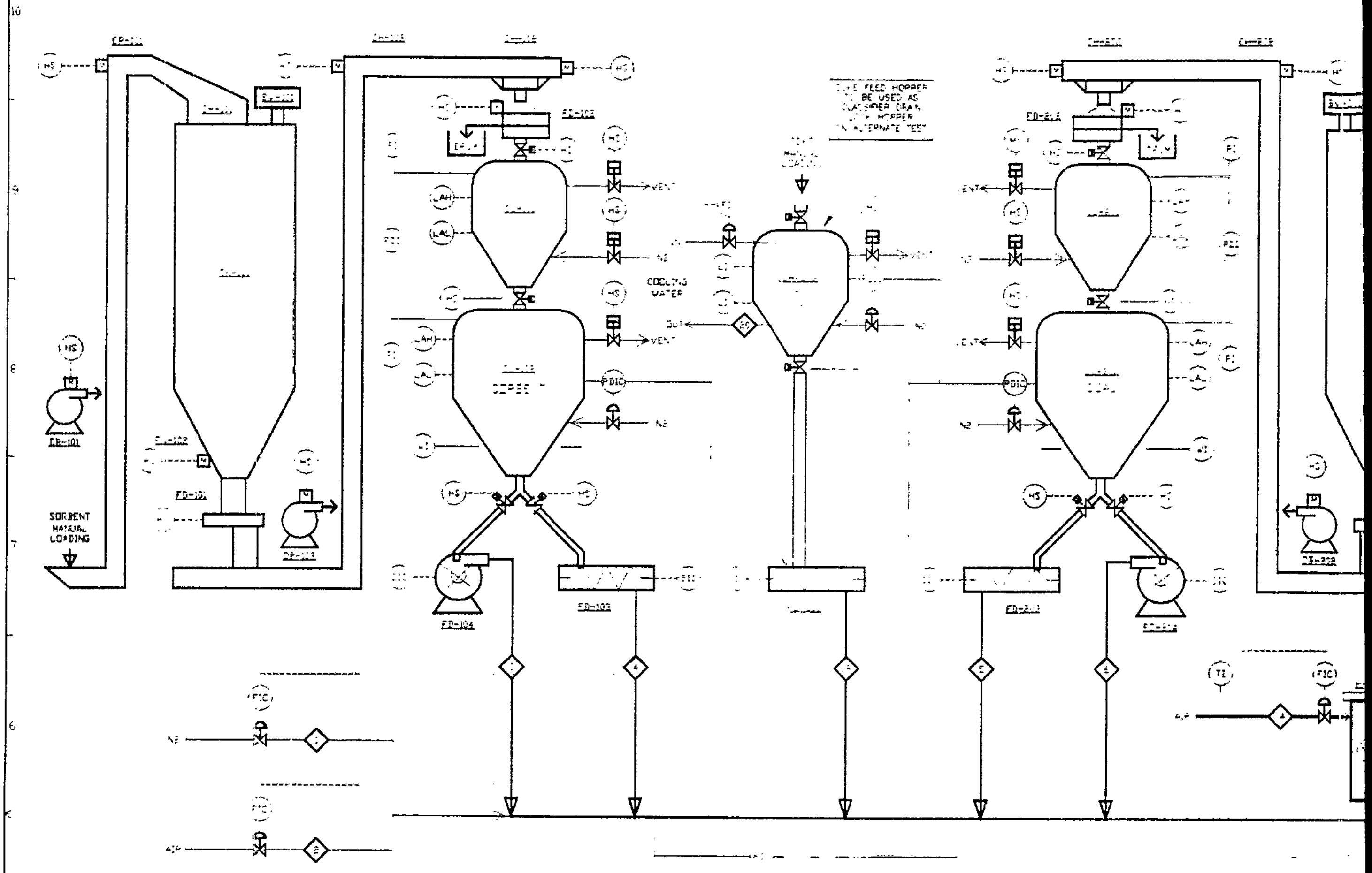

5

DB-101
DUST BLOWER #1
HP ____ CFM

CH-101
SORBENT SHUTE #1
MAX ____ LB/HR

BV-101
SORBENT SILO BIN VENT
HP ____ CFM

DB-102
DUST BLOWER #2
HP ____ CFM

CP-102
SORBENT FEED CONVEYOR
MAX ____ LB/HR

FD-103
SORBENT SILO SCREEN DECK
MAX ____ LB/HR

FD-104
FIRTH PUMP
MAX ____ LB/HR

CK-302
COKE FEED HOPPER

CL-202
COAL FEED HOPPER
VOL ____ ft
LO LVL ____ ft
HI LVL ____ ft

FD-
COAL SCREE
MAX

4

CR-101
SORBENT SILO BUCKET ELEVATOR
MAX ____ LB/HR

TK-101
SORBENT SILO
MAX ____ LB/HR

FD-102
LIVE BOTTOM
HP ____

FD-101
SORBENT VIBRATING FEEDER
MAX ____ LB/HR

CH-102
SORBENT CHUTE #2
MAX ____ LB/HR

SL-101
SORBENT PRESSURIZING LOCK HOPPER
VOL ____ ft
LO LVL ____ ft
HI LVL ____ ft

SORBENT FEEDER
MAX ____ LB/HR

FD-204
FIRTH PUMP
MAX ____ LB/HR

FD-203
COAL SCREW FEEDER
MAX ____ LB/HR

CL-
COAL PRE LOCK H
VOL
LO LVL
HI LVL

3

STREAM NUMBER	1		2		3		4		5		6		7			8		9		10	11	12
	AIR TRANSPORT		NITROGEN TRANSPORT		FIRTH PUMP FEED		SORBENT FEED		FIRTH PUMP FEED		COAL SCREW FEED		PYROLYZER COMBINED FEED			RETURN J VALVE HEEL		RETURN J VALVE TOE		PYROLYZER BOTTOM N2	PYROLYZER DRAIN	CLASSIFIER DRAIN
	FPS	LB/HR	FPS	LB/HR	RPM	LB/HR	RPM	LB/HR	RPM	LB/HR	RPM	LB/HR	FPS	LB/HR		FPS	LB/HR	FPS	LB/HR	LB/HR	LB/HR	LB/HR
														AIR	SOLID							
DESIGN FLOW																						
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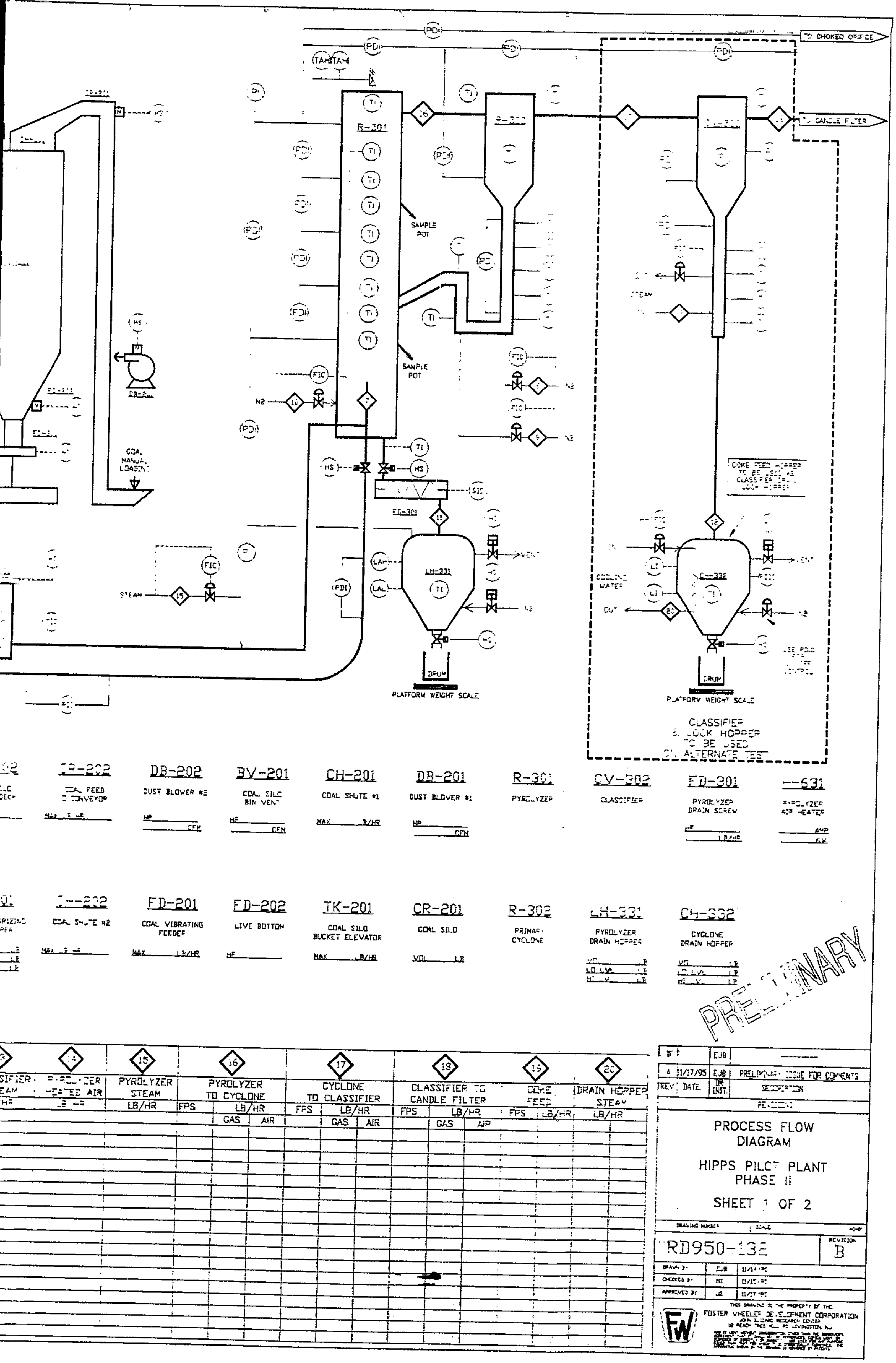
TO CHOKED ORIFICE
TO CANDLE FILTER
PDI
TAH
TAH
PI
TI
R-301
16
SAMPLE POT
SAMPLE POT
FIC
N2
10
7
HS
SIC
FD-301
11
LH-331
LAH
LAL
PDI
VENT
N2
PLATFORM WEIGHT SCALE
DRUM
STEAM
15
FIC
COAL MANUAL LOADING
STEAM
COKE FEED HOPPER TO BE USED AS CLASSIFIER LOCK HOPPER
12
COOLING WATER
OUT
20
CH-332
VENT
N2
CLASSIFIER & LOCK HOPPER TO BE USED ON ALTERNATE TEST
CR-202
COAL FEED CONVEYOR
DB-202
DUST BLOWER #2
HP
CFM
BV-201
COAL SILO BIN VENT
HP
CFM
CH-201
COAL SHUTE #1
MAX LB/HR
DB-201
DUST BLOWER #1
HP
CFM
R-301
PYROLYZER
CV-302
CLASSIFIER
FD-301
PYROLYZER DRAIN SCREW
HP
LB/HR
-631
PYROLYZER AIR HEATER
AMP
KW
CH-202
COAL SHUTE #2
FD-201
COAL VIBRATING FEEDER
MAX LB/HR
FD-202
LIVE BOTTOM
HP
TK-201
COAL SILO BUCKET ELEVATOR
MAX LB/HR
CR-201
COAL SILO
VOL LB
R-302
PRIMARY CYCLONE
LH-331
PYROLYZER DRAIN HOPPER
VOL LB
LO LVL LB
HI LVL LB
CH-332
CYCLONE DRAIN HOPPER
VOL LB
LO LVL LB
HI LVL LB
PRELIMINARY
14
PYROLYZER HEATED AIR
LB/HR
15
PYROLYZER STEAM
LB/HR
16
PYROLYZER TO CYCLONE
FPS
LB/HR
GAS
AIR
17
CYCLONE TO CLASSIFIER
FPS
LB/HR
GAS
AIR
18
CLASSIFIER TO CANDLE FILTER
FPS
LB/HR
GAS
AIR
19
COKE FEED
FPS
LB/HR
20
DRAIN HOPPER STEAM
LB/HR
EJB
A 11/17/95 EJB PRELIMINARY ISSUE FOR COMMENTS
REV DATE DR INIT. DESCRIPTION
REVISIONS
PROCESS FLOW DIAGRAM
HIPPS PILOT PLANT PHASE II
SHEET 1 OF 2
DRAWING NUMBER
SCALE
RD950-13E
REVISION
B
DRAWN BY EJB 11/14/95
CHECKED BY MI 11/15/95
APPROVED BY JG 11/17/95
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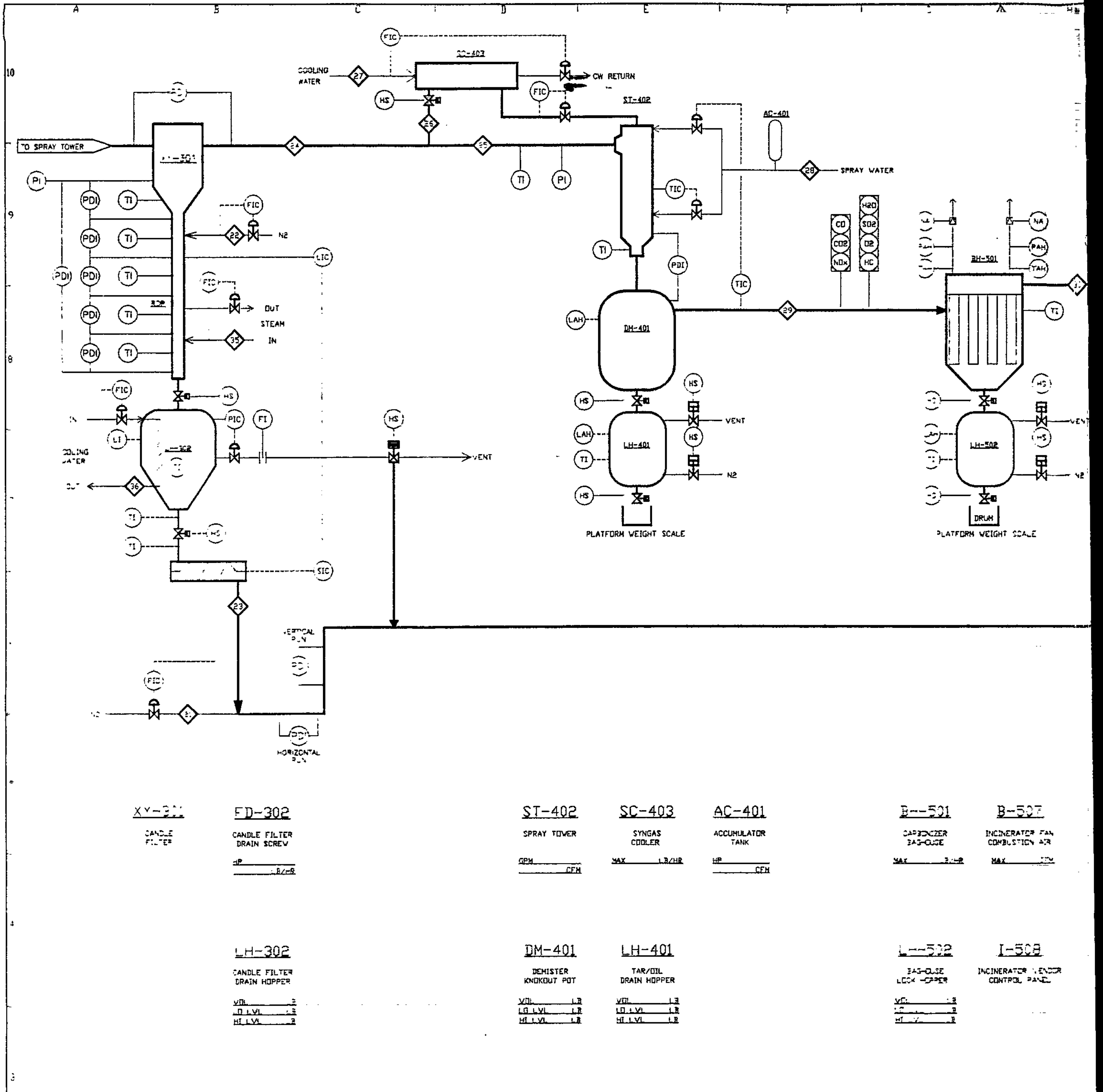
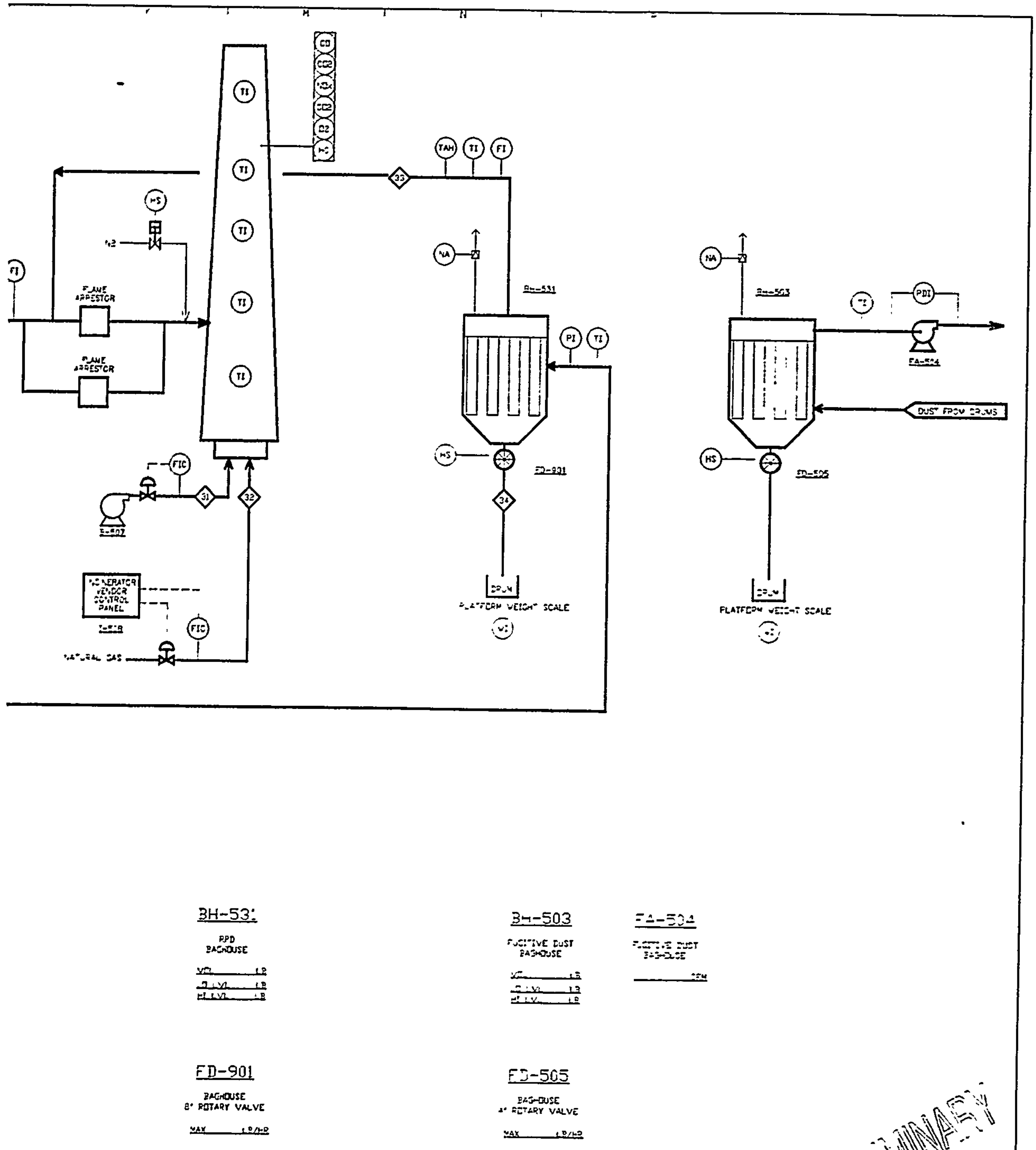
Figure 10a



STREAM NUMBER	20	21		22		23	24	25	26	27	28	29	30
	RPD SCREW COOLING WATER	RPD AIR TRANSPORT		RPD N2		CANDLE FILTER DRAIN	CANDLE FILTER TO SPRAY TOWER	SPRAY TOWER INLET	SYNGAS COOLER INLET	SYNGAS COOLER COOLING WATER	SPRAY TOWER SPRAY WATER	BAGHOUSE INLET	BAG- TO STA
	GPM	FPS	LB/HR	FPS	LB/HR	LB/HR	LB/HR	LB/HR	LB/HR	GPM	GPM	LB/HR	B/HR
DESIGN FLOW													
MAX FLOW													
MIN FLOW													
DESIGN PRESS													
MAX PRESS													
MIN PRESS													
DESIGN TEMP													
MAX TEMP													
MIN TEMP													
DENSITY													



PRELIMINARY

E K	31 INCINERATOR AIR	32 INCINERATOR NATURAL GAS	33 RPD BAGHOUSE TO STACK		34 RPD BAGHOUSE DRAIN	35 RPD STEAM	36 RPD LOCK HOPPER VENT
	LB/HR	LB/HR	FPS	LB/HR	LB/HR	LB/HR	LB/HR

B		E.B.	---------
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REVISIONS

PROCESS FLOW
DIAGRAM

HIPPS PILOT PLANT
PHASE II

SHEET 2 OF 2

DRAWING NUMBER	SCALE		REVISION
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Figure 10b

The fuel gas leaving the barrier filter will be divided into two streams. One stream will go to a fixed orifice. This type of backpressure device approximates the pressure-flow characteristics of a gas turbine, but it will result in nearly constant pyrolyzer superficial velocity over the range of testing. It is desired to investigate the affects of velocity in the pyrolyzer, so a branch line with a control valve has been added to the system. Adjusting this control valve will, in effect, allow us to simulate changes in pyrolyzer diameter by operating at superficial velocities that would result from those diameters.

Next the fuel gas goes through a spray cooler and then a final baghouse. After the baghouse, it goes to an incinerator where it is burned before being discharged from the stack.

Test Matrix. The purpose of the PCTT is to obtain the necessary information to design the following systems for the Integrated System Test (IST):

- Pyrolyzer
- Cyclone System
- Char Depressurization System
- Char Transport System

We have considerable information on the chemistry of the pyrolysis process from the Second-Generation PFB test program. However, that testing was primarily done with a jetting fluidized bed. The HIPPS pyrolyzer will be a circulating fluidized bed because that type of reactor is better suited to the finer char particle size required for PC combustion. The focus of the PCTT pyrolyzer testing will be on the hydrodynamics of the process.

Figure 11 illustrates the objectives of the pyrolyzer testing. Ideal operation of the pyrolyzer system would be to have a steady state condition where all the char leaves the primary cyclone gas outlet with a PSD suitable for firing in the char combustor. This char would then be separated downstream and sent directly to the char combustors. To the extent that this is possible, it will reduce capital costs and simplify operation. In practical operation, a stream of solids can also be taken from the bottom of the bed. This stream would require further processing so it will be beneficial to keep it as small as possible. The parameters that will have the greatest effect on the particle size and flow rate leaving the primary cyclone are the riser velocity, feedstock PSD's and cyclone design.

The PCTT testing will be done in a manner to provide enough variations of these parameters to provide a map of possible design and operating regions. The data will also be used to benchmark cold models and computer models of the pyrolyzer/cyclone system. The riser velocity will be the easiest parameter to vary on-line so the procedure will be to fix the cyclone design and feedstock size distribution and then operate at different riser velocities. Each riser velocity set point will be maintained for sufficient time to reach steady state operation.

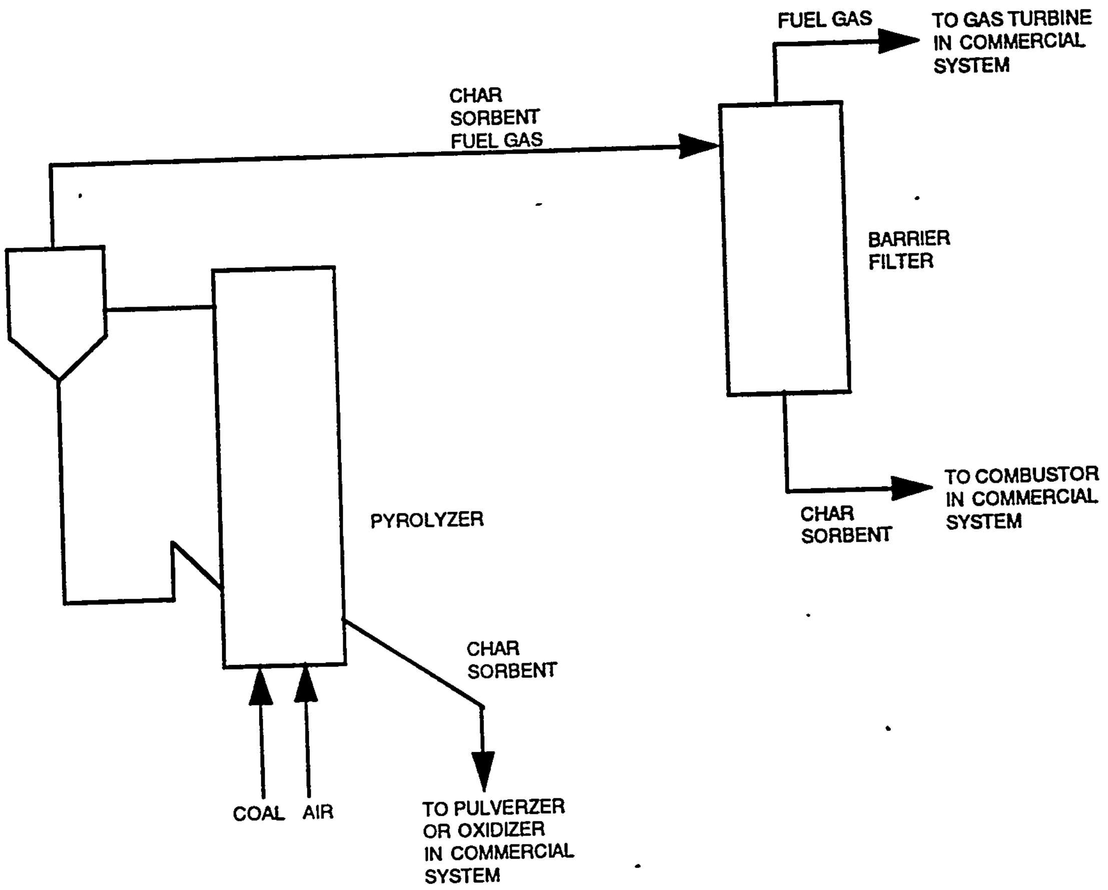


Figure 11 Illustration of Flow Streams

In a commercial system with a pyrolyzer and a gas turbine, the diameter of the pyrolyzer riser will fix the riser velocity. This velocity will be relatively constant over the range of loads because of the nature of gas turbine operation. The gas turbine acts like a fixed orifice, and as the load changes system pressure changes in a way that will maintain a fairly constant riser velocity. In order to explore the effects of riser velocity, the PCTT is being designed so that the riser velocity can be varied without changing the riser diameter. A parallel control valve and fixed orifice will provide the back pressure, and adjustment of this valve and the coal input will provide a range of riser velocities from 5 to 12 fps. The conditions to achieve these velocities are listed in Table 3.

Six test runs of one week duration are planned for the PCTT. The actual parameter changes during the test program will depend on the results of previous tests, but a possible test matrix is shown in Table 4. The first run will establish the base point with a cyclone design and feedstock chosen based on our current models. This test run will establish the performance of these fixed parameters over a range of riser velocities. This data will then be reviewed to determine the changes that should be made for the next test run. If the PSD's leaving the primary cyclone look good, but the bed drain rate of char is too large, the feedstock PSD's will be varied first. If the PSD's leaving the primary cyclone are unacceptable, the cyclone design will be varied first. Although not as easy as riser velocity, feedstock size and cyclone design can be changed during a run. The cyclone is being designed so that modifications can be made during a brief shutdown. Depending on results, it may be desireable to reduce the riser velocity test points in later runs and vary feedstock size or cyclone design during these runs.

Operating Conditions. As a basis for the hardware design of the PCTT pilot plant, the system process was modeled on ASPEN. Runs were made for the range of test conditions that are planned. The pyrolyzer yields are based on the computer model developed for the Second-Generation PFB. The feedstocks are Pittsburgh No.8 coal and Longview limestone. The system flows, temperatures and pressures shown in Figures 12 through 15 correspond to the conditions listed in Table 3 for riser velocities of 5 through 12 fps respectively.

Plant Design. The PCTT plant general arrangement is shown in Figures 16 and 17. Modifications to the existing pilot plant have been minimized as much as possible without compromising the operation of the PCTT. The system is in the process of being modeled to determine the vessel nozzle and support loads caused by weight and thermal expansion in the new arrangement. Detailed design of the systems is also currently being done. A preliminary P&ID drawing has been completed and an inventory of existing instrumentation is in the process of being compiled.

Table 3

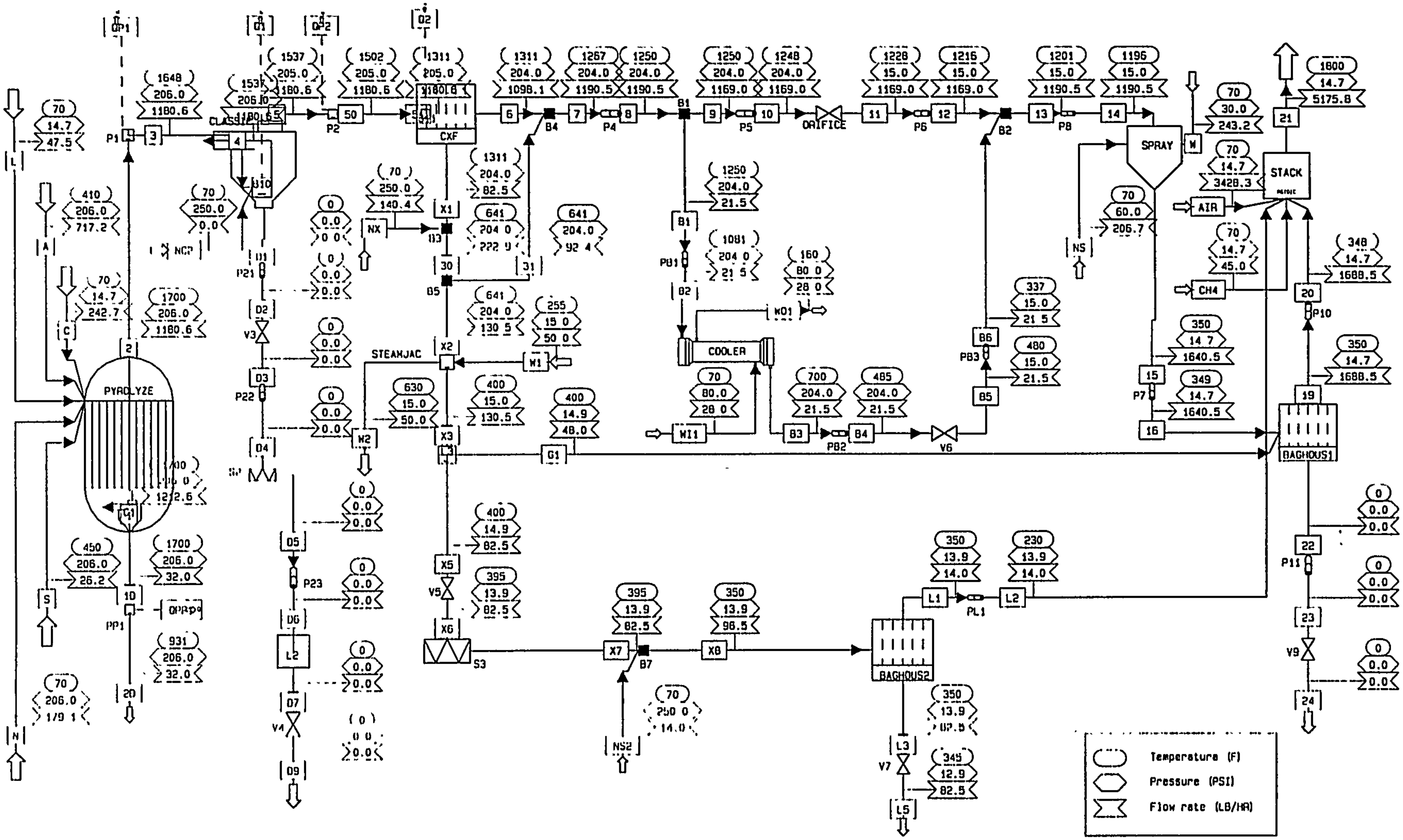
Parameters Varied During Test Runs

Riser Velocity (ft/sec)	Pressure (psia)	Coal Flow (lb/h)	Gas Flow (lb/h)
5	206	243	1098
7	206	362	1537
9	206	500	1977
12	154	500	1977

Table 4

Possible Test Run Matrix

Test Run	Coal PSD	Sorbent PSD	Cyclone Design
1	C1	S1	CY1
2	C2	S1	CY1
3	C2	S2	CY1
4	C2	S2	CY2
5	TO BE DETERMINED		
6	TO BE DETERMINED		



HP50 1/16/96 15:20 Q=3% W/Steam 1098lb/hfuelgas 206psi dori=.404"

Figure 12 PCTT Process Conditions at 5 FPS Riser Velocity

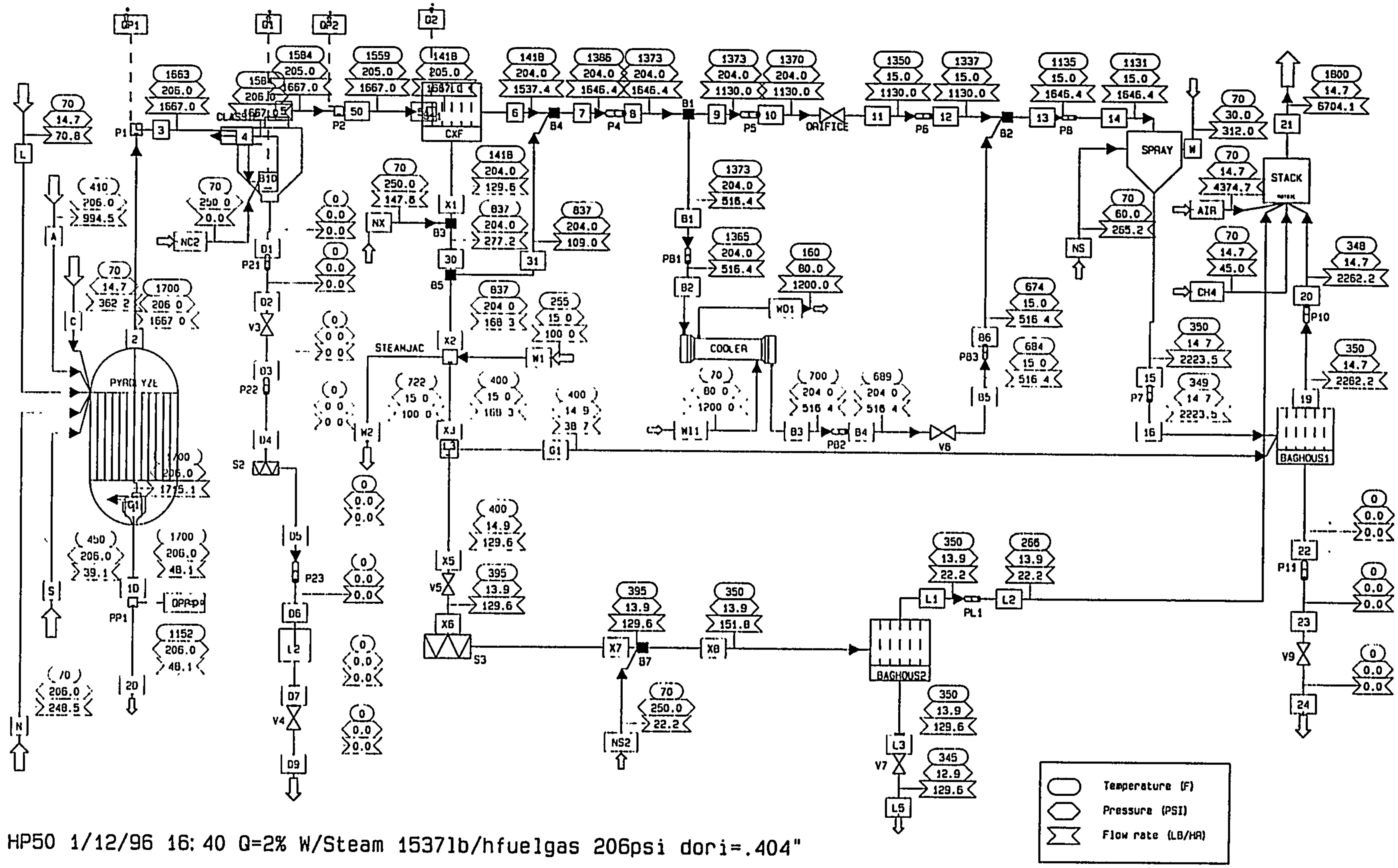
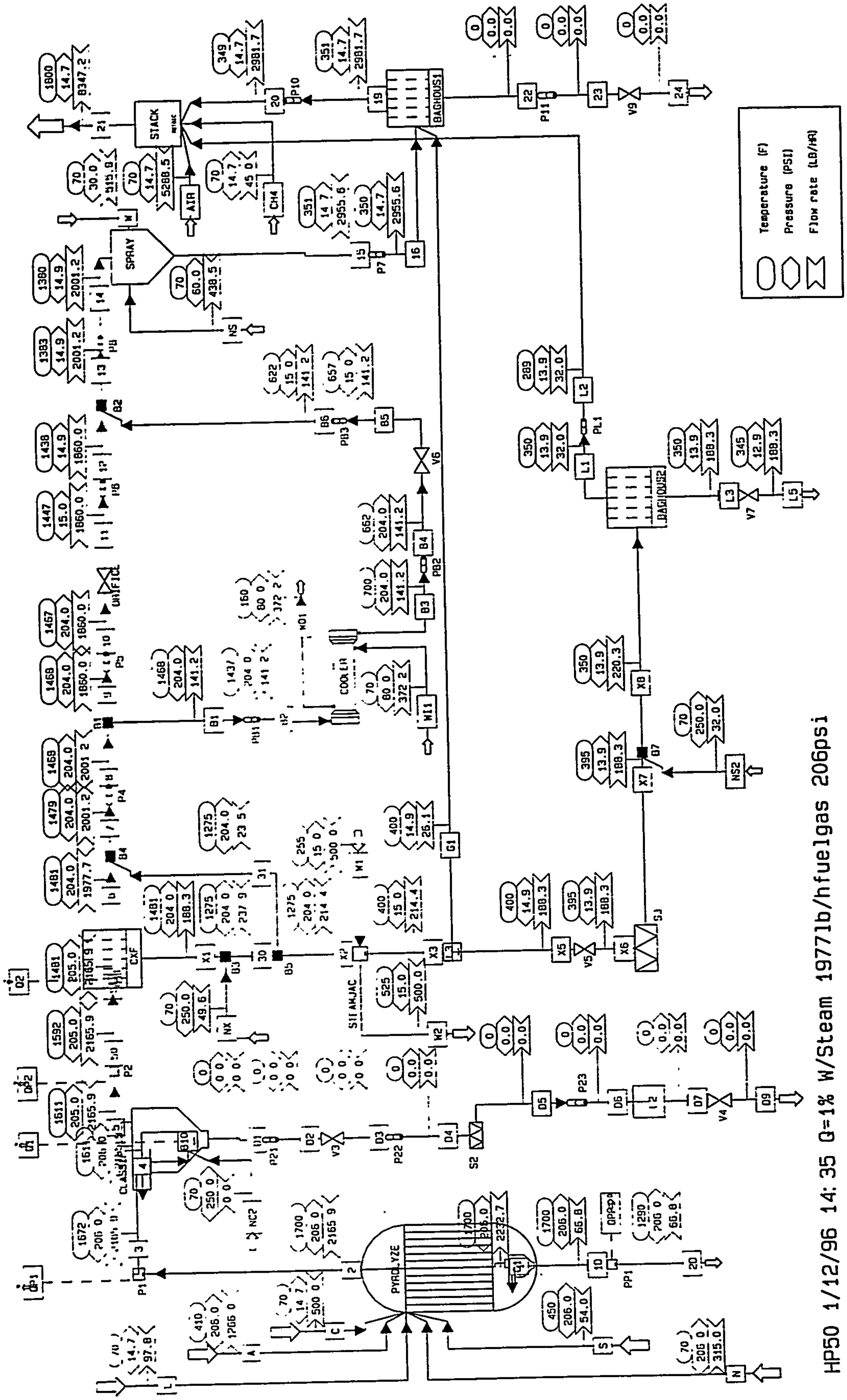
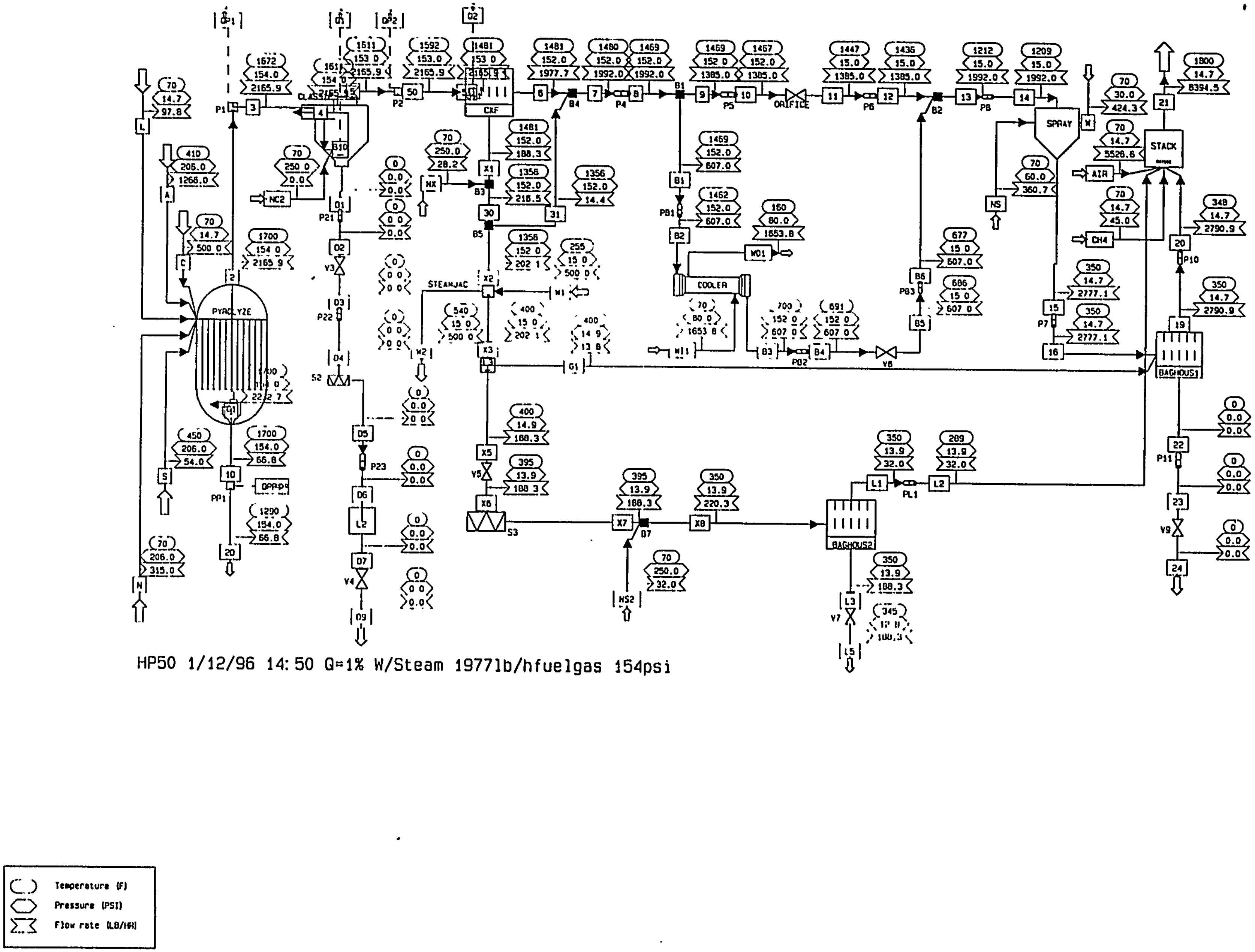


Figure 13 PCTT Process Conditions at 7 FPS Riser Velocity



HP50 1/12/96 14:35 Q=1% W/Steam 1977lb/hfuelgas 206psi

Figure 14 PCTT Process Conditions at 9 FPS Riser Velocity



HP50 1/12/96 14:50 Q=1% W/Steam 1977lb/hfuelgas 154psi

Figure 15 PCTT Process Conditions at 12 FPS Riser Velocity

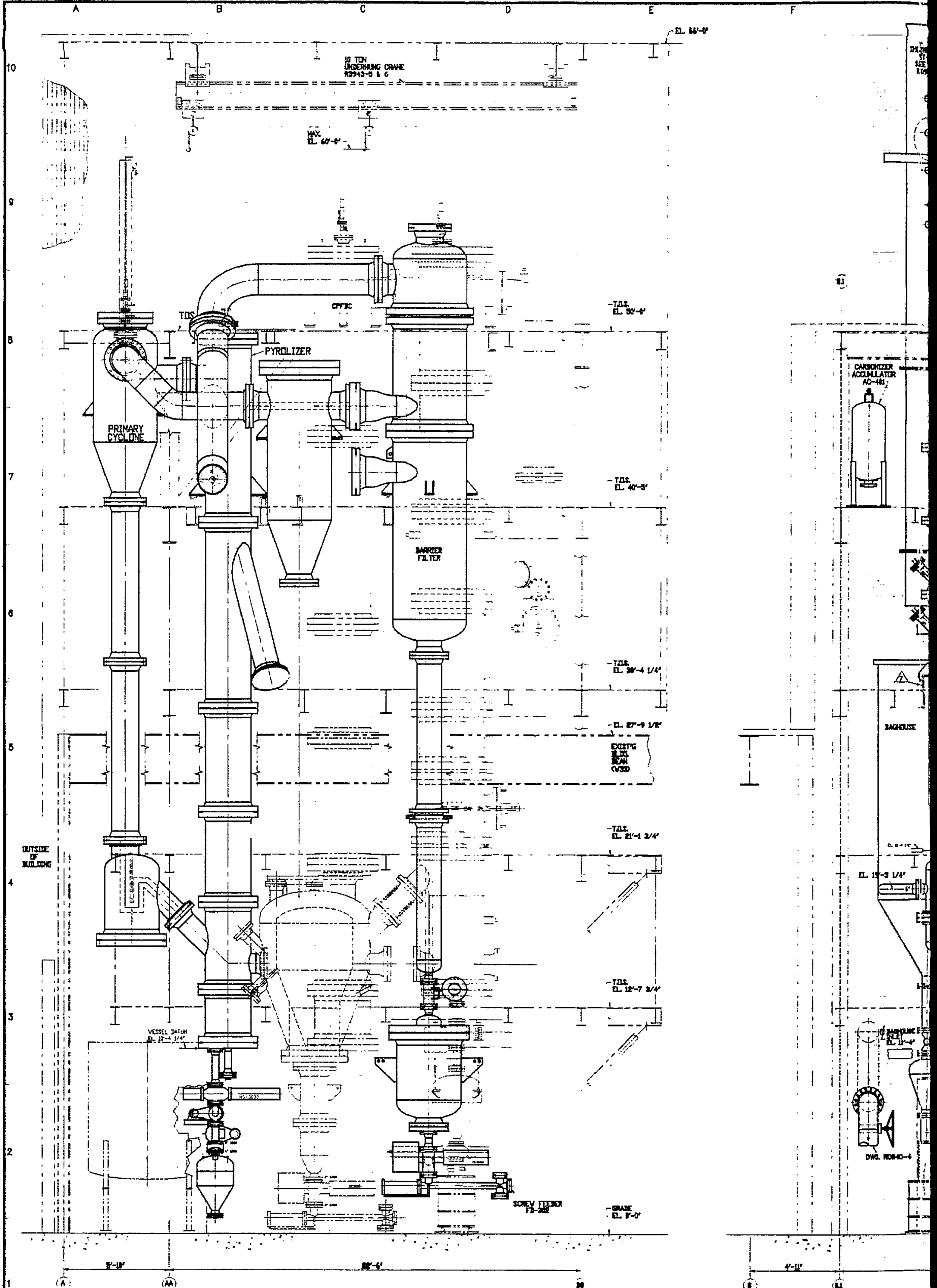
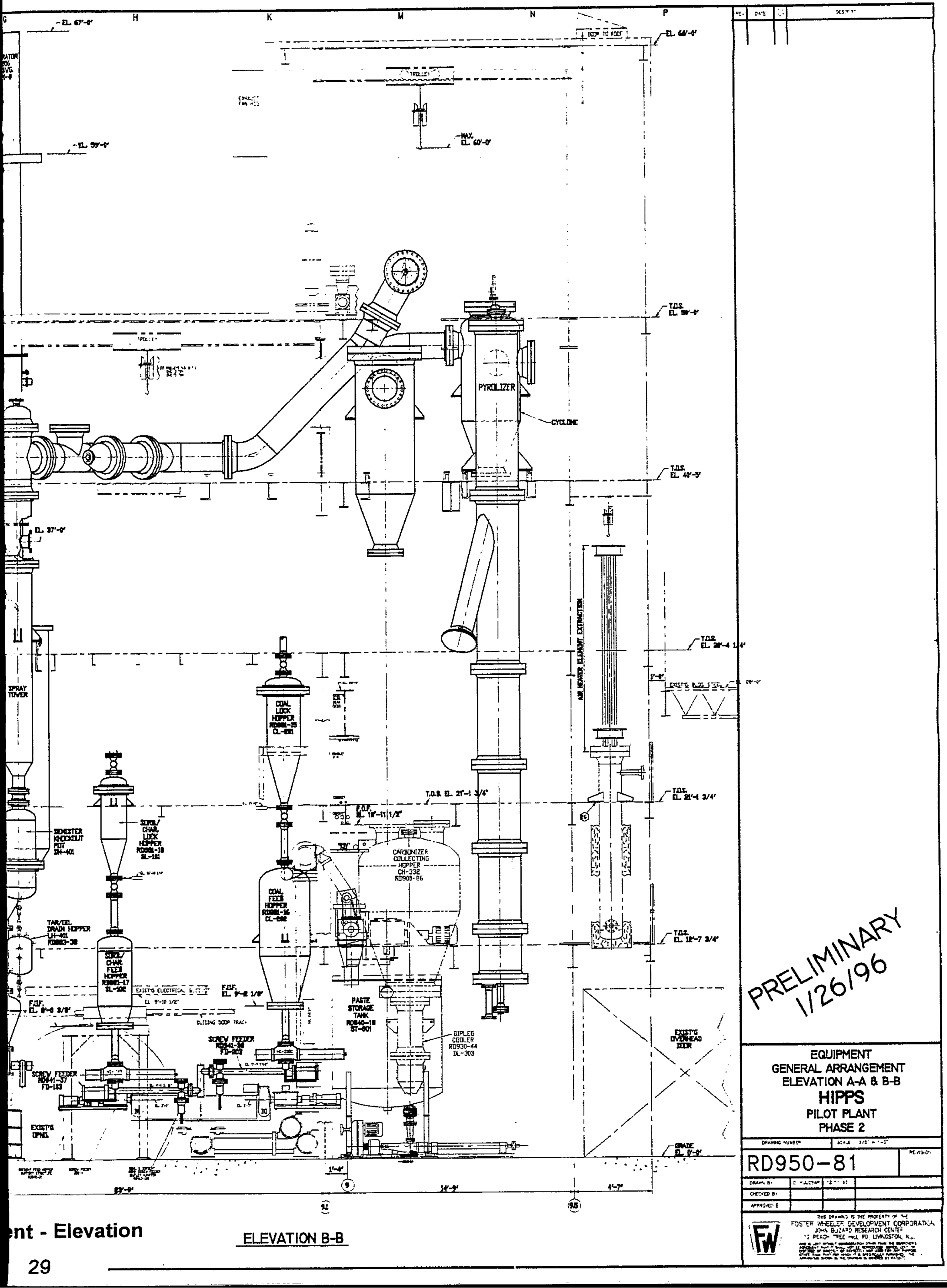


Figure 16 PCTT General Manageme



ELEVATION B-B

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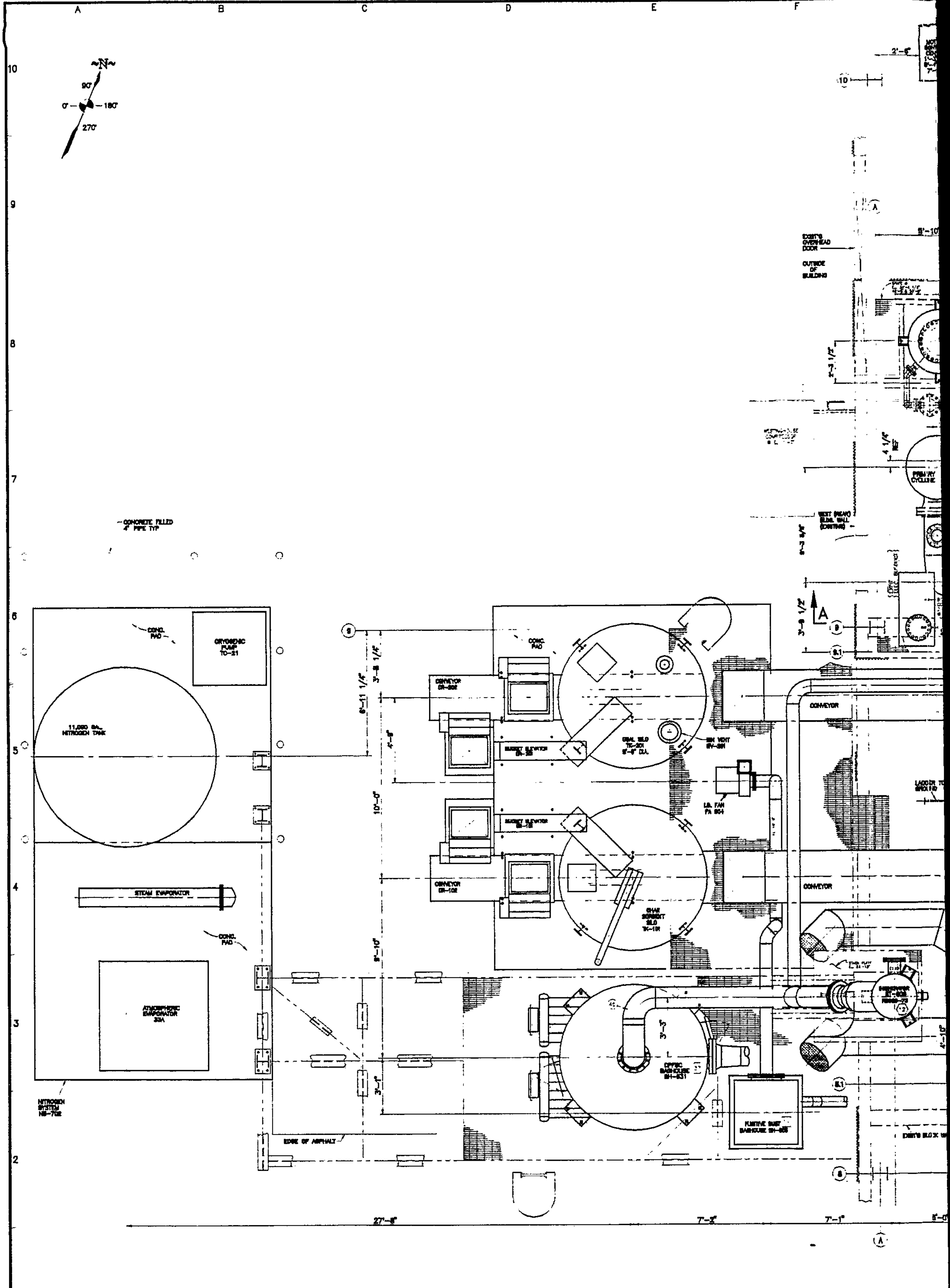

HIPPS PILOT PL
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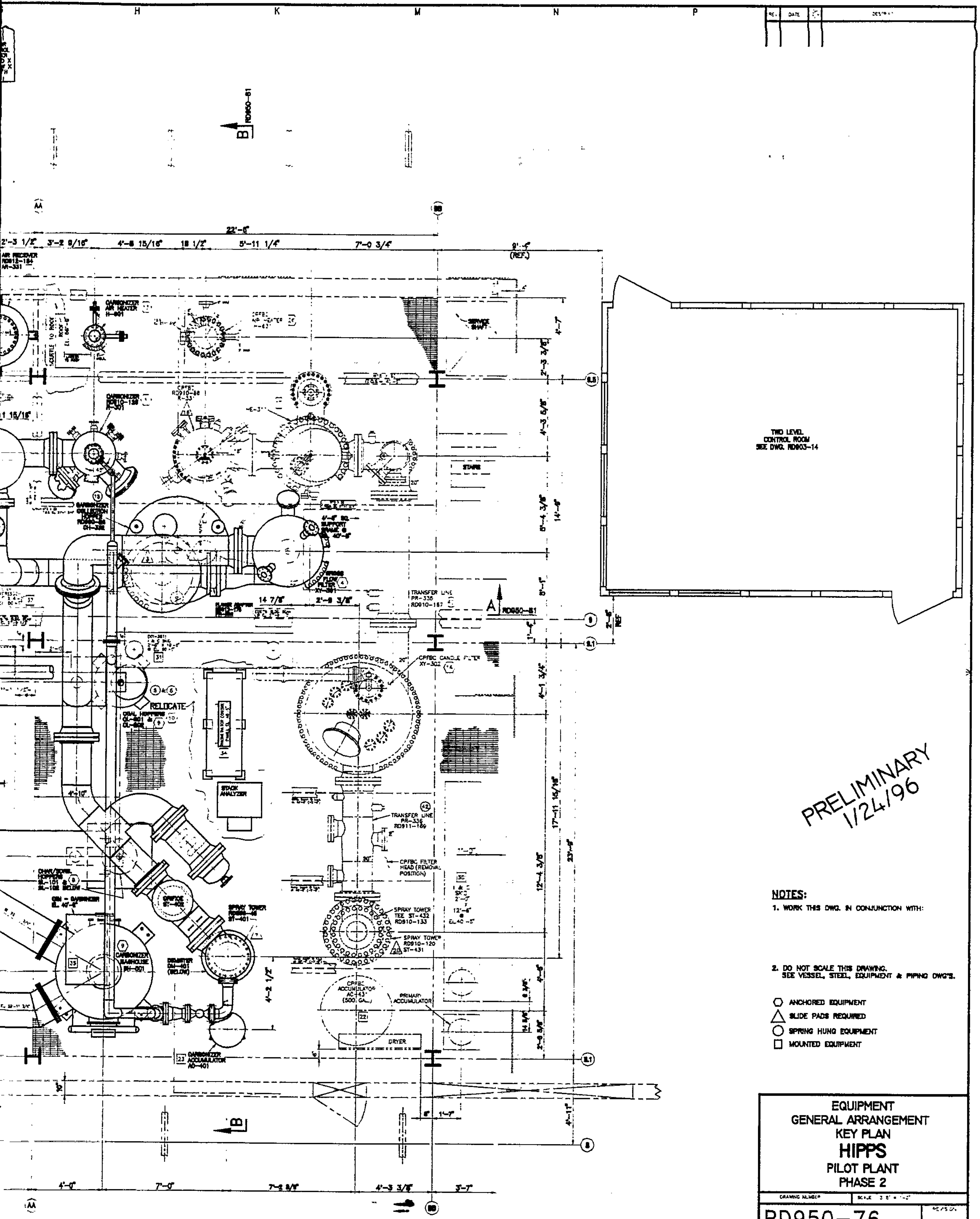

PRELIMINARY
1/24/96

NOTES:

1. WORK THIS DWG. IN CONJUNCTION WITH:

2. DO NOT SCALE THIS DRAWING.
SEE VESSEL, STEEL, EQUIPMENT & PIPING DWG'S.

⬡ ANCHORED EQUIPMENT
△ SLIDE PADS REQUIRED
○ SPRING HUNG EQUIPMENT
☐ MOUNTED EQUIPMENT

EQUIPMENT
GENERAL ARRANGEMENT
KEY PLAN
HIPPS
PILOT PLANT
PHASE 2

DRAWING NUMBER	SCALE 3/8" = 1'-0"	
RD950-76		REVISION

DRAWN BY	D. KULCSAR	12/11/95	
CHECKED BY			
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EY PLAN

Figure 17 PCTT General Management - Plan

Subtask 3.2 - Char Combustor Test

The char combustor development test activities will be performed utilizing an existing TRW-owned, workhorse, modular, 40 MMBtu/hr combustor, appropriately modified for the specific needs of the HIPPS program. The combustor will be integrated into an existing test cell at TRW's Fossil Energy Test Site (FETS) located in San Clemente, California.

During the last quarter, planning efforts were initiated to reactivate the TRW facility for char combustor development testing. The baseline test set-up shown in Figure 18 was identified. A preliminary heat and material balance was generated, for the purpose of specifying flow and instrumentation requirements. Long lead items were also identified, which include combustor hardware evaluation/refurbishment and test cell modifications. A preliminary combustor layout drawing was completed, along with layouts of the required modifications to the test cell. Updated quotes were also obtained for the test cell modifications, and for the purchase of a 1200°F duct burner (Duct Burner #2) to supply vitiated air to the precombustor burner.

The total duration of the hardware refurbishment and upgrade, facility modification, hardware installation, and the test activities is estimated to be approximately 18 months including periods of time for hardware modifications. as required. A summary of the test objectives and the test configuration is contained in the following sections.

Test Objectives. The primary objectives of the char combustor development tests are to verify and optimize the char combustor performance and operational characteristics, and define the combustor operating envelope. Specific objectives include:

- Obtain test data to verify and optimize the char combustor key performance parameters including combustion characteristics such as ignition, flame stability, and carbon burn-out, NO_x control, and slagging behavior and slag recovery.
- Obtain test data to characterize the char combustor operating envelope including firing rate, air preheat temperature, stoichiometric ratio, and turndown. Characterize the performance over a wide range of loads in order to verify the minimum and maximum firing rate of the subscale combustor.

Test Configuration. The test series will be performed with an existing TRW-owned, modular, 40 MMBtu/hr combustor, appropriately modified to burn char. The combustion system includes a char-fired precombustor, a char-fired slagging stage, a slag recovery section, a slag tank, a windbox, and a boiler simulator. A schematic of the test set-up is shown in Figure 18. The combustor is shown integrated with an existing boiler simulator in Figure 19.

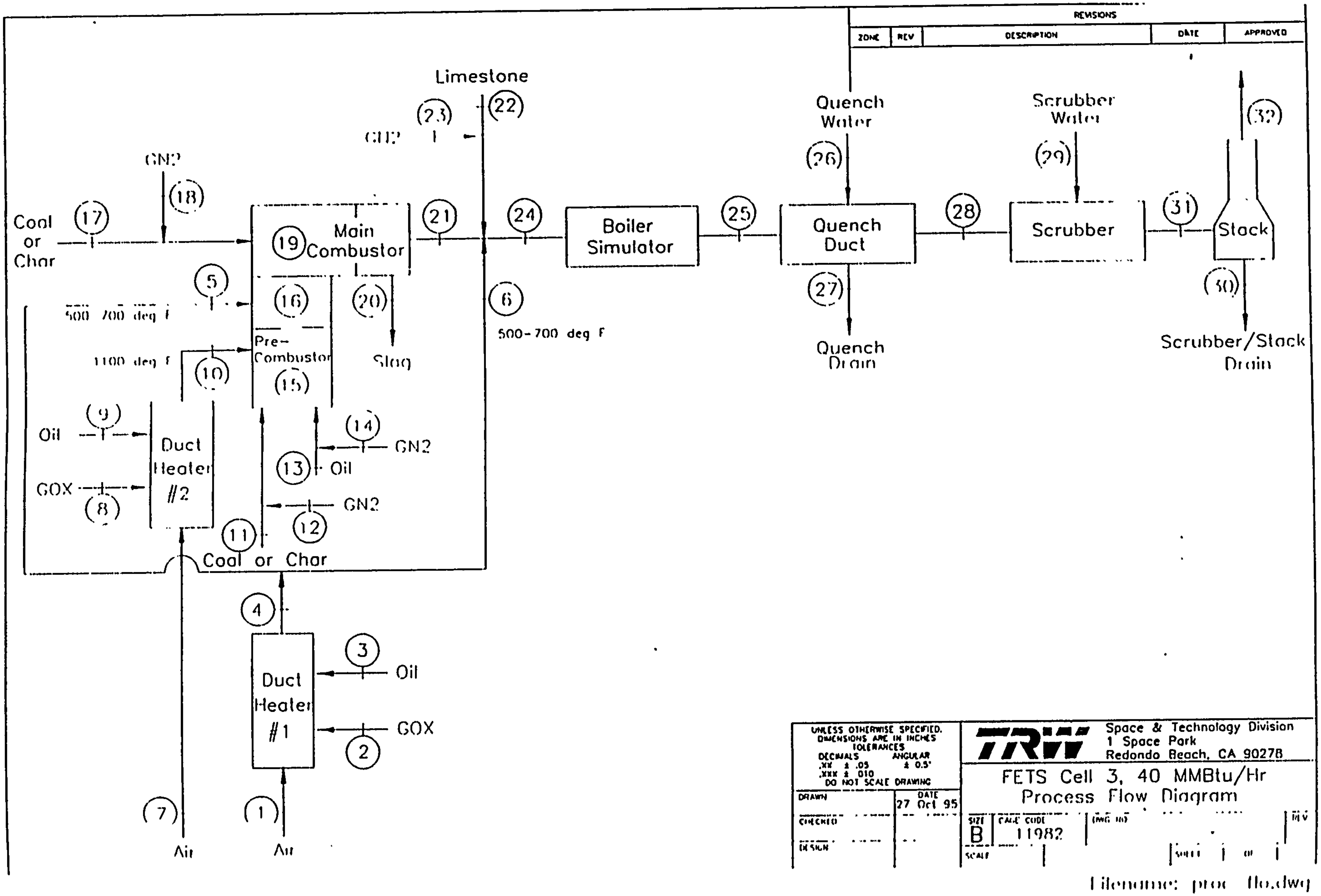
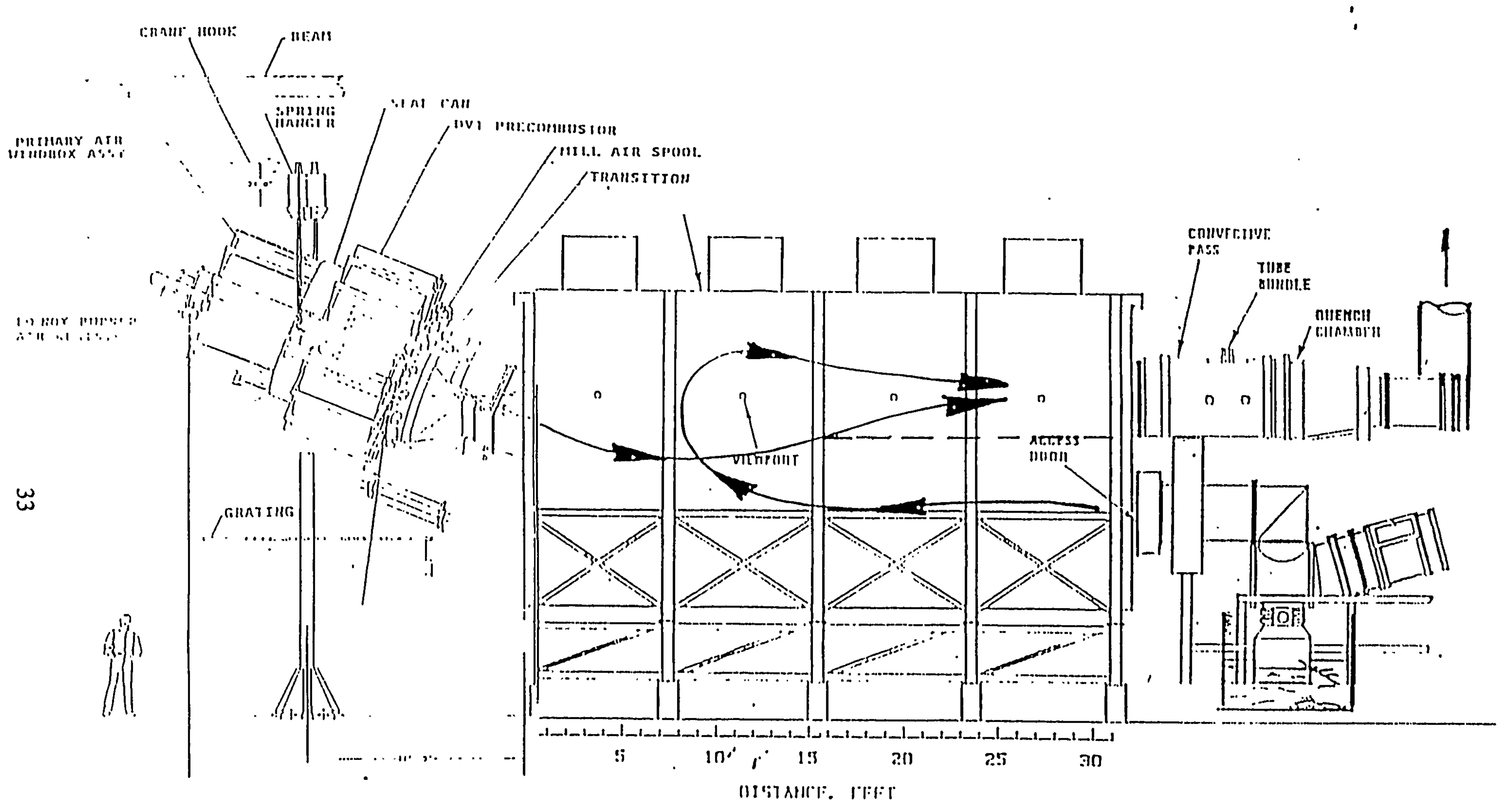


Figure 18 FETS Cell 3 Process Flow Diagram



120 MMBtu/hr Precombustor
(from Healy Design Verification Testing)

Boiler Simulator

40 MMBtu/hr Workhorse Combustor
(New Location)

Figure 19 Subscale Char Combustor Installation at TRW's Fossil Energy Test Site

The majority of the combustion air will be delivered to the combustor via an existing blower system. An existing oil-fired duct heater (Duct Heater #1) will be used to preheat the secondary and tertiary air (Streams 5 and 6, respectively) to approximately 700°F. A smaller, oil-fired duct heater (Duct Heater #2) will be added to preheat the primary air stream (Stream 10) to temperatures of up to 1200°F. The precombustor primary air windbox is refractory-lined to accommodate the higher temperature vitiated air stream. Oxygen will also be added to each air stream as required to achieve the desired vitiated air oxygen content at the combustor interface. The baseline oxygen content is 15% (by weight).

An existing coal feed system will be used to transport the coal or char to the combustor system. Two pressurized 5-ton feed hoppers are available to support testing, with one dedicated to the precombustor and one dedicated to the main, or slagging stage. This configuration readily allows for coal-firing in both stages, coal-firing in the precombustor and char-firing in the slagging stage, or char-firing in both stages. Coal/char blends can also be tested, to simulate the fuel feed projected for a HIPPS repowering application. The coal or char are transported to the combustor using nitrogen as a carrier gas. If desired, a small amount of propane could be added to the nitrogen carrier gas to simulate fuel gas, which is the expected carrier gas for the HIPPS Commercial Plant. The planned solids-to-gas ratios for the precombustor and main combustor feed lines is 5:1 and 10:1, respectively.

The combustor test hardware is modular in construction consisting of several flanged components bolted together: Precombustor assembly, headend plate, air inlet section, chamber section spools, slag recovery section, dipper skirt and slag tank. The hardware is constructed from carbon steel and is designed for operation with low pressure, low temperature cooling water. The existing hardware will be refurbished in support of the test program. Refurbishment will include a new precombustor assembly, a multi-port headend assembly, and a new slag tank.

The combustor will be installed to fire into an existing boiler simulator, which allows the post-combustion gases to cool at rates representative of a typical coal-fired furnace. Tertiary air (Stream #6) is added at the boiler simulator inlet to complete combustion to the desired stoichiometry. Limestone is also injected at this point to reduce SO_2 emissions as required by the air quality permit at the test site. The boiler simulator also includes a convective pass test section for evaluation of tube deposition and flyash characteristics (see Figure 17). Following the boiler simulator, the combustion gases enter a quench duct and venturi scrubber system, where the gases are cooled and the remainder of the flyash particulate is removed from the gas stream prior to exhaust through the stack.

Existing facility support equipment will be used to support the planned char combustor testing. This equipment includes the cooling water system (cooling towers, pumps, distribution plumbing), air fans and heaters, nitrogen system, char loading, storage and transport system, oil storage and transport system, instrumentation and data acquisition equipment, and emission monitoring equipment. Modifications will be made to all of these systems, as required, in support of the test activities. The majority of the modifications are associated with integrating the existing facility support equipment into the new test stand location at the backend of the boiler simulator.

According to the preliminary project schedule, the current plan is to initiate char combustor testing during the last quarter of 1996, however, the schedule for hardware refurbishment, facility reactivation, and test preparation is expected to be revised based on contract negotiations and expected funding levels. In order to initiate testing during the last quarter of 1996, the following activities are currently planned to be performed during the next quarter (first quarter of 1996): Precombustor preliminary design, combustor hardware refurbishment, detail design of test cell modifications, and layouts for other facility system modifications.

Subtask 3.3 - Integrated System Test Design (IST)

For the most part, design of the IST is not scheduled to start until the second half of 1996. Some preliminary work has been done analyzing operation of the existing furnace under HIPPS conditions, and in reference to environmental permitting. A meeting will be held at the University of Tennessee Space Institute in March to review the site and kick-off the design work on the IST.