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FOSSIL ENERGY

ENGINEER, DESIGN, CONSTRUCT, TEST AND EVALUATE A PRESSURIZED FLUIDIZED BED PILOT PLANT USING HIGH SULFUR COAL FOR PRODUCTION OF ELECTRIC POWER

Phase II Pilot Plant Design. Pilot Plant Configuration Report

MASTER

October 1977

Work Performed Under Contract No. EX-76-C-01-1726

Power Systems Division
Curtiss-Wright Corporation
Wood-Ridge, New Jersey

U. S. DEPARTMENT OF ENERGY

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PHASE II PILOT PLANT DESIGN

PILOT PLANT CONFIGURATION REPORT

Curtiss-Wright Corporation
Power Systems Division
Wood-Ridge, New Jersey 07075

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Prepared for the United States
Energy Research and Development Administration

Under Contract No. EX-76-C-01-1726

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SUMMARY

A comprehensive program to perform engineering analyses and design evaluations of commercial and pilot PFB power plants, conduct related technology support experiments and design, construct and operate a PFB pilot plant using high sulfur coal for the generation of electric power was initiated in March 1976 under support of the Energy Research and Development Administration. The work is being performed by Curtiss-Wright Corporation, Power Systems Division, Wood Ridge, N. J., with major supporting studies being supplied by Dorr-Oliver Corporation, Stamford, Connecticut and Stone and Webster Engineering Corporation, Boston, Mass. Phase I - Preliminary Engineering, involved performance of conceptual design and supporting analytical evaluation of commercial and pilot PFB power plants and conducts of technology support experiments.

The power plant configuration selected for the application of the pressurized fluidized bed (PFB) process for direct combustion of high sulfur coal (≥ 3%) in a combined gas turbine/steam turbine cycle includes:

a) gas turbines to provide compressed air for coal combustion (1/3 of the airflow) and air cooling in the PFB heat exchanger (2/3 of the airflow).

b) recombination of the total compressor airflow after heating for expansion in the compressor drive turbine and further expansion in a power turbine which drives an alternator.

c) gas turbine waste heat recovery in a steam boiler which powers a steam turbine/alternator.

The selected power plant configuration limits the hot gas flow which must be passed through a particulate clean-up system to approximately 1/3 of the total gas turbine flow and reduces the concentration of corrosive combustion products in the recombined turbine gas steam to 1/3 of the concentration which exists in the combustion gas exiting the PFB.

A PFB Pilot Plant preliminary design has been completed and is described in an earlier report. The PFB Pilot Plant will be located at the Curtiss-Wright Wood-Ridge, New Jersey location where an existing 7 MW Gas Turbine Total Energy Power Plant has been in operation since 1970. The PFB Pilot Plant design incorporates the use of this existing power plant with considerable utilization of currently operating equipment.

The pilot plant is configured for ease of maintenance and component servicing and replacement which would be expected in a pilot test program. Area is provided for alternate types of equipment for possible future test programs, and includes space for such items as hot gas clean-up systems, sorbent regeneration equipment, etc. The pilot plant is designed for a wide range of operating flexibility to facilitate rapid test evaluation of the PFB combustion and process concepts.

INTRODUCTION

Performance analysis and conceptual design of a 500 MW commercial power plant have identified a modularized plant arrangement with three pairs of gas turbines, each pair driving a 100 MW alternator for a total of 300 megawatts (MW). Six waste heat boilers (one for each individual gas turbine) produce steam which drives one 200 MW turbine/alternator. The modularized arrangement provides low plant heat rate over a broad output range (below 50%) and high proportion of plant power availability during major component unscheduled or scheduled maintenance.

The 500 MW PFB commercial plant design is described in an earlier report on Task I - Preliminary Engineering.

The pilot plant design is fully representative of the PFB Commercial Power Plant which was conceptually designed earlier in this program. The pilot plant includes a gas turbine powered alternator wherein the gas turbine is approximately 42% of the size (diameter) of the proposed commercial module and a PFB combustor which is 12 ft 4" in I.D. compared to a 28 ft I.D. for the proposed commercial unit.

The final design of the pilot plant is expected to be completed in the first half of 1978, construction and checkout completed by early 1980, and operational testing will occur largely during 1980 and 1981.

A simplified flow diagram of the pilot plant is shown in Figure 1. The major categories of equipment for the pilot plant are listed below:

BASIC EQUIPMENT AND FUNCTIONS:

- COAL AND SORBENT UNLOADING AND STORAGE SYSTEMS
- COAL SIZING AND DRYING SYSTEM

- COAL AND SORBENT FEED SYSTEM
- REMOTE START-UP COMBUSTORS LIQUID OR GAS FUEL FIRED
- PFB COMBUSTOR WITH ASH HANDLING EQUIPMENT
- COMBUSTOR BED HEAT EXCHANGE SYSTEM
- GAS CLEANING SYSTEMS
- COMBUSTION AND COOLING AIR COMPRESSOR AND TURBINE
- GAS TURBINE ALTERNATOR DRIVE
- ALTERNATOR AND SWITCH GEAR
- WASTE HEAT RECOVERY BOILER
- COMPUTERIZED CONTROL SYSTEM

Pilot Plant Arrangement

The PFB Pilot Plant is a total energy system consisting of 7.15 megawatts generated by a CW 6515 gas turbine powered alternator and 58000 pph of steam generated by a waste heat boiler.

The plant area including existing bunker coal storage area is approximately 2 acres with an additional 1.5 acres available for a coal pile on the north side of the boiler house.

Complete coal and dolomite unloading and storage facilities are provided. Coal will be received from 10-12 rail car shipments per week and transportation into the existing boiler house 1700 ton storage bunkers. Additional coal storage up to 1200 tons is available from the reserve stockpile. Dolomite is received by rail, unloaded pneumatically, and stored in a 600 ton domed storage silo. Conveyors transport coal and dolomite from the storage facilitates to the pressurized lock hoppers, for injection into the pressurized fluidized bed combustor.

Ash flows out of the PFB and is fluidized by 100 psig air in a vertical column. As ash is lifted up the column, surrounding water jackets cool it until it is finally drawn off through a lock hopper system and pneumatically conveyed to a 100 ton silo storage system where it is retained until removed from the plant.

Because the commercial plant design incorporated a scaled-up version of the Curtiss-Wright 6515 gas turbine engine as a key component, it was decided that a cost-effective approach to provide a pilot plant is to convert the existing Mod Pod 8 Total Energy Power Generating System at the Curtiss-Wright Wood-Ridge Facility. An aerial view of the pilot plant into area is shown in Figure 2. Figure 3 indicates how the pilot plant will be arranged in relation to the existing boiler house and total energy system, Figure 4. The Mod Pod 8 system combines an industrialized J65 type gas turbine engine, the C-W 6515, with an industrial power turbine driving an alternator, and a waste heat recovery boiler. The system was designed to produce 7 MW of electrical power and 58,000 pph of saturated steam at 175 psig for plant heating and process use. The electrical system, which is used to supply plant load on normal working days, is connected to and synchronized with the local utility, Public Service Electric and Gas Co. of New Jersey, so that the system is operated as a utility unit although under local plant control.

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A comparison of the features of each of the two plant designs is tabulated in Figures 5 and 6. Figure 7 provides comparison of the major materials currently selected for the commercial and pilot plants.

A schematic description of the pilot plant in normal operating mode is shown in Figure 8. Elevation views are seen in Figures 9 and 10. Detail elevations of the process piping to and from the PFB combustor are provided in Figures 11 and 12. Figure 13 is the piping and instrumentation diagram for the pilot plant and Figure 14 presents an artist's view of the entire plant complex.

The existing gas turbine power train will be modified by removal of the oil fired combustor which will be replaced with a volute arrangement for routing compressor air from the gas turbine to the PFB combustor and hot gas from the PFB to combustor back to the turbine. The gas turbine shaft length and bearing support system will be maintained so changes to the gas turbine are minimized. Compressor air is divided between two flow inputs to the PFB combustor.

One third of the compressor airflow enters the bed through tuyeres for combustion and is subsequently rendered free of erosive particulate matter by a primary cyclone followed by a secondary gas cleanup system. The remaining two thirds of compressor air is utilized to cool the bed by flowing through a number of vertically oriented heat exchanger tubes immersed within the bed. The flows are rejoined to drive the compressor turbine, and the free power turbine driving the alternator. Finally, the flow passes through the waste heat boiler, generating stream for plant process purposes.

Pilot Plant Design Characteristics

Actual Plant Rating (Gas Turbine)	7.15 MW
Optimized Plant Rating	16 MW
Coal Sulfur Content	4.1 %
PFB Heat Exchanger Type	Air Cooled
Power Turbine Type	Free (Gas Coupled)
PFB Sorbent Material	Dolomite
Primary Cleanup	Cyclone
Secondary Cleanup	Double Flow Cyclone

The basic plant design guidelines were further defined as follows:

Fuel

Coal - Type #1	
Heating Value (HHV)	13,090 Btu/lb.
Proximate Analysis, Wt Pct	0.8
Moisture	0.8
Volatile Matter	23.0
Fixed Carbon	61.6
Ash	14.6
Ultimate Analysis, Wt Pct	
Hydrogen	4.3
Carbon	73.7
Nitrogen	1.4
Oxygen, by difference	1.9
Sulfur	4.1
Ash	14.6

Sorbent

Dolomite - U.S. No. 1337	
CaCO3	54.2%
MgCO3	44.8%
Inerts	1.0%

Environment

Noise Design Standard	NEMA D at 400 Ft
Air Pollutants Allowable	
SO_2 (New Jersey)	0.3 lb per Million Btu
NO_x	0.7 lb per Million Btu
Particulate	0.1 lb per Million Btu

Principle Plant Operating and Design Parameters

The following performance and operating parameters were established for the plant:

Gas Turbine Generator Performance

Total Power Output	7.15 MW
Gas Turbine Inlet Airflow	120 lb/sec
GT Inlet Pressure	-3" H_2O
GT Compressor Pressure Ratio	7:1
Exhaust Pressure	10" H_2O
Exhaust Temperature	961°F
Alternator Speed	7500 rpm

Pressurized Fluidized Bed Combustor

Combustor Gas Temperature	1650°F
PFB Superficial Velocity	2.7 FPS
PFB Heat Exchanger Tube Free Space	4 In.

Pilot Plant Performance

The existing Mod Pod 8 power system was installed in 1970 primarily as a demonstration and development unit. It employs an industrialized gas turbine, C-W J65 model, and a single stage power turbine coupled through a gearbox to an 1800 RPM alternator. Several components of this system are of older types, designed to special restrictions not applicable to a present day utility electric power plant. The gas generator turbine was limited in diameter to minimize the frontal area of the engine and therefore is approximately five points lower in efficiency than a modern industrial turbine of the same capacity would be. The power turbine was designed for peaking duty where low first cost dominates over high cycle efficiency. For economic reasons, therefore, it is a single stage design running at 7500 RPM to minimize its diameter. Base load design would dictate both a multistage design and direct drive at 3600 RPM for a 60 Hz generator.

Change to a two stage turbine of larger diameter would improve turbine efficiency by four points while elimination of the gear box and incorporation of a modern standard 3600 RPM alternator would gain four percent in power. The overall impact of these changes to improved design standards plus a four percent increase in turbine flow capacity and airflow to achieve better compressor matching would be a 34 percent increase in gas turbine output power (optimized plant performance). A comparison of the current and optimized plant performance at the design condition is shown in Figure 15. The equivalent power estimated for the pilot plant equipped with modern base load type turbine and electrical generator and with a steam turbogenerator of commercial plant type added is shown. The equivalent heat rate of the optimized pilot plant is somewhat higher than that of the commercial plant because electrical generators under 40 MW in size are not hydrogen cooled and therefore, not as high in efficiency and also because the pilot plant PFB will have a higher dolomite to coal ratio in order to meet the New Jersey requirement on emission of sulfur oxides, which is more restrictive than the Federal EPA regulation.

Energy balance diagrams for the Pilot plant, current and optimized are shown on Figures 16 and 17 respectively.

COMBINED CYCLE PILOT PLANT SIMPLIFIED FLOW DIAGRAM

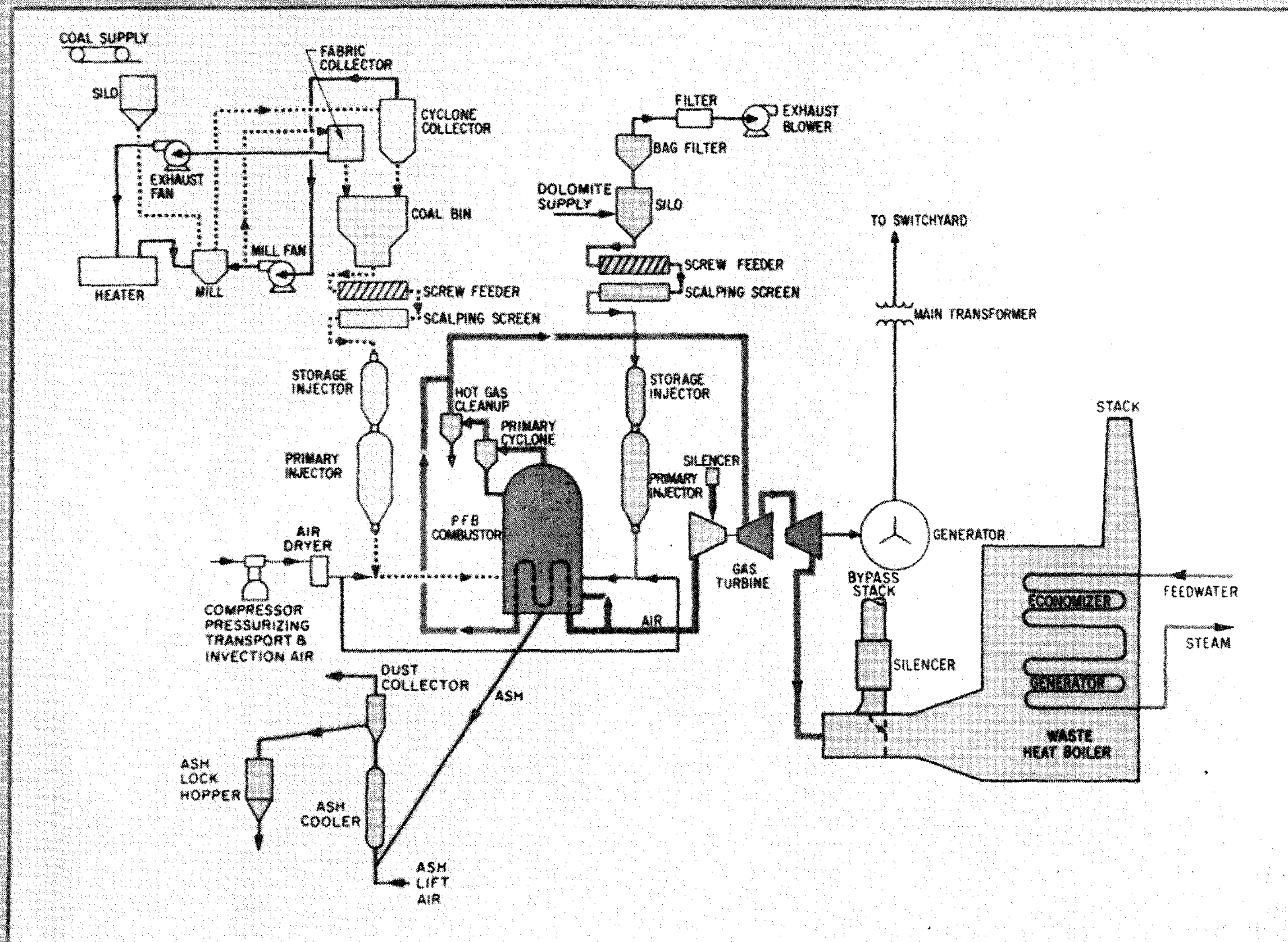
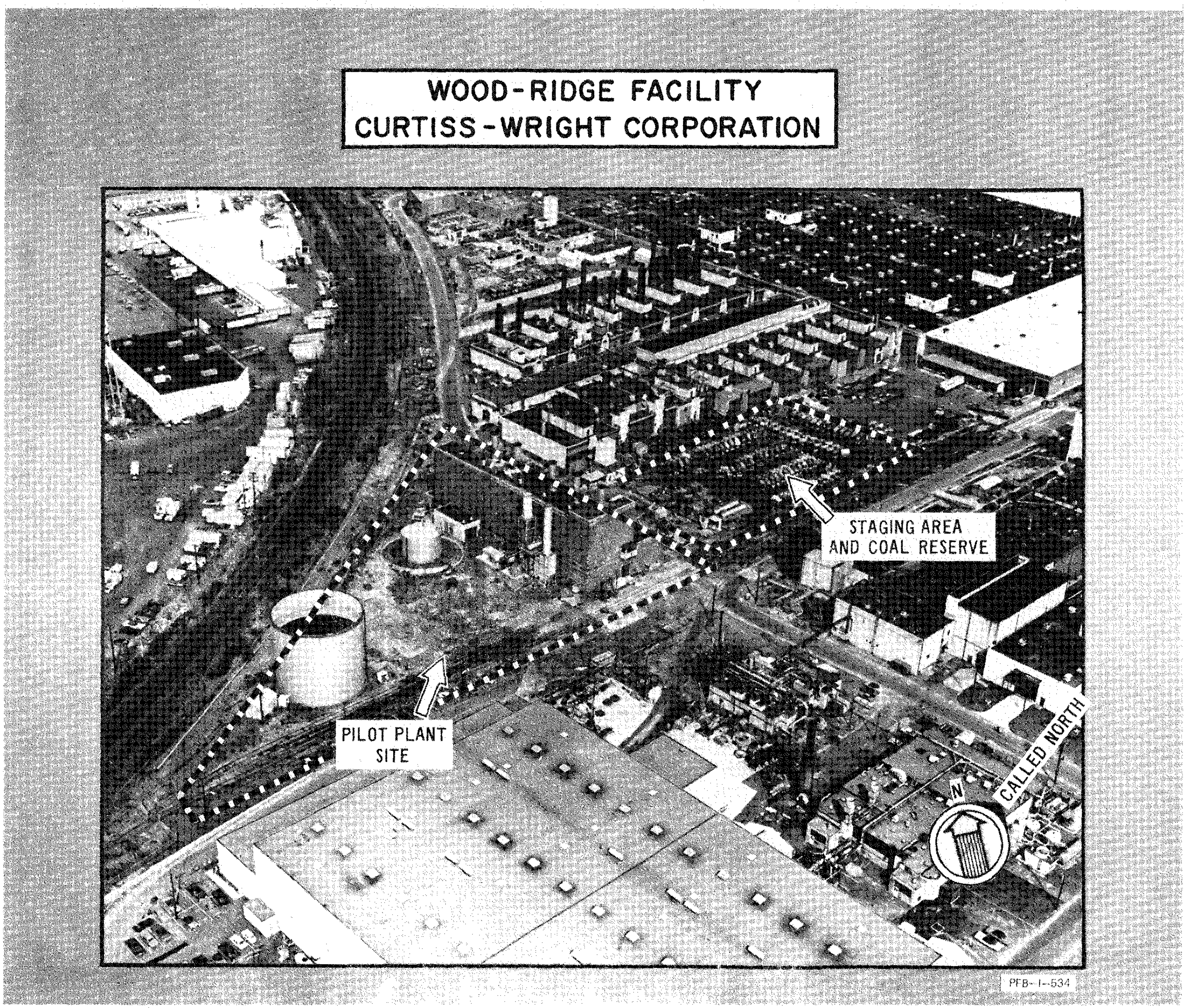


Figure 1



WOOD-RIDGE FACILITY
CURTISS-WRIGHT CORPORATION
STAGING AREA
AND COAL RESERVE
PILOT PLANT
SITE
CALLED NORTH
N
PFB-1-534

Figure 2

PFB PILOT PLANT - GENERAL ARRANGEMENT

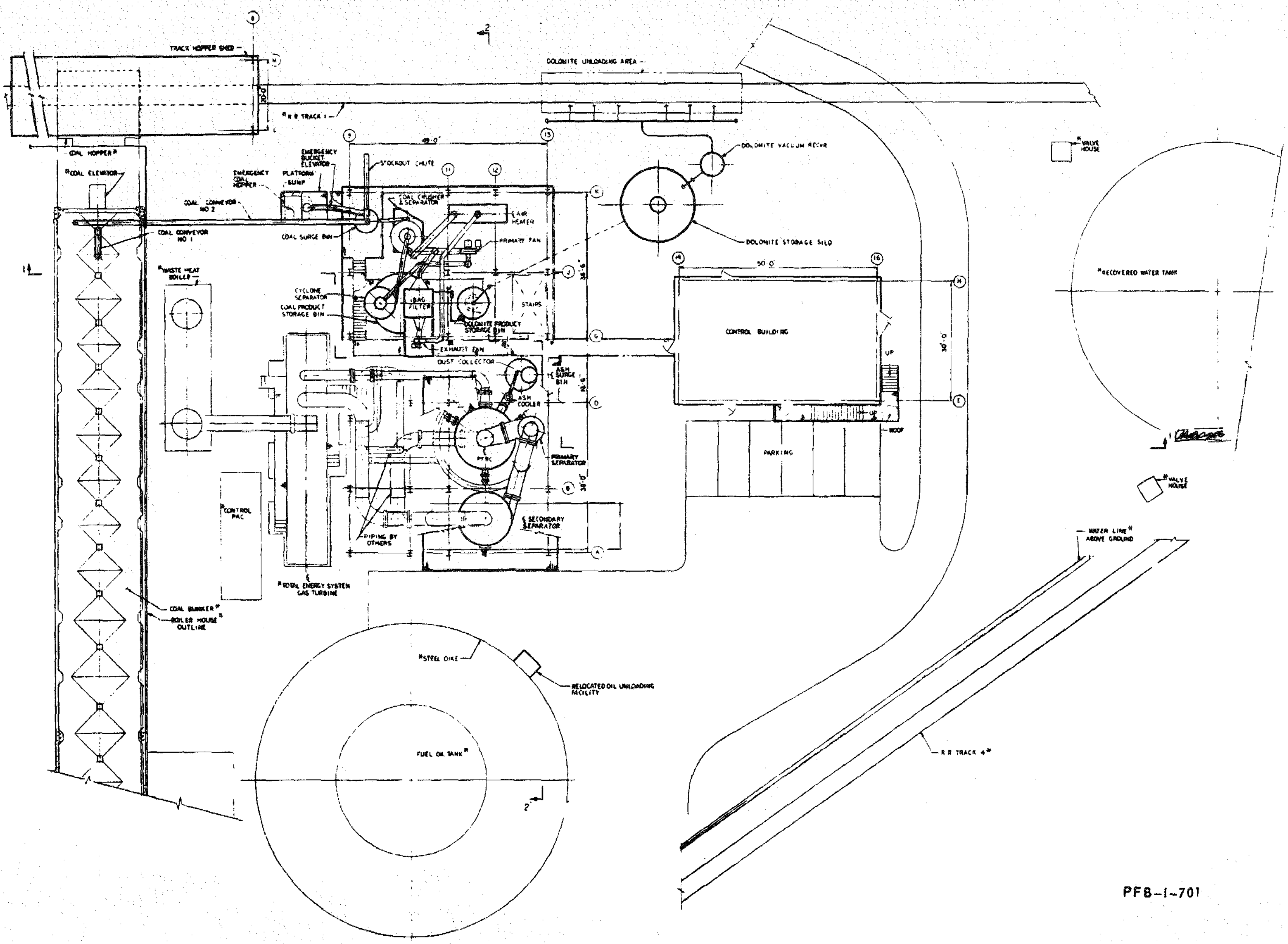


Figure 3

10

COMMERCIAL PLANT - PILOT PLANT COMPARISON

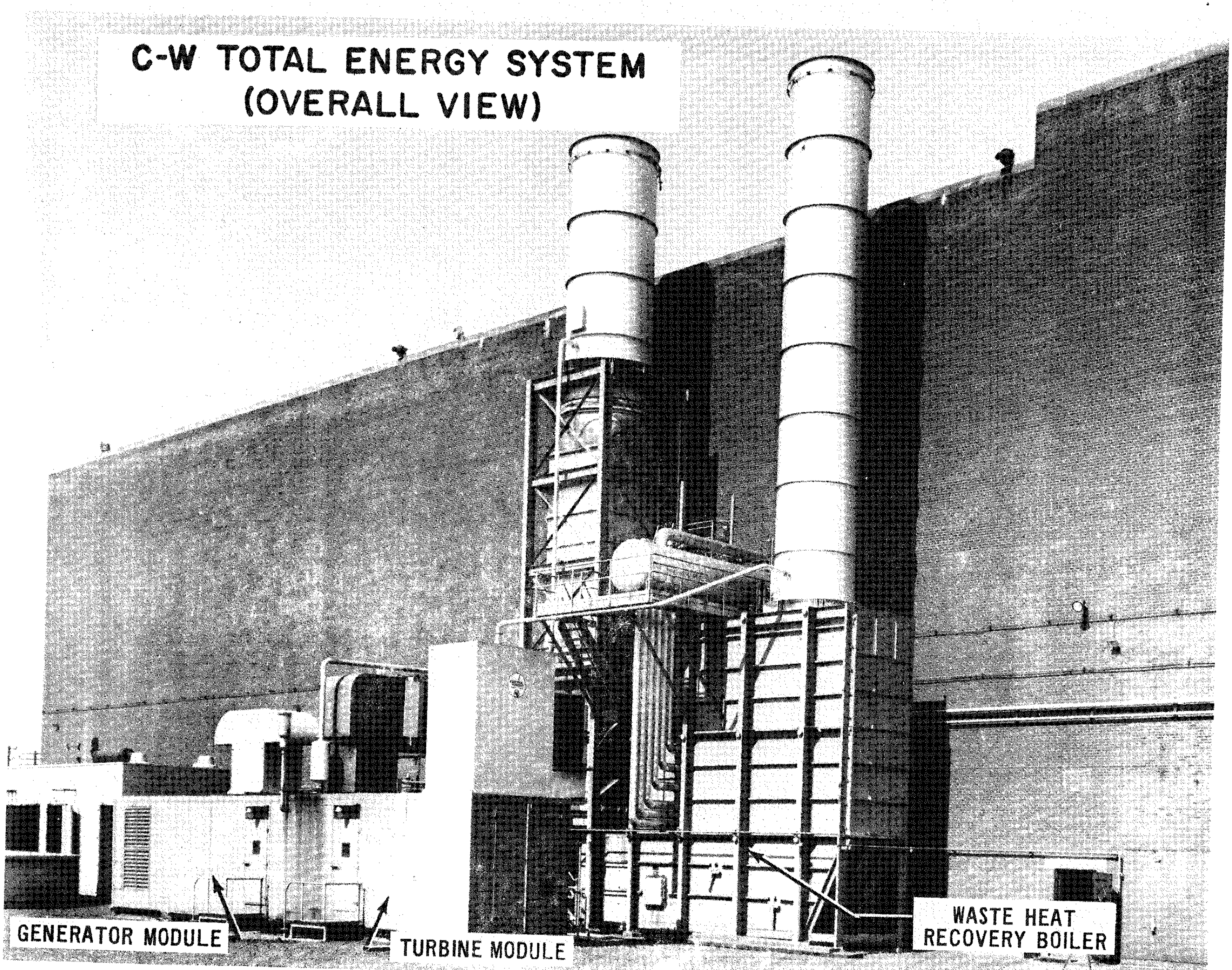


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Figure 4

	CATEGORY	COMMERCIAL PLANT	PILOT PLANT
100	COAL INCOMING	100 RAIL CAR UNIT TRAINS 10,000 TON LIVE STORAGE 330 TON COAL SILO SYSTEM 300,000 TON STOCK PILE	10-12 RAIL CAR TRAIN PER WEEK 1700 TON LIVE BUNKER STORAGE 10 TON SURGE HOPPER 1200 TON STOCK PILE
200	COAL PREPARATION	35-40 TONS/HR (6) CRUSHER, MILLING AND DRYING WITH OIL-FIRED HEATER	MILLING AND DRYING WITH OIL-FIRED AND/OR STEAM HEATER
300	LIMESTONE INCOMING	RAIL CAR, BOTTOM UNLOAD BELT CONVEYOR SYSTEM 4500 TON STORAGE SILO	RAIL CAR, PNEUMATIC UNLOADING AND CONVEYING TO 600 TON STORAGE SILO
400	COMBUSTOR & PROCESS	6 OF EACH: 28' I.D. PFB COMBUSTOR PNEUMATIC IN-FEED AND TRANSPORT SYSTEM FOR COAL & DOLOMITE AUXILIARY COMBUSTOR	1 OF EACH: 12' - 4" I.D. PFB COMBUSTOR PNEUMATIC IN-FEED AND TRASNPORT SYSTEM FOR COAL & DOLOMITE STARTUP COMBUSTOR AUXILIARY COMBUSTOR
500	GAS CLEANUP	3 OF EACH PER PFB PRIMARY CYCLONE SECONDARY AERODYNE ROTARY SPLIT FLOW SEPARATOR	1 PRIMARY CYCLONE 1 SECONDARY-AERODYNE ROTARY SPLIT FLOW

PFB-I-714

Figure 5

COMMERCIAL PLANT - PILOT PLANT COMPARISON

	CATEGORY	COMMERCIAL PLANT	PILOT PLANT
600	COMBINED CYCLE	6 - GAS TURBINES IN THREE DOUBLE ENDED SETS 50 MW/GAS TURBINE 1 - STEAM TURBINE PLANT COMPLETE WITH WASTE HEAT BOILER, CONDENSER, CONSENSER, COOLING TOWER, ETC. 200 MW STEAM TURBINE	1 - GAS TURBINE 7 MW/GAS TURBINE (42% SCALE) 1 - WASTE HEAT BOILER IN PARALLEL WITH EXISTING BOILERS STEAM TO WOOD-RIDGE PLANT
700	ASH FLOW	1 - FOR EACH PFB COMBUSTOR WATER & FLUIDIZED ASH COOLER WITH LOCK HOPPERS 1 - PNEUMATIC CONVEYING SYSTEM 2 - 2160 TON ASH STORAGE SILO	1 - WATER & FLUIDIZED ASH COOLER WITH LOCK HOPPERS 1 - PNEUMATIC CONVEYING SYSTEM 1 - 100 TON ASH HOPPER STORAGE
800	CONTROL	ANALOG & DIGITAL PROCESS CONTROL WITH AUTO DATA LOG BACKUP MANUAL CONTROL BOILER AND STEAM TURBINE CONTROLS BACKUP COMPUTER MULTIPLE PFB CONTROLS	ANALOG & DIGITAL PROCESS CONTROL WITH AUTO DATA LOG BACKUP MANUAL CONTROL
900	ENVIRONMENTAL MONITORING	OPACITY MONITORING SO_2 MONITORING CO MONITORING NO_x MONITORING PARTICULATE MONITORING	OPACITY MONITORING SO_2 MONITORING CO MONITORING NO_x MONITORING PARTICULATE MONITORING

PFB-1-715

Figure 6

MATERIAL SELECTION

PFB COMBUSTOR/HEAT EXCHANGER		COMM. PLANT	PILOT PLANT
PRESSURE VESSEL		SA-515 GR 70	SAME
BEDPLATE AND SUPPORT GRID		SA-387 GR 22 CL-1	409 STAINLESS
HEAT EXCHANGER TUBES		HAYNES 188 and/or FECIARY 600	SAME
BED REFRACTORY LINING	- HOT SIDE	BRICK (HW) UFLA	SAME
	- WALL	HW40-64	SAME
CYCLONE SEPARATORS			
PRESSURE VESSEL		SA-515 GR 70	SAME
REFRACTORY LINING	- HOT SIDE	KS4	SAME
	- WALL	VSL-50	SAME
AIR/GAS PIPING			
AIR		SA-515 GR 70	409 STAINLESS
GAS		SA-515 GR 70	SAME
INSULATION		INSBLANKET	SAME
LINER		HAST. "S" or 18SR	SAME

GAS TURBINE				STG. 1	STG. 2
GAS GENERATOR TURBINE	- VANES	IN-792	ALL	*INCO 738/CW-3	INCO 738/CW-3
	- BLADES	IN-792	ALL	*UDIMET 710/CW-3	U-500/CW-3
	- DISC	A-286	BOTH	D 979	SAME
POWER TURBINE	- VANES	U-500	ALL	HS-31	SAME
	- BLADES	U-500	ALL	U-500	NONE
	- DISC	AISI-422	BOTH	H-46	NONE

*ALT. TRANSPIRATION COOLED 1ST BLD. & VANE HAVE Ni-Cr V(Cb) AIRFOIL, U-500 STRUT

PFB-I-415B

Figure 7

NORMAL OPERATION

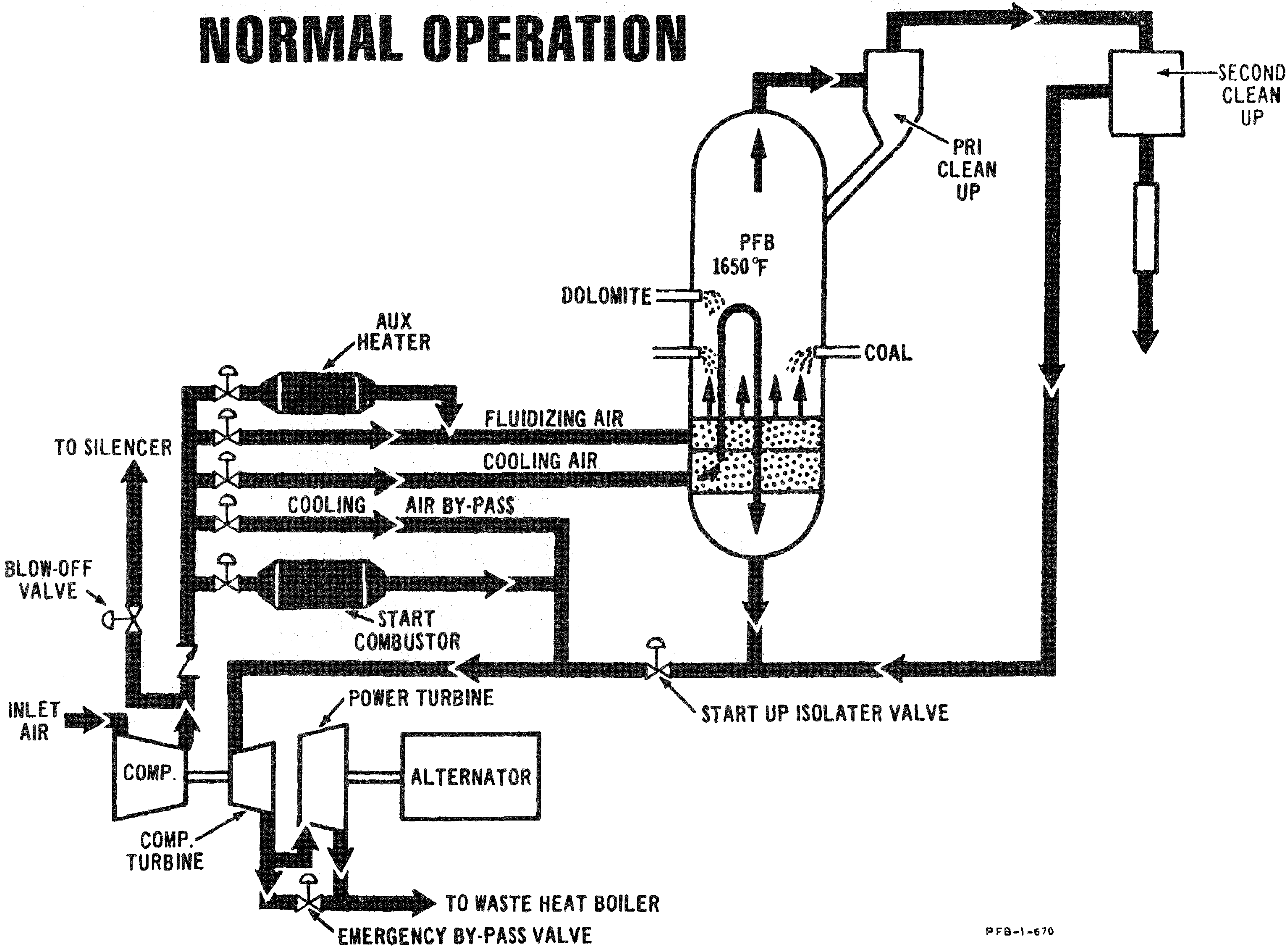


Figure 8

PFB PILOT PLANT – END ELEVATION

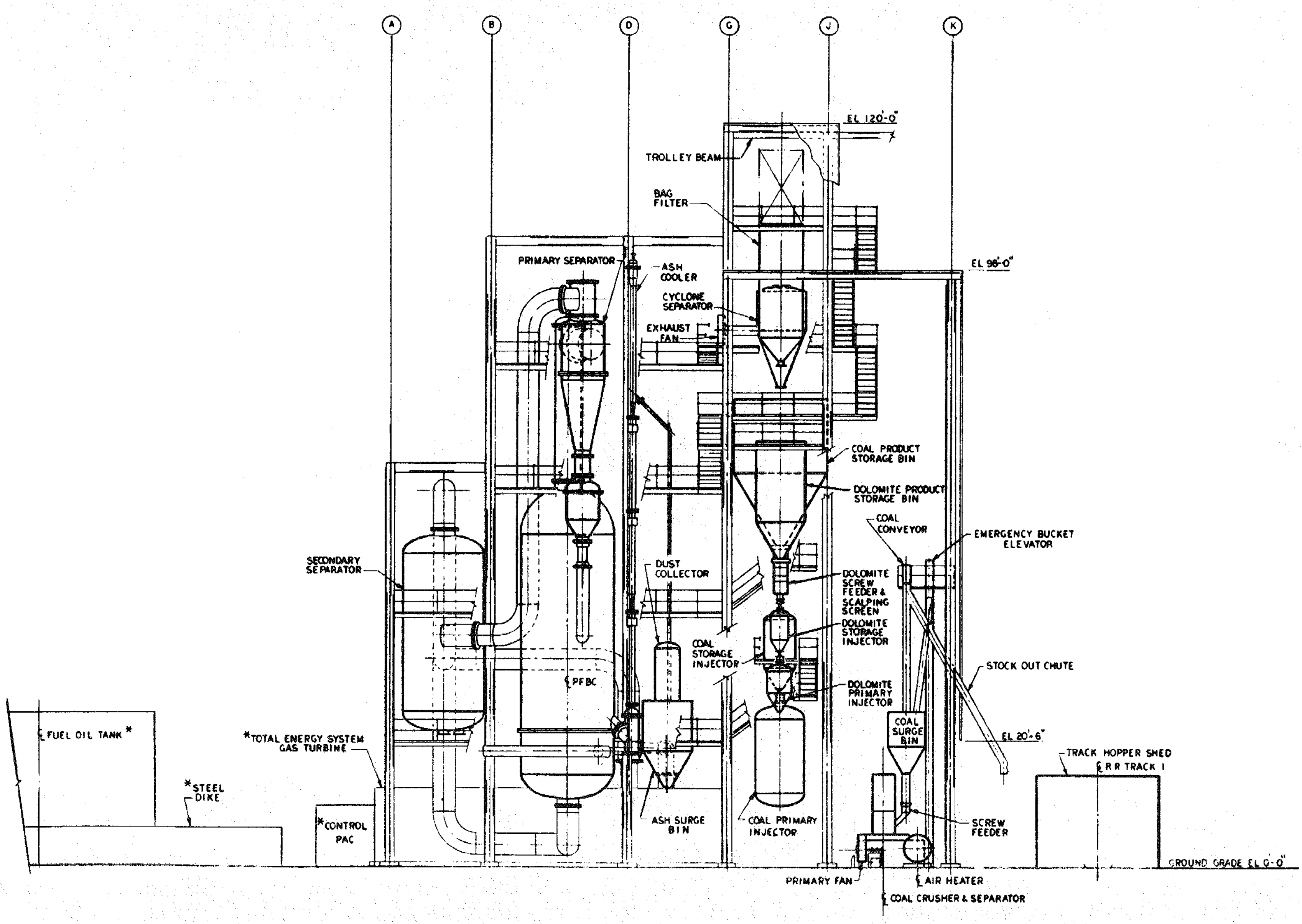


Figure 9

PFB PILOT PLANT - FRONT ELEVATION

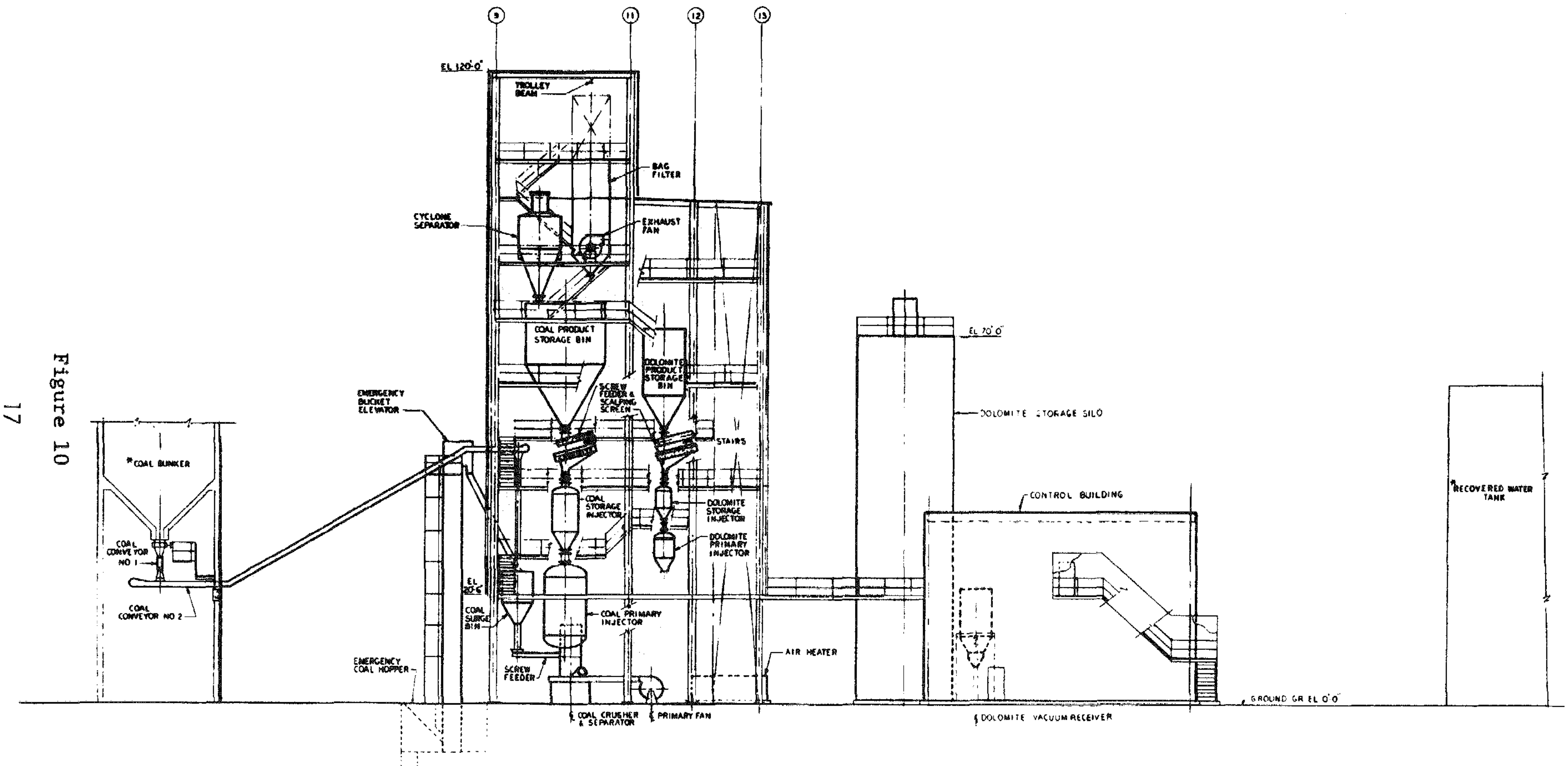


Figure 10

PFB COMBUSTOR PIPING
TOP ELEVATION

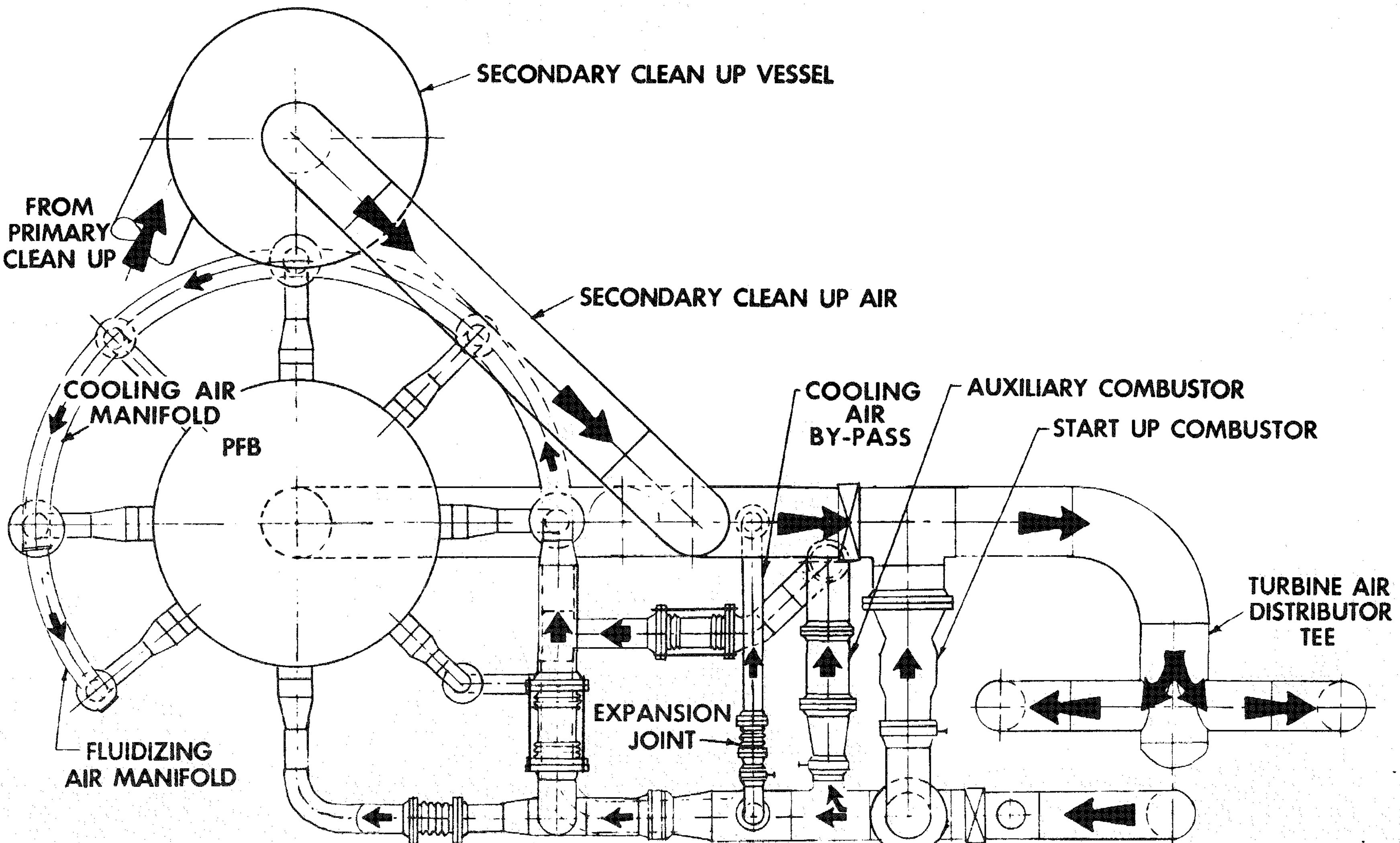


Figure 11

PFB COMBUSTOR PIPING
SIDE ELEVATION

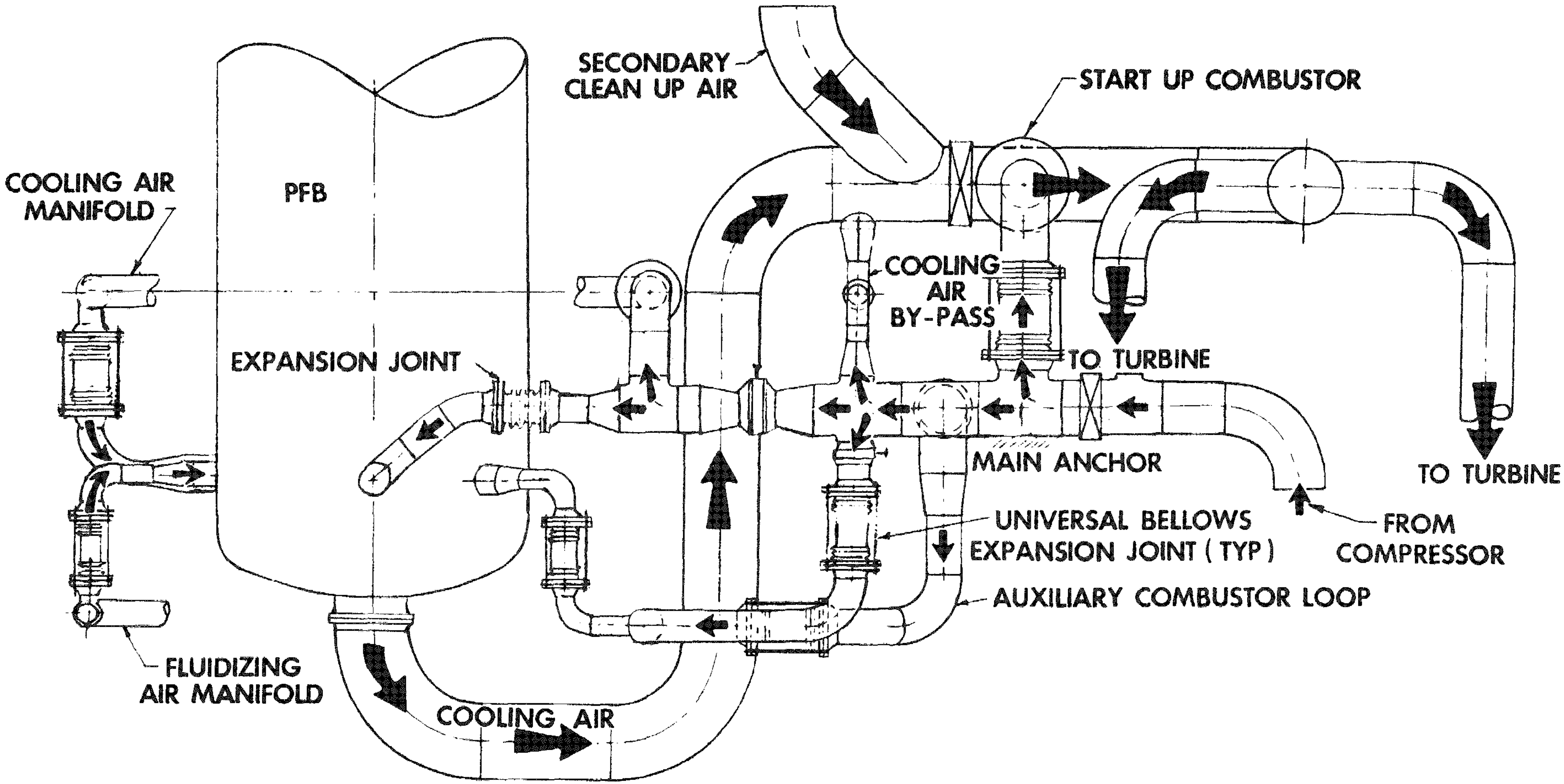


Figure 12

CONCEPTUAL PIPING AND INSTRUMENT DIAGRAM PFB PILOT PLANT

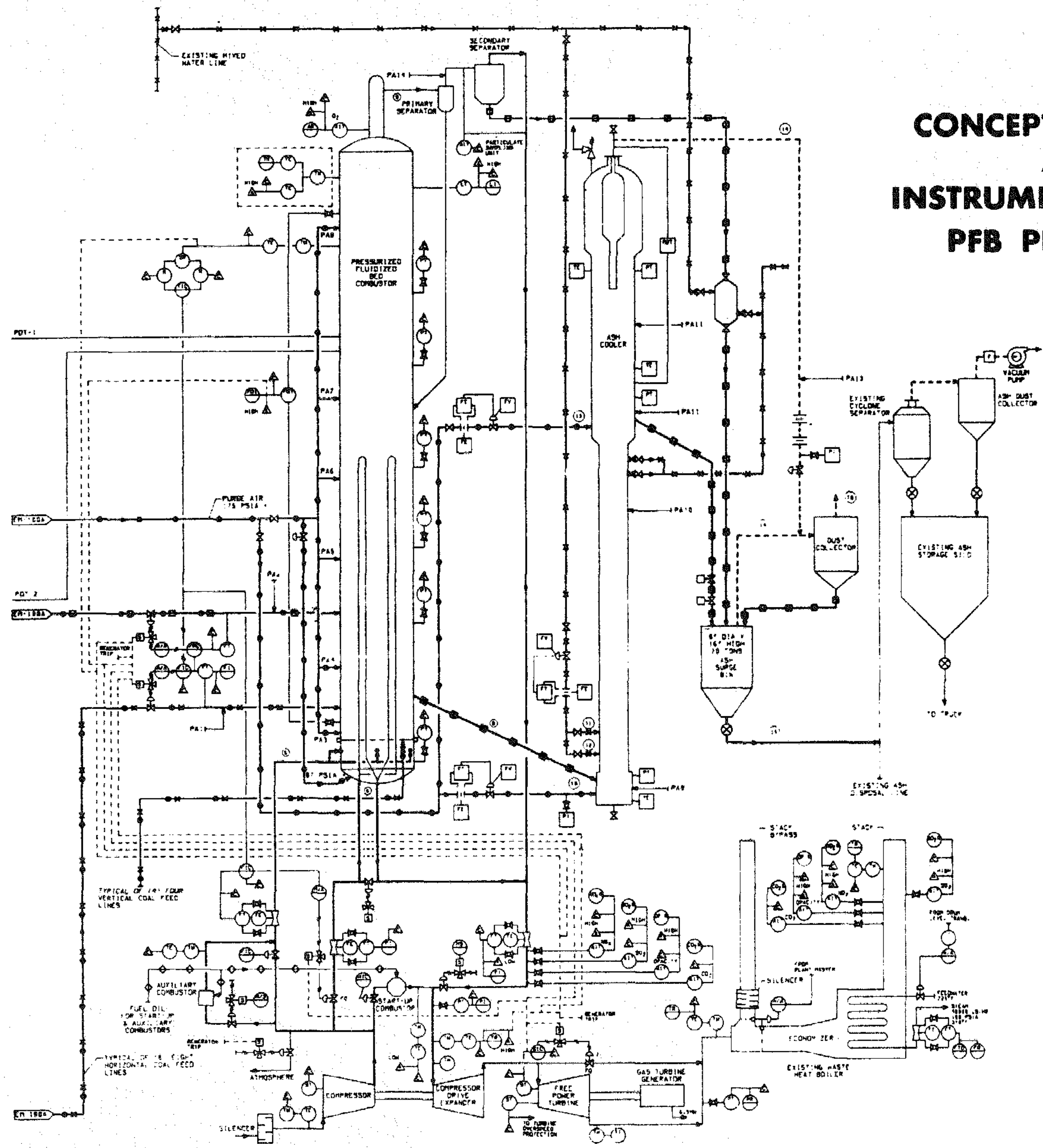
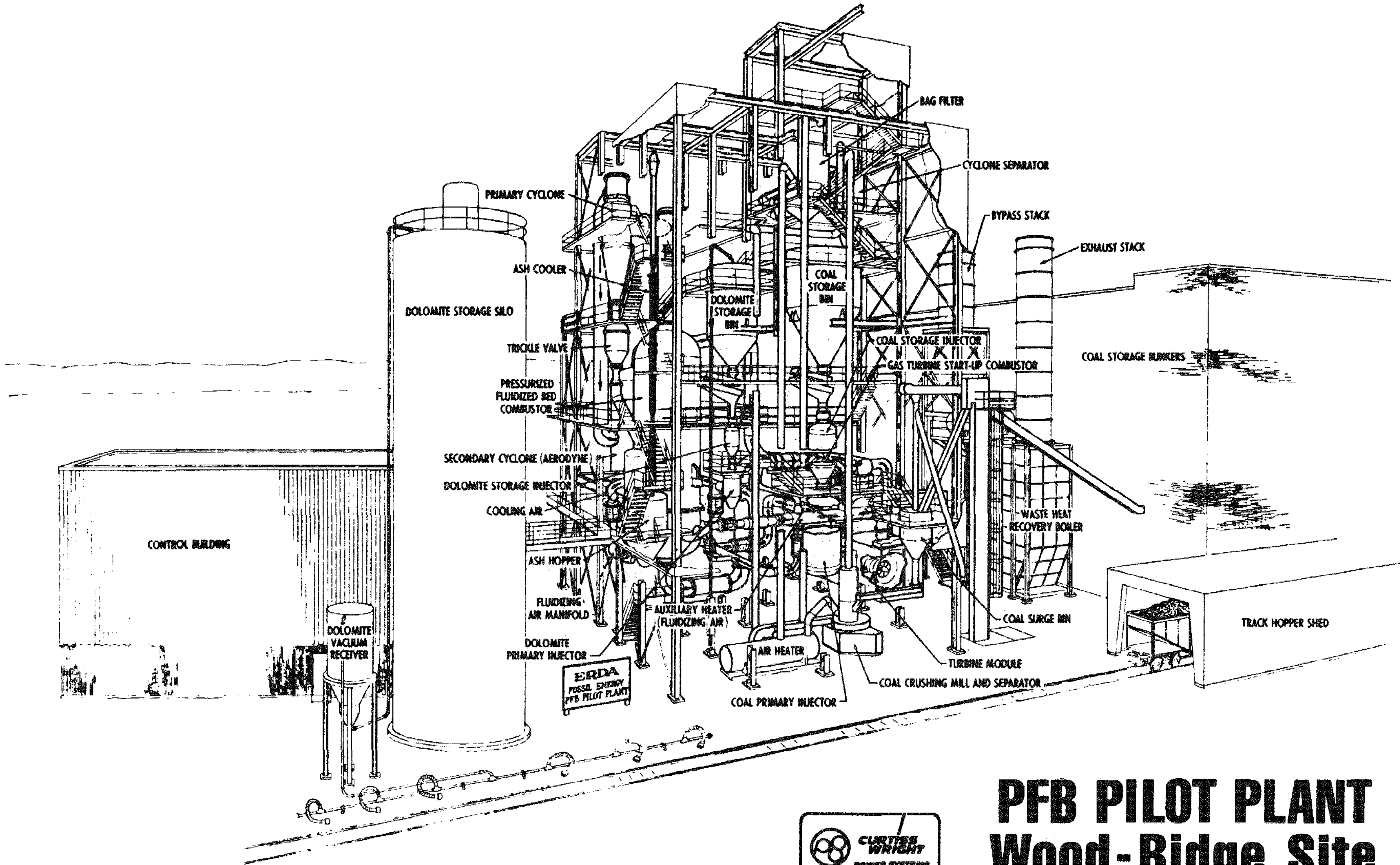


Figure 13



PFB PILOT PLANT Wood-Ridge Site

Figure 14

PFB PILOT PLANT DESIGN POINT

		CURRENT EQUIPMENT	OPTIMIZED EQUIPMENT
ELECTRIC POWER OUTPUT FROM GAS TURBINE	KW	7150	9580
ELECTRIC POWER FROM STEAM	KW	-	6527
HEAT RATE	BTU/KW/HR	-	8725
COAL FLOW	PPH	10,240	10,662
AIRFLOW	PPS	120	125
PFB AIR INLET	°F	505	506
PFB GAS EXIT	°F	1650	1650
PFB COOLING AIR EXIT	°F	1573	1573
TURBINE INLET	°F	1600	1600
POWER TURBINE EXIT	°F	961	906
PROCESS STEAM AT 175 PSIG	PPH	58,000	-

PFB-I-688

Figure 15

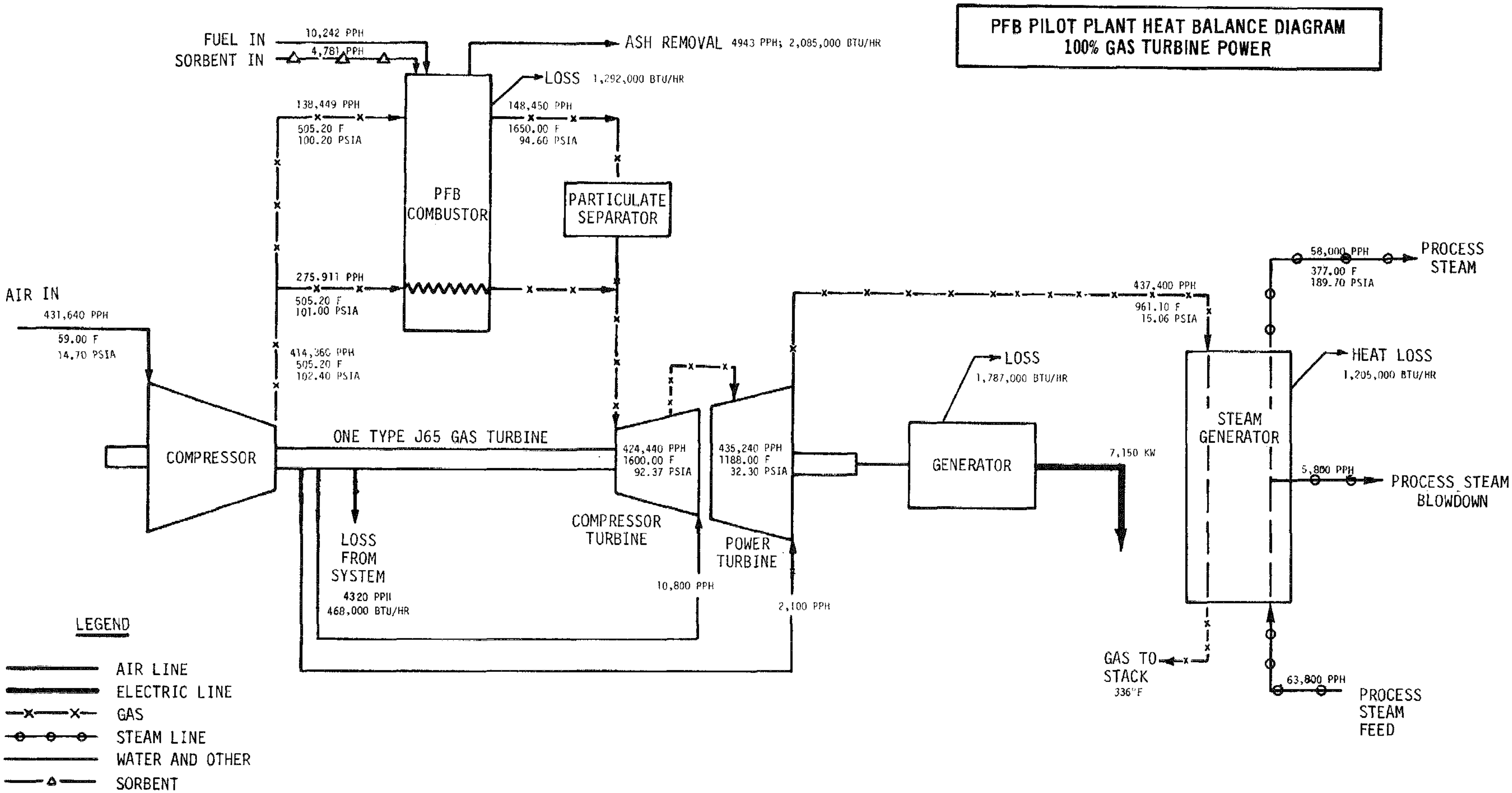

PFB PILOT PLANT HEAT BALANCE DIAGRAM
100% GAS TURBINE POWER
FUEL IN
SORBENT IN
10,242 PPH
4,781 PPH
ASH REMOVAL 4943 PPH; 2,085,000 BTU/HR
LOSS 1,292,000 BTU/HR
138,449 PPH
505.20 F
100.20 PSIA
148,450 PPH
1650.00 F
94.60 PSIA
PFB
COMBUSTOR
PARTICULATE
SEPARATOR
275,911 PPH
505.20 F
101.00 PSIA
AIR IN
431,640 PPH
59.00 F
14.70 PSIA
414,360 PPH
505.20 F
102.40 PSIA
COMPRESSOR
ONE TYPE J65 GAS TURBINE
424,440 PPH
1600.00 F
92.37 PSIA
435,240 PPH
1188.00 F
32.30 PSIA
COMPRESSOR
TURBINE
POWER
TURBINE
LOSS
FROM
SYSTEM
4320 PPH
468,000 BTU/HR
10,800 PPH
2,100 PPH
LOSS
1,787,000 BTU/HR
GENERATOR
7,150 KW
437,400 PPH
961.10 F
15.06 PSIA
58,000 PPH
377.00 F
189.70 PSIA
PROCESS
STEAM
HEAT LOSS
1,205,000 BTU/HR
STEAM
GENERATOR
5,800 PPH
PROCESS STEAM
BLOWDOWN
GAS TO
STACK
336°F
63,800 PPH
PROCESS
STEAM
FEED
LEGEND
AIR LINE
ELECTRIC LINE
GAS
STEAM LINE
WATER AND OTHER
SORBENT

Figure 16

PFB OPTIMIZED PILOT PLANT
HEAT BALANCE DIAGRAM
100% LOAD GAS AND STEAM TURBINES
NET HEAT RATE – 8725 BTU/KW-HR.

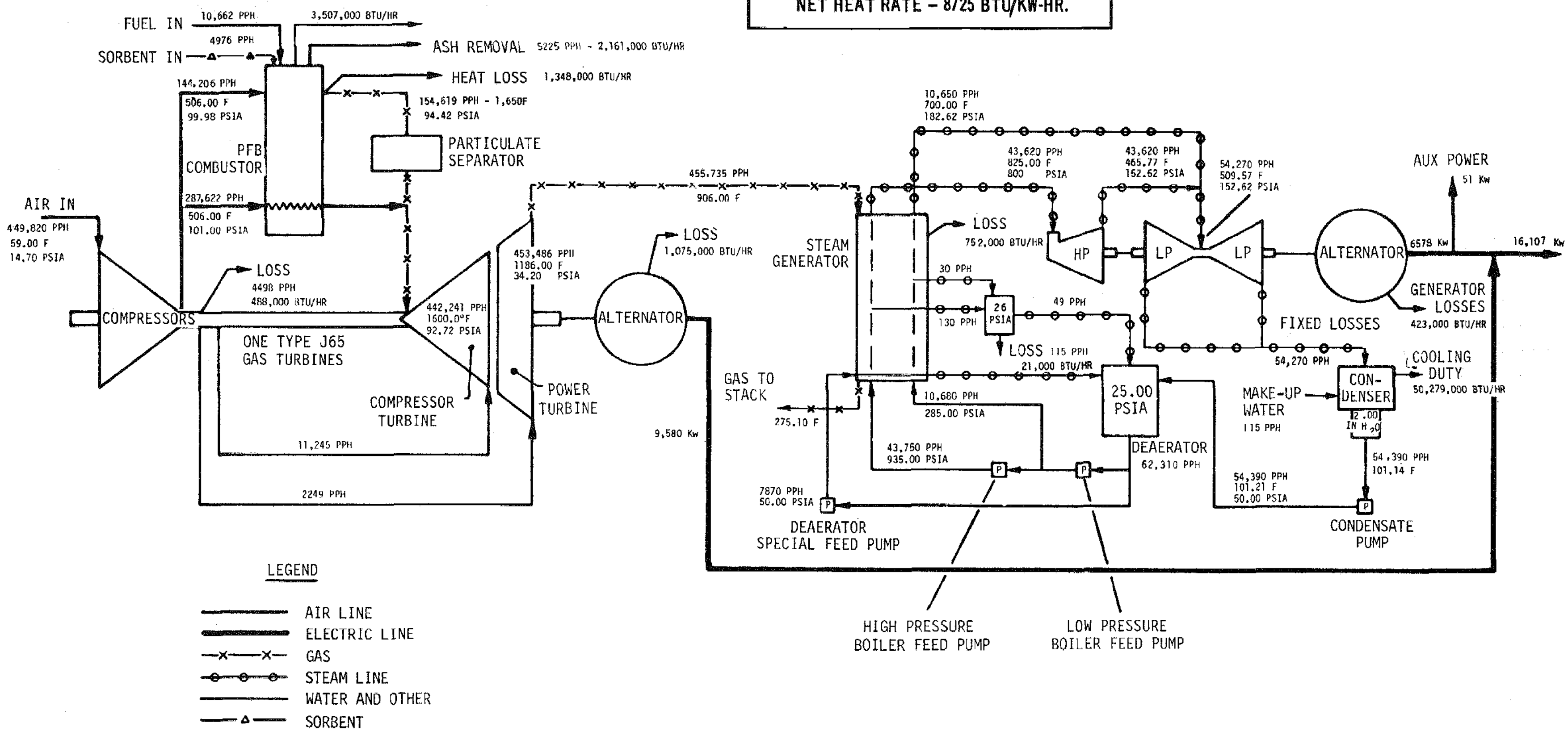


Figure 17

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