

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

PHASE I - PRELIMINARY ENGINEERING

QUARTERLY REPORT FOR THE
PERIOD JUNE 1 TO AUGUST 31, 1977

CURTISS-WRIGHT CORPORATION
POWER SYSTEMS DIVISION
WOOD-RIDGE, NEW JERSEY 07075

SEPTEMBER 1977

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Prepared for the United States
Energy Research and Development Administration

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

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED *RB*

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

TABLE OF CONTENTS

I OBJECTIVE AND SCOPE OF WORK

II SUMMARY

III WORK ACCOMPLISHED/WORK FORECAST

Task 1 - Preliminary Engineering

Task 2 - Preliminary Design Pilot Plant

Task 3 - Site Evaluation

Task 4 - Pilot Plant Environmental Analysis

Task 5 - Technology Support Rigs

Task 6 - Program Management

Task 8 - Documentation and Reporting

I. OBJECTIVE AND SCOPE OF WORK

Production of clean, cost-competitive electric power from coal requires advances in combustion and power conversion technology. One promising approach to improved power cycle efficiency involves application of a Pressurized Fluidized-Bed (PFB) Combustor for combustion of high sulfur coal in the presence of a sulfur sorbent material. Bed temperature is controlled to maintain the bed temperature below 1750°F by removing heat from the PFB with heat exchanger tubes using a portion of incoming compressed air as coolant, while the balance of compressed air is used for combustion. The coolant air is heated substantially to bed gas temperature and mixes with the products of combustion after they are cleaned of particulates but prior to entering a gas turbine expander. The reduced percentage of turbine gas directly involved in coal combustion results in substantially less gas to be cleaned of particulates.

The most obvious application of the PFB combustor to commercial, base load power production is in a combined-cycle system. The PFB combustor, in this concept, would supply energy to a gas turbine-generation unit, and a waste heat boiler at the exit of the gas turbine system would supply steam for a steam turbine-generator unit. A simplified flow diagram for the air-cooled PFB combined cycle system is shown in Figure 1.

The objective of this program is to evaluate the commercial potential of a power generating concept that includes the pressurized, fluidized-bed combustion of coal in conjunction with a combined gas-steam turbine cycle. The capability to burn high-sulfur coal in an environmentally acceptable manner is a major objective of the program. The program involves conceptual commercial design, supporting experimental work, and the design, construction and operation of a PFB pilot plant that can be used to evaluate the commercial concept.

The pilot plant will be located at Wood-Ridge, New Jersey and will utilize the existing MOD POD 8 Total Energy Power Generating Station. Where applicable, existing systems and equipment for materials receiving, laboratories and facilities will be used for the pilot plant program.

PRESSURIZED FLUIDIZED BED/GAS TURBINE HIGH SULFUR COAL COMBINED CYCLE PLANT

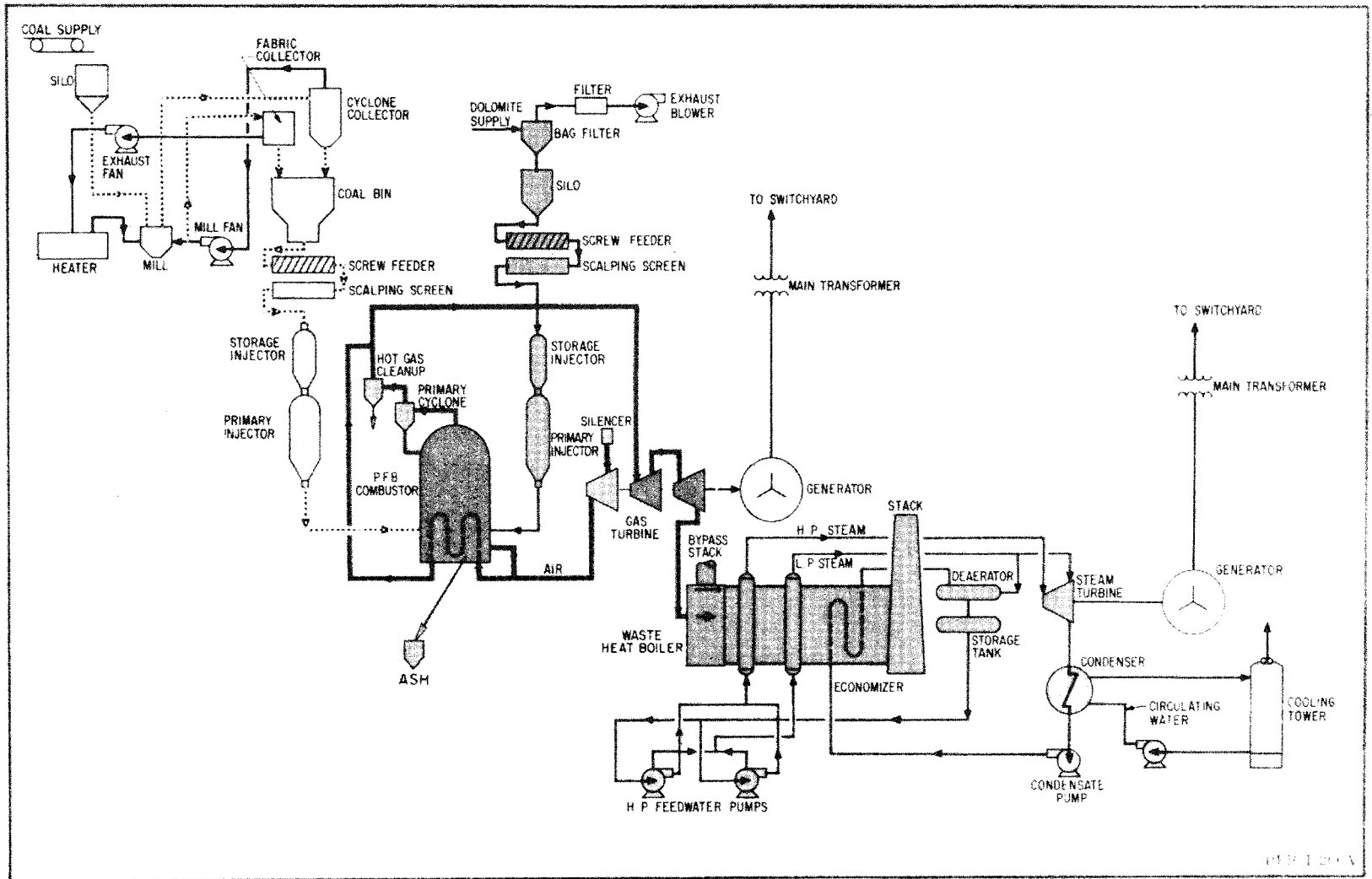


Figure 1

The major tasks of this program are summarized as follows:

- a. A conceptual design for a central station power plant consisting of a PFB combustor with a combined cycle power conversion system will be completed.
- b. A preliminary design of a pilot plant suitable for simulating and evaluating the central station design concept will be prepared. Supporting experiments to provide technical data for the pilot plant design will be conducted.
- c. The PFB pilot plant suitable for evaluation of the economic and engineering feasibility of the central station power plant concept will be designed and constructed.
- d. A test program with the pilot plant to assess the validity of a full-scale design concept, to identify design or component characteristics, to establish operating characteristics under nominal and off-design running conditions, and to provide a firm engineering base for full-scale plant development decisions, will be conducted.
- e. Engineering assessments of the commercial potential of the PFB concept for central station electric power production will be conducted and major design specifications for a plant using high-sulfur (> 3 percent by weight as received) coal while meeting applicable environmental standards will be provided.

II. SUMMARY

Phase I, Preliminary Engineering, Contract EX-76-C-01-1726 was initiated on March 1, 1976 and program accomplishments during the sixth quarter, June 1st through August 31st 1977 are summarized in the following:

The PFB pilot plant preliminary design and performance analysis were completed. During this reporting period the preliminary designs of the primary and secondary cyclones, air/gas piping and auxiliary combustor, materials handling and injection systems, and controls and instrumentation were finalized. Provision for maintenance and servicing have been incorporated and the plant arrangement includes area for alternate or advanced components for possible future evaluations. A complete description of the pilot plant preliminary design is contained in the Pilot Plant Facility Report submitted to ERDA.

Technology support tests of the heat exchanger tubes in both the AFB and PFB combustor rigs and tests of the heat exchanger and turbine candidate materials have been completed. The test results of the Dorr-Oliver 12" AFB are summarized herein and a draft test report was received from Dorr-Oliver and will be submitted early next month.

Heat exchanger tube candidate materials were tested in two Dorr-Oliver client FB reactors and test results are presented. The tests were of 670 and 1700 hours duration at temperature conditions representative of the Pilot Plant PFB. The specimens from one of the reactors was reinstalled for additional testing up to 5000 hours.

The heat exchanger module installed in the NRDC Leatherhead facility was tested for a total of 100 hours over a range of conditions up to 1750°F bed temperature. The heat exchanger has been returned to Curtiss-Wright where it will be inspected and analyzed. A test report is expected from NRDC next quarter.

The installation and checkout of the SGT/PFB technology unit were completed and testing was initiated. A significant portion of the checkout of individual pieces of equipment was carried out off-site and was followed by installation and systems checkout after connection to mating components. Following checkout of all systems, testing was initiated in July and ranged up to 1550°F bed temperature. Several problems with coal and dolomite feed and with heat exchanger tube lateral stiffness were identified during the test and corrective fixes are being applied.

Program review presentations were held at Curtiss-Wright in Wood-Ridge, New Jersey, and in Washington D.C. with ERDA and technical personnel of various Government agencies and advisory groups. As a result of these reviews, approval by ERDA was given to proceed with Phase II-Pilot Plant Final Design activity starting September 1, 1977.

III Work Accomplished/Work Forecast

Task 2 - Pilot Plant Preliminary Design

The PFB Pilot Plant preliminary design has been completed. The plant design is a total energy system consisting of 7.15 megawatts generated by a CW 6515 gas turbine powered alternator and 58,000 pph of steam generated by a waste heat boiler.

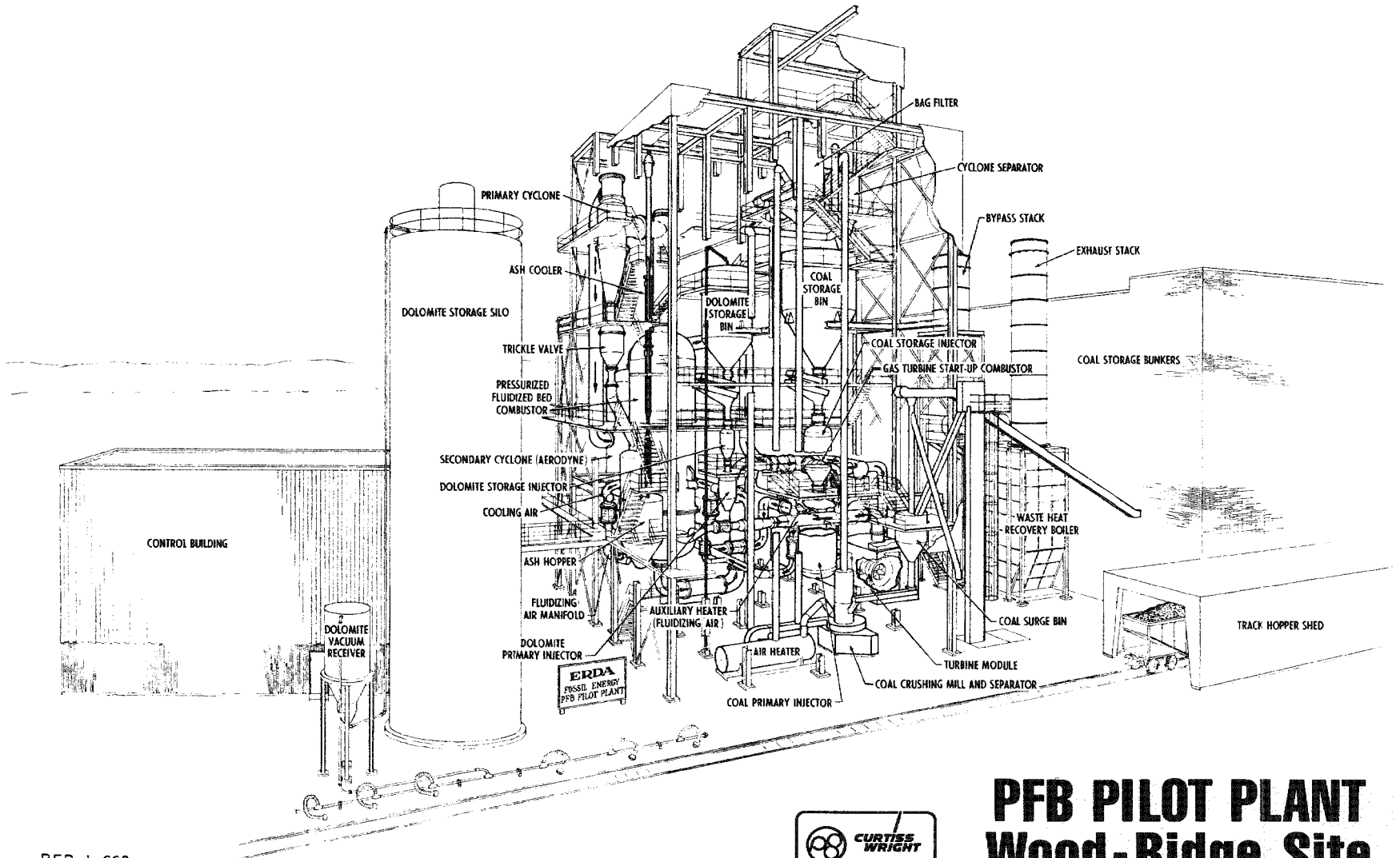
Figure 2 is an artist's conception of the pilot plant. The plant area including existing bunker coal storage area is approximately 2 acres with an additional 1.5 acres available for a coal pile on the north side of the boiler house.

Complete coal and dolomite unloading and storage facilities are provided. Coal will be received from 10-12 rail car shipments per week and transported 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 facilities to the pressurized lock hoppers for injection into the pressurized fluidized bed combustor.

Ash flows out of the PFB and is fluidized by 100 psia 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.

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 combustor back to the turbine. The gas turbine shaft length and bearing support system will be maintained so changes to the gas turbines 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



7

Figure 2

PFB-1-662



PFB PILOT PLANT Wood-Ridge Site

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 steam for plant process purposes.

The PFB plant design is completely described in the Pilot Plant Facility draft report (FE-1726-22, June 1977) prepared and submitted to ERDA.

Combustion Gas Particulate Removal

The primary cyclone is designed to handle hot effluent gas from the PFB combustor for primary separation of entrained particles before the secondary cleanup.

The cyclone consists of a tangential inlet nozzle, the cone section attached to the upper barrel section and a removable vortex finder (or outlet tube). The cyclone is internally lined for both abrasion resistance and thermal insulation, each separate layer thus forming a composite lining. The vortex finder is readily removable, if necessary, through a flanged connection and is constructed of SS-316L.

The cyclone shell is designed, fabricated and tested according to ASME Code, Section VIII, Boiler and Pressure Vessel, at the design pressure of 105 psig and the design temperature of 250°F.

The primary cyclone collected particles are returned through a trickle discharge valve so that most of the unburned coal and entrained sorbent can be fully reacted.

The valve is contained in the pressure seal tank to adapt to the high pressure operation.

The secondary clean-up will be an Aerodyne Cyclone or equivalent, designed to limit the outlet dust loading to a maximum of .0368 grs/acf. The pressure drop through the separator system at the design operating condition is not to exceed 1 psi. Inlet grain loading and particle size distribution were determined in laboratory tests conducted by Dorr-Oliver.

The Secondary Hot Gas Clean-Up Particulate Separator is designed and will be fabricated, tested, and stamped in accordance with Section VIII, Division 1, of the ASME Boiler and Pressure Vessel Code for Pressure Vessels.

The secondary separator (Aerodyne) is 13 ft-6 in. O.D., 36 ft-6 in. high, weighs approximately 202,000 lb, and is refractory brick-lined. The supporting structure and foundation is designed so that an alternate separator could be substituted for testing.

The Aerodyne cyclone operates as follows: 20,400 acfm of flue gas is conveyed to the lower gas chamber past an orifice plate and a stationary turning vane which imparts a rotary motion to the gas. Centrifugal force directs the particulate toward the outer wall of the vessel where it is engaged by a secondary gas stream of 8,100 acfm and is directed spirally downward. Particulate is collected in the base of the vessel and conveyed to a silo.

PFB Combustor and Gas Turbine Interconnecting Piping

The main compressed air and hot gas field piping interconnects the PFB combustor vessel, primary and secondary cyclones and gas turbine. The piping arrangement includes an air/gas ducting system having a low pressure drop and low heat loss, and also interconnects the start-up and heat-up combustors, cyclone separators and power turbine gas bleed. A schematic of the duct routing system is shown in Figures 3 and 4.

The piping is divided into two categories, unlined piping that goes from the compressor discharge to the PFB and lined piping that goes from the PFB to the turbine. The unlined piping is 2-1/4 percent CR - 1 percent Mo steel and the lined piping is carbon steel. All the unlined piping will be insulated on the outside to reduce heat loss to the ambient air. The lined piping will have an internal liner operating at 1650°F (maximum) and an outside pipe temperature at 300°F (Maximum) and 250°F (design nominal). VSL-50 castable refractory (A.P. Green Company, Inc.) fills the space between the pipe I.D. and the liner. Most of the piping is made from standard pipe and fittings.

PFB COMBUSTOR PIPING TOP ELEVATION

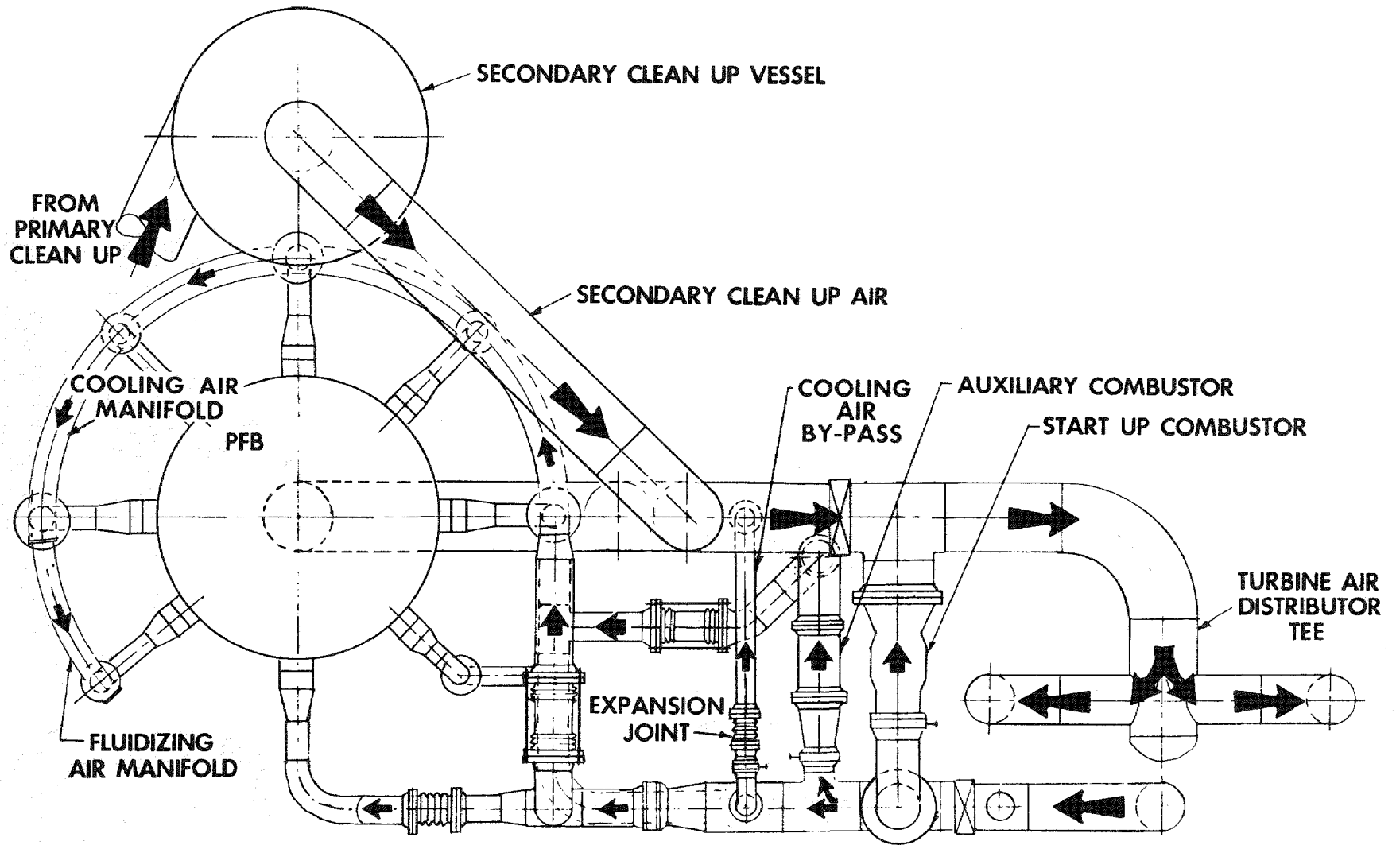


Figure 3
10

PFB COMBUSTOR PIPING SIDE ELEVATION

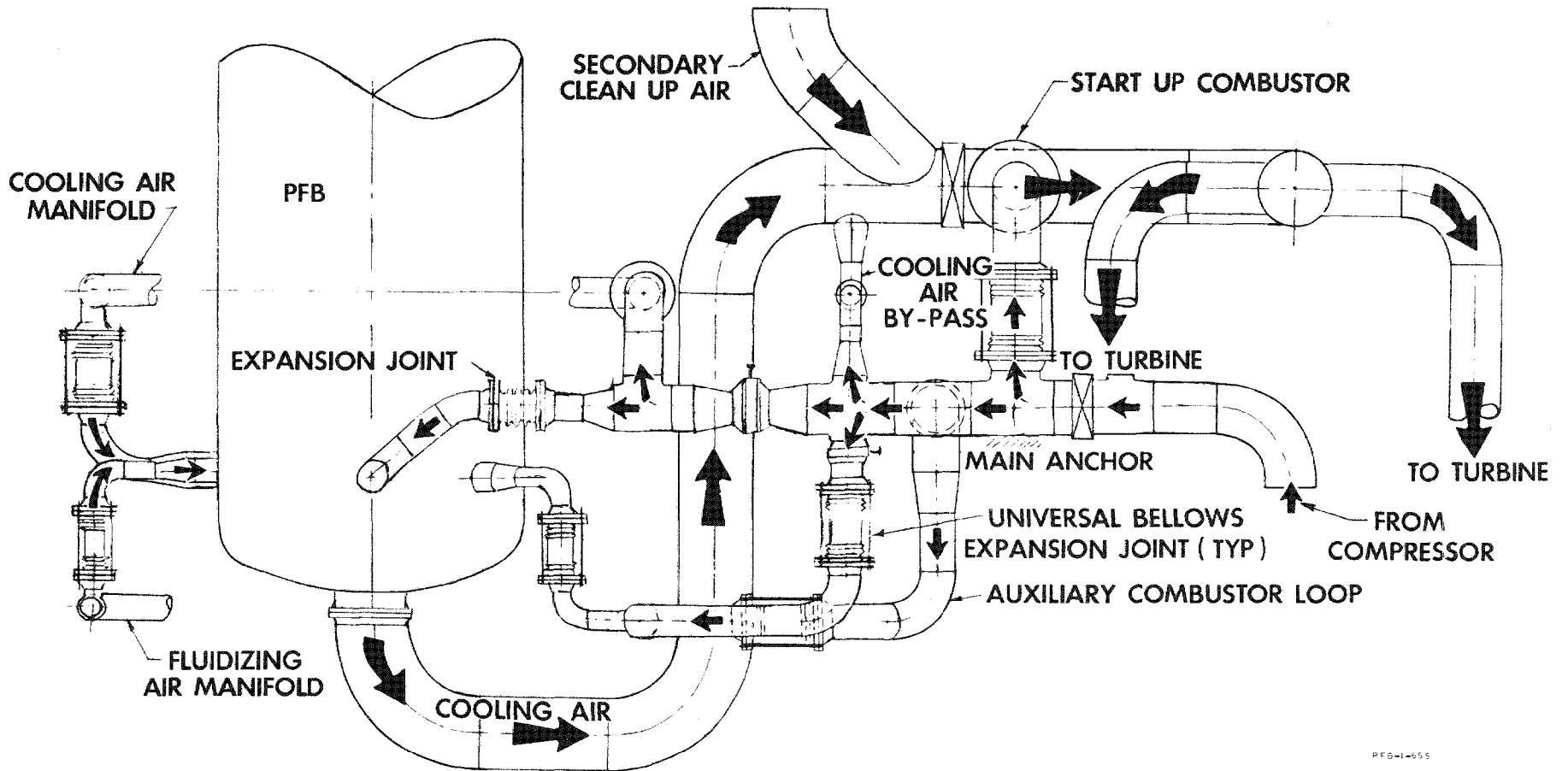


Figure 4
11

The start-up combustor consists of standard CW 6515 gas generator components including center main bearing support, combustion chamber inlet housing, combustion chamber and housing.

The inlet to the start-up combustor is a 30 in. diameter pipe that mounts on the forward outer flange of the center main bearing support housing. The outlet of the combustor exits through a 1.9 area ratio annular diffuser into a 30 in. I.D. pipe. A 30 in. butterfly valve is mounted upstream of the start-up combustor to regulate the flow through the combustor. The start-up combustor is located in an enclosure with the auxiliary combustor and adjacent to the turbine module.

Fluidizing Air - During the start-up cycle an auxiliary heater is required to heat the fluidized bed to 1000°F prior to injecting fuel into the bed. An existing combustor design has been modified to provide the desired temperature and airflow required. The combustor is mounted within a 12.5 in. diameter pipe (2-1/4 percent CR - 1 percent Mo). The outlet flange of the combustor is attached by a fishmouth seal to a flat support plate, and this support plate is sandwiched between two pipe flanges. The front end of the combustor is supported from the pipe with the same mounting arrangement used in the gas turbine engine from which the combustor is derived.

A 20 in. Butterfly valve controls the air flow to the auxiliary combustor. A pipe reducer (20 in. by 12.5 in.) will form the transition between the exit of the butterfly control valve and the pipe encompassing the combustor rig.

Work Forecast

During Pilot Plant Detail Design (Phase II) we will prepare component manufacturing drawings and specifications.

A study will be initiated to investigate PFB pilot plant operation alternatives with the gas turbine de-coupled from the PFB combustion gas stream.

Task 4- Pilot Plant Environmental Analysis

ERDA supplied comments on the "Environmental Assessment" draft report which are being reviewed.

Work Forecast

Prepare final draft of the "Environmental Assessment" report incorporating the review comments supplied by ERDA.

Task 5- Technology Support Rigs

Dorr-Oliver 12 Inch Diameter Atmospheric Fluosolids Reactor

Data from the final series of tests were analyzed and the final report was drafted.

Twenty-six tests were carried out with various fin configurations using space rate, metal skin temperature, and bed particle size as variables. Also, the system was operated with and without cyclone recycle and tests were conducted using dolomite and limestone as sorbents with a Ca/S atom ratio of approximately 2.0.

Results indicate that very high combustion efficiency, greater than 99%, can be obtained with a cyclone recycle system and a deep bed. Combustion efficiency was on the order of 97% without the cyclone recycle stream. Also, cyclone recycling increases the bed heat transfer coefficients due to the presence of fine recycled material. Thus a twofold advantage of an increase in combustion efficiency and an increase in heat transfer coefficient can be achieved with a cyclone recycle system.

The heat transfer coefficients were found to decrease with an increase in the number of fins. However, heat transfer rates ($hoAo$) increased with higher numbers of fins due to an increase in heat transfer area. The heat transfer coefficients were in the range of 50-60, 36-42, 37-40 Btu/hr ft² °F with 10, 15 and 20 fins respectively. Very high heat transfer coefficients, 120-140 Btu/hr ft² °F, were obtained with a bare tube. The heat transfer coefficients increased with a decrease in fin height, as expected. It was observed that

the mean bed particle diameter affected heat transfer coefficient significantly. The coefficient increased with a decrease in bed particle size. The density of the fluid bed was in the range of 70-75 lb/ft³.

A metallurgical analysis is being performed on the 10 fin tube assembly. This tube assembly was selected because it was run for the longest period of time. Fin specimens were taken after 86 hours and additional specimens were cut from walls of tubes after 110 hours. Both tubes and fins are Incoloy 800H. They were operated in a coal/dolomite bed at 1650°F with cooling air supplied at 500 and 1000°F. Resulting tube metal temperatures were:

<u>Cooling Air Temp. °F</u>	<u>Tube Metal @ Inlet °F</u>	<u>Tube Metal @ Outlet °F</u>
500	1475	1515
1000	1550	1550

Work Forecast

Analysis of testing will be completed and a final report published.

Commercial Fluid Bed Corrosion/Erosion Materials Test

The test loop assembly installed in the Pfizer Co. lime calciner at Adams, Mass. was removed and examined by Curtiss-Wright metallurgical personnel. The tube sections in this loop consist of short lengths of four tube materials; 304 S.S., Incoloy 800H, Inconel 601 and Inconel 690 in two inch schedule 40 size, with fins of the same materials (0.4" high x 0.125" thick) brazed to them. One tube, the 690, had Haynes 188 alloy fins brazed to the top half of the tube. All sections were joined together in a continuous loop.

Examination of the test loop assembly was conducted during a normal calciner maintenance outage. At that time, tubes had accumulated 1700 hours of exposure at 1550° to 1600°F in the fluidized limestone (velocity of particles

5 FPS max). Just prior to shutdown, an excursion in temperature occurred to about 2100°F, but of no more than 10 minutes duration. It is unlikely that tube temperatures approached the measured bed temperature for even that long.

Observation of the physical appearance of the materials showed virtually no change in the 304, 800H or 188 materials. Machining marks on these were still clearly distinguishable. The 601 and to a somewhat lesser extent, 690 showed evidence of metal attack manifested as a roughened surface and areas of metal wastage were visible.

Small samples of fin ends were cut from the fins of all but the 188 material (which proved too tough for the tools available) and these samples were returned to CW for evaluation. A sample of the loosely adherent limestone scale from fins and tubes was also obtained. Examples of the limestone feed and fuel oil used to heat the bed were subsequently forwarded to CW for analysis.

The tube assembly was reinstalled in the Adams Calciner and will be removed at the next maintenance interval for full laboratory evaluation at which time it should have accumulated 4000 to 5000 hours in the environment.

The test loop assembly installed in the Torrington, Connecticut incinerator is eight feet in length but materials are the same as those in the calciner test loop. After approximately 670 hours of exposure the Torrington assembly was removed. The tube specimen supporting structure had fatigued and the four vertical specimen tubes were lying in the bottom of the bed. There is evidence that the tube support was intact after 600 hours.

The four individual tubes have been returned to Curtiss-Wright for metallurgical analyses. Initial observations show no indication of corrosive or erosive attack.

Work Forecast

Complete metallurgical analysis and draft report for the materials tests conducted in the Commercial Fluid Beds.

NRDC-PFB Combustor/Heat Exchanger Rig

The 100 hour test program of the PFB heat exchanger module has been completed. The performance test was started on July 22, 1977 and the test was completed on July 29, 1977.

Full bed depth and operating pressure were reached 9 hours after starting to feed coal. The first 34 hours of the test were at the slightly lower fluidizing velocity of 2.25 ft/sec. When it became apparent that elutriation rates were normal the fluidizing velocity was increased to 2.6 ft/s. Operation included bed temperatures to 1750°F for about 6 hours duration during which recorded tube metal temperatures reached 1724°F. After 70 hours operation a gas leak developed in the pressurized exhaust duct downstream of the quench system and the plant was shut down for repairs. The combustor was restored after a delay of seven hours and the test continued for a total of 100 hours operation on coal.

The re-start was carried out with an initial bed depth of 6 ft., with no problems. This is in contradiction to experience with horizontal tube bundles where start-up with deep beds has so far not been possible. It is likely that the vertical tube arrangement leads to larger bubbles and provides an easier ignition path from the start-up burners down to the main gas/air mixture at the air nozzles.

Figure 5 shows the arrangement of the NRDC pressurized fluidized bed with the Curtiss-Wright vertically oriented heat exchanger tubes installed for test.

Work Forecast

The heat exchanger unit is currently being returned to Curtiss-Wright, Wood-Ridge for a complete metallurgical analysis. Data has been transmitted to Curtiss-Wright and is being analyzed. The NCB Coal Utilization Research Laboratory is preparing their input to Curtiss-Wright for the test report.

ARRANGEMENT OF FLUID BED COMBUSTOR MK IV

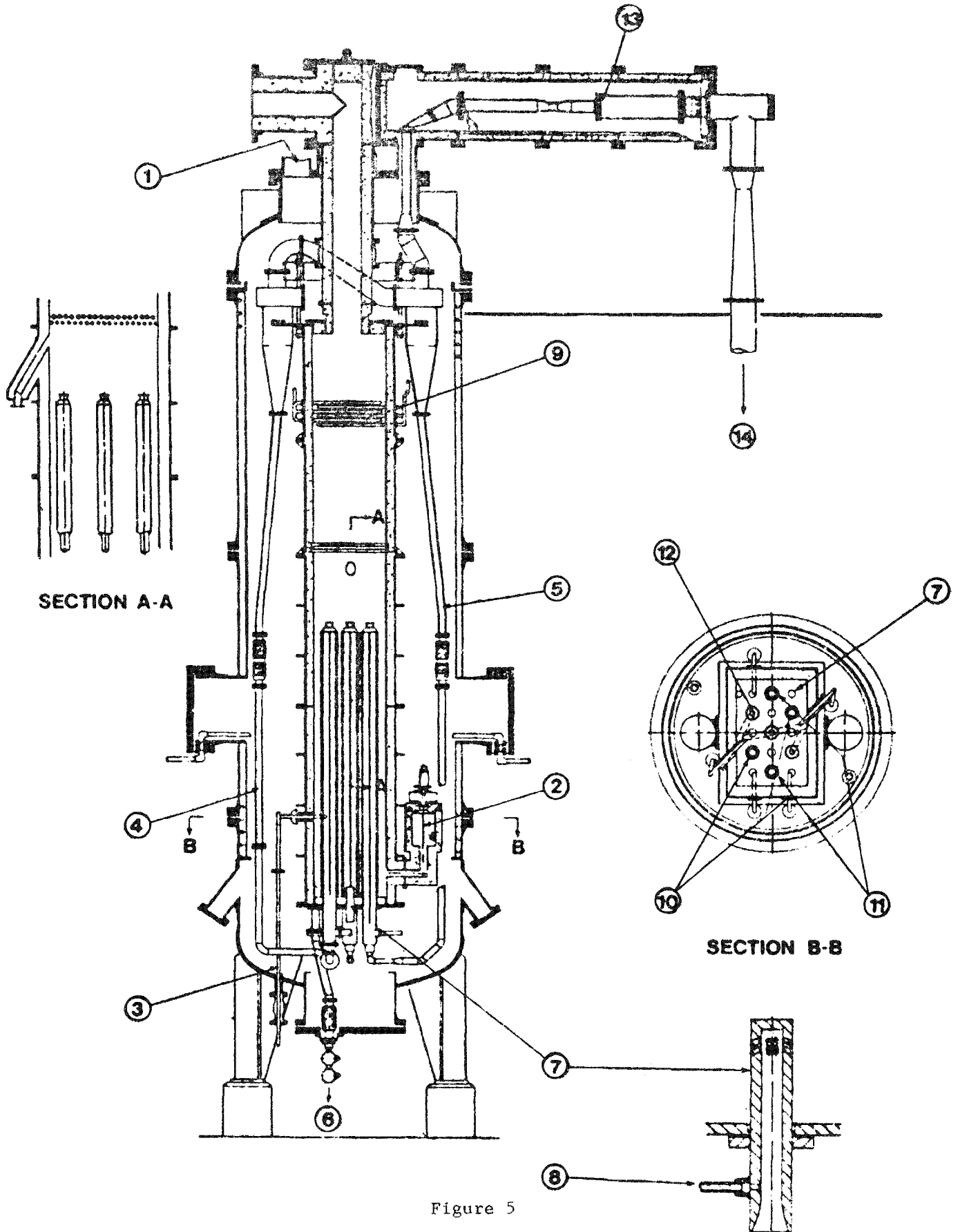


Figure 5

Key to Figure 5

1. Air inlet
2. Start-up burner (one of two)
3. Coal feed pipe (one of four positions)
4. Hot air exhaust line
5. Superheated steam exhaust line
7. Fluidizing air nozzles
8. Propane inlet to air nozzles
9. Freeboard cooling coils
10. Tubes cooled by steam (2 off)
11. Tubes cooled by water (2 off)
12. Tubes cooled by air (3 in series)
13. Quench water to cool hot air/steam exhaust
14. Hot air/steam exhaust to pressure let-down

SGT/PFB Technology Unit

During this reporting period, the SGT Technology rig installation was completed, see Figure 6, and testing was initiated. Rig installation involved the positioning, and mechanical and electrical connection and check-out of many major components.

SGT/PFB Technology Unit Installation and Check-out

The coal grinding equipment, coal feed injection equipment, and dolomite/limestone feed injection system installation was completed, coupled with mating system components and connected to all required utilities. Checkout of the above equipment was carried out to insure that coal grinding resulted in an acceptable particle size distribution. Extensive running on the coal and dolomite/limestone feed systems was necessary to produce operation considered satisfactory for shakedown testing. During check-out of all equipment, the Operating Procedures Manual for the SGT rig was up-dated to include final operating techniques.

Major components of the SGT/PFB combustor comprising center section, dome, upper freeboard, first stage cyclone, ash return loop and ash removal system were installed in the structural tower as shown in Figure 6.

For this initial build the ash return pipe was positioned in the combustor one foot below the bed level. The Aerodyne secondary clean-up system was delivered and installed. Ash hoppers for the Aerodyne separator and ash removal system were installed and the appropriate operating systems were connected for manual operation.

Fabrication of components for the PFB heat exchanger and distributor box assembly was completed. Following heat exchanger and windbox instrumentation, the tube bundle and base vessel were assembled, positioned beneath the PFB combustor and raised to the mating center section flange using the mounting dolly, and bolted in position.

Installation of the facility process piping, quench chamber, exhaust silencer and exhaust stack followed.

Following installation of the tube bundle all instrumentation was installed in the combustor, calibrated and checked out. All utility connections to the tower and PFB were made and verified. Pressure tests of the complete PFB combustor were made initially at 15 psig and finally at 90 psig. Cold and hot air flow tests were made to verify instrumentation and control valve integrity.

Hardware and software checkouts of the process control computer system, including diagnostics, were conducted at Fisher Controls during acceptance tests prior to shipment. Similar checks were conducted on site after receipt of the equipment. All Fisher DC² Process Control System hardware has been installed in the SGT/PFB control room along with peripheral items including the CRT, data terminal, disk recorder, and line printer. Software has been incorporated for use in data logging, alarming, and real time displays for process operations. The prime operator panel, consisting of Fisher AC² (analog control) equipment was received. This system will interface with the process control computer and will permit manual operation for initial start-up with automatic capabilities for subsequent operations.

The Thermo Electron gas analysis system (for SO₂, NO_x, CO₂, O₂, and CO) has been installed and checked out on site. Span gasses were procured and installed along with an improved air purge system. Field modifications were made so that 1-5 volt output signals can be supplied to the process computer, to log gas analysis data.

PFB/SGT Technology Unit Test Firing

On July 27, 1977 the shakedown test of the SGT/PFB Technology rig was initiated. Limestone was initially injected into the PFB combustor in an attempt to reduce excessive carryover during start-up, a phenomenon experienced in several pressurized fluidized beds. After preheating with laboratory supplied heated air, kerosene was injected upon attaining a bed height of six (6) feet, temperature of 1000°F and pressure of 50 psia. Kerosene injection continued until the bed temperature reached 1200°F at which point coal injection was initiated. Transition to coal combustion was immediate and smooth and bed thermocouples indicated constant bed and freeboard temperatures. Coal and limestone injection continued in an attempt to reach design conditions, i.e., full bed depth and pressure.

During this period several interruptions of coal feed occurred and after several hours of operation the limestone feed was interrupted by feed line plugging. Attempts to continue operation of the PFB combustor were hampered by intermittent plugging of both the dolomite/limestone and coal feed systems so the rig was shut down. Approximately 24 hours of running time elapsed from combustor bed light up to shutdown. The maximum bed height obtained was 11 ft at a temperature of 1550°F and pressure of 50 psig.

PFB/SGT Rig Post Test Inspection and Analysis

The feed and injection systems were checked in the presence of manufacturers representatives and both coal and dolomite were flowed to determine causes for the aperiodic plugging experienced in both systems. It was recommended that coal with a reduced percentage of fines be obtained from the grinding mill to reduce the likelihood of plugging. Investigation and development of the dolomite and coal injection systems to provide improved operational reliability are continuing.

Visual inspection of the PFB heat exchanger through pressure vessel viewing ports showed that the top of the center tube was displaced several inches, and it was decided to lower the assembly for more detailed inspection.

Following withdrawal of the tube bundle and base vessel assembly it was evident that the tube bundle retaining ring was damaged. The two straps locating the central tube were both severed and the outer ring ovalized. In addition, several bolts securing the heat exchanger tubes to the divider plate were found to be loose. No structural damage to heat exchanger tubes, divider plate or base vessel was evident and all welds performed in the fabrication of these components were dye penetrant inspected and found to be structurally sound.

Inspection indicated that the finned tube base bolts (connecting the outer finned tubes to the windbox) had, in most cases, either deformed plastically or lost preload due to differential tube/bolt thermal expansion such that they were non-functional. A design revision to Inco 718 self-locking bolts (409 stainless steel bolts were used), with an altered installation torque has been developed to eliminate this problem, and this change is now being incorporated.

Lateral support for the tube bundle in the tested configuration was provided at an approximate fluidized bed height of sixteen feet by a caged structure composed of 1 x .375 inch strap. The support for the center tube was designed to support the tube in one radial direction only (two spokes). Inspection revealed that the spokes had bent and were broken off perpendicular to this direction, indicating the presence of nonsymmetric forces in the bed which can be significant. Strain gage instrumentation will be utilized for the next test to measure the dynamics of the tubes under bed forces, but with a revised support system. With the redesigned tube lateral support, tubes are now supported at the seven and sixteen foot fluidized bed elevations with a considerably stiffened structure such that no radial motion is permitted on any of the tubes.

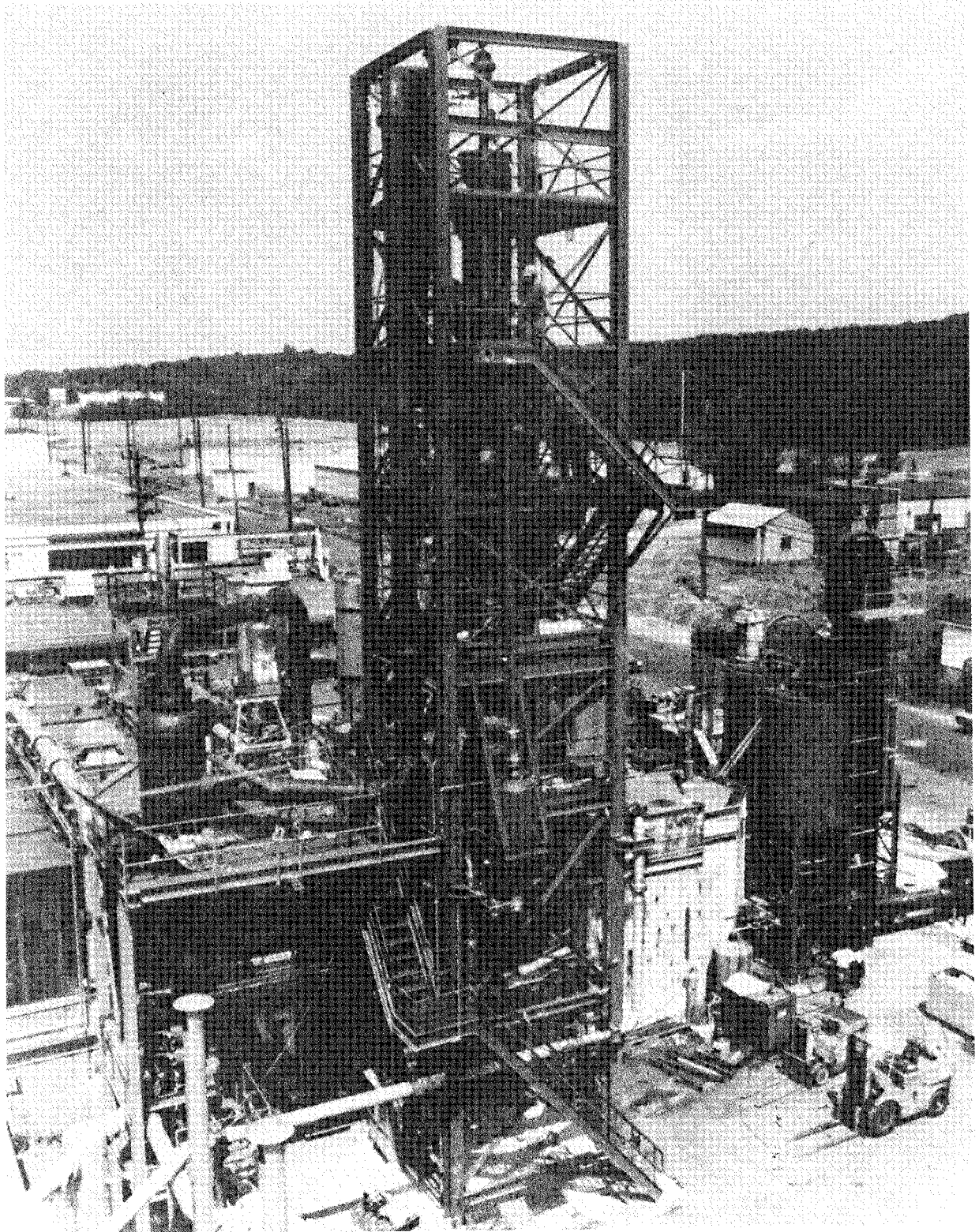
Following disassembly of the heat exchanger and during modification of the tube support structure, cold flow tests were conducted on the 9 tube assemblies of the PFB heat exchanger plus one new spare tube and also on the tuyeres used in the distributor.

The purpose of the flow tests was to determine the isothermal pressure drop and weight flow characteristics of these components to augment data obtained during the rig test.

All of the heat transfer tubes demonstrated similar pressure drop/flow characteristics. The magnitude of the pressure drop measured for the tubes was lower than was predicted, but the tests did not include the additional pressure drop from heat addition along the tube. Based on estimates made both with and without heat addition along the tube, the pressure drop with heat addition was about 1.8 times that of the isothermal condition. Allowing for this effect results in a tube pressure drop of about 6.5 psi for the Pilot Plant design conditions. The 7.8 psi allowed in the Pilot Plant design provides a margin of 1.3 psi for the control valve and piping. If necessary, the tube pressure drop could be reduced by internal fin modifications.

The tuyeres provided almost 50% higher pressure drop than was estimated for the original design point, and an increase in the diameter of the flow holes from 0.184" to 0.225" was incorporated to obtain the desired pressure drop/flow characteristics. Test of two tuyeres with resized holes indicated achievement of the desired flow characteristics.

Small Gas Turbine/PFB Rig



PFB-I-788

Figure 6

Work Forecast

Continue to check out and flow coal and dolomite feed systems and work with the equipment manufacturers, to isolate causes and solutions to plugging.

Modify the PFB heat exchanger tube supports and reassemble and install the heat exchanger.

Install and calibrate additional strain gage instrumentation to monitor tube movement during test.

Conduct SGT/PFB heat exchanger performance test program.

Task 6 - Program Management

A program review was held with ERDA representatives at the Wood-Ridge plant on June 10.

A program technical review was held in Washington, D.C. on July 28 for ERDA and technical personnel of various Government agencies and advisory groups. A summary of the Phase I technical results was presented.

A proposal for continuation of testing on the SGT/PFB rig, during which substantially more candidate PFB and turbine materials would be evaluated over a much longer operating period, was prepared and submitted to ERDA.

Task 8 - Documentation & Reporting

The new Uniform Contractor Reporting Guidelines have been incorporated into the contract and have been implemented.

The following reports were issued during the reporting period:

Pilot Plant Facility Report

Technology Support Test Plan - SGT Technology Unit

PFB H.E. Fin & Tube Mat'l - Erosion Rig Evaluation Report

Turb. Mat'l. Hot Corrosion/Erosion Report

Test Plan - NRDC - PFB Combustor/H.E. Rig