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INTRODUCING COAL-WATER-MIX FUELS TO THE PHILIPPINES

Assessment of Project Feasibility

Volume III
Power Plant Retrofit and Performance

Report to the
National Economic and Development Authority
Republic of the Philippines

on behalf of the

National Power Corporation
Development Bank of the Philippines

Report by

Burns and Roe, Inc.

for

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The work and results described in this report represent the efforts of the following:

John Philipp	-	Vice President and Director, Power Technology
Egon A. Kimel	-	Project Manager
Peter Kemeny	-	Supervisor, Steam Generator Engineering
Martin A. Schmidt	-	Principal Investigator - Mechanical Systems
Glenn A. Fontana	-	Principal Investigator - CWM Systems
Peter P. Maccari	-	Principal Investigator - Slagging Combustors
Robert J. Hatch	-	Electrical Engineering
Anthony C. Denike	-	Instrumentation and Controls
Eugene W. Eng	-	Steam Generator Performance Analysis
Lawrence P. Reinert	-	Plant Layout

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1.0 SUMMARY AND CONCLUSIONS

This volume describes the modifications, performance and costs for converting the Sucat Thermal Power Station to coal-water-mix (CWM) fuel firing. Sucat is the largest generating station in the Philippines, with a nameplate capacity of 850 MW, and serves the Luzon Grid. The station is located in Mantinlupa, metro Manila, on the western shore of Laguna de Bay. The station capacity comes from four generating units, whose steam generators have been designed only to fire residual fuel oil. Individual unit nameplate capacities and commissioning dates are No. 1, 150 MW (1968); No. 2, 200 MW (1970); No. 3, 200 MW, (1971); and No. 4, 300 MW (1972).

The site is flat and at an elevation of 44 feet above sea level. The neighboring area is congested and residential. Access to the site is by truck, railway, and barge. The neighboring highway area is heavily traveled and the railway presently is inoperative. Lake barge traffic is restricted and access to Manila Bay is via a narrow lock on the Pasig River which was installed to restrict salt water intrusion.

Conversion to CWM firing requires new installations within the station in addition to the steam generator modifications. New installations are the CWM fuel storage and distribution system, including modifications to existing storage tanks such that this new system can operate in parallel with the existing fuel oil storage and distribution system; an electrostatic precipitator for each steam generator to control particulate emissions to suit local standards; a system to handle and dispose of ash and slag collected from within the furnace; and a system to handle flyash collected from the electrostatic precipitators. Associated with these new installations are modifications to existing instruments and controls; modification to the plant electrical supply and distribution system; new and altered foundations; and new civil-structural work.

Steam generator modifications are of two types: modifications that are mandatory, such as installations of new burners and equipment to manage ash and slag deposits; and modifications that are optional and selected on the basis of trading off the cost of modification with the improvement offered in increased capacity and reliability. Two particular schemes were selected involving the two types of modifications for each steam generating unit, and each scheme was evaluated in terms of cost and performance.

Minor modification of a steam generator involves the minimum modifications to maintain a low level of capital investment while still producing a reasonable capacity. Minor modifications include:

- Enlargement of the furnace hopper throat opening from 24 to 36 inches;
- Replacement of the oil burners with burners capable of firing either CWM or oil;
- Addition of sootblowers, wall blowers and a new sootblower control system;
- Addition of new induced draft (ID) fans to change the steam

generators from pressurized to balanced draft operation;

- Modification of the forced draft (FD) fans to increase flow and reduce the discharge head;
- For Sucat 2, 3 and 4 respacing of secondary superheater and pendant reheater elements to minimize the chance of ash bridging and to reduce the flue gas velocities;
- Installation of a new dual fuel burner management system;
- Addition of turning gear and new dampers for the gas recirculation fan (gas recirculation will be used only during oil firing).

Major modification of a steam generator involves achieving the highest capacity rating at a capital investment that is still considered reasonable. The major difference between the two types of modifications is the installation, in the major modification, of additional furnace height in Units No. 2, No. 3, and No. 4, and the rebuilding of the convective sections in Unit No. 1.

CWM fuel is received at Sucat by pipeline and stored in tanks. The amount of CWM fuel stored on site will sustain about 10 days of operation at maximum load. At least one of the existing oil tanks remain for storage of oil that is used for startup and as a backup to CWM fuel. Initially, several existing oil tanks are modified for CWM service. Their floating roofs are secured by an internal steel structure which also supports the new agitators. As CWM conversion extends beyond Sucat 2, new CWM storage tanks are added. There is a common CWM fuel transfer system but each unit has its own day tanks and burner feed systems. The present fuel oil systems remain in place for operation on oil when needed.

The existing mechanical dust collectors can not reduce particulates emissions to the level specified by the Philippine National Pollution Control Commission regulations. To meet the requirements, the dust collectors are replaced by electrostatic precipitators designed to remove 98.2% of the flyash from the flue gases.

A new bottom ash hopper with a wet sluicing system is added for each unit. The ash is collected in storage tanks, dewatered and removed by truck or barge for disposal off-site. Flyash is collected and conveyed to storage silos by a new pneumatic conveying system. Flyash may be used as a cement additive or for making building blocks. Trucks or barges are used to transport flyash off-site for sale or disposal in an environmentally acceptable manner.

Performance of the modified steam generators was estimated for the following fuels:

- CWM made from 50% (by dry weight) Semirara coal and 50% water
- CWM made from 55% (by dry weight) Semirara coal and 45% water
- CWM made from 60% coal blend and 40% water. The coal blend consists of 75% Semirara and 25% Malangas coals (by dry weight).

For the baseline fuel (50% Semirara coal), the estimated plant performance is as follows:

Performance - CWM Fuel Firing

	Sucat 2 (3)		Sucat 4		Sucat 1	
	Minor	Major	Minor	Major	Minor	Major
Steam Flow, 10^3 lbs/hr	813.4	1,016.7	1,217.1	1,521.4	635.8	733.7
Rating, %	60	75	60	75	65	75
Gross Output, MW	128	156	195	238	97	113
Aux. Loads, MW	5	6	8	9	7	8
Net Output, MW	123	150	187	229	90	105
Boiler Efficiency, %	74.0	73.7	74.0	73.7	74.3	74.0
Net Plant Heat Rate, Btu/kWhr	11,080	11,070	10,930	10,880	11,960	11,900

With the Semirara/Malangas blend, steam generator loads increased 5% in each case.

After either minor or major modification, the units can operate at full turbine generator rating on fuel oil. The unit 2, 3 and 4 steam generator efficiency on maximum load is estimated to be 87.0% for minor modification and 86.7% for major modification.

Capital costs to achieve the modifications to the station for the baseline CWM fuel are shown below. The costs are in January 1985 dollars, and do not include contingencies, escalation of costs during the construction period, interest during the construction spare parts, and commissioning costs. About 75% of the costs shown are likely to be incurred in dollars and the remaining costs in local currency.

Total Plant Cost (million US $)

Modification	Sucat 2	Sucat 3	Sucat 4	Sucat 1	Total Sucat 1-4
Minor	21.0	18.5	26.0	15.0	80.5
Major	28.5	25.5	34.0	21.0	109.0

Sucat No. 2 is chosen as the first unit to be converted to CWM fuel. Retrofit of the No. 3 and No. 4 units follow upon initial operation of the No. 2 unit. No. 1 unit retrofit follows shortly thereafter.

Preliminary implementation schedules assume a two step approach. An initial step with a duration of 6 to 11 months is to fire Semirara CWM on a larger scale using commercial size burners and under conditions approaching

the Sucat steam generator furnace operating conditions. At the same time conceptual designs and optimization studies are completed.

The next step is to convert Sucat 2 in either a two-phase or a one-phase scheme. In the two-phase scheme, initially only those components, equipment and systems that are essential to CWM firing are installed. The unit is operated for 6 to 12 months on a demonstration-test basis. Experience gained during operation is evaluated and the results are used, if required, to modify the unit further and as input to the design basis for modification of units 3, 4 and 1. The equipment not installed originally, but necessary for long term efficient operation of unit 2 on CWM is added. The two-phase scheme allows deferring some capital investment and permits the acquisition of firm design data before larger investments are made. In the one-phase scheme, all equipment is installed before the unit fires CWM. It is estimated that with a fast track construction approach, minor conversion of Unit 2 can be accomplished in 24 months without an electrostatic precipitator and in 32 months with addition of a precipitator. A major modification of Unit 2 requires 32 months regardless whether an electrostatic precipitator is installed or not.

Conversion of all four Sucat units takes 73 months for the minor modification and 81 months for the major modification. Variations are possible depending on whether or not the operation of an electrostatic precipitator for the No. 2 unit can be deferred until initial operation has been achieved.

Staged slagging combustors firing CWM fuel may become an alternative to major modification of the existing steam generators. The staged slagging combustor is a new technology under active development. The results of current work in the United States by several firms to develop and demonstrate a slagging type combustor can affect whether or not the major modification type of retrofit is ever implemented. These combustors would serve as the burners for each unit, and in operation could retain up to 90% of the ash content in the fuel as a molten slag. This slag would be drained from the combustor and never enter the furnace. Operation of the Sucat steam generators with the cleaner combustion-gases firing Semirara CWM is expected to yield 80% of nominal unit capacities with only minor modification to pressure parts. The prospects are that burners of this type could become commercially available within a few years. Their development progress should, therefore, be monitored.

In addition to conversion of the Sucat Station to CWM fuel, other coal conversion alternatives were investigated. They were:

- Erection of new pulverized coal fired steam generators;
- Conversion of the existing Sucat steam generators to pulverized coal firing.

Both alternatives, erection of new pulverized coal fired steam generators and conversion of the existing steam generators to pulverized coal firing, are based on commercially-proved technologies but present some

unique problems. The Sucat Station has insufficient real estate for location of needed new equipment. Handling and storage of coal at Sucat will also produce social and environmental impacts that are clearly undesirable and cannot be quantified in terms of costs. To mitigate some of the environmental impacts associated with fugitive dust, leacheates and storm runoffs from coal piles, large expenditures will be required. Land will have to be reclaimed by filling an area at the Laguna de Bay shore and some inhabitants will have to be dispossessed of their homes in the vicinity of the plant to provide for railroad delivery of coal.

Replacement of the present steam generators with new coal fired ones, addition of coal and ash handling, electrostatic precipitators and other required systems is expected to cost about US $450 million. The cost is in January 1985 dollars and does not include the cost of rebuilding the Batangas-to-Sucat railroad, contingencies, escalation and interest during construction.

Conversion to pulverized coal of the existing steam generators is technically feasible. Retrofit work includes the same modifications to the furnace, convection pass, forced and induced draft fans, and ash handling system as the modifications for conversion to CWM fuel firing. Additional steam generator modifications are needed to accommodate new primary air fans, primary air heaters, coal silos, feeders, pulverizers and pulverized coal piping. The existing oil burners are to be replaced with new dual fuel (coal and oil) burners and the burner management system is replaced with a new dual fuel operating-system.

Balance of plant additions and modifications include coal handling, electrostatic precipitators, ash handling, instrumentation and controls, auxiliary plant services (cooling and service water, compressed air, auxiliary steam), electrical and civil/structural works.

The total cost for conversion of all four Sucat units to pulverized coal firing is estimated at US $260 million for the minor modification scheme and US $320 million for the major modification alternative. These costs are in January 1985 dollars and do not include the cost of rebuilding the Batangas-to-Sucat railroad, contingencies, escalation and interest during construction.

Conversion of the Sucat steam generators to CWM fuel firing is technically feasible and appears the least cost route for conversion to coal of the Sucat Station.

The following follow-on work is recommended in order to advance the project to the point when implementation can begin:

- Continue research and development work in formulation of CWM fuel from Semirara coal
- Conduct a burn test of Semirara CWM fuel with commercial size burners

- Determine CWM fuel stability and rheological properties in a larger pipe loop installation
- Detailed conceptual engineering work for Sucat 2 retrofit and preparation of major bid packages
- Commence the environmental licensing process; determine emission limits; design considerations required to meet these limits
- Preparation of detailed engineering investigations in some critical areas such as excavation under the steam generator, modifications of existing oil storage tanks, location of potential off-site ash disposal areas
- Training and transfer of CWM technology to Philippine engineers to prepare them to take an active role in the implementation phase

2.0 INTRODUCTION

The report is organized in five volumes and an "Executive Summary and Overview."

This volume (Volume III) represents the work to establish the engineering, performance, schedule and cost bases for converting the Sucat Station to CWM fuel firing. Specifically, the work reported covers the following:

- Necessary steam generator modifications
- Required balance of plant additions and modifications
- Capital and operating costs for conversion to CWM fuel
- Predicted performance after conversion
- Schedules for project implementation

This volume also reviews previous studies for converting the Sucat Station to pulverized coal firing and updates the cost and performance data for use in comparing conversion alternatives.

The other volumes of the report cover the following:

- Volume I establishes the nature of the Philippine coal resource by presenting available information on quality and quantity for coal areas relevant to this project.
- Volume II presents the results of the research and development work on preparation of CWM fuels with acceptable characteristics for handling and combustion using Philippine coals.
- Volume IV describes the CWM supply system including coal mine development at Semirara, the CWM preparation plant and means of transporting CWM fuel to the Sucat Station.
- Volume V presents the economic and financial aspects of the total project.

3.0 STUDY BASIS

3.1 General

Performance required continuous information and data interchange among the different organizations participating in the assessment in order to assure the completion of the work on a consistent and compatible basis. This section summarizes the basis that emerged from this interchange upon which Burns and Roe and other members of the assessment team performed.

The work is a first step study meant to assess the technical feasibility and the financial and economic attractiveness of introducing CWM fuel to the Philippines. As such, detailed engineering and design for the conversion of the Sucat Station was not needed and was not undertaken. This section also summarizes the assumptions that had to be made and the technical approach used for this study.

3.2 CWM Fuel Formulation

As described in Volumes I and II of this report, a number of different coals were considered in the course of this study. Due to factors of coal resource availability, the subbituminous coal from Semirara Island was chosen as the basis of the study. A bituminous coal from the Malangas region was studied for its suitability for mixing with the Semirara coal in the CWM fuel formulation. The analyses of the Semirara and Malangas coals used in this study are shown in Table 3-1.

As described in Volume I, run-of-mine Semirara coal is a highly variable product. Changes in mining techniques, coal blending and introducing coal washing processes could serve to manage the variations in the ash content, moisture content, and heating value of the coal. The coal analysis used to establish the baseline fuel represents a conservative basis for the assessment. Although changes in coal quality will affect the performance of the steam generator, the effects are likely to improve the results found for technical feasibility and attractiveness.

Variations in ash analysis could have the most substantial effect on steam generator performance. The slagging and fouling propensities of coals are calculated from the analysis of the mineral matter (ash) present. Small changes in the level of certain constituents, especially sodium, potassium, iron, and sulfur, can change the slagging and fouling tendencies of the fuel tremendously. The analysis of the steam generator performance is based on the ash analyses shown on Table 3-1. Samples of Semirara coal have been found to have ash sodium content higher than 10%. A coal with such a high sodium content should not be used in a fuel conversion without extensive coal washing. Experiments at Brookhaven National Laboratories indicate that coal washing is feasible.

As described in Volume II, a number of different CWM fuel formulations were produced from the Semirara and Malangas coals. The baseline fuel consists of 50% Semirara coal (weight percentage, dry) and 50% water. No additives were used in this formulation. The Semirara sample used to

Table 3-1

Design Coal Analysis

	Semirara		Malangas		Blend of 75% Semirara 25% Malangas	
	Dry	As Received	Dry	As Received	Dry	As Received
	Proximate Analysis, % by weight					
Moisture	-	24.00	-	2.00		
Ash	17.95	13.64	15.48	15.17		
Volatile Matter	42.84	32.56	20.02	19.62		
Fixed Carbon	39.21	29.80	64.50	63.21		
	100.00	100.00	100.00	100.00		
	Ultimate Analysis, % by weight					
Hydrogen	5.50	4.18	4.28	4.20	5.20	4.18
Carbon	56.49	42.93	74.36	72.87	60.96	50.41
Nitrogen	0.98	0.75	1.97	1.93	1.23	1.05
Sulfur	0.76	0.58	0.50	0.49	0.69	0.56
Oxygen	18.32	13.92	3.41	3.34	14.59	11.28
Ash	17.95	13.64	15.48	15.17	17.33	14.02
Moisture	-	24.00	-	2.00	-	18.5
	100.00	100.00	100.00	100.00	100.00	100.00
	Higher Heating Value, Btu/lb					
	9,877	7,507	13,165	12,902	10,699	8,856
	Ash Fusion Temperatures, °F					
Initial Deformation						
Reducing	2220		N/A		2304	
Oxidizing	2440		N/A		2417	
Softening						
Reducing	2270		N/A		2462	
Oxidizing	2480		N/A		2530	
Fusion						
Reducing	2300		N/A		2591	
Oxidizing	2510		N/A		2599	

Ash Analysis, %

	Malangas	Semirara
Silicon Dioxide	47.20	51.6
Aluminum Oxide	29.94	27.7
Iron Oxide	4.39	4.2
Titanium Dioxide	1.20	1.5
Calcium Oxide	1.65	4.5
Magnesium Oxide	1.53	3.8
Sodium Oxide	.89	2.4
Potassium Oxide	.49	1.5
Phosphorus Pentoxide	.67	0.1
Sulfates	3.27	2.3
Balance	3.77	0.4

formulate the baseline slurry was of higher quality than the coal used in the steam generator performance analysis (shown on Table 3-2). However, BNL has indicated that a 50/50 slurry could be formulated from the design coal.

Additional research and development is likely to produce a fuel that is better in terms of heating value, viscosity, and stability. The baseline fuel, however, appears to be suitable for this project and represents a conservative formulation of a CWM fuel from semirara coal.

3.3 Power Plant Retrofit to CWM Fuel

The most important component in the assessment of conversion to CWM fuel is the performance of the steam generators. The furnace performance was analyzed on the basis that CWM fuel would behave as a 50% moisture coal fired in pulverized form. Steam atomized CWM burners of the size required for Sucat are under development. Test results are encouraging, and it is expected that proven burners will be available before needed for Sucat.

The storage and handling of moderately-loaded slurries is another area in which further work is required. It was assumed that the baseline CWM fuel can be stored in large tanks for 10 days or more through the use of agitators to keep the solid particles in suspension.

It was further assumed that cleaning of the in-plant CWM fuel handling system can be accomplished with an in-line PIG system and by water flushing. The practicality of this system will have to be confirmed in test loops and in smaller installations.

The existing oil storage tanks are assumed to become available to NPC at no charge to be used for CWM fuel storage.

The particulate removal system chosen for this study is an electrostatic precipitator. The sizing was based on the ash size distribution, flyash quantities, and unburned carbon content usually encountered with pulverized coal firing.

3.4 Schedules and Costs

The construction schedules were developed based on recent experience in Australia and Korea in the conversion of oil-designed units to pulverized coal firing with appropriate adjustments for labor productivity in the Philippines and the complexity of the project. The schedules assume that before the authorization to proceed with implementation is given the preliminary conceptual designs and optimization studies are completed.

The budget-type capital cost estimates are based on preliminary sizing and pricing of major equipment along with information on overall project cost from recent in-house studies and projects. The estimates are meant to be used as indications of the resources required for the conversions. Extension of life and improvement of station reliability are outside the scope of this study, therefore, the cost estimates do not include

Table 3-2

Design CWM Fuel Analysis

CWM Fuel	50% Semirara 50% Water	55% Semirara 45% Water	60% Coal Blend 40% Water
	Ultimate Analysis, % by Weight		
Hydrogen	2.75	3.02	3.12
Carbon	28.25	31.07	36.58
Nitrogen	0.48	0.54	0.74
Sulfur	0.38	0.42	0.41
Oxygen	9.16	10.08	8.75
Ash	8.98	9.87	10.40
Moisture	50.00	45.00	40.00
Total	100.00	100.00	100.00
	Higher Heating Value, Btu/lb		
	4,939	5,432	6,420

Notes:

- o Mixing ratios are based on dry weights of coal
- o Coal blend is 75% Semirara/25% Malangas on a dry weight basis
- o "As Fired" anlaysis

such work. The operating and maintenance costs were developed on the same basis. The estimates assume that Sucat 2 is converted first, followed by Sucat 3 and 4 with Sucat 1 last. The cost of facilities common to all four units were applied to the first unit.

Capital costs for conversion to pulverized coal firing of the existing steam generators were estimated by Burns and Roe. The costs of balance-of-plant systems and the costs for replacement with new steam generators were taken from INTEG's report and escalated to January 1985 based on an escalation rate of 10 percent per year. The cost for rebuilding the Batangas to Sucat railroad was also taken from INTEG's report and escalated to January 1985.

3.5 Technical Approach

The following overall technical approach was used in the assessment:

- Data gathering. We prepared a comprehensive questionnaire and enlisted the cooperation of the Economic Development Foundation and the National Power Corporation to provide the information and data required. We also received drawings of the Sucat Station and a report on previous coal conversion study work.

  A team of Burns and Roe engineers made a field trip to the Philippines, visited the Sucat Plant and other sites related to this study, and collected additional information through discussions with Philippine technical personnel.

  We participated in periodic technical review meetings with the other study team members, exchanged information and presented intermediate results for use by the others.

- Steam generator modifications. We undertook a preliminary analysis of performance for the Sucat 2 steam generator and identified the load limiting factors. Two alternative schemes for steam generator modifications resulted, a "minor modification" which is achieved with least investment and a "major modification" which yields higher unit capacity at the higher cost of more extensive modifications.

- Steam generator performance analyses. Steam generator performance was predicted for the following three alternative CWM fuels:

  - A mixture of 50% (dry weight) Semirara coal and water. Fuels with this coal loading were prepared by BNL and by commercial CWM manufacturers and tested at BNL.

  - A mixture of 55% (dry weight) Semirara coal and 45% water. As reported by Brookhaven National Laboratories pumpable slurries with this coal loading are believed achievable through further development work.

- A mixture of 60% (dry weight) of coal blend and 40% water. The coal blend consists of 75% Semirara and 25% Malangas coals. Acceptable fuels of this composition were prepared at the Brookhaven Laboratory.

  Steam generator performance was analyzed for the Sucat 2 unit for each fuel and for both the minor and major modifications. The results from Sucat 2 are fully applicable to the identical Sucat 3 unit. The results from Sucat 2 were extrapolated for Sucat 4. Separate performance evaluations were made for the Sucat 1 steam generator.

- Balance of plant equipment and systems. Major equipment such as electrostatic precipitators, CWM fuel storage tanks, ash storage silos, and flushwater storage tanks were sized and their arrangement determined. Conceptual design sketches were prepared to identify layout and space availability.

- Capital and operating costs. Budget type capital cost estimates were prepared for the steam and generator retrofit work and for balance of plant system modifications and additions. The estimates were based on Burns and Roe's in-house data for completed coal conversions and from CWM fuel conversion feasibility studies adjusted for escalation, equipment size, and Philippine labor rates and productivity.

- Construction schedules. Overall planning type schedules were developed for project implementation based on experience available for conversion of oil designed units to pulverized coal, adjusted for the differences in equipment types and sizes.

- Conversion to pulverized coal. Steam generator performance analyses were made for minor and major modification of the Sucat units to fire pulverized Semirara coal.

- Staged slagging combustors. The feasibility of burning CWM fuel in staged slagging combustors was investigated, and the performance estimated. A brief state-of-the-art report on development of staged slagging combustors was prepared and included in Appendix B. This combustion mode may offer a potential to avoid the need for a major modification of the steam generators because of its ash retention character.

4.0 CONVERSION TO COAL-WATER-MIX FUEL OF SUCAT STATION

The Sucat Thermal Power Station of the National Power Corporation is the largest generating plant in the Philippines, with a rated capacity of 850 MW. Assessment of the technical and economic feasibility of converting the Sucat Station to CWM fuel firing is a primary objective of this study. Major technical considerations for such a conversion are the suitability of the steam generators for CWM fuel firing, the practicality of CWM fuel delivery to the site, ash disposal and compliance with pollution control requirements. The technical aspects of conversion of the Sucat plant to CWM fuel as well as the associated cost estimates are presented in this section.

Sucat Unit 2 was selected as the first unit to be considered for conversion to CWM fuel. In the sequence of conversions, Unit 3 would follow, then Unit 4 and Unit 1 last. In view of this sequence the major focus of the study work has been on analyzing Unit 2. The results from Unit 2 are readily applied to its duplicate, Unit 3. Since Unit 4 steam generator is of similar design and configuration to Unit 2; the results obtained are readily transferable to Unit 4. The Unit 1 steam generator, being of drum design, will behave somewhat differently from the others after conversion. However, the information obtained from Unit 2 can also be used as a basis for estimating the performance of Unit 1.

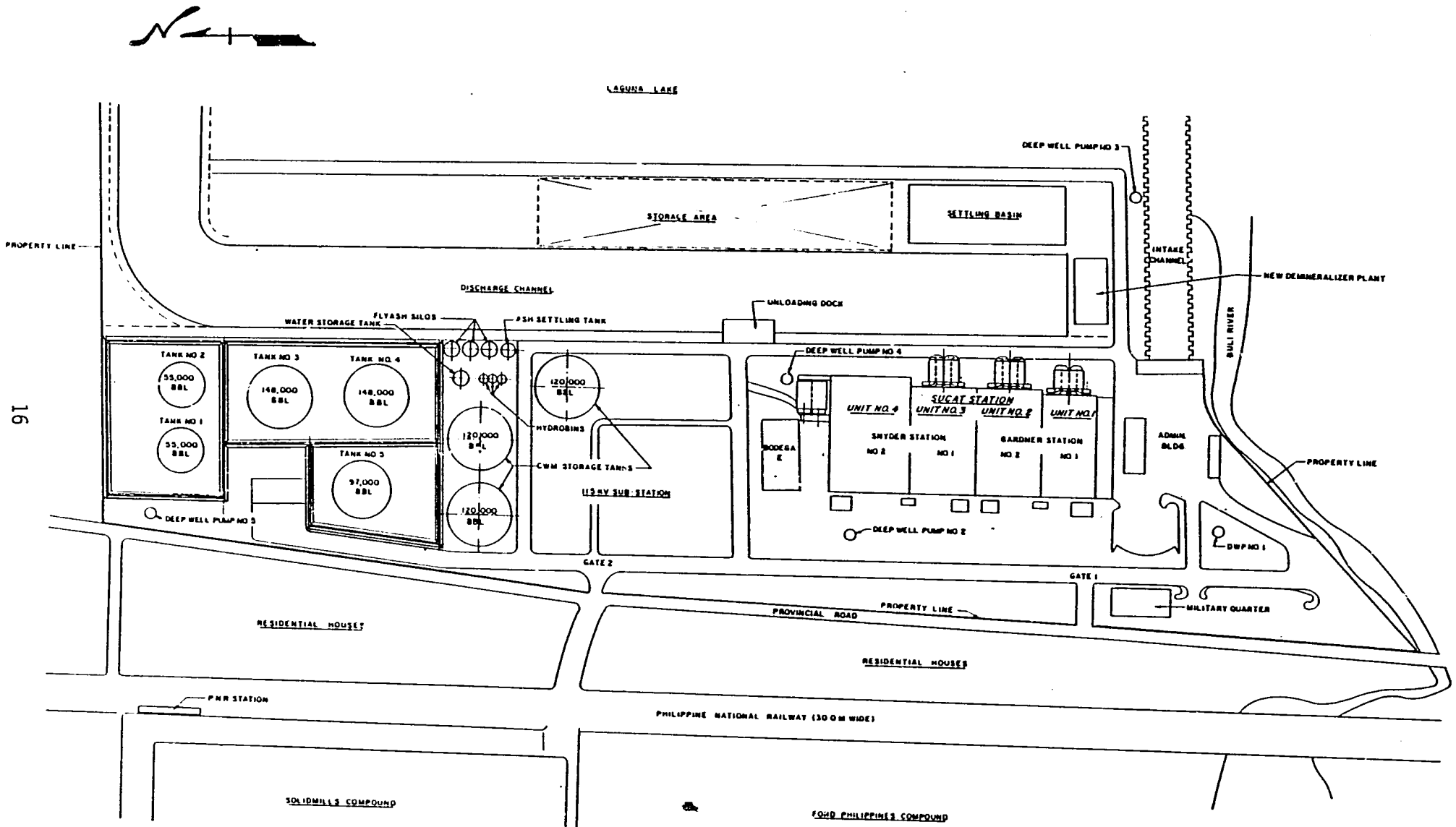
Conversion of the Sucat Station to CWM firing is envisaged to occur in two phases. In the first phase, Unit 2 will be converted and operated on CWM for a demonstration test period. Experience from operation of the unit with CWM fuel will provide the basis for proceeding with the second phase, which will consist in staged conversion of the remaining Sucat units to CWM fuel.

4.1 Description of the Sucat Station

4.1.1 General

The Sucat Station is located in Muntinlupa, Metro Manila on the western shore of Laguna de Bay. The station consists of four oil-fired units with a total nominal generating capacity of 850 MW. Units 1 and 2 were commissioned in 1968 and 1970 as Gardner 1 and 2 with capacities of 150 MW and 200 MW respectively. Units 3 and 4 were commissioned in 1971 and 1972 as Snyder 1 and 2 with capacities of 200 MW and 300 MW respectively. In 1980, the units were renamed Sucat 1, 2, 3, and 4.

The site is flat and at an elevation of 44 ft. above sea level. As shown on Figure 4-1, the site is very congested and is bordered to the west by a residential neighborhood. The tank farm at the north end of the site is owned by the First Philippine Industrial Corporation. Access to the site is by truck and barge. Recently, a lock was installed on the Pasig River to minimize sea water intrusion to Laguna de Bay. This lock restricts navigation between Manila Bay and Laguna de Bay. Therefore, barges can only be used as transport among the facilities on the lake.



SUCAT STATION - CONVERSION TO CWM FUEL FIRING
FIGURE 4-1

The administration building is south of the units. To the north is the switchyard and open storage areas. The small peninsula that separates the discharge channel from the lake is used for storage and for the wastewater settling basin. A demineralizer plant is under construction at the end of the discharge channel. A small peninsula belonging to Shell Oil, south of the present site boundary, may be available for use in the conversion.

4.1.2 Steam Generators

The Sucat Unit 2 steam generator is designed for a maximum continuous steaming capacity of 1,520,400 lb/hr (1005°F/2790 psig) to produce a gross generator output of 220 MWe. The steam generator is of the Babcock-Hitachi subcritical Benson type, residual oil fired, once-through design. Feedwater is fed into the economizer inlet and leaves as superheated steam at the finishing superheater outlet. The furnace enclosure is of horizontal meander-band type tube construction and is formed by water flow circuits and superheated steam flow circuits. Final steam temperature is controlled by the ratio of firing rate to feedwater flow for steady-state load operation. In the transient (load change) case the main steam temperature is controlled rapidly by injecting water into the main steam line (spray attemperation). Reheat steam temperature is controlled by flue gas recirculation as the normal control mode and by spray attemperation as backup. The steam generator is provided with two Ljungstrom horizontal regenerative air heaters and two sets of steam coil air preheaters.

The furnace is of pressurized construction with a horizontal opposed wall firing burner arrangement. The furnace rear wall tubes are bent to form a gas deflection arch. Above this arch are located the vertical superheater and reheater surfaces. The furnace is 30.5 ft. wide, 27 ft. deep and 115 ft. high. Furnace hopper slope is 52 degrees from horizontal, and hopper throat width is 24 inches. The economizer is of the horizontal type, with extended surface steel tubes. The tubes are arranged in a staggered pattern with a stud arrangement. The unit is equipped with 22 retractable soot blowers, 18 of which are installed at the reheater and superheater section and 4 in the economizer section. Furnace sizing and convective heating surfaces tube spacings are rather tight. Clear tube spacings of the finishing pendant superheater and reheater banks are both 4 in. Eighteen burners are arranged in the furnace front and rearwall on 8 ft. vertical and 7.25 ft. horizontal centerline spacing.

The Sucat 3 steam generator is a duplicate of the Sucat Unit 2 steam generator.

The Sucat Unit 4 steam generator is similar in design to those for Units 2 and 3. Its maximum continuous steaming capacity is 2,028,500 lb/hr (1005°F/2790 psig) to produce a gross generator output of 330 MWe. The steam generator is also a Babcock-Hitachi subcritical Benson design with a horizontal, meander-band, once through furnace. The furnace is 36.6 ft. wide, 29 ft. deep and 127 ft. high. Furnace hopper slope is 50 degrees from horizontal with a throat width of 24 inches. There are a total of 24 burners arranged on three levels on the front and rear walls. The steam

generator is equipped with 18 retractable sootblowers, 14 of which are installed in the reheater and superheater section and 4 in the economizer section.

Sucat Unit 1 has a natural circulation drum-type steam generator. Its maximum continuous steaming capacity is 979,200 lb/hr (1005°F/1855 psia) producing a gross generator output of 165 MWe. The steam generator is a single drum Babcock-Hitachi design with a box type convective section. The furnace is 33 ft. wide, 28 ft. deep and 74 ft. high. Furnace hopper slope is 50 degrees from horizontal with a throat width of 24 in. Sixteen burners are arranged on two levels on the front and rear walls, four burners per level per wall. The steam generator is equipped with 24 retractable sootblowers and no wallblowers.

4.2 Steam Generator Modifications

4.2.1 General

This section describes the modifications to the steam generators and their auxiliaries. The steam generator auxiliaries include burners, windboxes, air heaters, fans (forced draft, induced draft, gas recirculation), wall and sootblowers, ductwork, flues and ash collection hoppers.

Conversion to CWM fuel firing will require modification of the existing Sucat steam generators. Some of the modifications are necessary in order to enable the steam generator to operate on CWM fuel, while other modifications are desirable in order to improve unit performance. For the latter modifications, there are trade-offs between investment and achievable performance, which have to be taken into account.

Based on steam generator performance analysis work carried out for the Sucat units, two alternatives were developed for the steam generator modifications. The first, termed "minor modification", is aimed at lowest practical investment by keeping pressure parts modifications to a minimum consistent with an acceptable load. The second alternative, termed "major modification", involves extensive pressure parts modifications in order to achieve a higher steam generator output without incurring unreasonably high costs. These two steam generator modification alternatives apply to all four Sucat units, with some differences in the details of implementation.

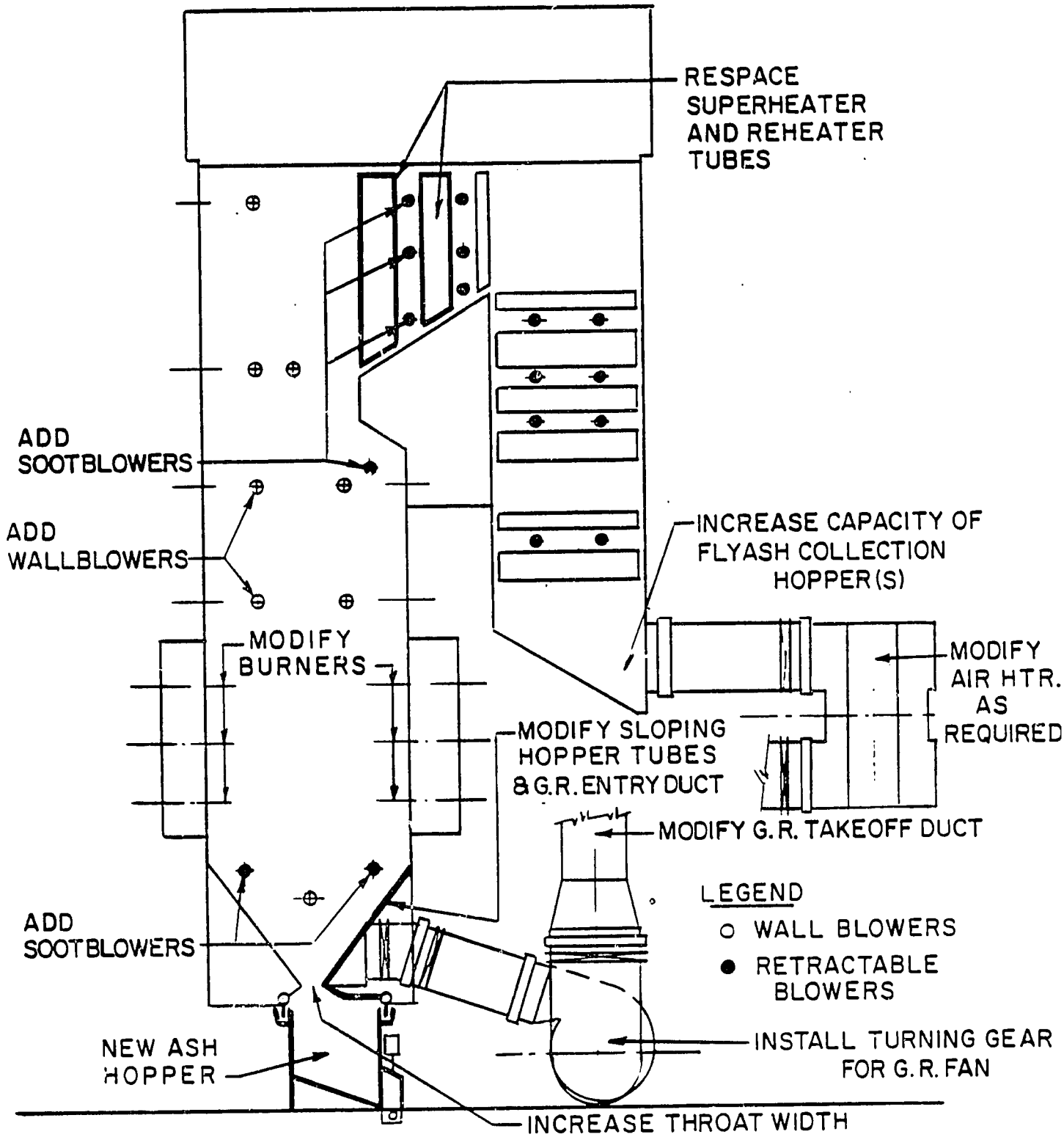
4.2.2 Minor Steam Generator Modification

The principal steam generator components and the required alterations for the "minor modification" scheme are briefly reviewed below, and schematically illustrated on Figures 4-2 and 4-3.

4.2.2.1 Sucat Units 2 and 3

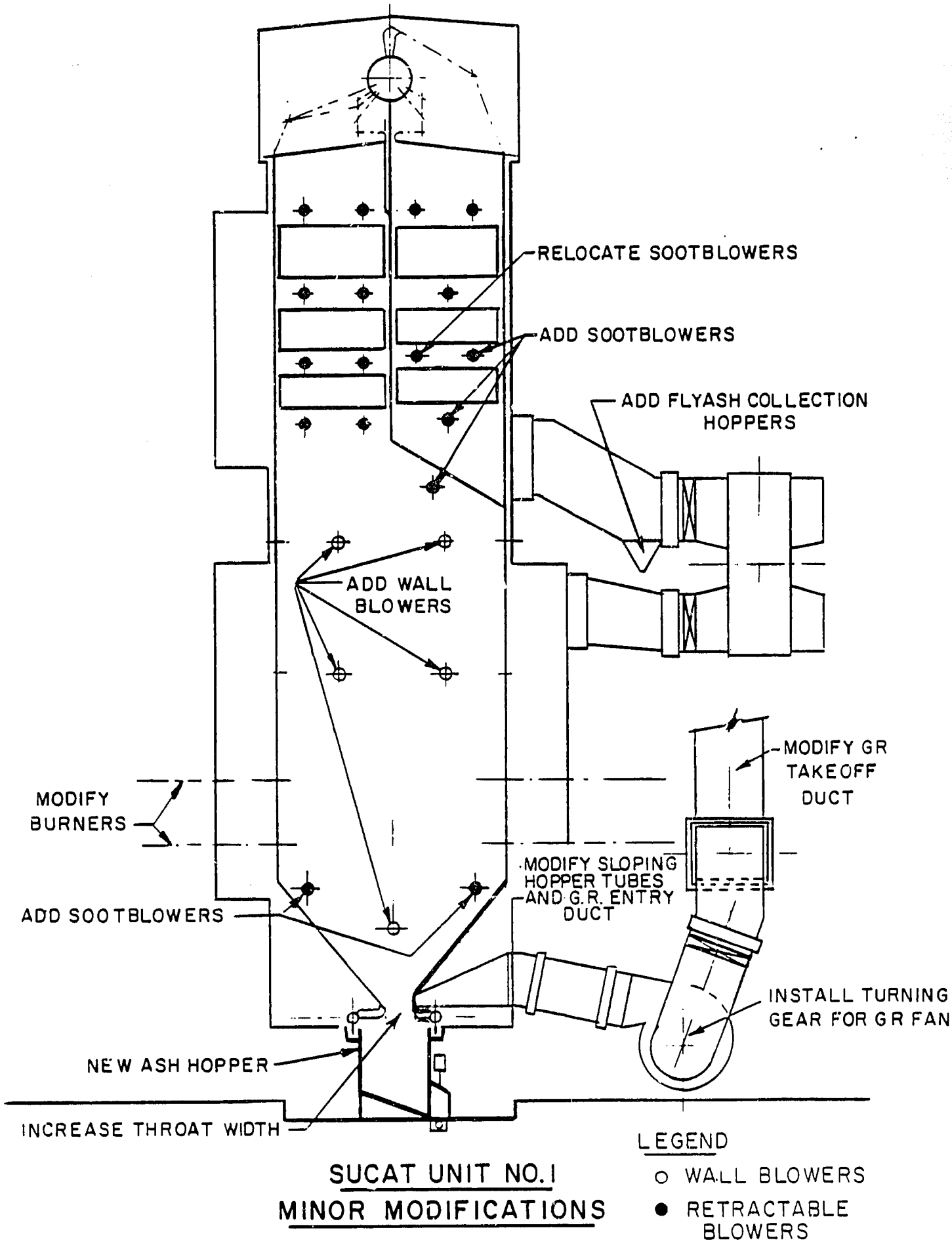
- Furnace Hopper. The slope of the front and rear furnace hopper walls, 52 degrees from horizontal, is adequate for CWM fuel firing. However, the 24 inch throat opening is too small for effective removal of large pieces of slag and bottom ash. Therefore, the throat opening is

FIGURE 4-2



SUCAT UNITS NO. 2,3&4
MINOR MODIFICATIONS

FIGURE 4-3



SUCAT UNIT NO. I
MINOR MODIFICATIONS

increased to 36 inches. This will be accomplished by removing the lower portion of the rear furnace hopper wall and replacing it with tubes shaped such as to create a larger throat opening. The new tubes will also provide an opening for gas recirculation into the throat area. Dip seals and drip shields will be added to seal and connect the furnace hopper with the new bottom ash hopper.

- Burners. The present eighteen burners are not suitable for CWM fuel firing. They will be replaced with new dual fuel burners capable of firing CWM fuel or fuel oil. The burner locations will not be changed and no modification to the existing burner openings in the furnace waterwalls is envisioned. The burners will be equipped with interchangeable CWM and oil guns. The present ignitors will be replaced by new higher heat input ignitors. New flame scanners and a scanner cooling air system will be provided. The windboxes will be modified to accommodate the new burners. Burners for CWM fuel are still under development. CWM burners of the size required for the Sucat units have been tested successfully in pilot furnaces and progress in development of commercial burners is encouraging. It is believed that burners for dual CWM and oil firing will be commercially available by the time needed for the Sucat conversion. A new burner management system will be required.

- Sootblowers and wallblowers. In addition to the existing twenty-two retractable sootblowers, twelve new sootblowers will be required. Six blowers will be installed between the secondary superheater and pendant reheater sections at the locations where provisions were made by the manufacturer for addition of future sootblowers. Four new retractable soot-blowers will be installed below the burner zone for cleaning the hopper knuckle areas and two new blowers will be installed for cleaning the sloping surfaces of the furnace rear wall arch. Twenty-four new wallblowers will be installed on the furnace walls to remove potential slag buildups in the zone of highest heat flux of the furnace. Modification of the existing sootblower control panel to accommodate the new blowers is not cost effective and a new control system will be provided.

- Gas Recirculation Fan. The fan discharge duct and the entry to the furnace hopper will require modifications. The gas recirculation system will be needed for reheat steam temperature control with oil firing. To protect the fan from high furnace gas temperatures during coal firing (when the fan is idle) new dampers and a turning gear will be provided.

- Draft Plant. For permanent conversion to CWM fuel firing, the steam generator will have to be converted from pressurized to balanced draft operation. This will be accomplished by addition of two new induced draft fans and modification of the existing forced draft fans to increase the flow rate and reduce the discharge head.

- Fly Ash Collection Hopper. The hopper in the flue gas ducting at the back of the steam generator is inadequate for conversion to CWM fuel. The capacity of this hopper will be increased.

- Secondary Superheater. The secondary superheater elements are spaced only 6 inches apart. The resulting relatively narrow gas passages are subject to pluggage by slag and fouling depositions, which is the principal factor limiting the steam generator load. To increase the load while satisfying the clear space requirements for CWM firing and thus reduce the susceptibility to pluggage, the lateral space between the secondary superheater elements will be increased to 12 inches, by removing every second element. The number of elements in parallel will be reduced from 60 to 30, leading to an increase in pressure drop in the steam circuit. At the derated load, the working pressures are well below design values and safety valve settings. The steam generator was designed for a peak evaporative load of 105% BMCR (Boiler Maximum Continuous Rating) permissible for up to 8 hours. After removal of 30 elements from the secondary superheater, the steam generator will still be capable of operating at 100% BMCR on oil without exceeding the allowable pressures. To maintain the main steam pressure, economizer inlet pressure will be increased as necessary to compensate for the added secondary superheater pressure drop. However, after modification, operation on oil above 100% BMCR is not recommended, since allowable pressures and safety valve settings would be exceeded.

- Final Pendant Reheater. Similarly to the secondary superheater surfaces discussed above, the side spacing of the final pendant reheater is too tight and subject to pluggage. The lateral space between elements will be increased by removing elements. The horizontal reheater inlet and intermediate tube banks consist of 90 elements spaced 4 inches apart. The outlet legs are then regrouped to form a pendant tube bank with 60 elements with transverse spacing of 6 inches. Two alternate modification schemes were identified and analyzed. In both cases, the horizontal primary and intermediate reheater sections remain unchanged. The first modification scheme reduces the number of final pendant reheater elements from 60 to 30. The pressure drop through the reheater (including piping) will increase about 1.8 times with a penalty to turbine heat rate of 0.9 percent at 100% BMCR on oil firing. The design reheat steam outlet temperature will be maintained over the control range by means of increased gas recirculation. Since in this modification scheme the final reheater elements will be in line with the modified secondary superheater elements, the likelihood of fouling and pluggage of pendant reheater surfaces is lower.

  The second modification scheme reduces the number of final pendant reheater elements from 60 to 45. The pressure drop through the reheater (including piping) will increase by about 1.2 times with a penalty to turbine heat rate of 0.2 percent at 100% BMCR on oil firing. Gas recirculation will be used to maintain reheater outlet temperature. The pendant reheater tubes will be staggered with respect to secondary superheater elements, which makes them more susceptible to fouling depositions and pluggage.

Both modification schemes will permit operation at 100% turbine rating on oil, with the above indicated heat rate penalties. The decision on which of the two alternatives to use will be made during the implementation phase.

- Economizer. The existing economizer tube banks are closely spaced and are susceptible to pluggage by fly ash. Sootblowers will be added to control fly ash deposition in this area. During the demonstration test firing period on Sucat 2, these surfaces will be carefully monitored for fly ash deposition patterns and rates, then modifications will be made to reduce ash deposition on the economizer tube banks.

4.2.2.2 Sucat Unit 4

Since the Unit 4 steam generator is similar to that of units 2 and 3, the "minor modifications" to Unit 4 will be qualitatively similar to those previously described for units 2 and 3.

4.2.2.3 Sucat Unit 1

Modifications required to convert Sucat Unit 1 to CWM firing are summarized as follows:

- Furnace Hopper. The slope is sufficient for CWM fuel firing but the throat opening is not. The opening will be increased to 36 inches by replacing the bottom portion of the rear furnace hopper wall. Dip seals and drip shields will be added. A pit 6 ft. deep will be excavated under the furnace to accommodate the new bottom ash hopper.

- Burners. The present sixteen burners will be replaced with new dual fuel burners capable of firing CWM fuel or fuel oil. The burner locations will not be changed. New ignitors and scanners and a new burner management system will be required.

- Sootblowers and Wallblowers. In addition to the existing twenty-four retractable sootblowers, ten new sootblowers will be required. Four blowers will be installed below the burner zone for cleaning the hopper knuckel areas, two will be installed for cleaning the sloping surfaces of the furnace rear wall arch, and two will be installed at the economizer bank outlet. Two scotblowers will also be installed horizontally in-line with the existing sootblowers between the two economizer banks; this will necessitate moving the existing sootblowers approximately three ft. in order to space the blowers equally. Eighteen new wallblowers and a new control system will also be required.

- Gas Recirculation Fan. The fan discharge duct and the entry to the furnace hopper will require modifications. The gas recirculation system will be needed for reheat steam temperature control with oil firing. To protect the fan from high furnace gas temperatures during coal firing (when the fan is idle), new dampers and a turning gear will be provided.

- Draft Plant. Conversion to CWM firing requires changing from pressurized to balanced draft operation. The existing forced draft fans will be modified and new induced draft fans will be added.

- Erosion Shields. Shields will be installed on the headers located within the gas stream in the convection sections to protect the headers from the erosion expected with CWM fuel firing.

- Fly Ash Collection Hopper. A new fly ash hopper at the boiler outlet will be required. This will involve modifications to the existing boiler outlet flue gas ducting.

4.2.3 Major Steam Generator Modifications

To increase the steam generator capacities on CWM fuel beyond that expected for the minor modifications described above, major modifications to the furnaces of units 2, 3 and 4 and to the convective sections of unit 1 are required. These major steam generator modifications are described below.

4.2.3.1 Sucat Units 2 and 3

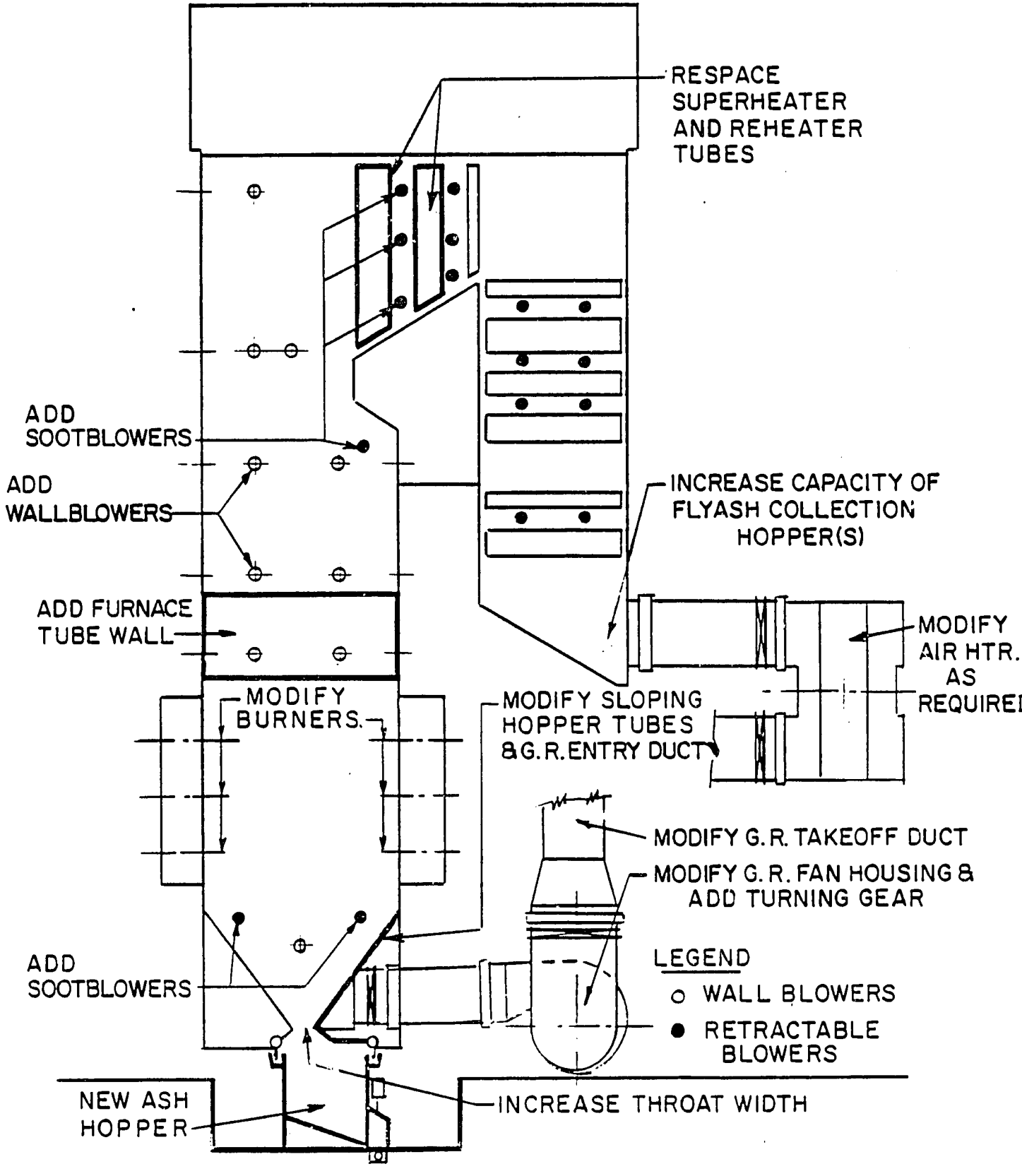
The major modifications to the steam generators of Units 2 and 3 will include all the minor modifications. In addition, an increase in size of the furnace will reduce the flue gas temperature at the furnace exit and reduce the possibility of slagging in the furnace. This will allow the steam generators to be operated at a higher load than is likely for the minor modifications. The major modifications are shown on Figure 4-4.

- Furnace Hopper. The furnace hopper rear wall will be modified in the same manner as in the minor modification. The throat width will be increased and the gas recirculation ductwork will be modified. Provisions will be made for the bottom ash hopper.

- Burners. All eighteen burners will be replaced with dual fuel burners in the same locations.

- Furnace. The maximum steam generator load achievable with the minor modification is limited by the heat release rates in the furnace. High furnace heat release rates can cause slagging and fouling. In order to decrease the furnace heat release rates, the volume and surface area of the furnace need to be increased. It was determined that increasing the furnace depth is not practicable; however, the furnace height can be extended. A furnace height increase of 12 ft. will be accomplished by cutting the furnace walls at elevation 104.5 ft. and installing an approximately 12 foot wide band of horizontal wall tubes, thereby lowering the burner section and furnace hopper section. This will require excavation of a 15 ft. deep pit beneath the furnace for the bottom ash hopper and associated equipment. Excavation of the pit will require sheet piling with proper sealing to prevent seepage of groundwater into the pit. A sump pump will be provided to pump out any water that may accummulate in the pit. Digging of the pit will be

FIGURE 4-4



SUCAT UNITS NO.2,3&4
MAJOR MODIFICATIONS

difficult and costly, however, it is based on proven experience. Conversion to coal of Kwinana Units 5 and 6 (200 MW each) in Western Australia required excavation of a 26 ft. deep pit in a terrain similar to that of Sucat. The pits were excavated in two steps, the first 12 ft. while the steam generators were still operating on oil. A 30 ft. pit was also excavated under Fynsvaerket 4 steam generator (app. 265 MW) in Denmark, when the unit was converted from oil to coal.

Feed pump auxiliary power consumption will increase due to the increased evaporative circuit water side pressure drop.

- Sootblowers and Wallblowers. All of the additions and modifications to the sootblowers and wallblowers described in the minor modification will be used for the major modification. The new furnace wall area will be equipped with eight wallblowers to control slag formation.

- Convective Sections. The secondary superheater and pendant reheater sections will also be modified as described in the minor modification. All other modifications are the same for the major and minor conversions. Full reheat steam temperature with oil firing will be achieved over the load range by increased gas recirculation.

4.2.3.2 Sucat Unit 4

As with the minor modifications, the major modifications to Unit 4 will be qualitatively similar to those for Units 2 and 3.

4.2.3.3 Sucat Unit 1

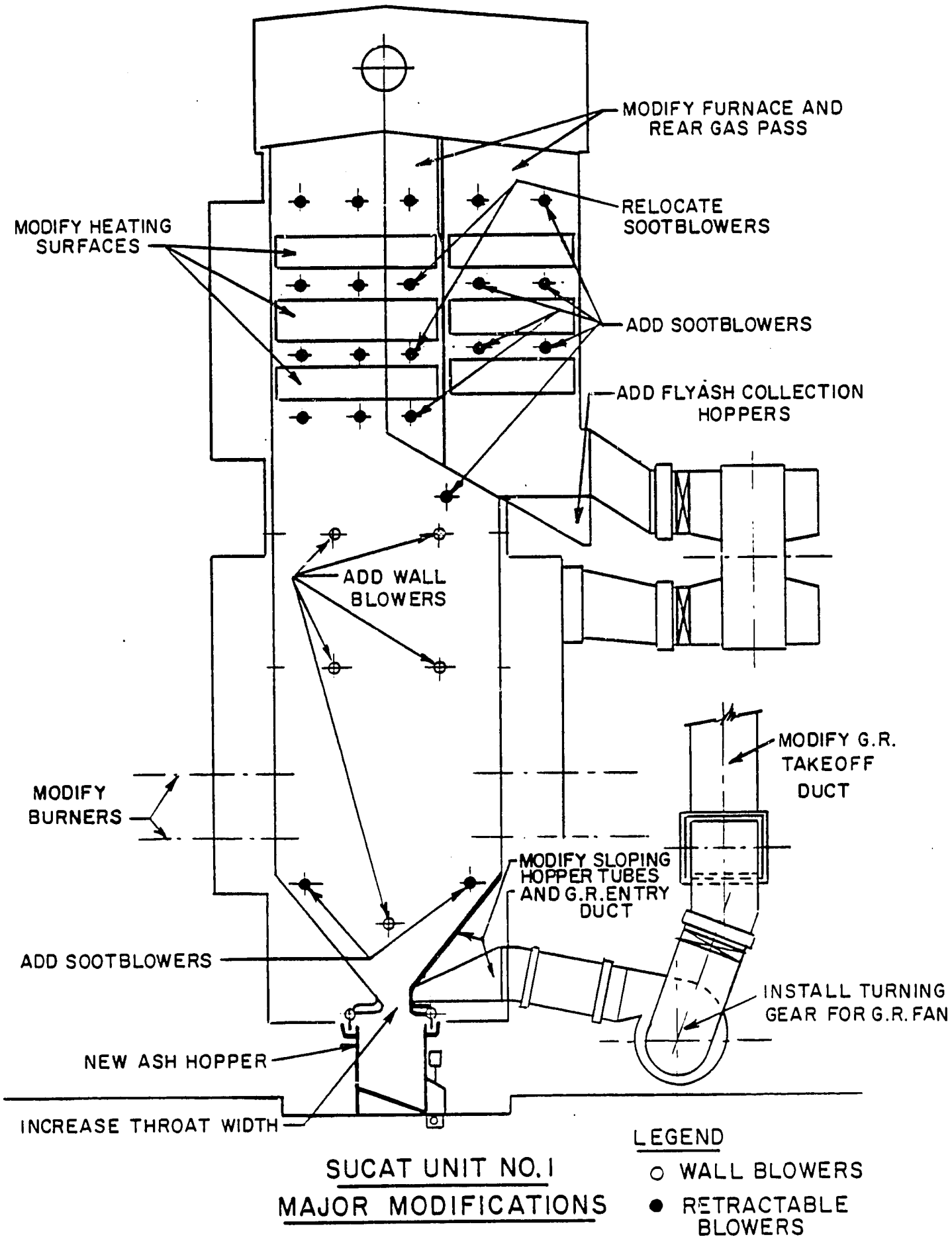
The steam generator of Unit 1 has a tight "box-type" configuration. Because of this, increasing the capacity with CWM fuel beyond that achieved with the minor modifications will require major rebuilding of the upper furnace and the convective section. As shown on Figure 4-5, this rebuilding will require enlargement of the gas passages and of the convective heat transfer surfaces. All other modifications will be very similar to those described in the minor modification. The major modifications are summarized below.

- Furnace Hopper. The furnace hopper rear wall will be modified as in the minor modification to accommodate the bottom ash associated with CWM fuel firing.

- Burners. All sixteen burners will be replaced with dual fuel burners in the same locations.

- Sootblowers and Wallblowers. In addition to the existing 24 retractable sootblowers, 18 new sootblowers will be required to clean the furnace and the enlarged convection section. Four will be installed below the burner zone for cleaning the hopper knuckle areas. Two will be installed in the upper furnace to clean the sloping surfaces of the furnace rear wall arch. A total of 12 new sootblowers will be added in the enlarged convection sections. Four existing

FIGURE 4-5



SUCAT UNIT NO. 1
MAJOR MODIFICATIONS

sootblowers in the convective section will be relocated. A total of 18 wallblowers will be installed in the furnace. New piping and control systems will also be required.

- Modifications to convective section. A new furnace upper rear wall will be installed behind the existing wall. The present upper rear wall of the furnace will be converted to screen tubes. The rear wall of the convective section will be moved back 6 feet and new longer tube banks will be installed. The steam drum position will remain unchanged.

- All other modifications will be very similar to those described in the minor modification.

4.3 Steam Generator Performance

4.3.1 General

Sucat steam generator performance was analyzed to estimate the maximum practical operating load for each unit after conversion to CWM fuel firing. The analyses were based on the ground rules and procedures described in Appendix A. Physical data and operating performance on oil were supplied by NPC.

The analyses were performed for each minor and major steam generator modification alternative described in subsection 4.2. For each modification, the following three CWM fuels were considered:

- CWM fuel made from 50% (by dry weight) Semirara coal and 50% water
- CWM fuel made from 55% (by dry weight) Semirara coal and 45% water
- CWM fuel made from 60% by weight coal blend and 40% water. The coal blend consists of 75% Semirara and 25% Malangas coals (by dry weight).

All three fuels are expected to have relatively good ignitability and flame stability. The main CWM constituent, Semirara coal, has high volatile content and is of low rank and is reactive.

The dimensions of the furnaces impose limitations on the achievable output of CWM fuel. The furnace must provide sufficient residence time for the coal particles to complete combustion, and adequate clearances between burners and furnace walls to preclude excessive slagging and excessive localized heat absorption. If the furnace heat release rates (volumetric, effective projected radiant surface, plan area and burner zone) are too high, incomplete combustion and/or slagging could occur. To prevent this from happening, the steam generator load must be reduced (derating of the unit).

CWM fuel burns slower than fuel oil, and has lower flame temperature and emissivity. The ash present in the CWM coats furnace wall tubes, thus reducing heat transfer. Furnace heat absorption is reduced, and the temperature of the flue gases leaving the furnace is increased. The boiler load limit is reached when the gases leaving the furnace are high enough to

cause either fouling and ultimately pluggage, or overheating of the convection tube banks.

Presently, the Sucat 2, 3 and 4 steam generators have tight pendant secondary superheater and pendant reheater tube spacings. Considerations of fouling and pluggage on these surfaces would require derating of the units to about 50% load if no changes are made. For this reason, for both proposed minor and major modification schemes, the clear spacing between tubes in the secondary superehater and pendant reheater is increased by removing some of the existing tubes.

Slagging and fouling can be controlled to some extent by the operation of sootblowers and wallblowers which dislodge slag accumulations. The degree of slagging and fouling that will occur during operation and the effectiveness of sootblowers to control the ash deposition is difficult to predict, especially with a highly variable, low ash fusion temperature fuel such as Semirara coal.

The guidelines on steam generator performance given in Appendix A cover furnace heat release rates, furnace physical dimensions, convective tube spacings, flue gas temperatures, and flue gas velocities. These guidelines were considered to determine the maximum acceptable load for each modification.

The effect of each modification on the Sucat Station performance is shown on Tables 4-1 through 4-3. Each modification case, including the load limiting factor, is also discussed below.

4.3.2 Sucat Units 2 and 3

The steam generator load with CWM fuel firing is limited for these units by the furnace heat release rates and the flue gas velocities. In the minor modification the maximum load is about 60% of nominal rating for the two Semirara CWM fuels and 65% for the coal blend CWM fuel.

The secondary superehater and pendant reheater sections were modified to increase the spacing between the tubes. The furnace heat release rates at the maximum load indicate slagging could become uncontrollable if higher loads were attempted with only the minor modifications. The flue gas temperatures and velocities through the modified steam generator are shown for the minor modification on Figure 4-6.

The major modification was designed to decrease the furnace heat release rates by increasing the furnace volume and heat absorption surface area. With the larger furnace, the boiler load is limited by the flue gas velocity entering the primary superheater. It was determined that unacceptably high tube erosion would occur if the average flue gas velocity is higher than 80 fps. This requirement limits the maximum loads to 75% with the Semirara-based fuels and 80% with the CWM fuel based on the coal blend. The flue gas temperatures and velocities through the steam generator are sown on Figure 4-7 for the major modification.

TABLE 4-1

SUCAT PLANT - CONVERSION TO CWM FUEL
(50% Semirara coal/50% water)

	Sucat 2 (3)		Sucat 4		Sucat 1	
	Minor	Major	Minor	Major	Minor	Major
Steam flow, lb/hr	813,360	1,016,700	1,217,100	1,521,380	635,830	733,650
Load, %	60	75	60	75	65	75
Gross output, MW	128	156	195	238	97	113
Aux. loads, MW	5	6	8	9	7	8
Net output, MW	123	150	187	229	90	105
Boiler efficiency, %	74.0	73.7	74.0	73.7	74.3	74.0
Net plant heat rate, Btu/kWhr	11,080	11,070	10,930	10,880	11,960	11,900
CWM fuel flow, lb/hr	276,000	336,200	414,000	504,400	218,000	253,000
tonnes/hr	125.2	152.5	187.8	228.8	98.9	114.8
Parent coal flow (as received) lb/hr	181,600	221,200	272,400	331,800	143,600	166,400
tonnes/hr	82.4	100.3	123.6	150.5	65.1	75.5

TABLE 4-2

SUCAT PLANT - CONVERSION TO CWM FUEL
60% Coal Blend/40% water

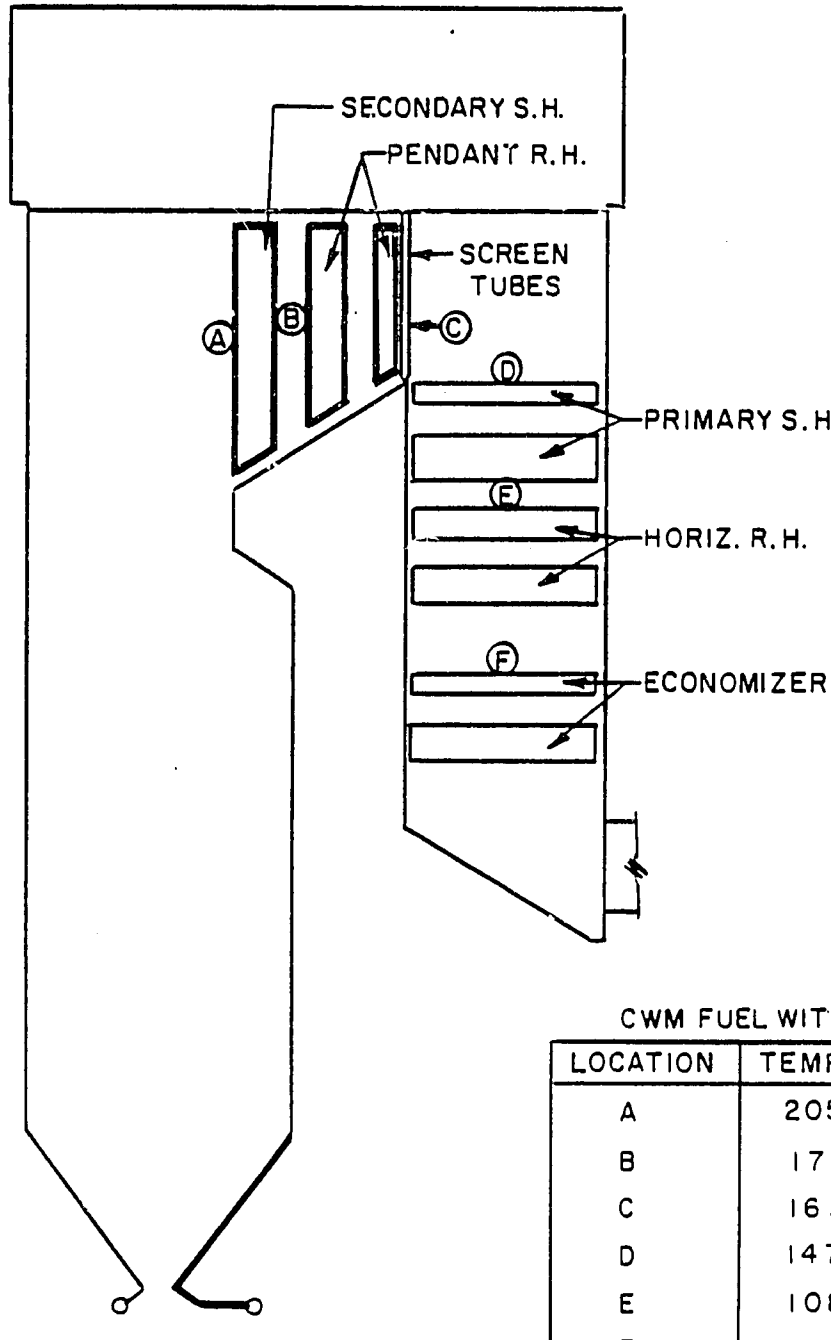
	Sucat 2 (3)		Sucat 4		Sucat 1	
	Minor	Major	Minor	Major	Minor	Major
Steam flow, lb/hr	881,140	1,084,480	1,318,530	1,622,810	684,740	782,560
Load, %	65	80	65	80	70	80
Gross output, MW	138	169	208	254	105	122
Aux. loads, MW	5	6	8	9	7	8
Net output, MW	133	163	200	245	98	114
Boiler efficiency, %	79.5	79.0	79.5	79.0	79.9	79.3
Net plant heat rate, Btu/kWhr	10,270	10,180	10,250	10,160	11,010	10,900
CWM fuel flow, lb/hr	212,800	258,400	319,200	387,600	168,050	193,640
tonnes/hr	96.5	117.2	144.8	175.8	76.2	87.8
Parent coal flow (as received)						
Malangas, lb/hr	32,600	39,600	49,000	59,400	25,670	29,580
tonnes/hr	14.8	18.0	22.2	26.9	11.6	13.4
Semirara, lb/hr	125,800	153,000	188,800	229,600	99,020	114,100
tonnes/hr	57.1	69.4	85.6	104.1	44.9	51.8

TABLE 4-3

SUCAT PLANT - CONVERSION TO CWM FUEL
55% Semirara coal/45% water

	Sucat 2 (3)		Sucat 4		Sucat 1	
	Minor	Major	Minor	Major	Minor	Major
Steam flow, lb/hr	813,360	1,016,700	1,217,100	1,521,380	635,830	733,650
Load, %	60	75	60	75	65	75
Gross output, MW	128	156	195	238	97	113
Aux. loads, MW	5	6	8	9	7	8
Net output, MW	123	150	187	229	90	105
Boiler efficiency, %	76.3	76.0	76.3	76.0	76.6	76.3
Net plant heat rate, Btu/kWhr	10,730	10,740	10,600	10,560	11,610	11,540
CWM fuel flow, lb/hr	243,600	296,600	365,400	445,000	192,400	223,000
tonnes/hr	110.5	134.5	165.7	201.9	87.3	101.2
Parent coal flow (as received) lb/hr	176,200	214,600	264,400	322,000	139,200	161,400
tonnes/hr	79.9	97.3	119.9	146.1	63.1	73.2

FIGURE 4-6



CWM FUEL WITH 55% SEMIRARA COAL

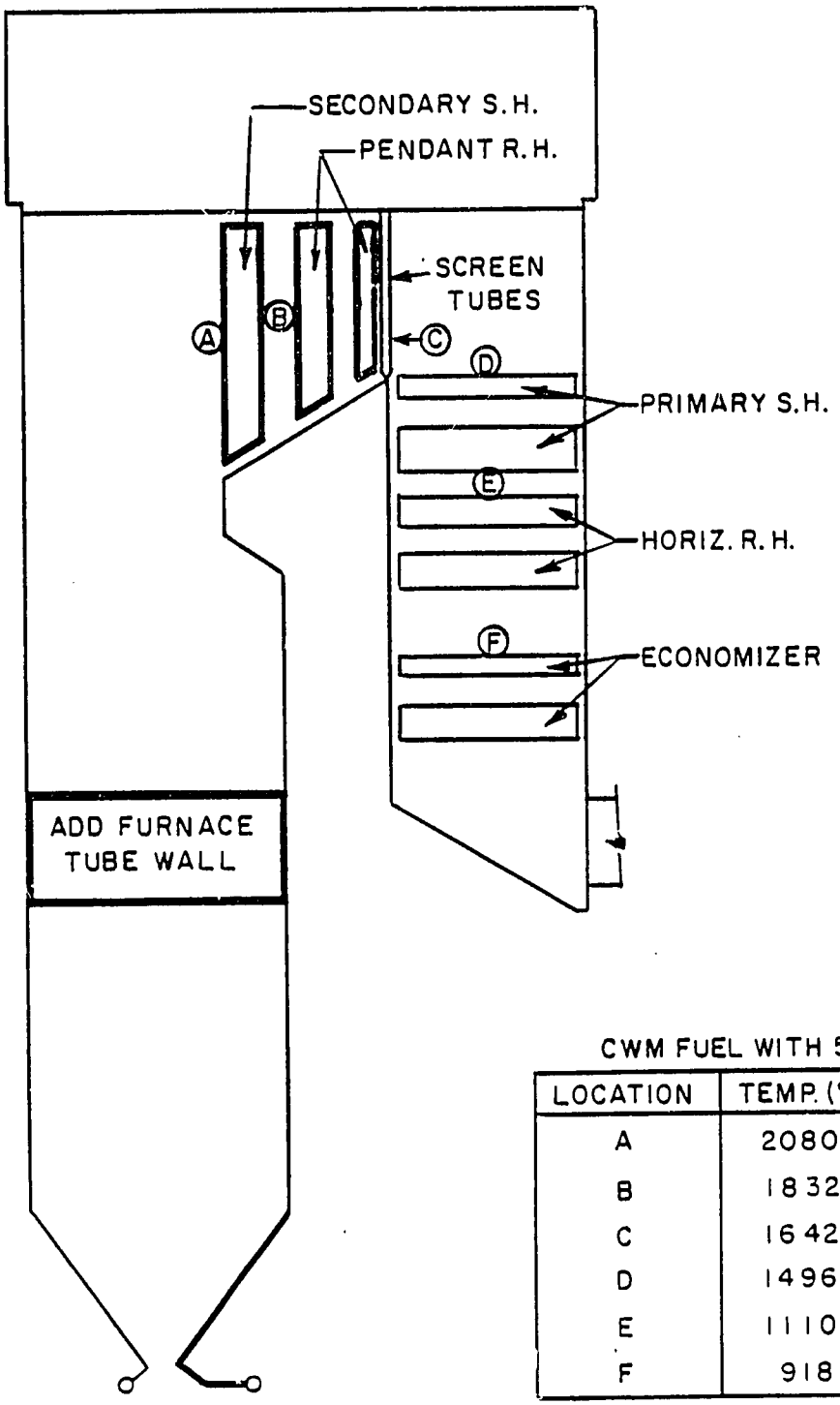
LOCATION	TEMP. (°F)	VELOCITY (FT/S)
A	2050	35
B	1783	36
C	1637	49
D	1477	62
E	1083	50
F	893	45

CWM FUEL WITH 50% SEMIRARA COAL

LOCATION	TEMP. (°F)	VELOCITY (FT/S)
A	2010	36
B	1763	37
C	1627	51
D	1475	66
E	1088	53
F	901	48

SUCAT UNITS 2 AND 3
MINOR MODIFICATION - 60% LOAD
FLUE GAS TEMPERATURES
AND VELOCITIES

FIGURE 4-7



CWM FUEL WITH 55% SEMIRARA COAL

LOCATION	TEMP. (°F)	VELOCITY (FT/S)
A	2080	43
B	1832	49
C	1642	59
D	1496	77
E	1110	62
F	918	56

CWM FUEL WITH 50% SEMIRARA COAL

LOCATION	TEMP. (°F)	VELOCITY (FT/S)
A	2045	44
B	1814	51
C	1635	63
D	1496	81
E	1118	65
F	927	60

SUCAT UNITS 2 AND 3
MAJOR MODIFICATION - 75% LOAD
FLUE GAS TEMPERATURES
AND VELOCITIES

After either minor or major modification the steam generator will be capable to operate up to 100% BMCR on oil. Steam generator efficiency at BMCR on oil is estimated at 87% with the minor modification and 86.7% with the major modification.

4.3.3 Sucat Unit 4

As described earlier, the steam generator design and the proposed modifications for Unit 4 are very similar to those for Unit 2 and 3. Therefore, the maximum capability on CWM fuel will also be very similar.

With the minor modifications the maximum load is predicted to be 60% of full load firing the Semirara based CWM fuels and 65% firing the coal blend CWM fuel. With the major modifications, the maximum load will be 75% firing the Semirara based CWM fuels and 80% firing the coal blend CWM fuel.

4.3.4 Sucat Unit 1

Although the Unit 1 steam generator is different in design from the others, its maximum load firing CWM fuel is also limited by furnace heat release rates and flue gas velocities. In this case, however, the load after the minor modification is limited by velocity and the load with the major modification is limited by furnace heat release rates.

With the minor modification, the Sucat 1 maximum load will be 65% of nominal rating with the Semirara CWM fuels and 70% with the CWM fuel made from the coal blend. The flue gas velocity at the screen tubes is the limiting factor.

With the major modifications, the maximum load will be 75% with the Semirara CWM fuel and 80% with the coal blend CWM fuel. The furnace heat release rates and the furnace exit gas temperature indicate that any higher load would result in excessive slagging and fouling.

4.4 Balance of Plant Systems

This section describes the modifications to existing balance of plant systems and the new plant systems that are required for the conversion of the Sucat Station to CWM fuel firing.

The new plant systems are associated with handling the CWM fuel and the ash that results from its combustion. The CWM fuel handling system uses some of the existing fuel oil tanks, with modifications, but is essentially a new system. Since CWM fuel firing produces substantially more flyash than fuel oil firing, the existing mechanical dust collectors will be replaced with electrostatic precipitators. The bottom ash and flyash produced after the conversion will be handled by a new system.

The existing electrical system and the instrumentation and control system will have to be expanded or upgraded to support the conversion. The conversion will affect the arrangements of the plant site and buildings.

4.4.1 CWM Fuel System

4.4.1.1 Overview

The CWM fuel system is designed to receive fuel from a pipeline, store it until needed and deliver it to the burners at the required flow rate, temperature and pressure. The CWM fuel system will be completely independent of the oil system. Fuel oil storage will remain available on site, and the fuel oil transfer and burner feed system will be retained for use on start-up, warm-up and as a back-up to CWM. These systems will be designed to provide the means to quickly switch from one fuel to the other.

Figure 4-8 schematically presents the proposed CWM fuel system. It will consist of the following major subsystems: CWM storage, CWM transfer to day tanks, burner feed, flushwater.

Two alternative designs are proposed, one for the minor and the other for the major steam generator modification. The same system arrangement is used for these alternatives, but the numbers and sizes of major components (tanks, pumps, etc.) differ as required by the fuel consumption rates.

4.4.1.2 CWM Storage

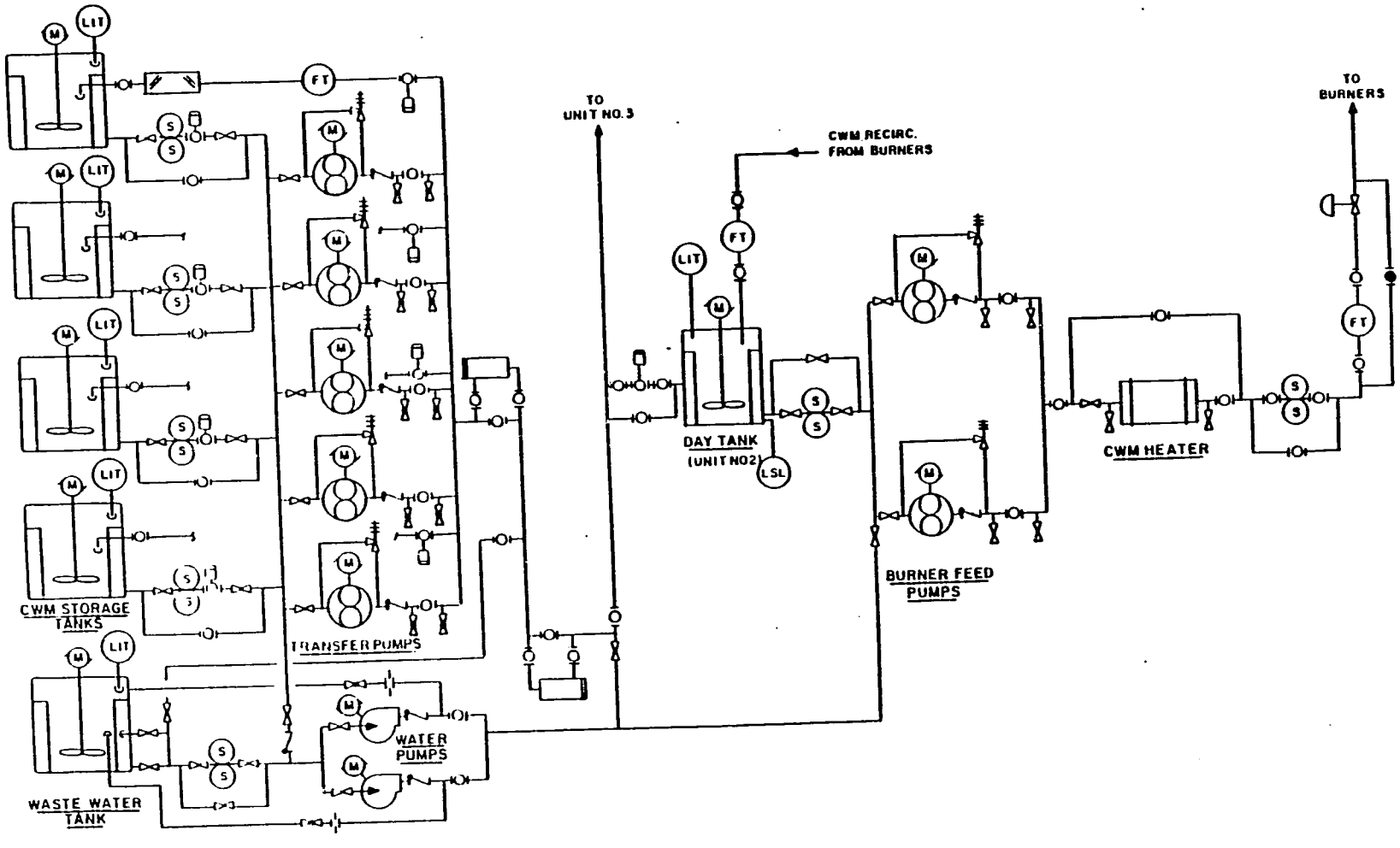
There are now five oil storage tanks on the Sucat site. Tanks 1 and 2 have a capacity of 55,000 barrels each, tanks 3 and 4 hold 148,000 barrels each and tank 5 holds 97,000 barrels. Tank 5 is used to store lube oil feed stock, and will remain in this service. Tank 4 will remain for storage of fuel oil. Tanks 1, 2 and 3 will be converted to CWM service.

Assuming that the sequence of CWM conversions starts with Sucat 2, followed by 3, 4 and 1, the storage tank modifications and additions will be as follows. With conversion of Sucat 2, tanks 1 and 3 will be converted to CWM. A new 120,000 bbl storage tank will be added for Sucat 3 and another for Sucat 4. The new tanks will be erected adjacent to the existing storage tank farm. For the major conversion of Sucat 4, it will be necessary to also modify tank 2. With the conversion of Sucat 1, an additional 120,000 bbl tank will be located in the present storage area between the switchyard and the discharge canal. The CWM storage tanks will provide storage to accommodate the needs for 7 days operation at maximum CWM capacity of the steam generators.

The existing oil storage tanks have floating roofs. For CWM, they must be modified to fixed roof construction by installing support pillars inside of the tanks. Each tank will be equipped with agitators mounted on the roof of the tank from a support structure and internal baffles to assist the agitation. Since CWM fuel has a higher specific gravity than oil, the tanks will have to be filled to a lower level in order not to exceed the allowable stress in their walls. The maximum CWM storage capacity for tanks 1 and 2 will be 45,000 bbl each and for tanks 3 and 4, 120,000 bbl each.

The new 120,000 bbl storage tanks will be of fixed roof construction, 130 ft in diameter and 48 ft high. Each tank will be equipped with four

FIGURE 4-8



CWM FUEL SYSTEM

top supported agitators. All agitators will be of the axial flow propeller type, with low rotating speed to reduce the support structure cost and limit the shearing effect of agitator blades on the CWM fuel.

The agitators will be provided as the main means of keeping the CWM fuel from settling. Additional preventive measures for control of deposition of solids at tank bottom are air lances and fuel recirculation. Openings will be provided on the roof for insertion of manually operated compressed air lances to dislodge deposits from the tank bottom. These lances will be used only as a measure of last resort. Each tank will be provided with lateral connections at chosen location into which some fuel will be recirculated to stir the contents in the tank. These connections will be fed from the transfer pump discharge headers. Arrangement of the fill lines will be such as to aid in the mixing within the tank. The tanks will be equipped with level indicators, relief vents, vacuum breakers, and overflow and level switches for alarms and to close the feed line valve at high tank level.

All tanks will be suplied from a pipeline, through individual tank fill lines. Each fill line will be provided with an electrically operated shut-off valve and a check valve. Tank level status and alarms will also be provided in the control room from where the filling operation will be controlled in coordination with the pumping station(s) at the other side of the pipeline.

4.4.1.3 CWM Transfer to Day Tanks

Each unit will be provided with a day tank sized for 12 hours operation at full load. Each day tank will be provided with an agitator to prevent settling of coal particles. A set of transfer pumps will take suction from the CWM storage tanks and supply the day tanks. The piping arrangement will be such as to permit suction from any or all storage tanks and supply any or all day tanks. Filling of the day tanks will be controlled manually.

As the system is expanded, additional transfer pumps will be installed. For Sucat 2 and 3, one pipe will be provided from the storage tank area to the day tanks. With conversion of Unit 4 an additional pipe will be installed in parallel. Each day tank will be provided with a strainer, shutoff valve and check valve on the supply side.

4.4.1.4 Burner Feed

The CWM fuel burner feed subsystem takes the fuel from the day tanks to the burners. Each system will have two low shear, variable speed drive, positive displacement pumps taking suction from the day tanks. The system will interface with the combustion control system to supply fuel at the required flow rate, temperature, and pressure. Although the CWM fuel piping to the burner front resembles that for oil firing, the two systems will be kept separate. Recirculation piping will be provided from each burner level back to the CWM day tank, maintaining a minimum of 15 percent flow through the system to prevent local settling of coal particles in idle

pipe sections. Provisions will be made at the burner front to pre-wet, flush and air flow individual burners for placement into our out of service.

4.4.1.5 Flushwater

CWM pipelines must be pre-wet with water before filling with slurry, and periodically emptied of slurry and flushed to prevent buildup of deposits on pipe interiors. When pipes full of water are placed back in CWM fuel service, the potentially contaminated water must be removed and treated for disposal or stored for reuse. This requires a water supply and waste collection system.

The filling/flushing method proposed for Sucat will use a mechanical cleaning device commonly known as a PIG, which will be inserted into the pipe to physically separate the CWM fuel from the flush water. The CWM fuel pumps will pump the flush water behind the PIG, forcing the slurry down the pipe ahead of the PIG and into the storage tank. Similarly, on refilling a line, the CWM fuel pumps will be used to pump slurry behind the PIG, forcing the waste water downstream into a collecting tank. The PIG can also be designed to scrape the interior of the pipe and remove any deposits.

This system requires only one system volume of water per flush and minimizes both the amount and particulate content of the wastewater. It also reduces the dilution and subsequent settlement of coal particles in the pipe after flushing. A simple flushwater system requires 25 to 50 system volumes per flush which can create a water treatment problem. However, a PIG pipe cleaning system involves a practical but somewhat more complicated piping design.

A wastewater collection/storage tank will be provided. The collected flushwater will be reused for subsequent flushing operations. The tank will be provided with means of removing sedimented material from the tank bottom for disposal.

4.4.1.6 Component Design Considerations

The following general guidelines will be observed for designing the CWM fuel system: Piping and pipe components will be designed for approximately 5 fps velocity to minimize erosion. Pipe materials will be carbon steel of standard wall thickness. Connections will be welded, except at pumps and strainers where flanged connections will be used. Flanged spool pieces or laterals will be installed in key locations to permit manual cleaning of deposits. Pipe runs will be as streamlined as space permits, using bends or long radius elbows, laterals and Y-fittings. The number of low points will be kept to a minimum.

Packingless knife gate valves will be used for low pressure service (75-100 psig) for general isolation. Full ported ball valves with stainless steel balls and metal seats will be used for high pressure service, or where frequently cycled in low pressure service in pipes served by

PIGs. Ball valves will be provided with cavity flush and drain connections. Plug valves with metal seats will be used for high pressure service or where frequently cycled in low pressure service in pipes not served by PIGs.

Pumps for CWM fuel transfer, and for waste/flush water service will be either rotary screw or low speed open impeller centrifugal type. Pumps will have external bearings and pressure controlled water flushed packed seal boxes for shaft sealing. Casings and implellers will be of cast iron. Pumps for burner feed service will be positive displacement (externally geared rotary screw or progressive cavity) type. Rotating speeds will be kept below 350 rpm to reduce shear damage to the fuel.

4.4.2 Particulate Control

All four Sucat Units are equipped with mechanical (cyclone) dust collectors designed for the low dust loadings associated with oil firing. (Reportedly, the existing dust collectors were designed to remove 80% of flyash and unburned carbon produced by oil firing.) Performance of mechanical dust collectors is strongly dependent on the particle size distribution of the fly ash. There are no data available on the flyash particle size distribution for firing CWM fuel in large steam generators. Even if such data were available for highly loaded CWM fuels it may not apply to a less-loaded CWM made from Semirara coal. Experience with mechanical dust collectors installed on pulverized coal fired units indicates that their collection efficiency generally varies between 50 and 65 percent. With an assumed collection efficiency of 60% the particulate emissions firing Semirara CWM will be about 6500 mg/SCM which is well in excess of the limit of 300 mg/scm specified by the Philippines NPCC Regulations of 1978. Particulate emissions can be controlled to meet the NPCC specified limit of 300 mg/scm by installing a fabric filter baghouse or an efficient electrostatic precipitator.

Fabric filters, or baghouses, are used on many utility steam generators because of their high efficiency and their tolerance of variations in coal ash characteristics. However, they were not chosen for Sucat because they require more space and produce relatively high pressure drop losses compared with electrostatic precipitators and are not satisfactory for fuel oil firing.

The major parameters considered in sizing an electrostatic precipitator are the gas flow, inlet ash loading, allowable particulate concentration at the outlet and the resistivity of the ash. These parameters are summarized on Table 4-2. To meet the particulate emission limit of 300 mg/scm at the stack outlet an electrostatic precipitator with a collection efficiency of 98.2% will be required. To achieve this efficiency, the precipitators must have a specific collecting area of about 325 sq. ft./1000 ACFM.

Table 4-4
Electrostatic Precipitator Design Data
(Semirara-CWM Fuel)

Modification	MINOR			MAJOR		
Unit	2 (3)	4	1	2 (3)	4	1
Flus Gas Flow Rate, 1000 ACFM	518	786	414	640	958	480
Collection Efficiency, %	98.2	98.2	98.2	98.2	98.2	98.2
Specific Collecting Area, ft^2/1000 ACFM	325	325	325	325	325	325
Plate Area, 1000 ft^2	168	255	135	210	311	156
Plate Height, ft	40	43	35	42	48	40
Dimensions of Shell, ft						
Length	42	55	42	49	60	42
Width	65	70	60	65	70	60
Height	45	48	40	47	53	45
No. of Chambers	2	2	2	2	2	2
No. of Fields per Chamber	4	4	4	4	4	4

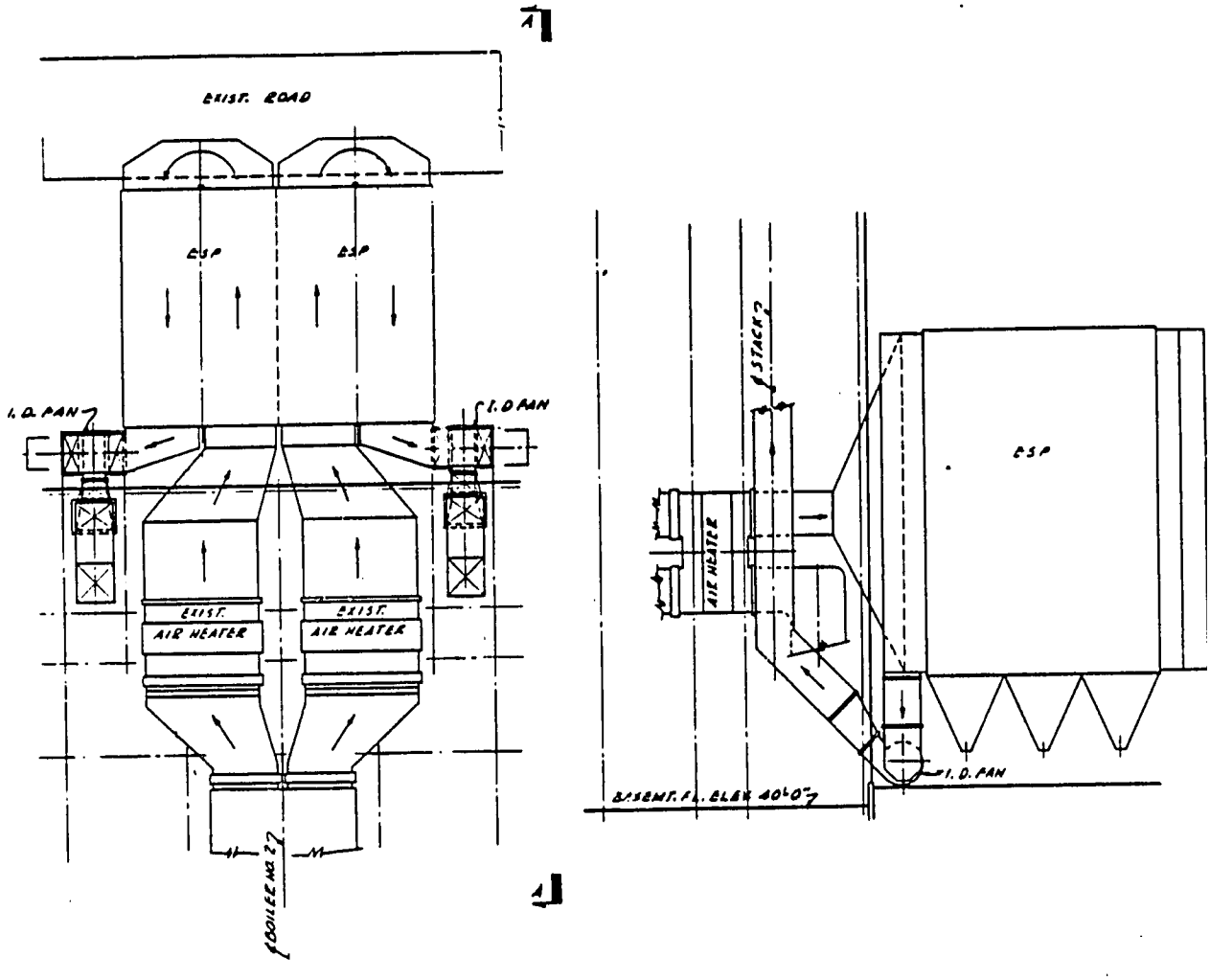
Figure 4-9 shows the layout of the electrostatic precipitator for Unit 2. Units 3 and 1 will have similar arrangements. Each of the precipitators will be arranged in two "U" shaped chambers so as not to block the existing road between the buildings and the discharge channel. Some of the existing tanks and structures directly behind the buildings will have to be relocated to allow for the new induced draft fans and the support structures for the precipitators.

The precipitator for Unit 4 will be placed next to the north wall of the boiler building as shown on Figure 4-10. A layout similar to the other three units would have blocked the road and extended to the edge of the discharge channel. The flue gas leaves the air heater and travels out to the precipitator through new ductwork inside the boiler building. The gas is drawn through the precipitator by the two new induced draft fans. The clean gas travels up and into the building through new ductwork that connects with the existing ductwork that passes into the stack.

The precipitator arrangements are similar for both conversion alternatives. The minor conversions will require somewhat smaller precipitators than the major conversions. There will, however, be little variation in the precipitator sizing for the different fuels. The sizing and performance of the precipitators would have to be optimized by testing and gas modeling to determine the best arrangement for each fuel conversion alternative.

4.4.3 Ash Handling

The existing ash handling systems at the Sucat Station are designed to handle the relatively low ash production associated with oil firing.

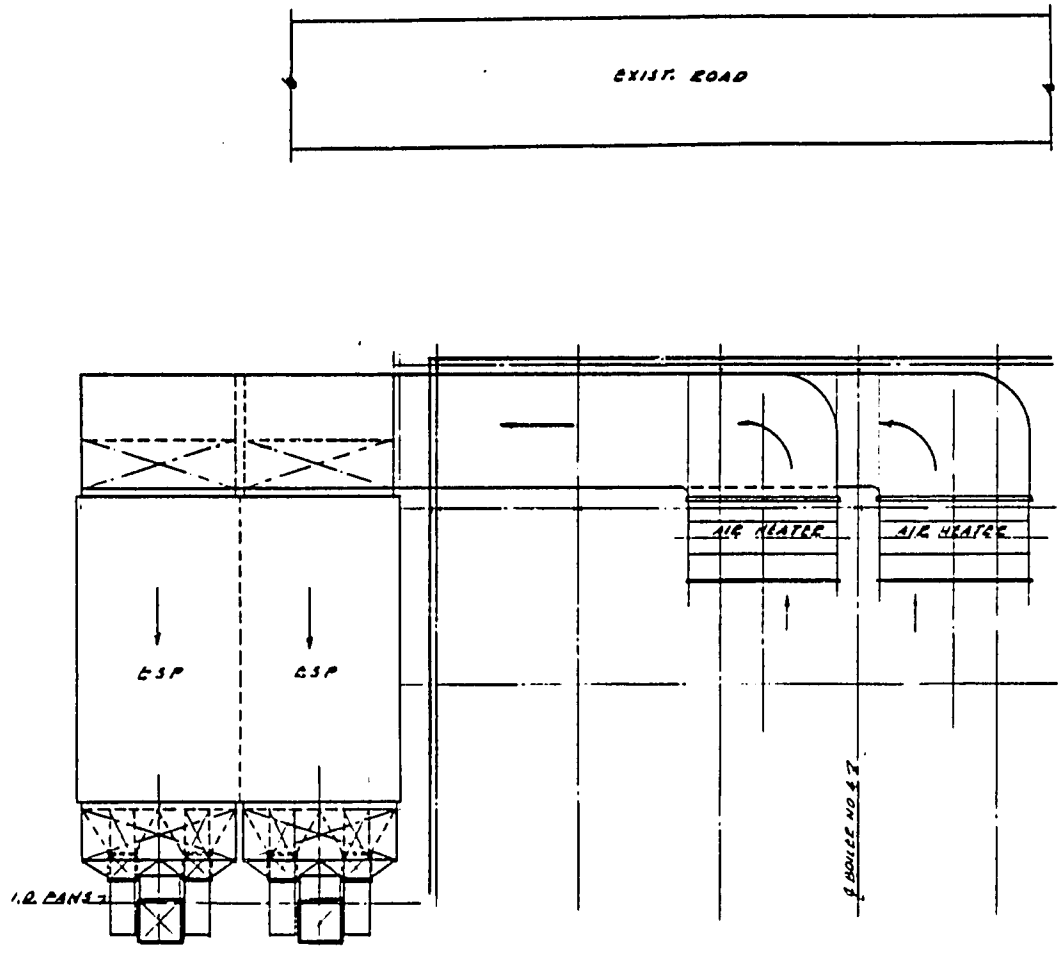


PLAN

ELEVATION A-A

ELECTROSTATIC PRECIPITATORS - UNITS 2, 3 AND 1

FIGURE 4-9



ELECTROSTATIC PRECIPITATOR - UNIT 4

FIGURE 4-10

Bottom ash is occasionally removed from the furnaces and disposed of in an on-site settling basin. Flyash is taken from the mechanical collectors and disposed of in the same manner. The converted units will require ash handling systems of much greater capacity. In addition, the ash will be removed from the site by truck or barge for disposal or sale.

4.4.3.1 Bottom Ash System

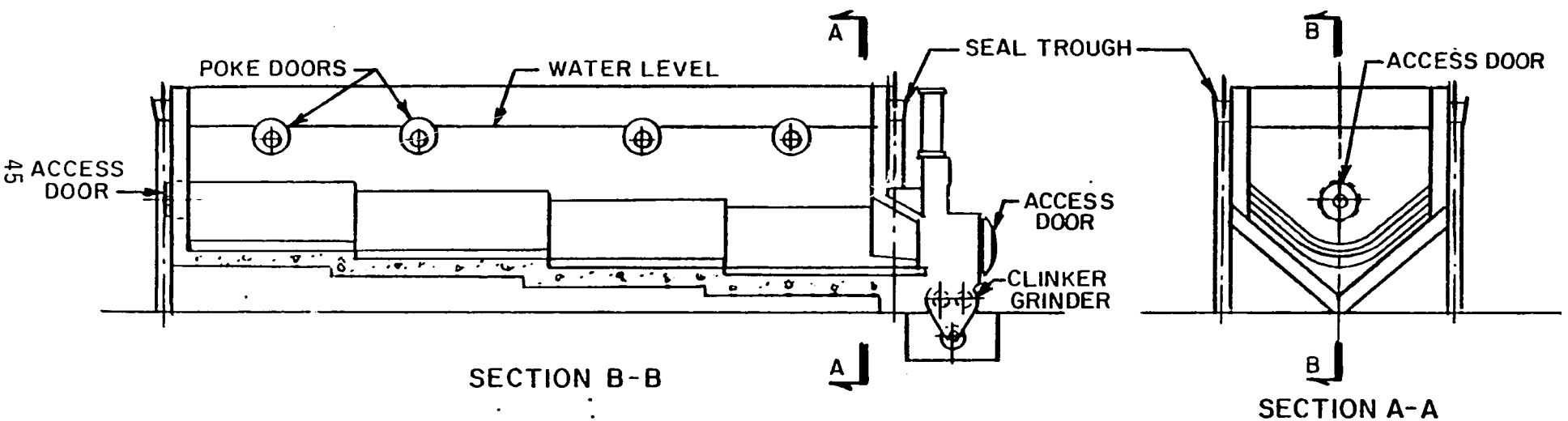
The most widely used system for bottom ash removal from coal-fired steam generators in the US is to store the ash from 4 to 8 hours in a refractory lined hopper and then sluice it out of the hopper with gravity assist. The ash is discharged through clinker grinders to facilitate transport. The ash-water slurry is then moved from the boiler area by means of jet or centrifugal pumps. This system is very reliable but uses large amounts of power and water. The water impounded ash hopper system transports the ash in a slurry form. Slurry piping can be routed to the ash disposal area by any convenient path.

A submerged scraper conveyor system, used extensively in Europe and lately introduced in the U.S. uses less power and water, and requires less head room. The submerged scraper conveyor removes bottom ash on a continuous basis. It requires availability of space around the boiler to accommodate the additional conveyors that take the ash to the disposal area. Although scraper conveyors could be accommodated under the Sucat boilers (within pits excavated for Unit 1 and for the other units for major conversion), transportation of the bottom ash from the scraper conveyors to the bottom ash storage tanks presents difficulties. Conceptual designs and an optimization study is recommended to determine the best system for Sucat.

A practical solution for immediate purposes is to use water impounded stepped end discharge hoppers (see Figure 4-11) with water jets located at the bottom to assist ash flow towards the discharge end. Each bottom ash hopper will have capacity sufficient to hold 4 hours of ash at full load operation. Two clinker grinders and an ejector feed sump are located at the discharge end. The cost estimates and plant arrangement in this study are based on the use of a sluicing system.

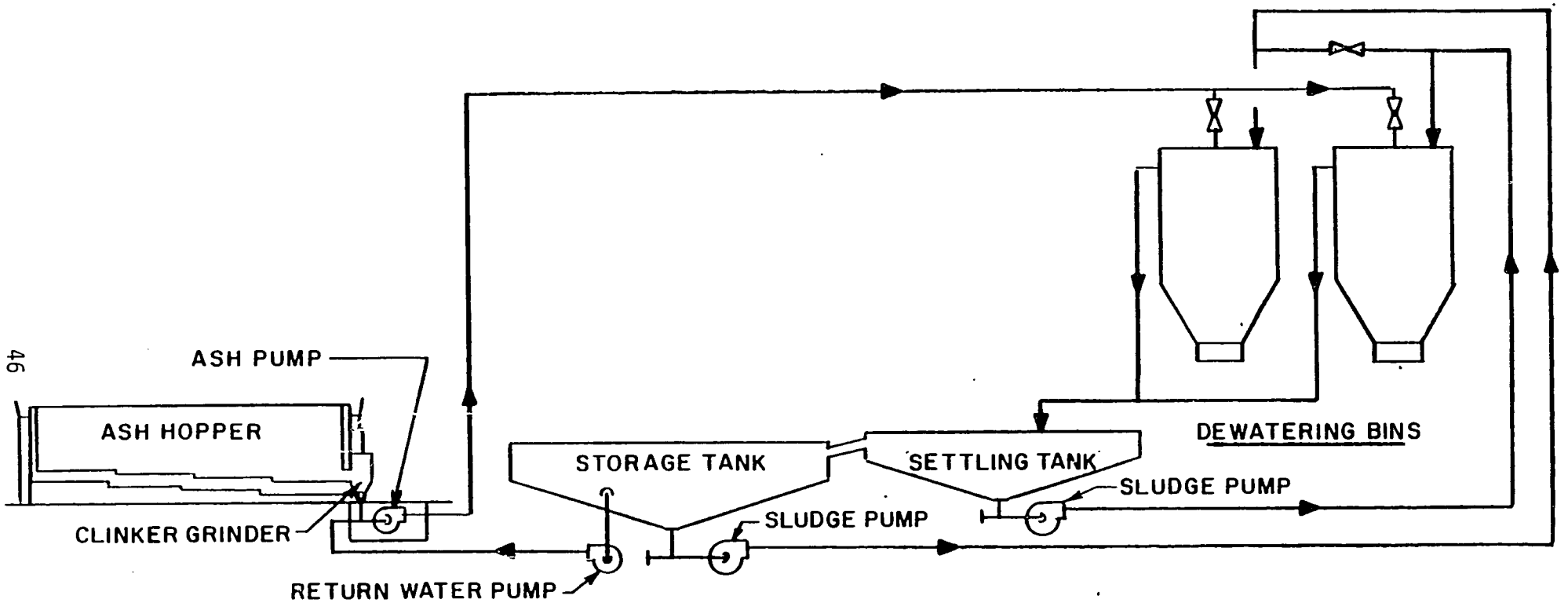
The bottom ash storage system will consist of two dewatering bins, an ash settling tank and a water storage tank. These tanks will be sized initially to accommodate the ash production expected from major conversion of Units 2 and 3. Upon conversion of Unit 4, an additional dewatering bin will be provided to augment the storage capacity for Units 4 and 1. The ash will be removed by truck for off-site disposal.

The bottom ash system (Figure 4-12) will operate as follows. The bottom ash slurry collected in the ejector feed sump will be conveyed by a jet stream to two dewatering bins located in the storage area next to the present fuel oil tank farm. The dewatering bins will serve the dual purpose of separating the ash from the conveying water and holding the ash for removal by truck to a disposal site. The two bins will have sufficient capacity to store about 3 days of full load bottom ash production. Since



BOTTOM ASH HOPPER FOR END DISCHARGE

FIGURE 4-11



BOTTOM ASH HANDLING SYSTEM

FIGURE 4-12

it is necessary to conserve water and limit the discharge of any ash contaminated water into the lake, a fully closed recirculating system will be provided to permit reuse of a large percentage of the conveying water.

Overflow from ash hoppers and dewatering bins will be caught in a settling and storage tank system. Water will be first allowed to enter a shallow settling tank of a diameter substantially greater than the dewatering bins. This will permit greater weir length so that overflow velocity is further reduced and fine particles which escaped from the dewatering bins can drop out and be recovered as sludge. The water finally will be drained to a storage tank for reuse.

Water will be returned to the ash conveying system by centrifugal type transfer pumps. High pressure sluice water pumps will be used to convey the ash slurry from the ash hoppers to the dewatering bins. Low pressure, continuous service pumps will be used to supply water seals, refractory and hopper cooling, window washing, clinker grinder and pump seals. For the latter sealing requirements, automatic self-cleaning filters will be used to remove the small amount of particulate matter that may be in the stored water.

Sludge accumulations in the settling and storage tanks will be returned continuously at a low rate to a dewatering bin, preferably the one into which ash is being pumped. Continuous withdrawal from these tanks during an ash handling cycle will prevent a sludge buildup in the tank bottom.

Since the water volume in the settling tank remains constant while the volume in all other vessels varies during different phases of operation, an emergency bypass will be installed between the settling tank and the storage tank to provide needed water in the event of temporary failure of outside makeup.

Makeup from plant service water will be provided to restore the water lost with the bottom ash discharged from the dewatering bins. If required, water from this system will also be used to condition fly ash before it is discharged from the silo to barges or trucks. This water will be supplied by a pump at the storage tank having sufficient capacity and pressure to operate the dustless unloaders. Makeup will be added at the storage tank.

The closed-loop recirculating system may show a marked change in the pH of the recirculated water although this will be tempered because of the amount and quality of outside makeup that must be added. Nevertheless, some ash is very high in basic compounds, therefore, a monitoring system will be provided and chemical additives to maintain recirculated water as neutral as possible in order to keep pipe scaling to a minimum.

Since it may be possible to sell fly ash as concrete additive, the economizer and air preheater hopper ash, which normally contains larger particles, will be handled and disposed of with the bottom ash system.

4.4.3.2 Fly Ash System

The fly ash will be removed from the hoppers of the electrostatic precipitators with a pressurized pneumatic conveying system and transported to fly ash silos located near the bottom ash tanks. These silos will be sized to provide about 3 days storage at full load operation and will be constructed of concrete. Each silo will be provided with an opening to fill trucks for ultimate off-site disposal. Dust suppression systems will be provided at each truck loader. Provisions can be made to transport the flyash by barge, should customers be found bordering the lake.

Three independent silos will be constructed to store the fly ash produced by all four units. The conversion of Unit 2 will require the construction of one silo 32 ft in diameter and a total height of about 65 ft. The other three units will require two more silos, 32 ft in diameter with total heights of 75 ft.

4.4.3.3 Ash Disposal

Operating on Semirara CWM fuel, Unit 2 will produce about 100,000 tonnes of ash per year. All four Sucat units converted to CWM fuel are expected to produce about 400,000 tonnes of ash per year. There is no available real estate for disposal of this ash on site. To store the ash produced by firing CWM for 15 years in all four Sucat units will require a landfill area of about 400,000 sq.m. Among the options to be investigated for ash disposal are:

- trucking to a landfill
- barging to a disposal area
- creating a diked area near the shores of Laguna de Bay for deposit (may require an impermeable layer of clay and/or plastic liner below and around the ash fill areas to prevent leachates from contaminating the lake)
- selling some segregated ash either as a cement additive (fly ash), or as fill/stabilizer material for road construction (bottom ash).

High quality, marketable fly ash is defined as a fly ash that can be used as a concrete additive. In the US the quality requirements are specified in ASTM C-618, "Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for use as Mineral Admixture in Portland Cement Concrete." Testing of fly ash is specified in ASTM C-311, "Standard Methods of Sampling and Testing Fly Ash or Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete." Other standards, or methods agreed to with fly ash purchasers, could be used for quality control purposes.

Study cost estimates assume disposal of all ash off-site via trucking or barging.

4.4.4 Civil/Structural

Available information indicates that the plant foundations are supported on 14 inch square prestressed concrete piles. All new foundations will be supported in the same manner.

New foundations will be required for the new CWM fuel storage tanks, bottom ash dewatering bins, storage and settling tanks as well as the flyash silos. The new induced draft fans and electrostatic precipitators will also require new foundations. A number of other tanks will be added or relocated, also requiring foundations.

Excavation will be required under the furnaces to accommodate the bottom ash hoppers in some of the conversion cases. These excavations can, in some cases, begin prior to the shutdown of the boiler. Both major and minor conversion of Unit 1 will require excavation. Preliminary investigations indicate that for minor modification of the other three units, bottom ash hoppers could be installed without excavation. Excavation under the furnaces will have to be done manually with the aid of pneumatic tools, since there is not sufficient headroom for excavation equipment.

For units 2, 3 and 1, the precipitators, fans and ducts are proposed to be located in the narrow strip of land east of boilers between the plant and the north-south road along the discharge channel. Presently, there are small tanks located in this area. To minimize the relocation of the existing tanks and service structures and to maintain clearance between the road and the precipitator duct which may project over the road, the precipitator will be supported on a steel framework at least 23 feet high to the hopper support line.

The electrostatic precipitators will be supported on new steel framework separate from the existing boiler steel. The effect of major steam generator modifications on the boiler structural steel will have to be evaluated. The capital cost estimates include provisions for reinforcing the boiler steel.

Conversion of existing oil storage tanks to CWM fuel service will require addition of a supporting structure that will change the tank from floating roof to fixed roof construction and addition of a supporting structure for mounting agitators.

4.4.5 Electrical

Conversion of Sucat 2 and 3 to fire CWM is expected to result in an auxiliary load increase of approximately 1650 kVA for each unit above the present maximum auxiliary load. This increase is primarily due to the additional power consumption of the electrostatic precipitators, the ash handling systems and the CWM fuel handling and storage systems. Secondary auxiliary load increases will be due to support services in CWM and ash handling areas such as lighting and ventilation. The additional auxiliary load for Unit 4 is 1900 kVA. The conversion of Unit 1 will result in an additional 1250 kVA of electrical load.

The present station service transformer for Unit 2 was manufactured by Siemens and is rated 17 MVA, self-cooled OA with 55° C temperature rise above ambient. Based on the present maximum auxiliary load of 6.6 MW, substantial spare capacity is available from the existing transformer. Therefore, no station service transformer modifications or additions appear to be necessary for conversion to CWM firing. The station service transformer for Unit 3 is also sufficient for conversion to CWM. It was also manufactured by Siemens and is rated 17 MVA, forced oil and air (FOA) type. The Unit 4 station service transformr is rated 18.75 MVA and also appears to be adequate for the conversion. The transformer for Unit 1 was manufactured by General Electric. It is rated at 10 MVA and is also adequate for the conversion.

The Unit 2 startup and emergency power supply is from Unit 1, 12 MVA startup transformer via 4160V Bus C. The transformer capacity appears adequate to carry the full load auxiliaries of one unit and the startup load of the other unit even after the Unit 2 CWM conversion. However, if this transformer is required to be capable of supplying the entire full load auxiliaries of both units simultaneously (which appears to be the case prior to CWM conversion), then cooling fan additions are recommended. In addition, CWM conversion of both units 1 and 2 would also require the addition of transformer cooling fans. The transformer's original design included provisions for future addition of fans.

In light of the relatively low cost of adding forced air (FA) cooling to the existing Emergency Station Service Transformer, it is recommended that the modifications be performed as part of the CWM conversion. The addition of fan cooling will increase the capacity of the Emergency Station Service Transformer to 16 MVA which will be more than adequate to supply all existing auxiliaries and the new CWM associated loads.

The Unit 3 startup and emergency supply is from the 15 MVA Common Emergency Station Service Transformer via 4160 V Bus E. This transformer also supplies startup and emergency power to Unit 4. This transformer will be adequate for the conversion.

The existing Unit 2 and 3 4160V switchgear with 2500 A main bus appears adequate to supply new CWM firing loads in addition to the existing plant full load auxiliaries. Busses A and D will be extended to include two new 4160 V circuit breakers which will be provided with auxiliary contacts, metering and relaying similar to the existing devices. The Unit 4 4160 V switchgear with 2000 A main bus (Bus F) capacity will be adequate for the conversion. The Unit 1 4160 V switchgear is also adequate for the conversion.

Two new unit substations will be added for the CWM conversion. The additions include an estimated 500 kVA unit for the CWM unloading and storage area and a 350 kVA unit for the boiler/precipitator area. As these loads are relatively small, it is intended to supply both unit substations from a single 4160 V feeder from Bus A. The feeder would extend from Bus A to the boiler/precipitator area unit substation and then on to the CWM tank area. Both unit substations would be provided with a primary fused switch,

oil filled transformer and secondary (277/480 V) switchgear and motor control section. Unit substations would be of weatherproof design and installed outdoors.

A primary oil switch will be provided for the boiler/precipitator area unit substation which will permit sectionalizing of the 4160 V feeder.

Power cables for 4160 V service will be rated 5kV and will be single conductor, stranded tinned copper with semiconducting tape, cross linked polyethylene insulation, tinned copper shielding tape and fire retardant, abrasion resistant jacket.

Power cables for 480 V service and below will be rated 600 V and will be single conductor, stranded tinned copper with polyethylene insulation and fire retardant, abrasion resistant jacket.

Control cables will be rated 600 V and will be multi-conductor, stranded tinned copper with color coded polyethylene insulation and a fire retardant, abrasion resistant overall jacket. Fillers, where used, will be non-hygroscopic. Cables will be two, three, four, seven or twelve conductor #12 AWG for general control circuit use and four conductor #9 AWG for control transformer secondary circuits.

Cable for general lighting and convenience power use will be rated 600 V, 75°C and will be single conductor, solid copper with moisture and heat resistant thermoplastic insulation.

Outdoor, 4160 V circuits will be run in rigid steel conduit on existing pipe racks where available. Where rack routing is not feasible or is impractical, 4160 V circuits will be routed below grade in duct banks of fibrous conduit encased in reinforced concrete. All other circuits will be installed in cable tray or galvanized rigid steel conduit. Liquid-tight flexible conduit will be used for raceway connections to motors and other vibration producing equipment.

Lighting will be provided at equipment and in areas requiring operator attention. Lighting will be supplied from local low voltage panelboards and will in general be by stanchion mounted luminaires.

The existing plant communications system will be expanded to include . new CWM work area.

4.4.6 Instrumentation and Controls

4.4.6.1 General

Conversion to CWM fuel will require modifications and additions to the existing plant instrumentation and controls in three major categories:

- o steam generator subsystems: burner management, steam temperature control, fan controls, combustion control and sootblower control.

- CWM fuel systems: fuel unloading, storage, transfer and burner feed

- balance of plant auxiliary systems: electrostatic precipitator, ash handling, compressed air and cooling water

The design of the instrumentation and controls will be such as to permit operation either on CWM or on fuel oil. Start-up and warm-up will always be on oil. The units will retain the capability to operate in a load following mode.

Instrumentation and controls will be designed for minimum possible cost while maintaining functionality. The system will be designed to allow convenient test of equipment components and fuel properties as part of the conversion program. The control system will use the latest state of the art distributed control components communication over a redundant data highway. Existing instrumentation that is suitable and in good operating condition will be used wherever possible.

4.4.6.2 Sucat Unit 2

The present control system is a Bailey Meter pneumatic control system that performs the following functions:

Automatic Combustion Control
Throttle Steam Pressure Control
Remote Throttle Pressure Set Point Control
Fuel-Air Ratio Control
Steam-Air Flow with Oxygen Trim
Boiler Purge Interlocks for Startup

The controls are located on a BTG board in a common control room. The board houses the required indicators and recorders for monitoring plant operation. The bench section of the BTG board houses all the required equipment switches and the Bailey manual/automatic (H/A) stations. At the top of the board is the plant annunciator system consisting of 148 points.

A distributed control system (DCS) will be added to control CWM transfer. This DCS will interface with the sootblower system, and the burner management system to report any critical alarms or react to trips. The sootblower and burner management systems will be controlled from their own insert panels which will be located in the main control room. In addition to this, the DCS will provide the combustion control system, furnance pressure controls, air/fuel controls, and the steam temperature controls which are designed for CWM firing.

Since certain instrumentation used to control CWM firing can also be used for oil firing, the combustion controls for oil firing will be upgraded and integrated into the DCS. The new capability will reflect the latest codes, as applicable.

All new control room instrumentation and controls will be installed on a new console in the main control room. The console will house the opera-

tor's CRT's and keyboards. The burner management and turbine control inserts will also be housed on this control. All controls and monitoring of the power plant will be accomplished through the CRT interface. Important controls and H/A stations will have "hard" backup mounted on the console.

The present burner management hardware will be replaced with a new system designed to operate on either CWM or fuel oil. The new system will interface with the DCS. A major modification of the existing sootblower system will be required, including the expansion or replacement of the controls.

The controls for the CWM handling system will be as follows:

The pumping of CWM from the main storage tanks to the day tank will be accomplished locally. Switches and lights for the operation of the transfer pumps will be provided. A local panel will be provided which will also contain indicators and alarms for high strainer differential pressure. The panel will provide for local operator control and monitoring of the entire process of transferring the CWM to the day tanks.

The remainder of the CWM fuel handling system, from the day tanks to the burners, will be controlled from the CRT-based DCS. The CRT will contain a graphic representation of the system's flow paths, showing all tanks, pumps, strainers, heaters, etc. The main control room operator will be able to start pumps, monitor flows, temperatures, etc., from the CRT and keyboard. The CRT will use "soft" H/A stations. All of the system's associated alarms will be scanned and alarmed through the DCS on the CRT.

An emission monitoring system will be provided to measure opacity, SO_2 and NO_x. This system will have a dedicated data reduction system that will have the capability to produce the required reports. Controls and instruments for the electrostatic precipitator, bottom ash and flyash systems will be supplied by the equipment manufacturers. All controls will be located in new auxiliary control centers located near the equipment they serve. The bottom ash sluice pumps, air operated valves, and clinker grinders will be operated on a pre-programmed basis. Flyash removal from precipitator hoppers and conveying to the flyash silo will be by a preprogrammed automatic control system with manual override.

4.4.6.3 Sucat Units 3, 4 and 1

The modifications and additions to the Sucat Unit 3, 4 and 1 instrumentation and control systems will be similar to those proposed for Unit 2. The CWM fuel unloading, storage and transfer systems will be common to all units. These systems will be first built for Unit 2 and then expanded as needed to accommodate the increased fuel use requirements. The bottom ash temporary storage, dewatering and water recovery systems will also be common to all units. The instrumentation and controls to Unit 2 CWM storage and transfer and for the bottom ash system will be designed to permit future expansion.

4.5 Initial CWM Fuel Conversion

4.5.1 Approach

Most experimental and development work to date on CWM fuel technology has been based on highly loaded (about 70% solids) slurries made from bituminous coals. Demonstration firing in industrial and small utility steam generators produced good results. Conversion to CWM of the Sucat units, firing moderately loaded slurries (about 50% solids) made from lower rank, subbituminous Semirara coal requires an extrapolation from existing experience. The first step taken in the direction of reducing these uncertainties was to test five small quantities of CWM made of Semirara coal in a small furnace at Brookhaven National Laboratories. (See description of test results in Volume II). The CWM fuel burned with a steady flame without any support fuel.

The next step would be to fire Semirara CWM fuel on a larger scale using a commercial size burner and under conditions approaching the Sucat steam generator furnace operating conditions.

A third step could be to convert Sucat 2 in two phases. Upon completion of the first-phase conversion, the unit would be operated on CWM for a period of about 6 to 12 months on a demonstration-test basis. CWM fuel handling, storage, combustion, and equipment performance and operating characteristics would be tested and evaluated. Following the completion of the demonstration-test program, further permanent retrofit work will be made to the Sucat 2 unit to correct deficiencies observed during operation and to add the equipment not installed originally but necessary for long term operation on CWM. The experience gained during the demonstration-test operation will be used in the engineering and design of second-phase modifications.

4.5.2 Modification of Sucat 2

In order to defer some capital investment and acquire firm design data before larger investments are made, a two-phase approach for modification of Sucat 2 is a possible scenario. The first phase would consist of a minor steam generator modification (see 4.2.2.1) leaving the unit as pressurized draft type. Dumpsters would be used for bottom ash collection. It aims at lowest initial investment provided safety and reliability of operation are not impaired.

The largest cost item would be for air pollution controls (addition of an electrostatic precipitator and a fly ash handling system). Should the National Pollution Control Commission (NPCC) allow temporary operation on CWM fuel without addition of an ESP the cost and duration of the first-phase implementation would be drastically reduced. An added advantage of delaying installation of the ESP would be the ability to collect design data during the demonstration test period which would then be used to design the ESP. (It is worthwhile to mention, that for its COM fuel demonstration at Sanford 4, Florida Power and Light Co. obtained a one year

variance from the US EPA and State of Florida Department of Environmental Regulation. It is believed that for a CWM demonstration at Sanford 4 a similar variance would be given.)

Should permission for temporary operation without an ESP be given, the existing dust collectors will be repaired and their present ash collection system will be refurbished. The steam generator will continue to operate with pressurized furnace and no modifications or additions will be made to the draft system. The furnace hopper throat opening will be modified to ease bottom ash removal. The existing 18 burners will be replaced with new dual fuel CWM/oil firing burners each with new ignitors, scanner and scanner cooling system. All required sootblowers and wall blowers will be installed and a new sootblower control panel will be added. Modifications to the secondary pendant superheater and to the finishing reheater will be made to reduce the hazard of pluggage and fouling of these surfaces.

Only one of the existing 55,000 bbl storage tanks will be modified for CWM service. Otherwise, the CWM handling equipment required for the "minor modification" will be installed. For bottom ash collection, dry dumpsters will be installed, rather than a wet sluicing system. Fly ash will be collected from the dust collectors and stored in a temporary silo, from which it will be trucked away for disposal. A new burner management system will be provided. The present combustion controls and other instruments and controls will be refurbished.

Upon completion of the demonstration-test period, the second phase of Sucat 2 modification will be carried out by installing the additional equipment and systems necessary for operation on CWM fuel.

4.6 Construction Schedules

4.6.1 General

Preliminary construction schedules were developed for the conversion of Sucat 2 to CWM firing. Construction schedules for the other Sucat units were derived by making appropriate adjustments to the Sucat 2 schedules. The Sucat 2 schedules are also used as the basic building blocks for modification of the entire Sucat station to CWM firing.

4.6.2 Modification of Sucat 2

Two steam generator modification alternatives were investigated for Sucat 2. The "minor modification" is designed for lowest capital cost, while "major modification" is designed to achieve least unit derating.

For each modification alternative, preliminary construction schedules were developed, with and without addition of electrostatic precipitators. These schedules are presented on Figures 4-13 and 4-14. The schedules show the time periods required for engineering and design, for procurement activities, manufacture, delivery and installation of major equipment and systems. The schedules assume that preliminary conceptual designs and optimization studies were complete before month 0 which is the date of

CONSTRUCTION SCHEDULE - CWM CONVERSION

SUCAT UNIT NO. 2 - MINOR MODIFICATIONS

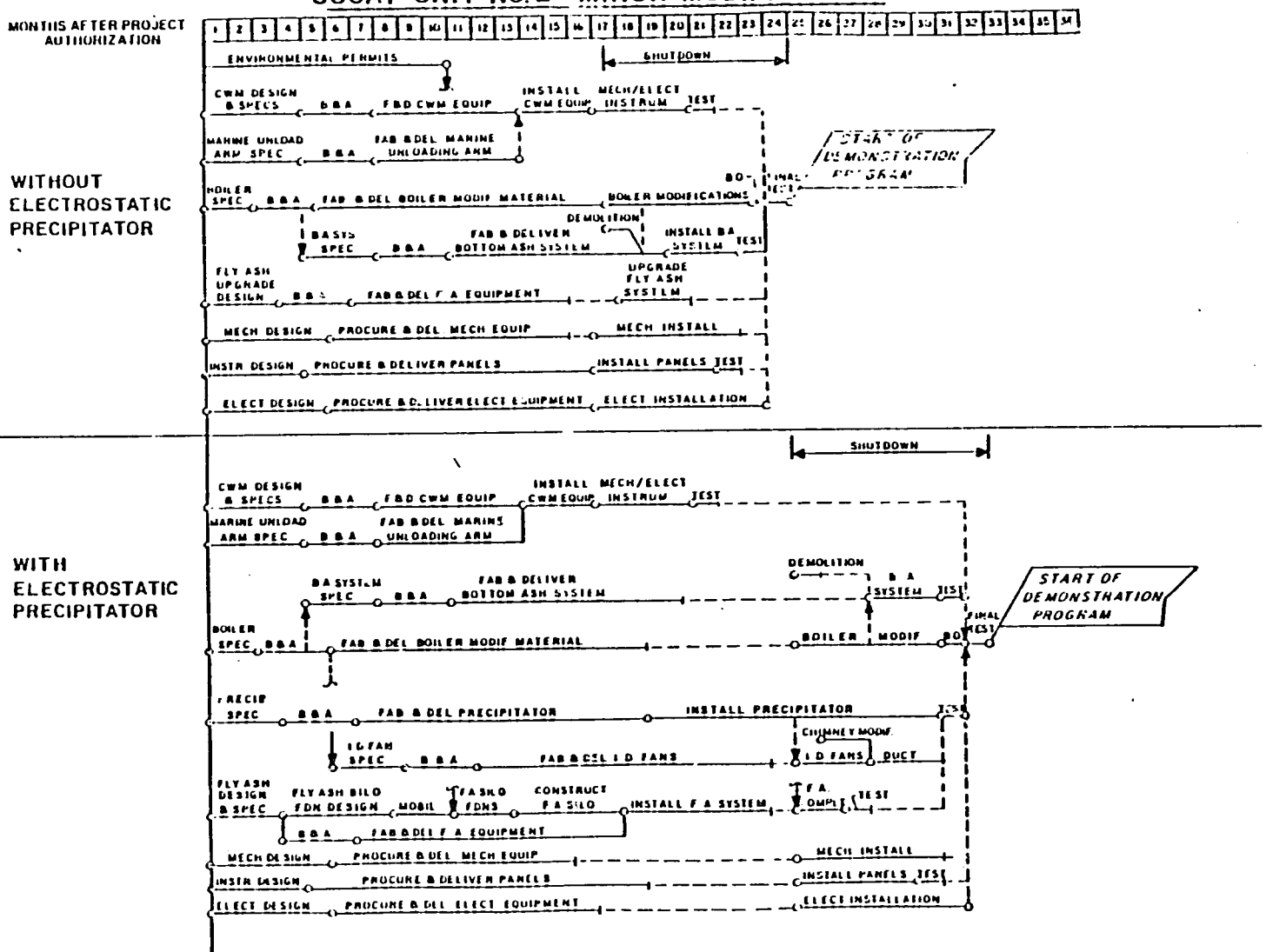


FIGURE 4-13

CONSTRUCTION SCHEDULE - CWM CONVERSION
SUCAT UNIT NO. 2 - MAJOR MODIFICATIONS

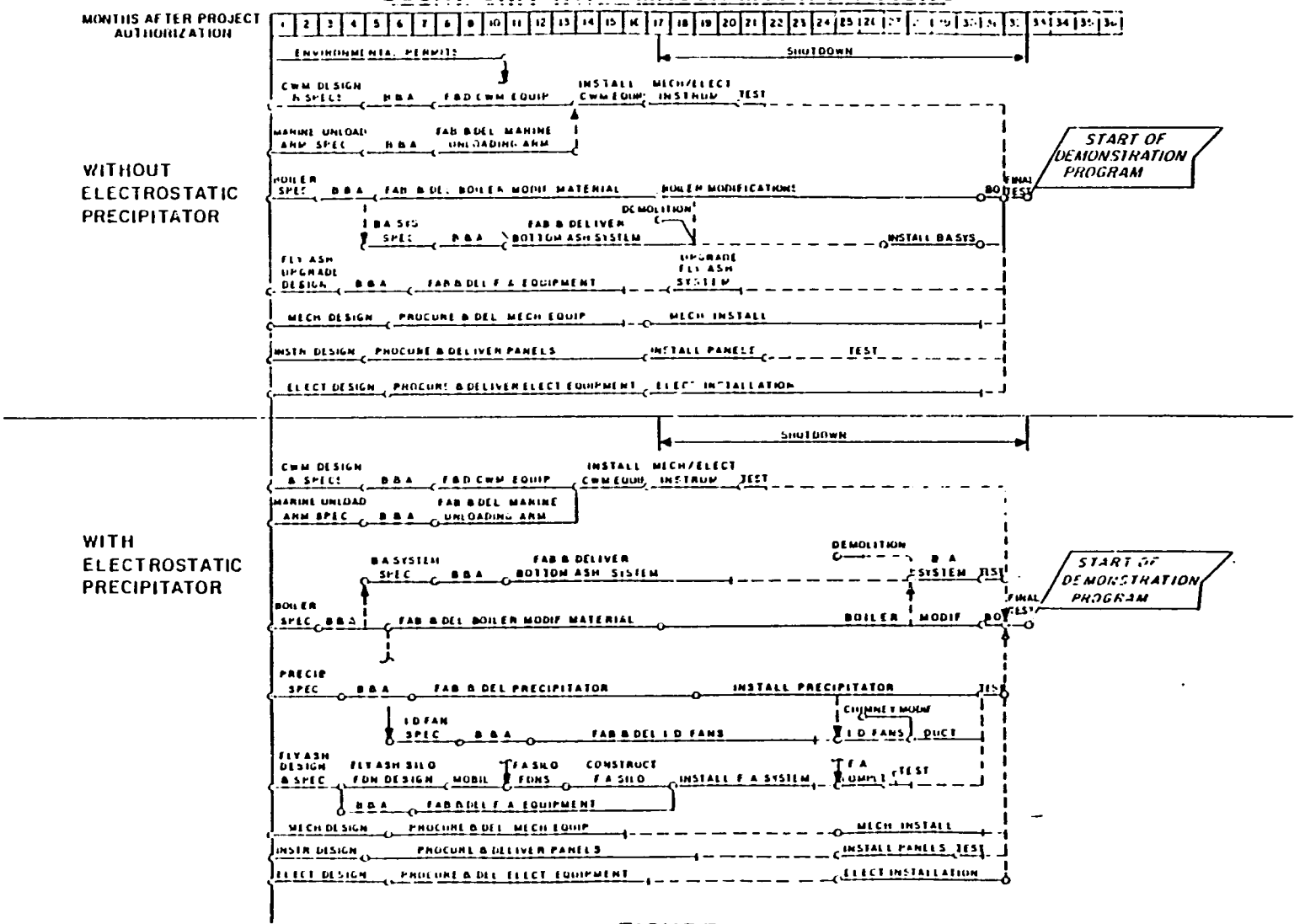


FIGURE 4-14

authorization to proceed with implementation of the project. It is further assumed that all required environmental permits are obtained within the first 10 months of the project and field construction activities can commence thereafter.

The schedules are based on recent experience in conversion of oil designed units to coal firing at Kwinana, Australia and Honam, South Korea, taking into account labor productivity in the Philippines and the differences in complexity of work for major equipment and systems. The schedules are based on fast track procurement and construction activities. Field work will be on a two shift basis with careful coordination between craft activities to keep pace with the requirements of a relatively tight schedule. Construction activities be carried out to the greatest extent possible while the units are still in operation. Each unit will be shut down for about eight months to complete a minor modification and sixteen months for the major modification. Erection of the electrostatic precipitators and the steam generator modifications are on the critical path.

Minor modification of Unit 2 can be completed in 24 months without an electrostatic precipitator and in 32 months with addition of a precipitator. A major modification of Unit 2 requires 32 months regardless whether an electrostatic precipitator is installed or not.

4.6.3 Two-Phase Modification of Sucat 2

The first phase consists of a minor steam generator modification, leaving the unit as pressurized draft type (induced draft fans are not provided). The existing dust collectors are left in place and dumpsters are used for bottom ash collection. The first phase, without an ESP, has a duration of two years, after which the unit is operated on CWM fuel.

Performance and operating data are collected during the first six months of CWM operation, after which a decision should become practical to proceed with the second step which will consist of procurement, delivery and installation of the electrostatic precipitator, the ash handling system and the balance of plant systems. The second phase is completed in about 27 months. During the last 6 months, the unit is shut down to carry out construction activities that can not be performed on an operating unit and to connect the existing and new systems.

The two-phase construction approach for Sucat 2 is shown on Figure 4-15.

4.6.4 Modification of Sucat Units 3, 4 and 1

After satisfactory operation on CWM of Unit 2, conversion of other units follows. The preferred sequence of conversion is Unit 3, followed by Unit 4 and then Unit 1.

Since Unit 3 is generally a duplicate of Unit 2, most of the engineering work done for Unit 2 will also apply for Unit 3 and equipment and material procurement can be made more expeditiously than for the other

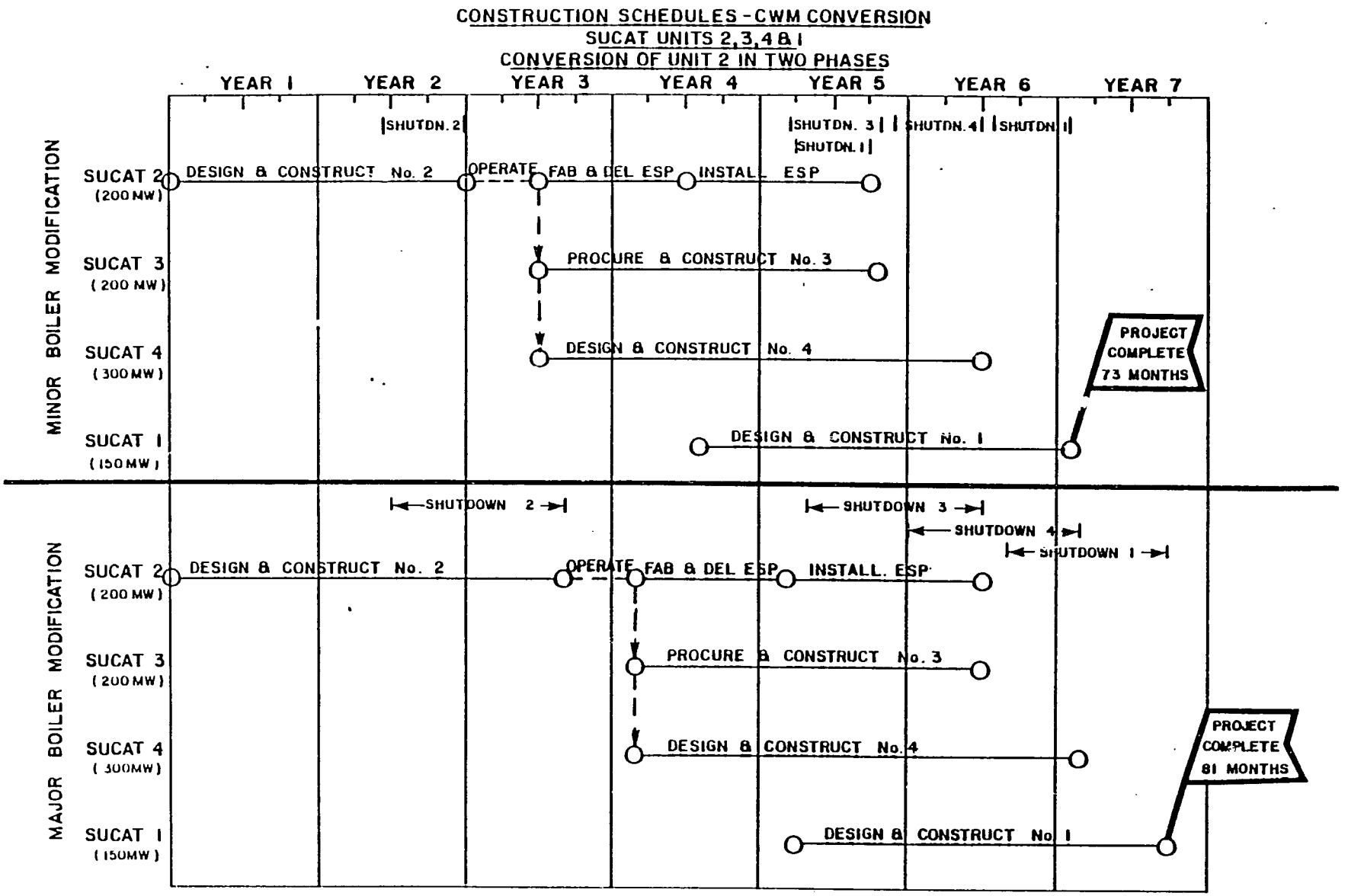

CONSTRUCTION SCHEDULES - CWM CONVERSION
SUCAT UNITS 2,3,4 & 1
CONVERSION OF UNIT 2 IN TWO PHASES
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
MINOR BOILER MODIFICATION
SUCAT 2 (200 MW)
SUCAT 3 (200 MW)
SUCAT 4 (300 MW)
SUCAT 1 (150 MW)
SHUTDN. 2
SHUTDN. 3
SHUTDN. 4
SHUTDN. 1
DESIGN & CONSTRUCT No. 2
OPERATE
FAB & DEL ESP
INSTALL ESP
PROCURE & CONSTRUCT No. 3
DESIGN & CONSTRUCT No. 4
DESIGN & CONSTRUCT No. 1
PROJECT COMPLETE 73 MONTHS
MAJOR BOILER MODIFICATION
SHUTDOWN 2
SHUTDOWN 3
SHUTDOWN 4
SHUTDOWN 1
SUCAT 2 (200 MW)
SUCAT 3 (200 MW)
SUCAT 4 (300MW)
SUCAT 1 (150MW)
DESIGN & CONSTRUCT No. 2
OPERATE
FAB & DEL ESP
INSTALL. ESP
PROCURE & CONSTRUCT No. 3
DESIGN & CONSTRUCT No. 4
DESIGN & CONSTRUCT No 1
PROJECT COMPLETE 81 MONTHS

FIGURE 4-15

units. Construction schedules for conversion of all four Sucat units are presented on Figures 4-15 and 4-16. The schedules shown on Figure 4-15 for minor and major modification are based on a two step approach for Unit 2. The schedules assume that Units 3 and 4 are modified simultaneously. Overall project duration for all four Sucat units is 73 months for the minor and 81 months for the major modification.

Figure 4-16 presents the overall project schedules for minor and major modifications, based on completion of Sucat 2 before work on the other units is started (single phase approach for Sucat 2). The overall project duration is 81 months for either minor or major steam generator modification scheme.

4.6.5 Accelerated Construction Schedule

The overall construction schedules described previously are based on conversion of Sucat 2 first, and only after completion of a six month demonstration-test period, other units are converted. On that basis, conversion of all four Sucat units will take 81 months. To shorten the overall schedule to 73 months, the accelerated construction schedule as shown on Figure 4-17 could be used. The accelerated schedule differs from the other schedules by an earlier start of engineering and design work on Sucat 3 and 4 and by procurement of major equipment through a two stage procurement process.

Sucat 2 will be modified as previously described. About six months before Sucat 2 is ready for operation on CWM fuel, engineering and design will commence for Sucat 3 and 4. Equipment and material specifications will be prepared and issued for bidding. The bids will then be evaluated and awards will be made for work on the first stage of supply. All equipment and material supply contracts are broken down in two stages. The first stage consists of detailed design, material specification and preparation of material lists. The second stage consists of procurement of materials, fabrication and delivery. The second stage is released to the contractors after Sucat 2 has operated satisfactorily on CWM for about 6 months. At that time, NPC can either release the manufacturers to proceed with stage two of their contract or negotiate required modifications before such release is given. For the last unit to be converted, Sucat 1, engineering design and procurement will start after completion of the six months demonstration-test on CWM at Sucat 2, and all equipment procurement can be made in one step.

4.7 Cost Estimates

4.7.1 Capital Costs

4.7.1.1 Basis of Estimates

Budget type capital cost estimates were prepared for conversion to CWM fuel of each of the Sucat units. The estimates assume that the conversion sequence is as described in section 4.6, namely the first to be converted is Sucat 2, followed by Sucat 3, 4 and 1. Facilities common to several or

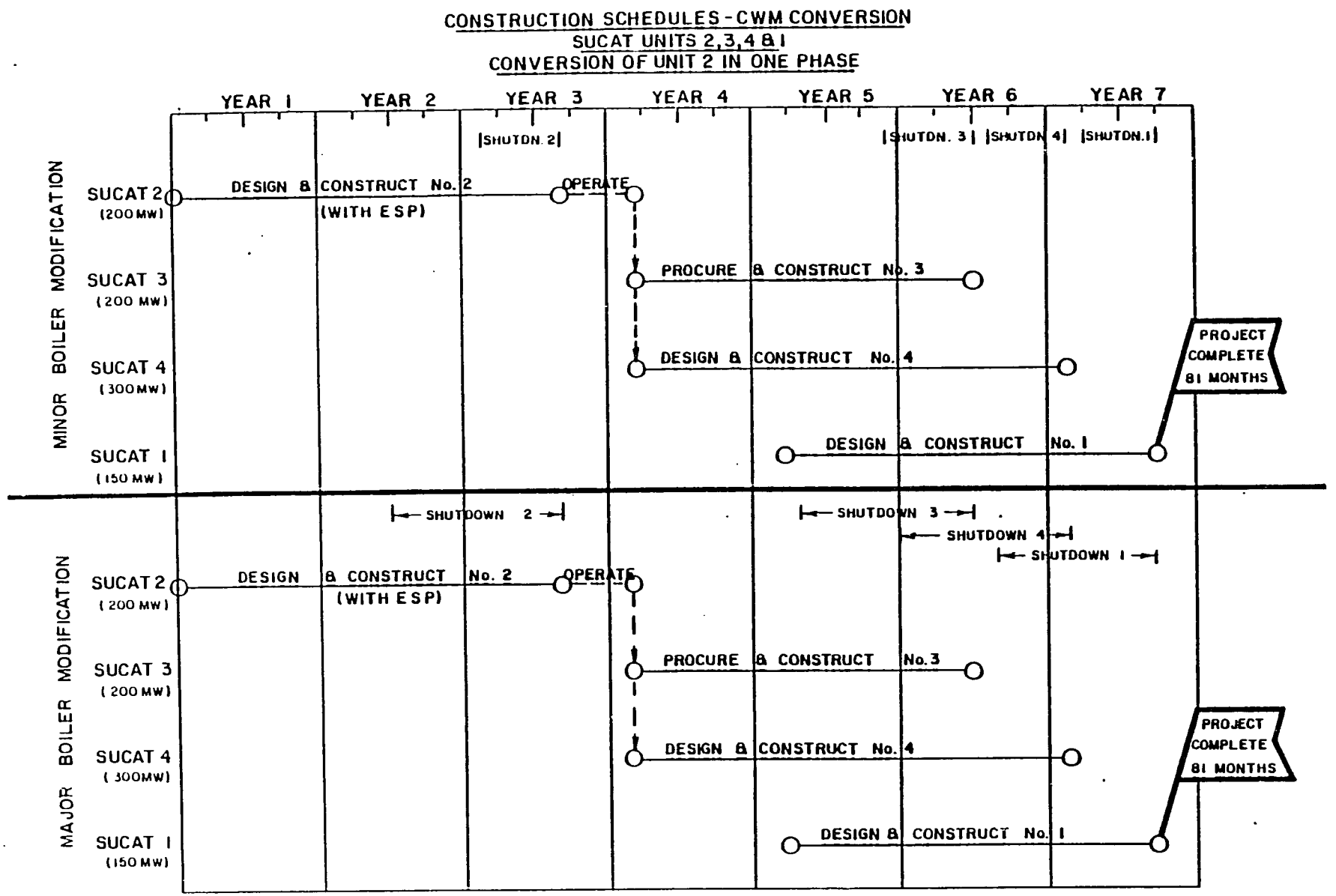

CONSTRUCTION SCHEDULES - CWM CONVERSION
SUCAT UNITS 2,3,4 & 1
CONVERSION OF UNIT 2 IN ONE PHASE
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
MINOR BOILER MODIFICATION
SUCAT 2 (200 MW)
SUCAT 3 (200 MW)
SUCAT 4 (300 MW)
SUCAT 1 (150 MW)
SHUTDN. 2
SHUTDN. 3
SHUTDN 4
SHUTDN. 1
DESIGN & CONSTRUCT No. 2 (WITH ESP)
OPERATE
PROCURE & CONSTRUCT No. 3
DESIGN & CONSTRUCT No. 4
DESIGN & CONSTRUCT No. 1
PROJECT COMPLETE 81 MONTHS
MAJOR BOILER MODIFICATION
SHUTDOWN 2
SHUTDOWN 3
SHUTDOWN 4
SHUTDOWN 1
DESIGN & CONSTRUCT No. 2 (WITH ESP)
OPERATE
PROCURE & CONSTRUCT No. 3
DESIGN & CONSTRUCT No. 4
DESIGN & CONSTRUCT No. 1
PROJECT COMPLETE 81 MONTHS

FIGURE 4-16

ACCELERATED CONSTRUCTION SCHEDULE - CWM CONVERSION
SUCAT UNITS 2,3,4 & 1
CONVERSION OF UNIT 2 IN ONE PHASE

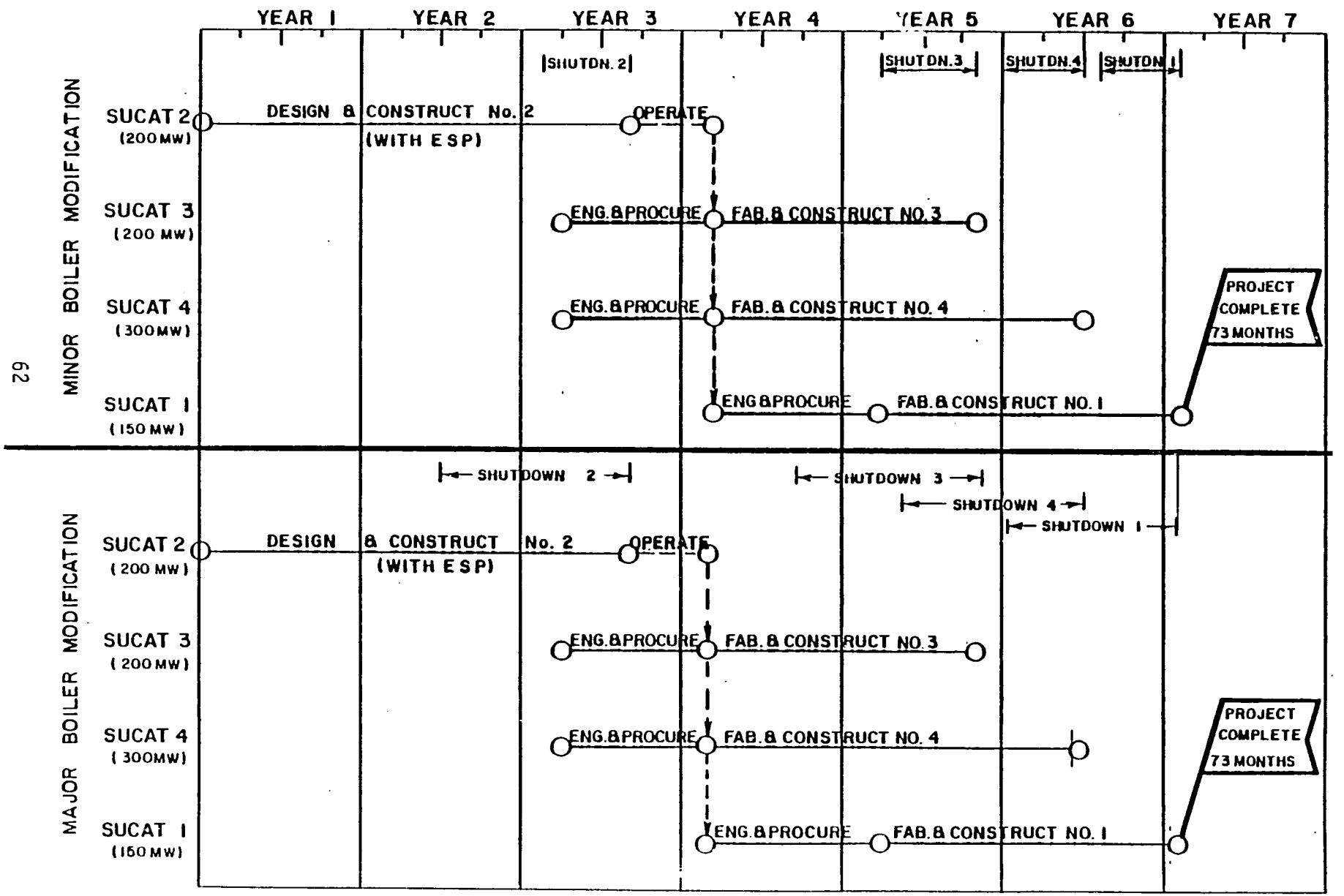


FIGURE 4-17

all units will be built with the first unit converted, hence their cost is borne entirely by the first unit.

The estimates assume that procurement of major equipment and services will be by competitive bidding. The estimates are based primarily on cost data from similar projects, adjusted as appropriate for unit size, escalation and labor rates and productivity in the Philippines. Only limited conceptual design work was carried out in this study. The results of this work were used in making adjustments to available cost data.

Of particular use were the costs on recently completed coal conversion projects at Kwinana, Australia (Units 5 and 6 - 200 MWe each and Units 1 and 2 - 120 MWe each) and at Honam, S. Korea (Units 1 and 2 - 300 MWe each). Data from recent studies for conversion of oil designed units to CWM fuel was also used in estimating the Sucat conversion costs.

4.7.1.2 Summary of Capital Costs

Summaries of the estimated capital costs for conversion of the Sucat units are presented on Tables 4-5 through 4-7 for conversion to Semirara CWM fuel and on Tables 4-8 through 4-10 for the Semirara-Malangas coal blend CWM.

The costs for Unit 2 are presented in two alternatives, corresponding to conversion to CWM in one or in two phases. When work is done in one phase, all required equipment including the electrostatic precipitator is installed prior to commissioning the unit on CWM. The two phase approach is based on an initial conversion as described in subsection 4.5 followed by a demonstration-test on CWM and then a second phase of work when the remaining equipment is installed. Tables 4-6 and 4-9 include installation of an ESP and fly ash system during phase I work. If the phase I work is performed without the ESP and fly ash system, the phase I total plant cost would be reduced by 5.5 million dollars.

The costs are presented in January 1985 U.S. dollars. For each unit a breakdown of direct costs by major systems is also given. Total plant cost include the direct cost; engineering and owner's costs and other direct costs. Total plant costs shown on Tables 4-5 through 4-10 do not include contingencies, escalation during construction, interest during construction and preproduction costs. A breakdown by required currency exchange (foreign or domestic) is also given for each case presented.

4.7.1.3 Construction Expenditure Curve

For conversion of the Sucat units to CWM, a generalized construction expenditure ("S") curve was developed. It is shown on Figure 4-18 and in tabular form on Table 4-11. This curve can be used for any Sucat unit to be converted to CWM for which the total project cost and project duration are known. It shows the costs as a percentage of total project cost as a function of construction period expressed as a percentage of total project duration. The curve was derived from actual rates of expenditure on completed coal conversion projects.

TABLE 4-5

CAPITAL COST SUMMARY (JAN 1985 US DOLLARS)

MINOR CONVERSION
(Semirara CWM Fuel)

DESCRIPTION	SUCAT #2	SUCAT #3	SUCAT #4	SUCAT #1
Steam Generator & Aux.	5,000,000	5,000,000	7,000,000	4,000,000
CWM Handling & Storage	1,600,000	1,800,000	1,900,000	1,100,000
Electrostatic Precipitator	2,600,000	2,600,000	4,300,000	2,600,000
Ash Handling & Storage	3,400,000	1,500,000	2,900,000	1,300,000
Misc. Mechanical Systems	500,000	500,000	500,000	300,000
Civil-Structural	700,000	700,000	900,000	400,000
Electrical, Instr. & Controls	2,350,000	2,100,000	2,700,000	1,800,000
Total Direct Costs	16,150,000	14,200,000	20,200,000	11,500,000
Engineering & Owner's Cost	2,400,000	2,000,000	2,800,000	1,800,000
Other Indirect Costs	2,450,000	2,300,000	3,000,000	1,700,000
Total Plant Cost (*)	21,000,000	18,500,000	26,000,000	15,000,000
Breakdown by Currency Exchange:				
Foreign	15,800,000	14,000,000	19,500,000	11,000,000
Domestic (Philippines)	5,200,000	4,500,000	6,500,000	4,000,000

* Total plant costs do not include escalation, contingencies and interest during construction.

TABLE 4-6

CAPITAL COST SUMMARY (JAN 1985 US DOLLARS)

TWO-PHASE CONVERSION UNIT #2
(Semirara CWM Fuel)

DESCRIPTION	SUCAT #2** PHASE I	SUCAT #2 PHASE II	SUCAT #2 TOTAL COSTS	
Steam Generator & Aux.	3,500,000	2,000,000	5,500,000	
CWM Handling & Storage	1,200,000	600,000	1,800,000	
Electrostatic Precipitator	2,600,000	-	2,600,000	
Ash Handling & Storage	1,700,000	2,200,000	3,900,000	
Misc. Mechanical Systems	400,000	200,000	600,000	
Civil-Structural	600,000	200,000	800,000	
Electrical, Instr. & Controls	1,200,000	1,300,000	2,500,000	
Total Direct Costs	11,200,000	6,500,000	17,700,000	
Engineering & Owner's Cost	1,800,000	800,000	2,600,000	
Other Indirect Costs	1,700,000	1,000,000	2,700,000	
Total Plant Cost (*)	14,700,000	8,300,000	23,000,000	
Breakdown by Currency Exchange:				
Foreign	11,000,000	6,200,000	17,200,000	
Domestic (Philippines)	3,700,000	2,100,000	5,800,000	

* Total plant costs do not include escalation, contingencies and interest during construction.

** Assumes ESP and fly ash handling system installed during first-phase.

TABLE 4-7

CAPITAL COST SUMMARY (JAN 1985 US DOLLARS)

MAJOR CONVERSION
(Semirara CWM Fuel)

DESCRIPTION	SUCAT #2	SUCAT #3	SUCAT #4	SUCAT #1
Steam Generator & Aux.	9,000,000	9,000,000	12,000,000	7,500,000
CWM Handling & Storage	2,100,000	1,800,000	2,300,000	1,600,000
Electrostatic Precipitator	3,200,000	3,200,000	4,700,000	2,600,000
Ash Handling & Storage	3,700,000	1,800,000	2,900,000	1,500,000
Misc. Mechanical Systems	500,000	500,000	500,000	300,000
Civil-Structural	1,000,000	1,000,000	1,200,000	900,000
Electrical, Instr. & Controls	2,500,000	2,300,000	2,900,000	2,100,000
Total Direct Costs	22,000,00	19,600,000	26,500,000	16,500,000
Engineering & Owner's Cost	3,200,000	2,900,000	3,500,000	2,000,000
Other Indirect Costs	3,300,000	3,000,000	4,000,000	2,500,000
Total Plant Cost (*)	28,500,000	25,500,000	34,000,000	21,000,000
Breakdown by Currency Exchange:				
Foreign	21,300,000	19,000,000	25,500,000	15,800,000
Domestic (Philippines)	7,200,000	6,500,000	8,500,000	5,200,000

* Total plant costs do not include escalation, contingencies and interest during construction.

TABLE 4-8

CAPITAL COST SUMMARY (JAN 1985 US DOLLARS)

MINOR CONVERSION
(Semirara-Malangas Blend - CWM Fuel)

DESCRIPTION	SUCAT #2	SUCAT #3	SUCAT #4	SUCAT #1
Steam Generator & Aux.	5,000,000	5,000,000	7,000,000	4,000,000
CWM Handling & Storage	1,400,000	1,800,000	1,900,000	1,100,000
Electrostatic Precipitator	2,900,000	2,900,000	4,550,000	2,900,000
Ash Handling & Storage	3,400,000	1,500,000	2,900,000	1,300,000
Misc. Mechanical Systems	500,000	500,000	500,000	300,000
Civil-Structural	800,000	800,000	1,000,000	500,000
Electrical, Instr. & Controls	2,400,000	2,100,000	2,750,000	1,900,000
Total Direct Costs	16,400,000	14,600,000	20,600,000	12,000,000
Engineering & Owner's Cost	2,425,000	2,000,000	2,800,000	1,800,000
Other Indirect Costs	2,475,000	2,300,000	3,100,000	1,800,000
Total Plant Cost (*)	21,300,000	18,900,000	26,500,000	15,600,000
Breakdown by Currency Exchange:				
Foreign	16,000,000	14,100,000	19,900,000	11,700,000
Domestic (Philippines)	5,300,000	4,800,000	6,600,000	3,900,000

* Total plant costs do not include escalation, contingencies and interest during construction.

TABLE 4-9

CAPITAL COST SUMMARY (Jan 1985 US Dollars)

TWO-PHASE CONVERSION UNIT #2
(Semirara-Malangas Blend - CWM Fuel)

DESCRIPTION	SUCAT #2 ** PHASE I	SUCAT #2 PHASE II	SUCAT #2 TOTAL COSTS	
Steam Generator & Aux.	3,500,000	2,000,000	5,500,000	
CWM Handling & Storage	1,200,000	500,000	1,700,000	
Electrostatic Precipitator	2,900,000	-	2,900,000	
Ash Handling & Storage	1,700,000	2,200,000	3,900,000	
Misc. Mechanical Systems	400,000	200,000	600,000	
Civil-Structural	450,000	400,000	850,000	
Electrical, Instr. & Controls	1,300,000	1,350,000	2,650,000	
Total Direct Costs	11,450,000	6,650,000	18,100,000	
Engineering & Owner's Cost	1,800,000	800,000	2,600,000	
Other Indirect Costs	1,700,000	1,000,000	2,700,000	
Total Plant Cost	14,950,000	8,450,000	23,400,000	
Breakdown by Currency Exchange:				
Foreign	11,200,000	6,300,000	18,300,000	
Domestic (Philippines)	3,750,000	2,150,000	5,100,000	

* Total plant costs do not include escalation, contingencies and interest during construction.

** Assumes ESP and fly ash handling system installed during first-phase.

TABLE 4-10

CAPITAL COST SUMMARY (JAN 1985 US DOLLARS)

MAJOR CONVERSION
(Semirara-Malangas Blend - CWM Fuel)

DESCRIPTION	SUCAT #2	SUCAT #3	SUCAT #4	SUCAT #1
Steam Generator & Aux.	9,000,000	9,000,000	12,000,000	7,500,000
CWM Handling & Storage	1,900,000	1,800,000	2,400,000	1,600,000
Electrostatic Precipitator	3,500,000	3,500,000	5,000,000	2,800,000
Ash Handling & Storage	3,700,000	1,800,000	3,200,000	1,500,000
Misc. Mechanical Systems	500,000	500,000	500,000	300,000
Civil-Structural	1,100,000	1,100,000	1,300,000	1,000,000
Electrical, Instr. & Controls	2,600,000	2,400,000	3,000,000	2,200,000
Total Direct Costs	22,300,00	20,100,000	27,400,000	16,900,000
Engineering & Owner's Cost	3,200,000	2,900,000	3,500,000	2,000,000
Other Indirect Costs	3,300,000	3,000,000	4,100,000	2,500,000
Total Plant Cost *	28,800,000	26,000,000	35,000,000	21,400,000
Breakdown by Currency Exchange:				
Foreign	21,600,000	19,500,000	26,300,000	16,000,000
Domestic (Philippines)	7,200,000	6,500,000	8,700,000	5,400,000

* Total plant costs do not include escalation, contingencies and interest during construction.

CONSTRUCTION EXPENDITURE CURVE

CONVERSION TO CWM FUEL

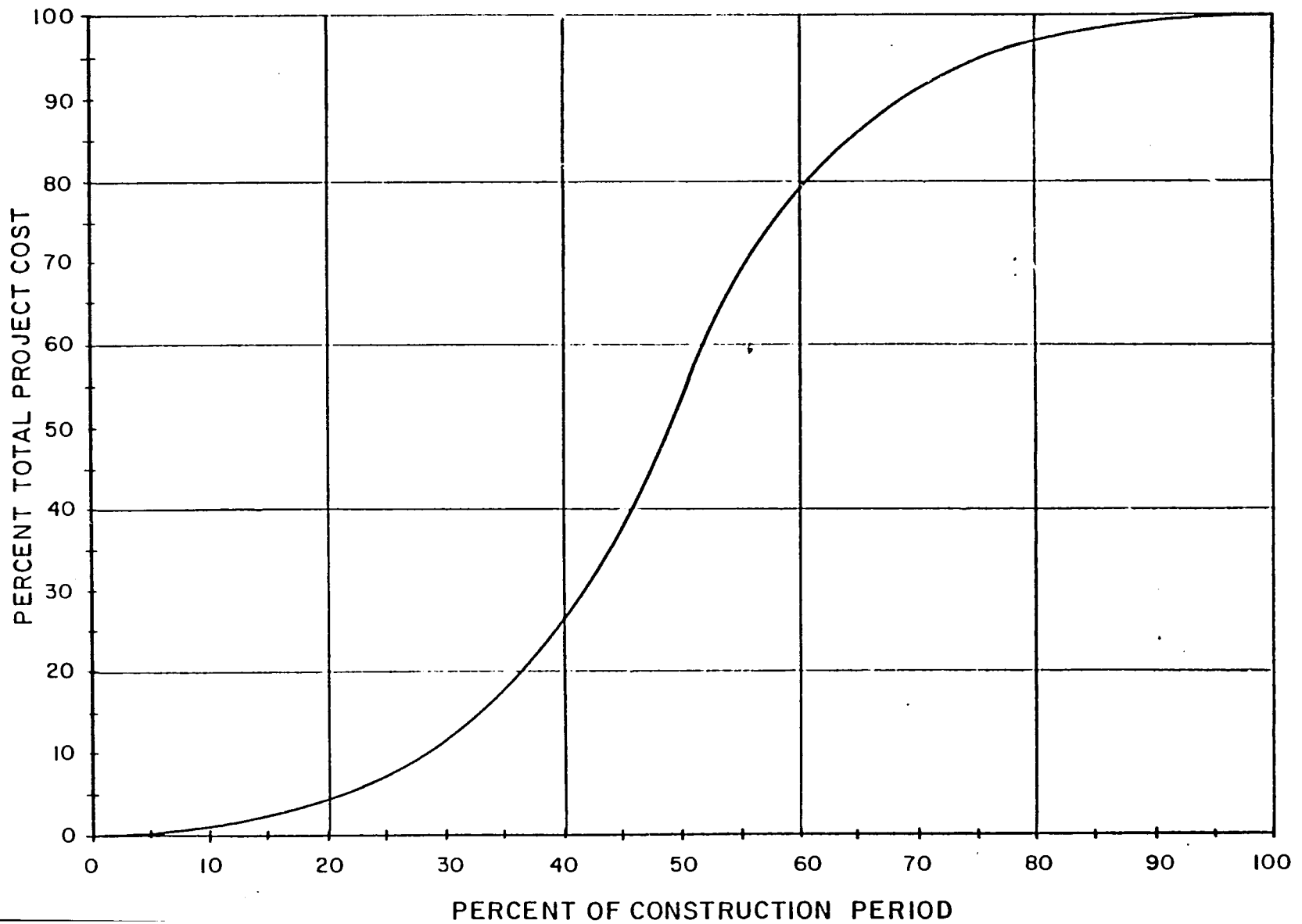


FIGURE 4-18

TABLE 4-11

CONVERSION TO CWM FUEL
SUCAT UNITS 1, 2, 3 AND 4

CONSTRUCTION EXPENDITURES

Percent Complete	Percent Expenditure In Period	Percent Expenditure Cumulative
5	0.5	0.5
10	0.5	1.0
15	1.0	2.0
20	2.5	4.5
25	2.5	7.0
30	4.0	11.0
35	6.0	17.0
40	10.0	27.0
45	11.0	38.0
50	16.0	54.0
55	14.0	68.0
60	11.0	79.0
65	7.0	86.0
70	6.0	92.0
75	2.0	94.0
80	2.0	96.0
85	2.0	98.0
90	1.0	99.0
95	0.5	99.5
100	0.5	100

4.7.1.4 Operating and Maintenance Costs

After conversion to CWM fuel the estimated increase in the Sucat station staff is:

	Operators	Maintenance	Laborers
Sucat 2	12	4	2
Sucat 3	8	2	2
Sucat 4	8	2	2
Sucat 1	8	2	2
Total	36	10	8

The annual additional operating and maintenance costs with CWM fuel will increase (in Jan. 1985 US $) by:

Unit	US Dollars/year
Sucat 2	320,000
Sucat 3	300,000
Sucat 4	430,000
Sucat 1	240,000

These costs cover the additional labor, consumables, and spare parts. They are based on the assumption that the units are operated in a base load mode.

4.7.1.5 Philippine Employment Opportunities

Conversion of Sucat station to CWM fuel will provide employment to Philippino personnel. Estimate of crafts and labor requirements for the conversion to CWM of each Sucat unit is presented on Tables 4-12 and 4-13. In addition to the craft labor shown, the conversion of each unit will also require bout 180,000 manhours of technical (engineering, design, foremen), 80,000 manhours of clerical labor and 80,000 manhours of low grade auxiliary help (warehouse stockmen, watchmen, cleaning) of Philippino origin.

TABLE 4-12

CONSTRUCTION LABOR REQUIREMENTS

CONVERSION OF SUCAT PLANT TO CWM (SEMIRARA COAL)

MANHOURS (PHILIPPINE CRAFTS LABOR)

DESCRIPTION	SKILLED LABOR	UNSKILLED LABOR	TOTAL LABOR
CONVERSION IN TWO PHASES			
Phase I Work-SUCAT 2	416,000	104,000	520,000
Phase II Work-SUCAT 2	208,000	52,000	260,000
TOTAL SUCAT 2 (Two Phase Work)	624,000	156,000	780,000
MINOR CONVERSION TO CWM			
SUCAT 2	573,000	143,000	716,000
3	546,000	136,000	682,000
4	745,000	187,000	932,000
1	391,000	98,000	489,000
TOTAL SUCAT 2, 3, 4, & 1	2,255,000	564,000	2,819,000
MAJOR CONVERSION TO CWM			
SUCAT 2	709,000	177,000	886,000
3	654,000	164,000	818,000
4	882,000	220,000	1,102,000
1	563,000	141,000	704,000
TOTAL SUCAT 2, 3, 4 & 1	2,808,000	702,000	3,510,000

* Total plant costs do not include escalation, contingencies and interest during construction.

TABLE 4-13

CONSTRUCTION LABOR REQUIREMENTS

CONVERSION SUCAT PLANT TO CWM (SEMIRARA/MALANGAS BLEND)

MANHOURS (PHILIPPINE CRAFTS LABOR)

DESCRIPTION	SKILLED LABOR	UNSKILLED LABOR	TOTAL LABOR
CONVERSION IN TWO PHASES			
Initial Conversion SUCAT 2	416,000	104,000	520,000
Additional Work SUCAT 2	235,000	59,000	294,000
TOTAL SUCAT 2 (Two Phase Work)	651,000	163,000	814,000
MINOR CONVERSION TO CWM			
SUCAT 2	600,000	150,000	750,000
3	564,000	141,000	705,000
4	773,000	193,000	966,000
1	446,000	111,000	557,000
TOTAL SUCAT 2, 3, 4, & 1	2,383,000	595,000	2,978,000
MAJOR CONVERSION TO CWM			
SUCAT 2	718,000	180,000	898,000
3	682,000	170,000	852,000
4	909,000	227,000	1,136,000
1	582,000	145,000	727,000
TOTAL SUCAT 2, 3, 4, & 1	2,891,000	722,000	3,613,000

Note: No contingencies are included in these estimates.

5.0 OTHER CONVERSION ALTERNATIVES

In addition to conversion of the Sucat Station to CWM fuel, other coal conversion alternatives were investigated. They are:

- Erection of new pulverized coal fired steam generators;
- Conversion of the existing Sucat steam generators to pulverized coal firing;
- Use of staged slagging combustors firing CWM fuel, as an alternative to major modification of the existing steam generators.

The first two alternatives, erection of new pulverized coal fired steam generators or conversion of the existing steam generators to pulverized coal firing, are based on commercially-proven technologies but present some unique problems. The Sucat Station has insufficient real estate for location of needed new equipment. Handling and storage of coal at Sucat will also produce social and environmental impacts that are clearly undesirable and cannot be quantified in terms of costs. To mitigate some of the environmental impacts associated with fugitive dust, leacheates and storm runoffs from coal piles, large expenditures will be required. Land will have to be reclaimed by filling an area at the Laguna de Bay shore and some inhabitants will have to be evicted from the vicinity of the plant to provide for railroad delivery of coal.

The third alternative, staged slagging combustors, is a new technology under active development and expected to become available commercially in a few years.

5.1 Conversion to Pulverized Coal Firing

5.1.1 Previous Coal Conversion Studies

Conversion of the Sucat Station from oil to pulverized coal firing was studied by Intercontinental Engineering Limited (INTEG) of Canada. Their findings and conclusions were presented in a final report, dated August 1982. The alternatives studied by INTEG include:

- Modify the existing oil firing steam generators for pulverized coal and oil firing.
- Relocate two units to Batangas near the proposed coal port and equip them with new steam generators for pulverized coal and oil firing.
- Relocate the four units to Batangas near the proposed coal port and equip them with new steam generators for pulverized coal and oil firing.

- Replace the existing steam generators with new ones designed for pulverized coal and oil firing. The following ways of achieving this option were identified:

  - Locate the new steam generators in the same positions as the existing ones.

  - Locate the new steam generators on the sites of the existing ones, but offset to the north by one steam generator space.

  - Locate the new steam generators on a new site to the east of the existing boiler building.

  - Locate the new steam generators on a new site to the west of the existing turbine building.

Comparing the costs of relocating the Sucat units to Batangas, versus modification in-situ, INTEG concluded that relocation would be more expensive, and recommended against it. Burns and Roe did not investigate the relocation alternatives.

INTEG concluded that conversion to coal of the existing Sucat steam generators would be extremely difficult due to space considerations. They also indicated that the modification is not as attractive economically as replacing the steam generators. However, new steam generators would have the advantages of greater reliability, no reduction in station output and shorter outage time. INTEG also recommended replacement of the existing Sucat 2, 3 and 4 once-through steam generators with drum type units.

Burns and Roe briefly reviewed the INTEG report and found that some of the assumptions and premises are no longer valid. Comments on some INTEG findings and conclusions follow.

5.1.2 New Pulverized Coal Fired Steam Generators

Of the four alternate schemes, location of new steam generators to the west of the existing turbine building was the one recommended by INTEG. This arrangement requires the acquisition of a strip of land between the west property line and the Philippine National Railway right-of-way. The strip includes an 800 ft length of the provincial road and an area filled with new residential housing, and is, therefore, no longer available for plant expansion without a legal condemnation and eviction proceeding. Since the land was essential for the installation of the new steam generators, precipitators, stacks and coal unloading and storage facilities, this scheme is likely to be socially unfeasible.

Location of new steam generators to the east of the existing boiler house is costly and impractical for the following reasons: The new location would be on land reclaimed from the existing cooling water discharge channel and Laguna de Bay. This will be expensive as it requires heavy piling, landfill, rebuilding of the discharge channel, and relocation of

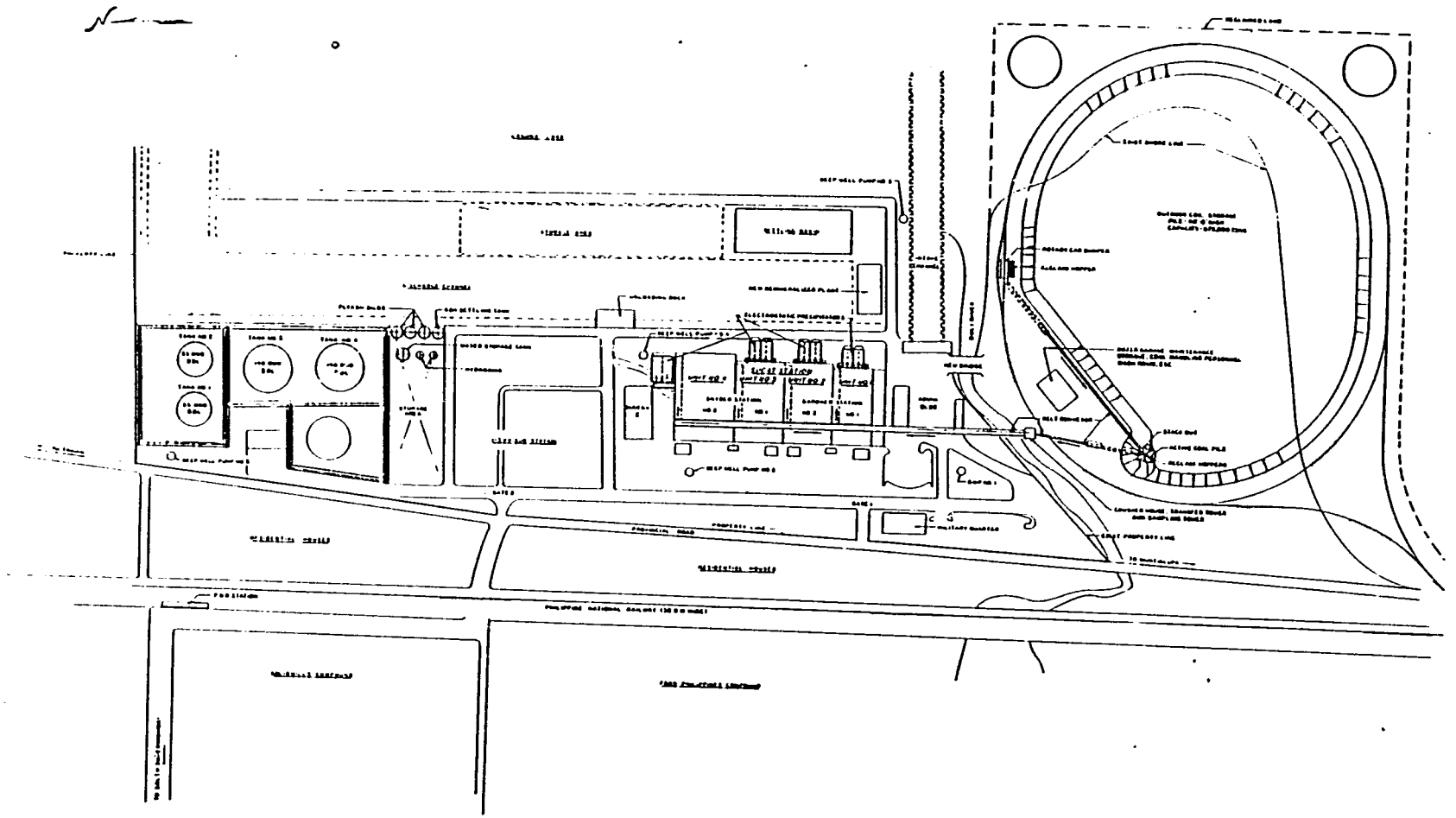
the new demineralizer plant. The new steam generators would be approximately 425 ft. further from the turbines. Main and reheat steam piping, feedwater piping, and plant services (compressed air, service water, fire protection, electrical and control systems, etc.) would have to be extended. Also, the relocation of the discharge channel lengthens the circulating water discharge piping from Units 1, 2 and 3 condensers by 425 ft. The circulating water pumps may require upgrading or replacement due to longer discharge piping. It is assumed that the condenser waterboxes would be adequate for the additional pressure.

The other two alternates involve the replacement of the existing steam generators by new ones in the same area. One of these schemes involves demolition of each steam generator and replacing it with a new one in the same location, the other is based on an offset replacement scheme. In the offset replacement scheme, a new steam generator is erected to the north of the existing boiler house and would supply the Sucat 4 turbine-generator. The new steam generators are erected for Sucat 3, 2 and 1 similarly offset to the north of the existing unit, on the space now occupied by decommissioned steam generators. Since an existing steam generator must be dismantled and new foundations put in place before new steam generator erection can be started, the conversion period will be very long and the cost high.

Complete demolition of each steam generator, auxiliary equipment, piping systems, boiler support steel and foundations would be required, including the boiler house structure and stacks supported on building structure. Each stack serves two boilers so that each stack must be left in place till demolition of the second unit. The coal receiving, handling and storage system would have to be in place to feed the first unit without interfering with work on the following units. This problem could be circumvented by firing all units with fuel oil till all new units are completed, but this would delay coal firing by several years and would delay the benefits of oil replacement.

Erection of new steam generators on or offset from the old units does not require acquisition of new land for the steam generators and, therefore, appears to be somewhat easier to implement, although the cost is expected to be high. However, new land will be needed for coal handling and storage. A preliminary layout of the coal handling system is shown on Figure 5-1.

Replacement of the present steam generators with new coal fired ones, addition of concrete coal storage silos, coal and ash handling, electrostatic precipitators and other required systems was estimated by INTEG to cost $337 million (January 1982) without contingencies, escalation and interest during construction. Escalated to January 1985 (at 10% per year) the total plant cost becomes $450 million. The advantage of new steam generators is that they can be built to attain full nameplate capacity with Semirara coal.



CONVERSION TO PULVERIZED COAL FIRING

FIGURE 5-1

5.1.3 Conversion of the Existing Steam Generators to Pulverized Coal Firing

5.1.3.1 General

INTEG dismissed as impractical and uneconomical the conversion to pulverized coal of the existing Sucat steam generators. The reasons given for this conclusion are:

- Station reliability. The present once-through steam generators (2, 3 and 4) are less reliable than drum type units, and reliability on coal will be even less.

- Loss of unit and station output. INTEG assumed that on coal the units would be derated by 40 to 50%.

- Space considerations. There is no room to accommodate the coal silos and pulverizers within the existing boiler house due to the steelwork layout. As an alternate, an indirect system with a central coal pulverizing station was considered and dismissed as impractical.

- Capital cost. INTEG estimated that the steam generator modification costs added to the capital cost of replacement of 340 MW capacity due to derating, will be more than 2-1/2 times the cost of new steam generators.

- Outage time. Each steam generator will be out of service for about one year.

Burns and Roe's investigations indicate that conversion to pulverized coal of the existing steam generators is technically feasible, though difficult and costly. With commissioning of the new coal fired Calaca unit (300 MW) and the completion of the nuclear station (650 MW), the Luzon system will have adequate power reserve, and outage of any of the Sucat units for fuel conversion will not be a problem. The capacity replacement charge (assumed by INTEG) to compensate for derating may also not apply, since the units will be capable of operating at nameplate capacity on oil whenever needed. Therefore, prospects for converting the existing Sucat steam generators to pulverized coal should be further evaluated, especially since Burns and Roe has successfully completed several oil to coal conversions, which were technically more complex than the conversion of the Sucat units.

The Kwinana units 5 and 6 (200 MW each), in Western Australia, have been in operation on coal for over five years with plant availability in excess of 95%. Space near the steam generator was a problem and the pulverizers had to be installed 220 feet away from their steam generators. The furnace hopper had to be cut and modified and a 26 foot deep pit was dug under the boiler for bottom ash handling. At the same station, the Kwinana 1 and 2 units (120 MW each) were converted and have operated on coal since November 1982 and May 1983. More recently, the Honam 1 and 2

units (300 MW each), in South Korea, were converted and now operate on coal.

5.1.3.2 Steam Generator Modifications and Performance

For the Sucat conversion to pulverized coal, the modifications to the furnace, convection pass, forced and induced draft fans, and ash handling system will be the same as the modifications for conversion to CWM fuel firing described in Section 4. Additional steam generator modifications will be needed to accommodate new primary air fans, primary air heaters, coal silos, feeders, pulverizers and pulverized coal piping. The existing oil burners will be replaced with new dual fuel (coal and oil) burners and the burner management system will be replaced with a new one suitable for dual fuel operation.

Balance of plant additions and modifications will include coal handling, electrostatic precipitators, ash handling, instrumentation and controls, auxiliary plant services (cooling and service water, compressed air, auxiliary steam), electrical and civil/structural works.

The expected performance for firing pulverized coal in the converted Sucat units calculated for minor and major modifications and is presented on Table 5-1. The minor modification, in brief, includes widening furnace hopper throat, respacing convective sections, new coal-oil burners and burner management system, new wall blowers and sootblowers, new I.D. and P.A. fans, modifications of F.D. fans and flues, and replacement of mechanical dust collectors by electrostatic precipitators. Major modification includes, in addition, an increase of furnace height by twelve feet and modification of the convection pass surfaces of the superheater and reheater.

5.1.3.3 Capital Costs

The total cost for conversion of all four Sucat units to pulverized coal firing is estimated at US $260 million for the minor modification scheme and US $320 million for the major modification alternative. These costs are in January 1985 dollars and do not include the cost of rebuilding the Batangas-to-Sucat railroad, contingencies, escalation and interest during construction. This compares with U.S. $450 million estimated for replacement of the steam generators with new pulverized coal fired units.

5.1.4 Coal Delivery to Sucat

5.1.4.1 General

Conversion to pulverized coal firing requires delivery of coal to the Sucat Station either dry by rail or as a slurry by pipeline.

- By railroad. Sized coal can be delivered from the mine by barge to a transshipment facility on the coast from where it is transferred to railroad cars and shipped to the station. At Sucat the coal is unloaded from the railroad cars, stored, reclaimed,

TABLE 5-1

SUCAT PLANT - CONVERSION TO PULVERIZED SEMIRARA COAL

	Sucat 2 (3)		Sucat 4		Sucat 1	
	Minor	Major	Minor	Major	Minor	Major
Steam flow, lb/hr	840,470	1,043,810	1,257,670	1,561,950	655,390	753,210
Load, %	62	77	62	77	67	77
Gross output, MW	131	162	198	242	99	115
Aux. load, MW	6	7	9	10	8	9
Net output, MW	125	155	191	232	91	106
Boiler efficiency, %	83.0	82.0	83.0	82.0	83.5	82.5
Net plant heat rate, Btu/kWhr	10,260	10,420	10,070	10,440	10,770	10,750
Coal flow, lb/hr	170,840	215,150	256,200	322,640	130,550	151,800
tonnes/hr	77.5	97.6	116.2	146.3	59.2	68.8

crushed, distributed to day-use silos, pulverized and delivered to the burners.

- By pipeline. Sized coal is shipped by barge from the mine to a slurry preparation facility. There the coal is mixed with water to form a dilute slurry and pumped to Sucat by pipeline. Alternatively, the dilute coarse slurry is prepared at the mine and barged to the pipeline terminus and pumped to Sucat. At the station, the slurry is stored in tanks or reservoirs. The slurry is reclaimed, dewatered in centrifuges, then dried, pulverized and delivered to pulverized-coal burners for combustion. Reclaimed water is either treated and then discharged in an environmentally acceptable manner or returned by pipeline to the slurry preparation plant.

Delivery of coal by truck is not practical, since many trucks would be required to meet the consumption, access roads to the plant are already very congested and truck transport is an excessively high cost option.

Delivery only by barge from the mines to the Sucat station was also ruled out, since traffic from Manila Bay to the Laguna de Bay is restricted by a lock installed on Pasig River to minimize sea water intrusion.

Use of conveyors to transport coal to Sucat is also considered impractical. A conveyor would have to pass through populated areas, presents environmental problems and except for short distances would be unreliable.

The INTEG coal conversion study analyzed all the above transportation modes for imported bituminous coal. Their conclusion was that the rail option is the least expensive to build and operate. A detailed study on the feasibility of coal transportation by rail to Sucat was also performed by Canadian Pacific Consulting Services (CPCS).

5.1.4.2 Transportation by Rail

Converting the Sucat Station to burn subbituminous Semirara coal in pulverized form will require a yearly coal delivery of about 3 million tonnes. Coal will be loaded on barges at Semirara and unloaded at the San Pascual port facility near Batangas. A new railroad of about 100 kilometers will be built between San Pascual and Sucat to replace the inoperative existing railroad. To accommodate the coal requirements of both the Calaca and Sucat station, enlargement of the San Pascual port facilities may be required. Rehabilitation of the existing railway and acquisition of new locomotives and rail cars was estimated by CPCS to cost $76,500,000 which when escalated to January 1985 (at 10% per year) becomes $102,000,000.

Unloading railroad cars at Sucat will require extensive land reclamation to the south of the plant as shown on Figure 5-1. This land will be used for the coal storage piles and to provide necessary railroad trackage for maneuvering railroad cars. Railroad car unloading is associated with noise and fugitive dust, which will affect the quality of life of the neighborhood. To prevent seepage of leachates and of contaminated storm

rainwater into the Laguna de Bay, the entire area under the coal pile may have to be covered with an impermeable layer of clay and/or plastic liner. Storm water will be collected in ditches and catch basins, then treated before discharge into the bay. Alternatively, coal could be stored in concrete silos.

5.1.4.3 Slurry Pipeline

Transportation of coal from Batangas to Sucat was studied by INTEG in 1982 and them more thoroughly in 1983 by Broken Hill Proprietary Company, Ltd. of Australia. These studies were based on the use of the technology employed on the Black Mesa-Mohave pipeline in the US. The slurries considered were made of imported bituminous coal in concentration of about 48% by weight in water. These slurries exhibit very low viscosity (about 50 centipoise), settle rapidly and are transported in turbulent flow mode at velocities of 5 to 8 ft. per second. The investigations, conducted by Brookhaven National Laboratory, indicate that, in order to obtain slurries of such low viscosities using Semirara coal, the coal concentration in the slurry has to be at about 40 to 42%. The coal would have to be dewatered and reground at the station, which presents substantial difficulties. It is assumed that the existing Batangas to Sucat black products pipeline would be available for this service. The pipeline belongs to the First Philippine Industrial Corporation.

The rough budget estimate for modification of the existing pipeline, addition of slurry preparation facilities at Batangas, new pumping stations for CWS, and dewatering facilities at Sucat is U.S. $45 million.

Transportation by pipeline and dewatering the slurry has fewer environmental problems than transportation by rail. The major problem is the dewatering of the slurry, treatment and disposal of the wastewater.

5.2 Staged Slagging Combustors

5.2.1 General

Conversion of existing oil-designed steam generators to burn either pulverized coal or CWM fuel could be simplified if it were practical to prevent ash from entering the furnace. Staged slagging combustors are being developed to achieve such ash retention. When available, they may be a means of converting oil-designed steam generators with a minimum of pressure parts modification and nameplate derating. The combustors would be used in place of conventional burners.

Development of staged slagging combustors has not yet reached the stage where equipment has been built, installed and continuously operated under industrial or utility plant conditions. The feasibility of the technology has been demonstrated in laboratory and small scale tests with combustor ratings of 1 to 50 MMBtu/hr. About 800 hours (in short runs) of testing has been done firing various pulverized eastern and western U.S. coals, and a few test runs firing CWM fuel. Larger scale tests of a single combustor installation on industrial and small utility steam generators are

planned in the US with combustors of 50 to 100 MMBtu/hr rating. These tests are designed to provide continuous operation of 1000 to 4000 hours under actual plant operating conditions. If these tests prove successful, it is possible that in several years (within the time frame of the implementation of Sucat 3 and 4 conversions) commercial size units and systems will become available and utilities would have the confidence to commit a unit to full-scale conversion from oil to coal using the slagging combustors.

The staged slagging combustors will be mounted external to the host furnace and will discharge the combustion products through the same, or enlarged, tube-wall openings previously utilized by the oil burners. In principle, coal is burned within the combustor either in the dry pulverized state or as a coal-water slurry, in a highly turbulent regime under reducing conditions, and at heat release rates up to 50 times greater than that for normal coal firing. This generates internal temperatures of about 2700°F, sufficiently high to consume up to 99% of the carbon and liquify most coal ash. Up to 90% of the ash is removed as molten slag from the combustor and never enters the furnace, and the remaining fly ash is extremely fine (less than 20 micron). The theory is that the fine ash will follow the aerodynamic path of the flue gas and not impinge on convective tube surfaces within the host steam generator, but this has yet to be demonstrated in either a full-scale test or a subscale simulation. Oxides of nitrogen formation are held at relatively low levels by maintaining initial combustion at substoichiometric conditions. SO_x can be controlled by limestone injection in the primary combustion zone.

The leading US developers of staged slagging combustors are TRW, Rockwell, Avco-Everett and Coal-Tech. Their combustor designs and performance differ in the following major respects:

- Rockwell has emphasized low NO_x/SO_x operation, and their design seeks to optimize the time and stoichiometry to control NO_x to very low levels (50-100 ppm) while simultaneously removing enough sulfur to meet US EPA New Source Performance Standards (NSPS) for sulfur dioxide (70-90% SO_x removal). The Rockwell design uses an additional fly ash removal stage after the first combustion stage This is done with a slag/fly ash separator unit which fits between the combustor and the boiler and comprises about one-half the weight and size of the overall system. The combustion stages of the Rockwell system are refractory-lined, and the slag/fly ash separator is composed of water-cooled studded-metal tubes.

- TRW emphasizes oil-design boiler retrofit, and their design goal is to aerodynamically remove 90% of slag/fly while simultaneously achieving 90+% carbon burnout within the combustor. Their emission goals are for NO_x levels similar to oil-firing (250 ppm) and sulfur capture of 70-90%. The TRW design uses all water-cooled studded-metal surfaces and no refractory.

- The Coal-Tech design also emphasizes oil-design boiler retrofit, but unlike the others, it is air-cooled. The cooling air is used

as preheated combustion air, thus avoiding the requirement of integrating cooling water into the steam generator water/steam cycles.

- The Avco Everett combustor employs inertial particle separation from the flow field, using toroidal vortex flow geometry. Mineral matter particles are impacted on the wall to form a steady-state flow of molten slag, which is removed from the combustor. The combustion products of the external combustor are discharged into the slag separator where more than 90% of the slag is inertially separated and collected. The hot gases, rich in CO, are then mixed with secondary air and the combustion is completed in the furnace of the steam generator.

The technology has several prospective advantages over conversion to standard pulverized coal or CWM fuel firing. The major possible benefit is that a steam generator can be converted with little or no derating, and with only minor furnace and pressure parts modifications. Coal and ash systems and particulate control equipment will still be required, the fans will need modification because of increased pressure losses, and the combustors will replace the existing burners. New combustion controls will also be required. However, NO_x and SO_x emission control equipment is not necessary since these emissions can be controlled within the combustors.

Appendix B presents a brief state-of-the-art review of the staged slagging combustor technology. A steam generator converted to CWM fuel with slagging combustors could achieve a higher load than one converted to conventional burners, given the same steam generator modifications. This is due to the fact that higher flue gas velocities and temperatures can be tolerated in the slagging combustor application due to the reduced ash in the flue gas.

5.2.2 Application to Sucat Steam Generators

Preliminary performance calculations, based on firing CWM fuel consisting of 50% Semirara coal and 50% water, indicate that Sucat 2 and 3 could be operated at 80% rating with slagging combustors and with the minor modifications to furnace and convection pass described in this report for conventional CWM fuel firing. Due to space constraints, the 18 burners will be replaced by sixteen 120 MMBtu/hr combustors, eight each in front and rear walls. Combustor developers project building combustors of over 100 MMBtu/hr rating with TRW proposing up to 250 MMBtu/hr commercial scale combustors. The combustor size and weight is relatively large, and requires space and an adequate support structure.

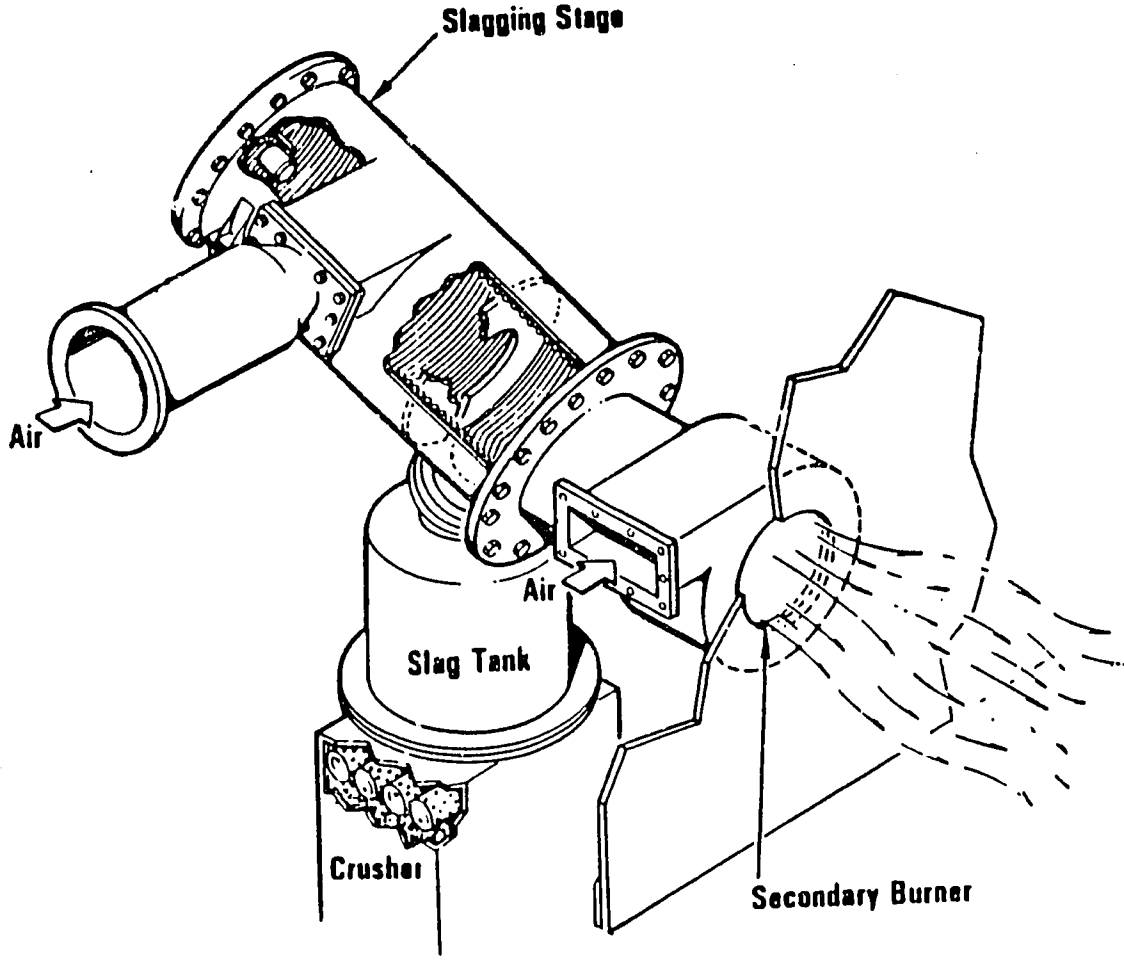
With slagging combustors, the expected performance for Sucat 2 firing a CWM fuel made of 50% Semirara coal and 50% water is:

Steam Flow (lbs/hr)	1,084,480
Load, %	80
Gross output (MW)	169
Aux. loads (MW)	6
Net output (MW)	163
Boiler efficiency, %	73.4
Net plant heat rate (Btu/kWhr)	10,880
CWM fuel flow (tonnes/hr)	162.8
Parent coal flow (tonnes/hr)	107.1

The conceptual design was based on the TRW slagging combustor shown in Figure 5-2. Figure 5-3 shows the arrangement of eight slagging combustors on one wall of the Sucat 3 furnace. The opposing wall will have an identical arrangement. Figure 5-4 shows the modifications envisaged for a conversion of Sucat 2 to slagging combustors.

The control of SO_x emissions is one of the most important aspects of slagging combustor use in the US. However, due to the low sulfur content of the Semirara coal, limestone injection for sulfur removal is not required at Sucat. This capability can be added to a slagging combustor conversion, if necessary.

The staged slagging combustors are a promising new coal firing technology and when fully developed and tested could provide a viable alternative for conversion of the Sucat units to CWM fuel.



TRW STAGED SLAGGING COMBUSTOR
FIGURE 5-2

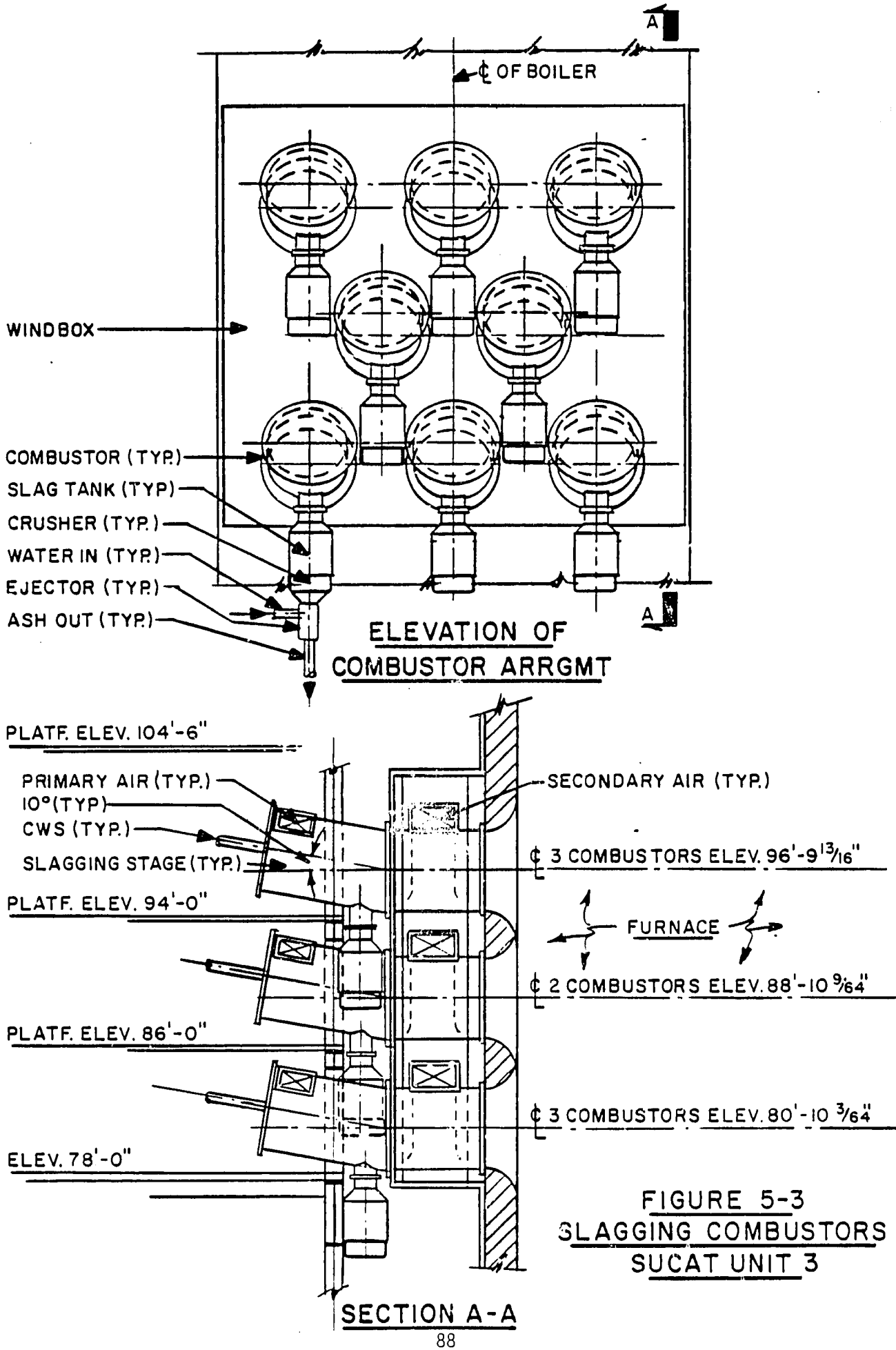
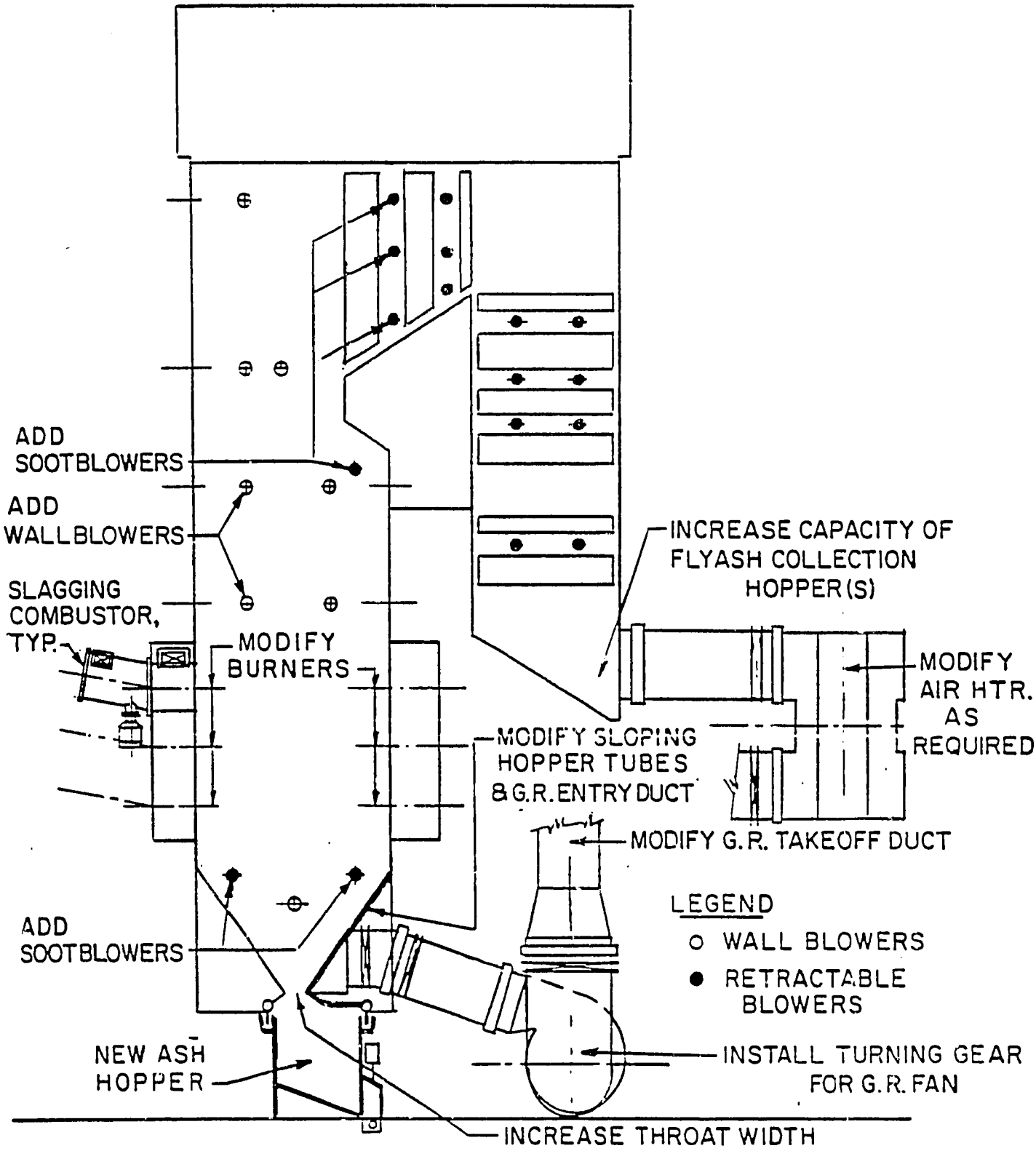


FIGURE 5-3
SLAGGING COMBUSTORS
SUCAT UNIT 3



SUCAT UNIT NO. 2
WITH SLAGGING COMBUSTORS
FIGURE 5-4

APPENDIX A - BOILER EVALUATION METHODOLOGY

1.0 GENERAL

Firing coal-water-mix fuel (CWM Fuel) in oil-designed boilers will cause performance changes. For most boilers, the maximum achievable output will be decreased. The maximum output and performance will depend on specific boiler design characteristics, CWM fuel properties and the extent of boiler modifications made to enhance CWM fuel firing capabilities.

2.0 LOAD LIMITING FACTORS

Fuel ash composition and quantity determine the acceptable limits for principal boiler design parameters. The following potential load limiting factors were considered in the study:

- Erosion in the convection sections
- Furnace slagging
- Convective pass fouling
- Carbon burnout
- Tube metal overheating
- Control flow limits
- Draft plant capacity

2.1 Erosion in the Convection Sections

Flue gases produced by oil firing are almost ash free and erosion of convective pass tube banks is not a concern. On the other hand, CWM fuel flue gases contain relatively large quantities of fly ash which could produce tube erosion. Excessive erosion of tube banks must be avoided, since it could lead to tube leaks that would necessitate costly repairs and unit outages.

Among the principal factors that affect the erosion rate are flue gas velocity, quantity of ash, relative abrasiveness and size of ash particles. The most effective way to control erosion is reduction of gas velocities by lowering the boiler output (derating the unit). The rate of tube erosion is proportional to gas velocity to an exponent that ranges between 3 and 5. In oil-designed boilers, gas velocities can reach 120 ft/sec, whereas in coal-designed units, design flue gas velocities are normally kept below 70 ft/sec. The maximum allowable gas velocities, which depend on ash quantity and quality, can limit boiler output.

2.2 Furnace Slagging

The primary mechanism for heat transfer in the furnace is radiation, which is governed by flame temperature and surface temperatures at furnace walls. Oil burns rapidly with high flame temperature and high emissivity. Furnace walls remain clean, the surface temperature of the waterwalls is typically 100 to 200°F above the temperature of the water in the tubes and heat transfer rates to the tubes are high. CWM fuel burns slower than oil and the coal ash present in the CWM fuel coats furnace waterwalls with

deposits thick enough to reduce heat transfer significantly. The surface temperatures of these deposits can be 500 to 1500°F above the temperature of the water in the tubes.

Waterwall surface temperatures generally vary with load as illustrated on Figure A-1. At very low loads, gas temperatures are low and water wall tubes are clean and relatively cool. Ash deposits on the walls are friable and easily cleaned. As load increases, the ash particles become hotter, due to the relatively low thermal conductivity of the dry powdery initial deposit, and form sintered deposits that are moderately cleanable. At higher load,s the surface deposits become highly bonded (semi-molten or molten) and difficult to clean, reaching the point when the surface temperature approaches the ash fusion temperature and thick deposits of slag build up on the walls. Boiler load must be limited to below the point at which excessive slag deposits build up on the waterwalls.

2.3 Convection Pass Fouling

Fouling is a complex process that is related to slagging but with the added complexity of coal mineral matter vaporization/condensation. The transverse spacing between convection bank tube assemblies in oil units is often half the spacing in coal units. As a result, ash deposition conditions which would be controllable in coal-designed units would cause bridging of the spaces and plugging of the convection pass in oil-designed units. This characteristic requires setting an upper limit on furnace exit gas temperature, which is lower than the limit for coal designs.

Ash deposits on furnace walls reduce heat transfer and raise the temperature of the flue gases leaving the furnace. A boiler load limit is reached in a furnace designed for oil-firing when the furnace outlet temperature is high enough to cause either fouling or plugging of the convection pass tube banks.

2.4 Carbon Burnout

The fuel must complete combustion within the furnace. Unburned carbon affects boiler thermal efficiency and contributes to total particulates emission, due to lowered fly ash resistivity and ESP dust hopper fires. Among the factors that affect carbon burnout are pulverized coal particle size, atomization quality, residence time within the furnace, excess air and turbulence in the burner flame zone furnace that enhances intimate mixture of fuel and combustion air. Atomization quality is the predominant factor and is dependent on burner design. Burners for CWM fuel are still in the development stage, and it is not known what the ultimate capabilities of commercial CWM burners will be. Recent tests of large scale burners are very encouraging.

Furnace parameters and the distance between the top burners and furnace exit plane have an effect on carbon burnout. Inadequate carbon burnout is a fuel related property that could limit boiler output on CWM fuel.

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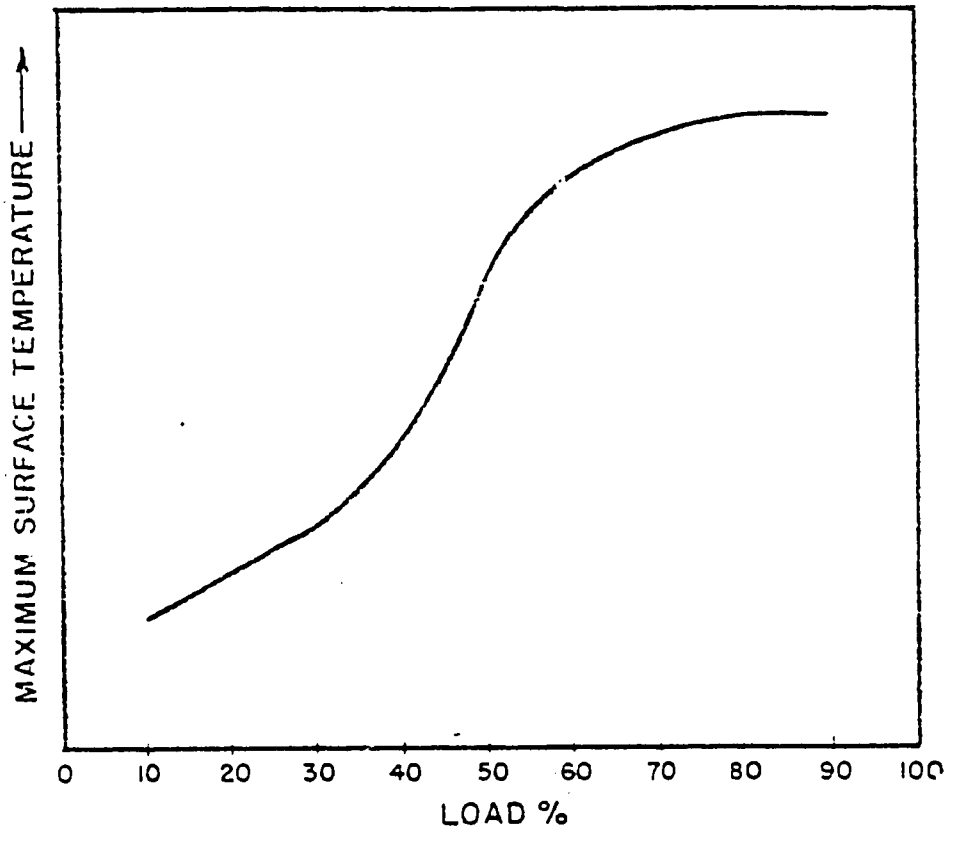

FURNACE WATERWALL TEMPERATURE VS. LOAD

FIGURE A-1

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2.5 Tube Metal Overheating

The increased gas flow rates and higher gas temperatures through the convective passes could lead to higher tube metal temperatures. As part of the performance analysis work, tube metal temperatures are checked. If the allowable metal temperatures in any section exceed permissible values, either the section is replaced with tubes of upgraded materials or, in most cases, the boiler load is reduced as required to keep the tubes within allowable limits.

2.6 Control Flow Limits

The higher convective heat transfer rates and higher gas temperatures lead to increased steam outlet temperature in the superheater and/or reheater. Spray attemperation is used to reduce main steam temperatures to within acceptable limits. The amount of spray water must not exceed 10% of steam flow in order to prevent water droplet carryover and thermal shock in gas-swept tube banks. Gas recirculation is used to increase the mass flow through the convective pass and raise reheat steam temperature at lower loads. Gas recirculation flow must not exceed 40% of flue gas flow at part loads due to flame stability considerations. Boiler load may have to be reduced should spray flow exceed the allowable limits. Reheat steam temperature may decrease at part load if the 40% flow limit is to be maintained.

2.7 Draft Plant Capacity

The greater quantities of air and flue gas associated with combustion of CWM versus oil and the larger draft losses due to ash deposition on convective tubes may exceed the capabilities of present FD and ID fans. Addition of an electrostatic precipitator or other means of particulates removal, if required to meet environmental impositions, would further increase the demand on the fans.

A decision has to be made either to modify or replace the draft equipment to meet the higher operating requirements or to reduce the boiler load to within the capabilities of the existing installation.

When no additional pollution control equipment is added, small draft plant deficiencies are generally covered by derating the units. When an electrostatic precipitator is added to the system, modification and/or relocation of the ID fans may be necessary.

3.0 OPERATING LIMITS

The operating limits discussed below were used to establish the maximum boiler load when firing CWM fuel. The values adopted for these parameters are shown on Table A-1.

3.1 Combustion Air Temperature

In spite of the high moisture content of a CWM fuel, it has been found that exceptionally high combustion air temperature is not necessary for stable combustion in a utility boiler combustion chamber. It is assumed that the temperature range used for conventional pulverized coal-firing, 400 to 600°F, is sufficient. If combustion air temperature cannot be made high enough with existing equipment, steam coil air preheater capacity will be increased.

3.2 Heat Release Rates

Since different fuels have different slagging and fouling properties, different heat release rate limits were adopted for the CWM fuels in this study and are shown in Table A-1. The volume used in calculating the volumetric heat release rate includes the entire furnace and hopper up to the first convective section. The area used in the burner zone heat release rate is the flat projected area of the perimeter walls between an elevation 5 ft below the centerline of the lowest burner in service to 5 ft above the centerline of the highest burner in service.

The burner heat input will be calculated for the rated load on each CWM. However, since CWM burners have not yet been developed and because burner designs tend to vary greatly, a single limit will not be imposed.

3.3 Furnace Exit Gas Temperature

A furnace exit gas temperature limit is employed to prevent fouling or ash bridging problems in the convective passes of the boiler. The furnace exist gas temperature limits are listed in Table A-1.

3.4 Clear Space Requirements

To prevent ash bridging between tubes in the convective passes, minimum limits are imposed on the side-to-side clear space between assemblies. The clear space is defined as the cross-pitch between assemblies minus the outside diameter of the tubes. The minimum clear space required for a given ash generally increases with temperature. The maximum temperature permitted for a given space is shown in Table A-1. An allowance of an additional 100°F is permitted for platen surfaces because the gas flow around them is less turbulent thereby reducing the likelihood of impingement and sticking of the ash particles. The limits set in Table A-1 reflect the fouling potential of the CWM fuels. Problems can be reduced in tightly spaced banks by additional use of sootblower equipment.

3.5 Flue Gas Velocity

To avoid tube erosion in the convective sections, maximum gas velocity must be limited. The limits listed in Table A-1 are average values. Peak gas velocities in a tube bank can be considerably higher than the average and are a function of boiler configuration, tube bank type, degree of fouling, etc.

3.6 Maximum Allowable Metal Temperature for Gas Swept Tubes

Maximum metal temperatures must be limited to prevent failure of tubes. Full tube metal temperature calculations were not performed. Steam temperatures through the system were checked to ensure that there are no large increases from oil-fired conditions. Since most oil/gas design boilers will have to be derated, no large increases of superheater spray water flows (indicating large increases of superheater heat absorption), relative to full load oil/gas firing, are anticipated. The maximum allowable tube surface metal temperatures for tubes exposed to the flue gas for various materials are listed below:

SA192	950°F
SA210,A-1	950°F
SA178, A	850°F
SA178, C	950°F
SA209, T1	975°F
SA213, T12	1000°F
SA213, T11	1050°F
SA213, T22	1125°F
SA213, TP304	1400°F

These temperature limits apply to CWM firing.

4.0 ASSUMPTIONS USED IN PERFORMANCE ANALYSIS

A summary of the assumptions used in projecting boiler performance with CWM firing is presented below.

4.1 Excess Air

For all calculations, 20% excess air is used unless more is required for steam temperature control at part loads or for combustion stability.

4.2 Unburned Carbon Heat Loss

It was assumed that there would be a 1.5% unburned carbon heat loss (98.5% carbon conversion efficiency). As indicated above, this loss is increased for special cases in which the furnace residence time is exceptionally short. A 98.5% carbon conversion efficiency is quite low for conventional coal firing, but available research indicates that this is all that can be achieved at present for CWM combustion.

4.3 Unaccounted Losses

For consistency, unaccounted loss is always assumed to be 0.5%. No adjustment is made for margins because these calculations attempt to predict performance, not guarantee it. Heat credits for auxiliary equipment such as gas recirculation fans and/or boiler water circulating pumps are not included.

4.4 Flue Gas Acid Dew Point

Flue gas acid dew point is computed based on flue gas composition and conditions at the air heater outlet. These values are predicted for the flue gases with 20% excess air.

4.5 Air Heater Cross Leakage

Air heater cross leakage (air to gas) is calculated using a drop in flue gas CO_2 concentration of 1.1% for loads between 45% and 75% of boiler MCR and 1.2% for loads between 75 and 100%. Actual leakage data is used, if available.

5.0 PROCEDURE FOR BOILER ANALYSIS

To evaluate the effects of CWM firing, calculation techniques and computer programs were used. The steps taken to analyze each unit firing CWM fuel are discussed in the following paragraphs. This method is applicable to any fuel and for any degree of modification.

Analysis of boiler performance begins by developing a numerical computer model of the boiler. The model includes all furnace dimensions, areas and volumes, as well as information regarding burner location and upper furnace type. All convective banks are described in the model by their arrangement, configuration, tube diameter, tube spacings, surrounding tube enclosure or duct area, and other descriptive details. Interbank cavities, screen tubes, attemperators, gas flow splits, and gas flow combinations are also included in the model. Interconnections among the various components of the model are made by describing the flow progression of all steam circuits, gas circuits and calculation order.

Once the numerical model has been established, it is calibrated with performance data for the original design fuel. Any available field performance data is used as input to the performance section of the overall boiler model. The model is then used to compute outlet steam and gas temperatures. Any discrepancy between the results from the model and actual data can indicate an error in the model and can imply that some surfaces have an effectiveness other than unity. The numerical model is then corrected or adjusted to achieve agreement with the da[illegible] less than 5°F for all steam and gas temperatures available.

The first step in calculating boiler performance for a given load is to estimate the total heat which must be transferred to water and steam to achieve the desired outlet conditions, given the incoming conditions. The computer program which performs this calculation uses temperature and pressure at the endpoints of each boiler circuit to find heat transferred to the circuit. Generally, the circuits included are main stream, reheat steam, and economizer and attemperator water flows.

The results of the heat-to-steam calculation are used together with the fuel analysis and design parameters and assumptions listed previously to carry out the combustion calculations. The computer program which per-

forms this calculation computes the quantity and composition of the gases produced, as well as furnace heat release rates and rate of fuel consumption. Overall boiler efficiency is computed by the losses method as part of this calculation. Furnace exist gas temperature is estimated using graphical means developed for coal firing. The estimate is primarily a function of heat release rate and effective furnace surface area, with corrections made for wall cleanliness, firing method, fuel type, burner location, furnace surface-to-volume ratio, excess air quantity and gas recirculation rate. Direct radiation leaving the furnace is also estimated graphically based on the furnace exit gas temperature and metal temperature of the receiving surface.

The computer program which estimates convective pass performance calculates the heat transfer coefficient for each bank and then iterates to find the incoming or outgoing steam and gas temperatures. If iteration results in substantially different temperatures, the heat transfer coefficient is recalculated and the interation process is repeated. The calculation proceeds automatically through each component included in the numerical model. Control settings such as attemperator flow, burner tilt, gas recirculation rate, split backpass gas flow ratios, and excess air are set manually until the results are within the acceptable range. During calibration, however, the controls are set as specified in the data, and the model is adjusted to obtain the required results.

Air heater performance is estimated by computer program. Given the temperature of the incoming gas, together with air and gas flow rates, this program iterates until it finds an incoming air temperature which will satisfy the minimum cold-end temperature and acid dew point temperature requirement for the existing gas. If the resulting air or gas temperatures are substantially different from those used in the efficiency calculation, the process is started again with the combustion calculation. A convergence with assumed values to less than 5°F is required.

TABLE A-1

SUCAT UNIT NOS. 1, 2, 3 & 4 BOILER PERFORMANCE WITH SEMIRARA CWM FUEL

Design Parameters		Desired Values
Furnace Exit Gas Temp. °F		2200°F maximum
Plan Area HRR	Btu/hr $ft^2 x 10^6$	1.9 maximum
Volumetric HHR	Btu/hr $ft^3 x 10^6$	18 maximum
Burner Zone HHR	Btu/hr $ft^2 x 10^3$	500 maximum
Maximum Average flue gas velocity	ft/s	70-75 Structural Members 75-80 Non-Structural Members
Maximum Allowable flue gas temp. for clear space of:	10 in. 6 in. 4 in. 3.75 in. 2.5 in. 2.0 in.	2050°F 1900°F 1800°F 1800°F 1700°F 1600°F
Gross heat input per burner	Btu/hr$x10^6$	150 maximum
Furnace Dimensions for max. heat input (top burner row to upper furnace outlet plane (ft))		50 — 60 (or at least 1.2 x Furnace depth)
Wing Burner to furnace side wall (ft)		8.0
Bottom horizontal row to hopper knuckle (ft)		5.0

APPENDIX B: SLAGGING COMBUSTORS - STATE OF THE ART

1.0 STAGED SLAGGING COAL COMBUSTORS

Several advanced Staged Slagging Coal Combustors (SSCC) currently under development in the USA may have potential application for the retrofit of oil- and gas-fired boilers to coal. These combustors also offer the potential of reduced NO_x and SO_x emissions in existing or new coal-fired units without post-combustion controls. This technology has been proposed for several different utility applications such as:

- o Retrofit of gas- and/or oil-designed boilers to coal firing.
- o Retrofit of existing coal-fired boilers for reduced NO_x and SO_x emissions without post-combustion controls.
- o New coal-fired boilers for low NO_x and SO_x emissions without post-combustion controls.

Boilers designed for oil are generally 20-40% smaller in furnace volume than those designed for coal. Attempts to fire pulverized coal in the smaller furnaces would result in high levels of unburned carbon and operating difficulties due to slagging and fouling of the furnace and convective surfaces. Use of SSCC's in retrofit of oil-designed boilers has the potential of reducing these problems. With the external SSCC's, most of the carbon is consumed within the combustor, and between 1/4 and 1/3 of the heat content of the fuel is released in the host furnace, primarily by the combustion of CO and H_2. Furthermore, NO_x formation is controlled by the use of staged combustion in which primary burning takes place in the combustor under substoichiometric conditions. SO_x emissions are controlled by capturing sulfur in the primary combustion zone with a sorbent such as calcium, generally in the form of limestone.

Gas velocities in superheaters and convection surfaces in oil-designed boilers are about double those in coal units. This could lead to severe erosion of tube surfaces with the high flyash loadings associated with coal firing. In addition, the closer spacings of tubes in oil units could cause plugging and fouling of convective heat transfer surfaces. The SSCC's reportedly can remove up to 90% of the ash as molten slag, greatly reducing the flyash passing through the convection surfaces.

The atmospheric combustors being developed as oil-backout and/or low-emission devices evolved from pressurized designs developed in the mid 1970's for MHD applications. The combustors would be mounted external to the host boiler furnace and could emit the combustion products to the furnace through the same or enlarged tube-wall openings as previously utilized by the oil burners.

In principle, coal is burned in combustors either in the dry pulverized state or as a coal-water slurry in a highly turbulent regime at heat release rates up to 50 times greater than that for normal coal firing. This generates internal temperatures greater than 2700°F, sufficiently high

to consume up to 99% of the carbon and liquify most coal ash. Up to 90% of the ash is removed as molten slag from the combustor, and the remaining flyash is extremely fine - all less than 20 micron. The theory is that the fine ash will follow the aerodynamic path of the flue gas and not impinge on convective tube surfaces within the host boiler, but this has yet to be demonstrated in either a full-scale test or subscale simulation. Oxides of nitrogen formation are held at relatively low levels by maintaining initial combustion at substoichiometric conditions. SO_x is controlled by limestone injection in the primary combustion zone.

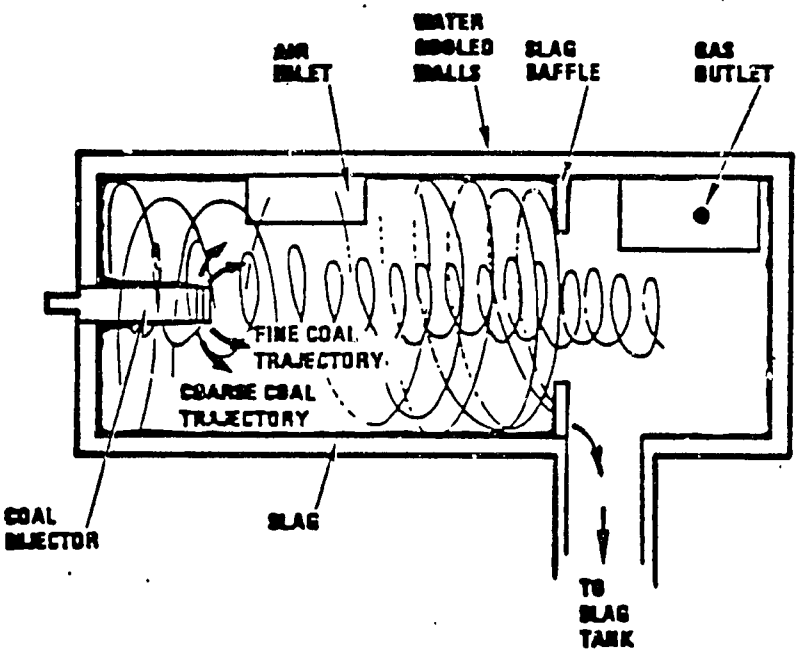
2.0 COMBUSTOR DESIGNS

Combustor designs and test units are being developed by several companies including: TRW, Rockwell, Coal Tech, and AVCO-Everett. Their designs and respective performances vary in some respects, and they are all still in the development-test stage. Several one-combustor test installations on small industrial or utility boilers are in the planning and preparation stage, but to date only test-stand short-term tests have been performed. The various designs of staged combustors are discussed below. For comparison, paragraph 2.6 describes an older version of a cyclone boiler (single stage slagging combustor) used for many years for coal firing in industrial and utility boilers.

2.1 TRW Design

TRW has emphasized oil-design boiler retrofit, and their design goal is to aerodynamically remove 90% of slag/flyash while simultaneously achieving 99+% carbon burnout within the combustor. Their emission goals are for NO_x levels similar to oil firing (250 ppm) and sulfur capture of 70-90%.

The basic design features of the TRW combustor are shown in the schematic and the complete combustor system illustrated on Figure B-1. Air is injected tangentially creating a highly swirled flow which entrains coal particles, producing volumetric combustion (over 90% of the powdered coal is burned in flight) and throwing slag to the wall. The wall is water cooled and utilizes studs to retain slag on its surface. The slag is solid at the metal wall but liquid on the surface facing combustion. Slag flows down the walls and toward the baffle under combined aerodynamic and gravity forces. This not only prevents erosion but also controls the rate of heat transfer to the walls. There is no refractory used in the design. The key-slotted baffle is located about two-thirds of the way down the combustor to collect and direct the molten slag to a single cylindrical tank partially filled with water. The tank can be equipped with a crusher in the bottom to break up large pieces of solidified ash. The slag particles can be removed with a conventional sluicing system or they can be dewatered and handled by a bulk conveyor. Combustion air is preheated in a separately fired "precombustor" using either pulverized coal or oil. Depending on the amount of air preheat available from facility heat recovery systems, 10-20% of the total energy input occurs in the precombustor. Coal is pulverized to about 70% 200 mesh and transferred to a small coal hopper. A dense-phase feeding system transports the coal to the burner with an approximate 10 lb coal/lb of conveying air or flue gas.



Schematic of TRW Combustor Design Features

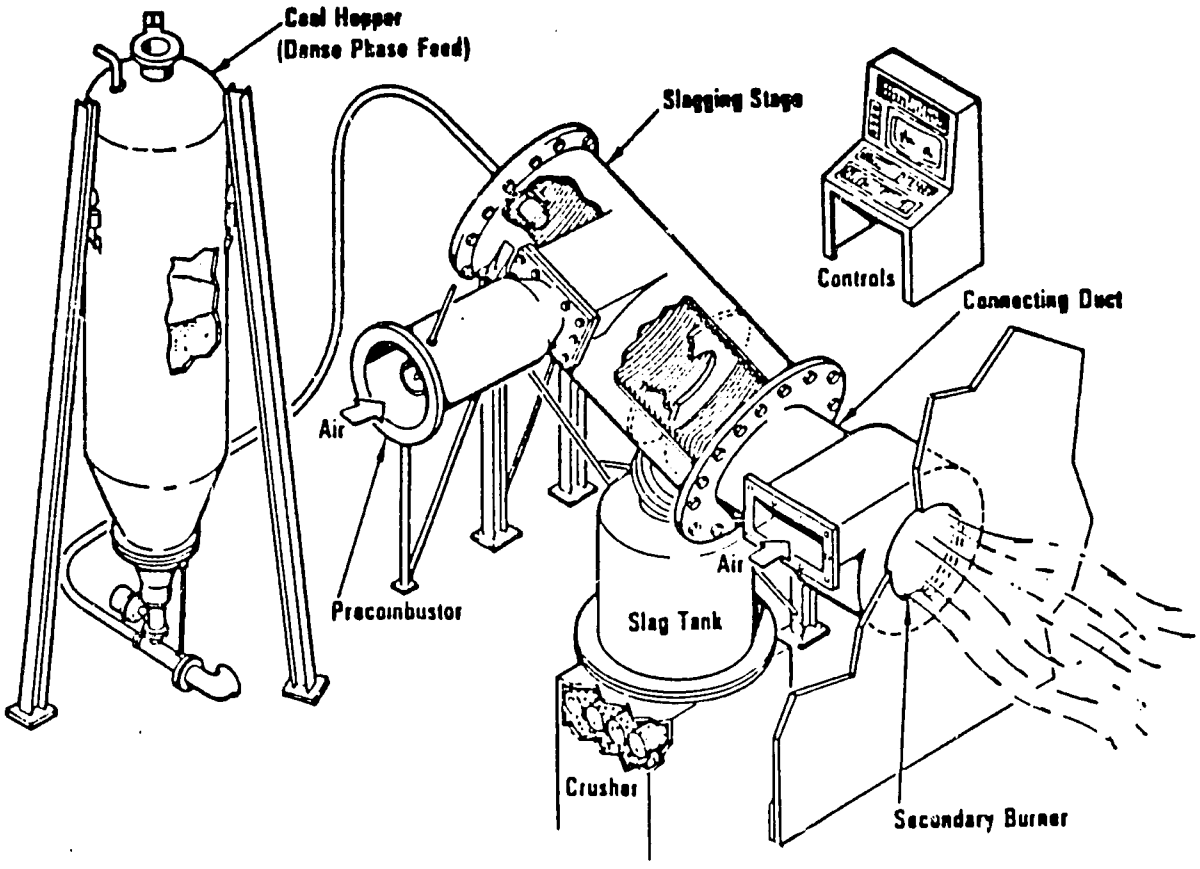


Figure B-1 TRW Slagging Coal Combustor System

TRW's initial experimental unit was rated at 1 MMBtu/hr, followed by a feasibility test unit rated at 10-30 MMBtu/hr when fired at 1-6 atmospheres. In 1980, an atmospheric unit rated at nominally 10 MMBtu/hr was fabricated. Testing on this unit continues to the present, and most reported data is from this unit. Various U.S. eastern and western coals were test fired successfully, as well as a 70/30 coal/water slurry. A second combustor, rated at 50 MMBtu/hr, was constructed, and testing has been conducted with the intention of maximizing combustion efficiency and slag removal while minimizing NO_x and SO_x emissions. In 1985, it is planned to fit this combustor to a large boiler simulator to study the effects of fine particulate slag carryover on fouling, slagging, and erosion of convective surfaces in industrial and utility boilers.

In addition to the testing at the Capistrano site, TRW is also actively pursuing a retrofit demonstration on an industrial boiler at a TRW Aircraft Component Parts plant in Cleveland. A User Advisory Group consisting of eight industrial and utility companies will monitor the demonstration and advise TRW on requirements, facilities, and operational procedures. The Cleveland unit is a D-type package boiler, rated at 30,000 lb/hr steam flow at 100-125 psig, saturated. A single retrofit combustor rated at 50 MMBtu/hr maximum will burn a medium-sulfur Ohio coal (1.9% S washed). The modifications to the Cleveland plant will include:

- New coal-receiving, storage reclamation, pulverizing, and feeding system
- New FD and ID fans and ductwork
- Combustor cooling and heat recovery system
- New heat exchangers to preheat combustion air with hot water from the combustor cooling circuit and flue gas from the boiler
- New baghouse filter and ash handling system
- Slag removal system installed on combustor
- New control system

A 4000-hour test is contemplated over a 6-month period. Hardware design and fabrication and facility preparation are now underway. Integration and checkout are scheduled for early 1985, and long-duration testing is expected to be accomplished in the second half of 1985.

TRW has performed several preliminary utility retrofit design studies for both tangentially-fired and wall-fired boilers, in addition to studies for industrial applications. TRW envisions commercial combustors from 20 to 250 MMBtu/hr in thermal capacity. Such combustors would range from approximately 2 ft. in diameter by 4 ft. in length to 7 ft. in diameter by 11 ft. in length. The retrofit approach is to replace the existing gas- or oil-fired burners with the coal combustor in a one-for-one fashion with a short duct connecting the combustor to the existing furnace wall burner

opening. Depending on combustor thermal capacity requirements, port configuration, availability of mounting room, etc., another concept would allow one large combustor to be ducted to multiple burner ports.

2.2 Rockwell Design

Rockwell has emphasized low NO_x/SO_x operation. Their combustor design seeks to optimize the time and stoichiometry required for simultaneous SO_x and NO_x control in combustion. Preliminary concept verification testing was performed from 1979 to 1981 in a 17 MMBtu/hr pressurized (6 atmospheres) test unit(see Figure B-2). The first section of this unit is refractory-lined, and the second section is water-cooled.

In this combustor (7.5-inch I.D.) about 50% of the molten ash particles were deposited on the combustor walls. A slag/fly ash separator designed to increase overall slag/fly ash removal to about 80% was also tested. The inertial impact separator consists of rows of studded metal tubes oriented vertically across the gas stream (see Figure B-3). The principle is that the large fly ash particles cannot negotiate the sharp turns around the tubes and thus impinge on the tube surfaces. The molten slag then runs down the tubes and joins the slag from the combustor walls and flows to the slag port near the end of the combustor.

Rockwell's proposed commercial combustors are designed to be direct-fired (i.e., coal is pulverized and blown directly into the combustor, with pulverizer air used as the carrier). All testing to date, however, has utilized indirect coal-feed systems. The 17 MMBtu/hr combustor used dense-phase coal feed, and the 25 MMBtu/hr pilot-scale combustor (described below) used an intermediate PC storage silo, from which the PC is picked up in carrier air and pneumatically transported to the combustor. Most of the testing in the 17 MMBtu/hr concept-verification facility was done without a separator or slag removal system. Slag deposits were collected in a well internal to the combustor and periodically removed during the facility down times. Coals tested in this mode of operation were several U.S. eastern and western coals; in addition, two coal-water slurries, a high-sulfur residual oil, and shale oil were tested.

Rockwell's combustor was initially conceived as a means of providing low-cost SO_x and NO_x control in combustion. In 1981 Rockwell fabricated and tested an inertial slag separator for the 17 MMBtu/hr concept-verification facility. The separator was equipped with an internal well for slag storage, and slag was not continuously removed from the combustor.

Subsequently, a 25 MMBtu/hr atmospheric pressure pilot-scale facility was constructed and testing began in 1982 and continues to the present. This pilot-scale combustor is refractory-lined throughout. Initially, the refractory was backed up with water cooling,but is now operated entirely uncooled. The combustor exhausts into the combustor bare steel ducting, which is externally water-spray cooled, to simulate the radiant section of a boiler. This is followed by a commercial waste-heat boiler, which simulates the back-end convective section of a boilers. Coals tested to date include two eastern coals and one western coal. The pilot-scale facility

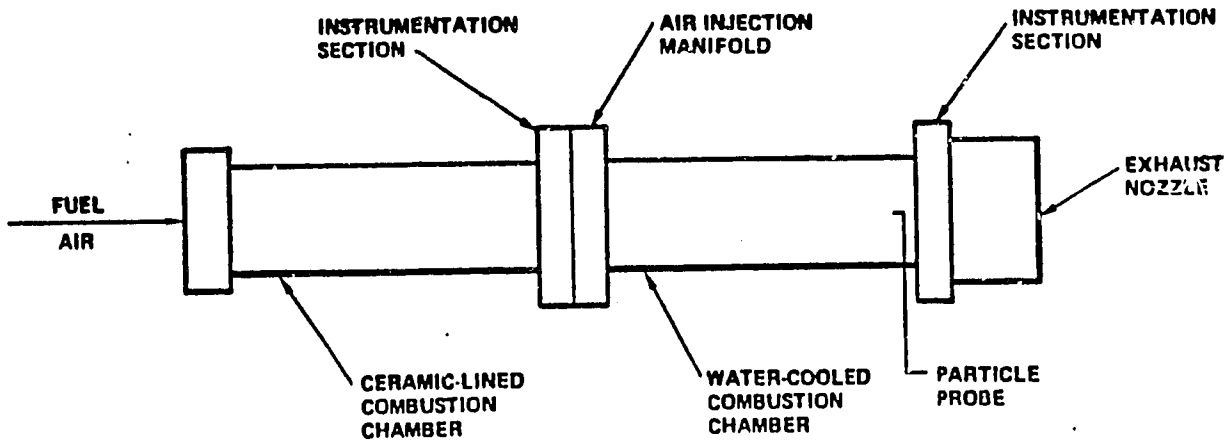


Figure B-2 Rockwell 17-MMBtu/h Pressurized Concept Verification Slagging Combustor

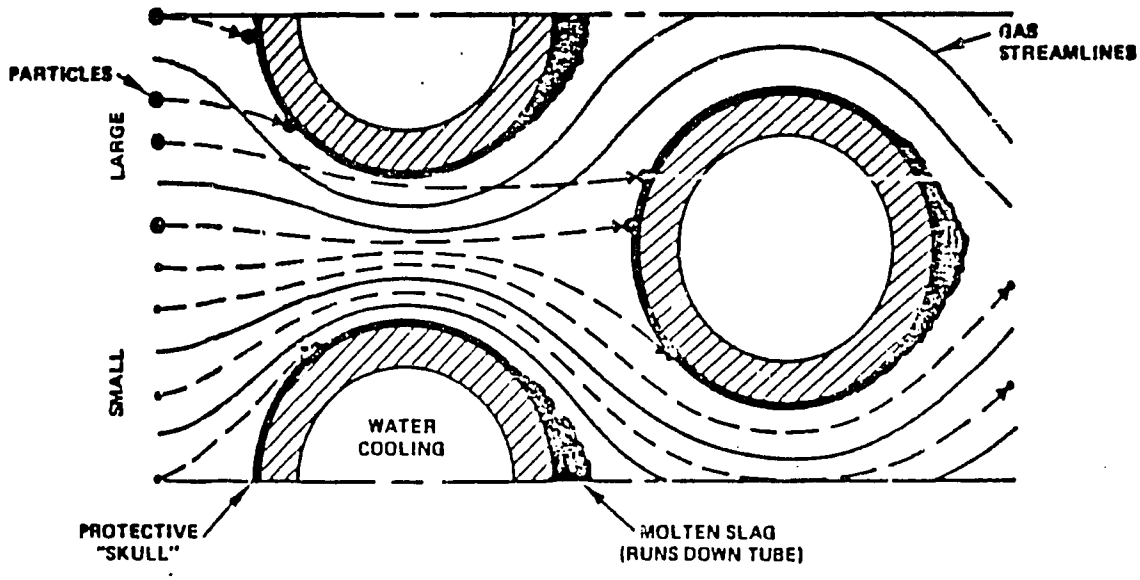


Figure B-3 Rockwell Particle (Fly Ash/Slag) Separator Schematic (Top View)

was not originally equipped with a slag/fly ash separator or with provision for continuous slag removal. However, a slag/fly ash separator incorporating continuous slag removal has now been installed.

Rockwell has performed preliminary design studies for retrofits to both tangentially-fired and wall-fired units. A conceptual schematic for a 100 MMBtu/hr commercial combustor is shown in Figure B-4. The large size of the Rockwell unit is due to the long residence time needed to achieve the necessary degree of carbon burnout and low NO_x/SO_x emissions, as well as to accommodate the slag/fly ash separator.

Tentatively, a 60 MW wall-fired boiler, designed for coal, in Alberta, Canada was selected for retrofit of a commercial burner. This boiler had been firing natural gas and is still gas-capable, but has recently been converted to coal firing, using conventional PC coal burners. The unit contains three rows of three burners each, and the program calls for replacement of one of the burners by a Rockwell combustor for a six-month test of operability and reliability. Two more burners will then be replaced, with one pulverizer feeding the three burners. The three-burner array will then be tested for 6-12 months. Single-burner testing is scheduled for 1985, with multiple-burner testing to follow in 1986.

2.3 Coal Tech Design

Coal Tech was formed by former members of GE's MHD group. Under DOE-sponsored MHD work, GE tested a 1 MMBtu/hr, air-cooled, ceramic-lined, slagging combustor (see Figure B-5). Two coals were tested in the unit, an eastern and a western coal, and testing was discontinued in June 1981 after about 200-300 hours of coal firing.

Based on experimental results from the GE test unit and theoretical calculations, Coal Tech is developing a design for a commercial-scale slagging combustor of 100 MMBtu/hr. Their commercial design retains the basic features of the GE test unit. These are:

- Predominantly air-cooled, with cooling air used as preheated combustion air
- Ceramic-lined
- Highly swirled air which throws slag out to the walls
- Short combustor residence time which results in a compact design (internal length/diameter ratio of about 1.5)
- Coal pulverized to about 70% minus 200 mesh and stored in a coal hopper; dense-phase feeding system

Coal Tech has recently performed a number of design studies for several utilities, and has prepared preliminary designs for utility boiler retrofits to both tangentially- and wall-fired units. They also have prepared a design and a plan for a demonstration test at Philadelphia

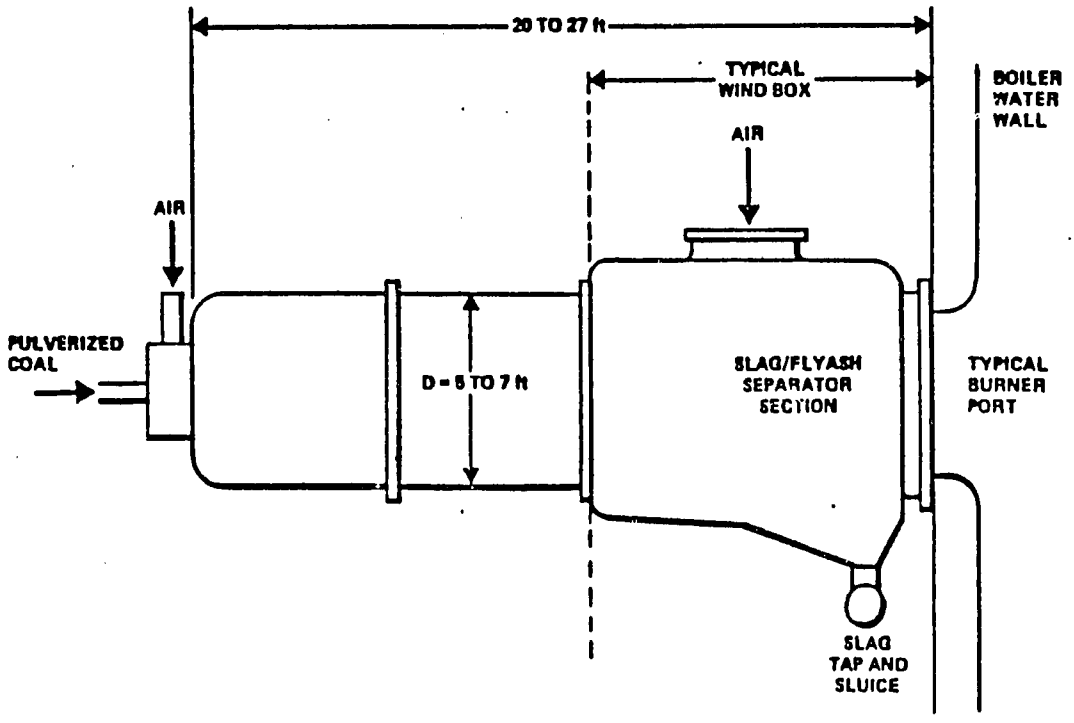


Figure B-4 Schematic of Rockwell Commercial-Scale (100-MMBtu/h) Slagging Combustor

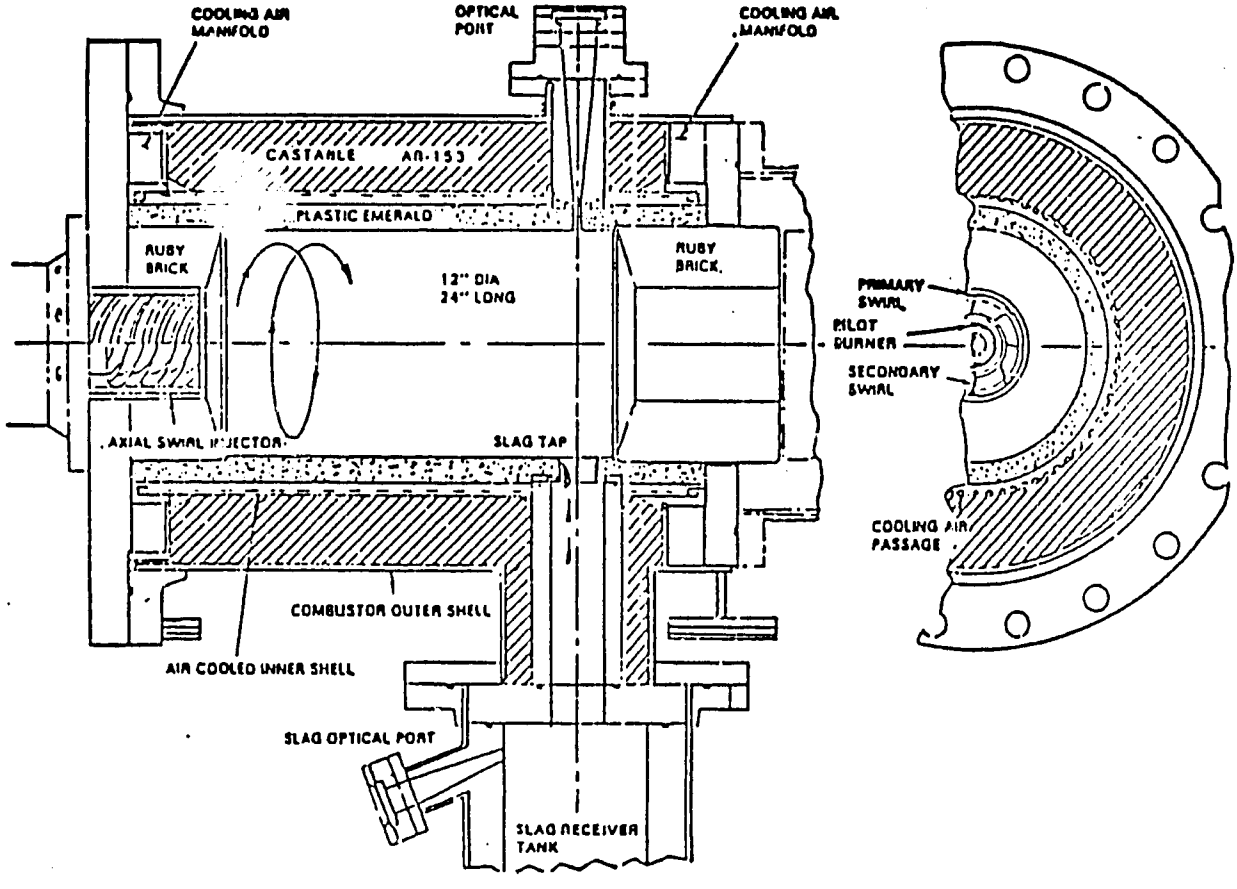


Figure B-5 Cross-section of GE 1-MMBtu/h test unit showing use of ceramic-liner materials: Castable AR-153, Plastic Emerald, Ruby Brick

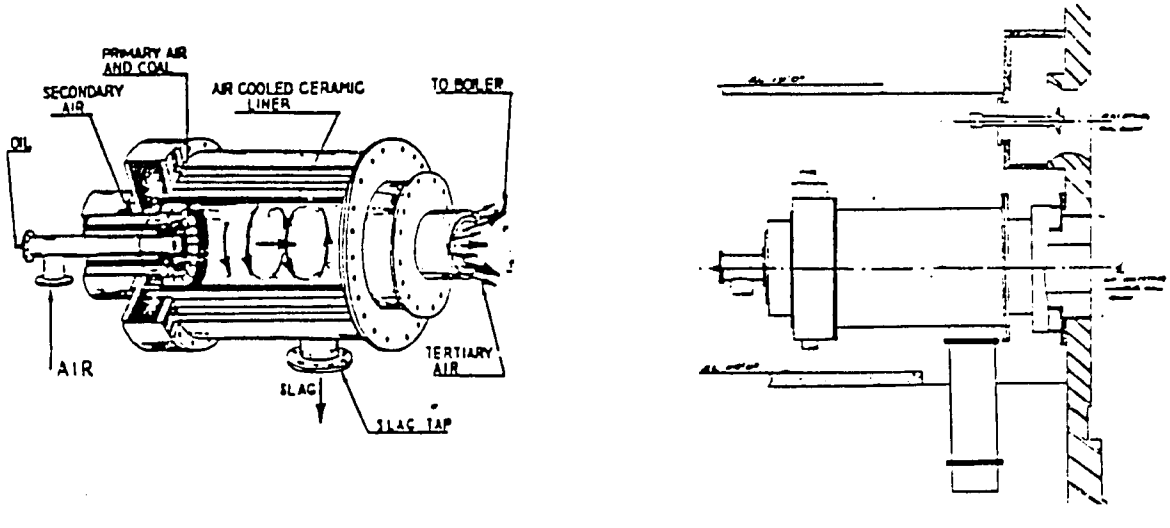


Figure B-6 Schematic of Coal Tech Commercial Scale Slagging Combustor and Proposed Installation

Electric's Delaware Station for a 120 MW wall-fired coal-designed unit with 12 burners. For the demonstration one of the 12 burners would be replaced with a 100 MMBtu/hr combustor. The proposed test is to fire for 1000 hours over a 6-month period with a low-sulfur West Virginia coal and a 2% sulfur Pennsylvania coal. In addition, Coal Tech is proposing a test of a smaller 30 MMBtu/hr combustor in an oil-designed package boiler as a feasibility test lasting several hundred hours. To date, no firm commitments have been established for these tests. Figure B-6 schematic shows Coal Tech's proposed commercial scale air cooled combustor design.

2.4 AVCO Design

AVCO combustor development is also based on a previous MHD pressurized combustor. At present, retrofit of oil-fired boilers with compact combustors and minimum unit derating is the major goal.

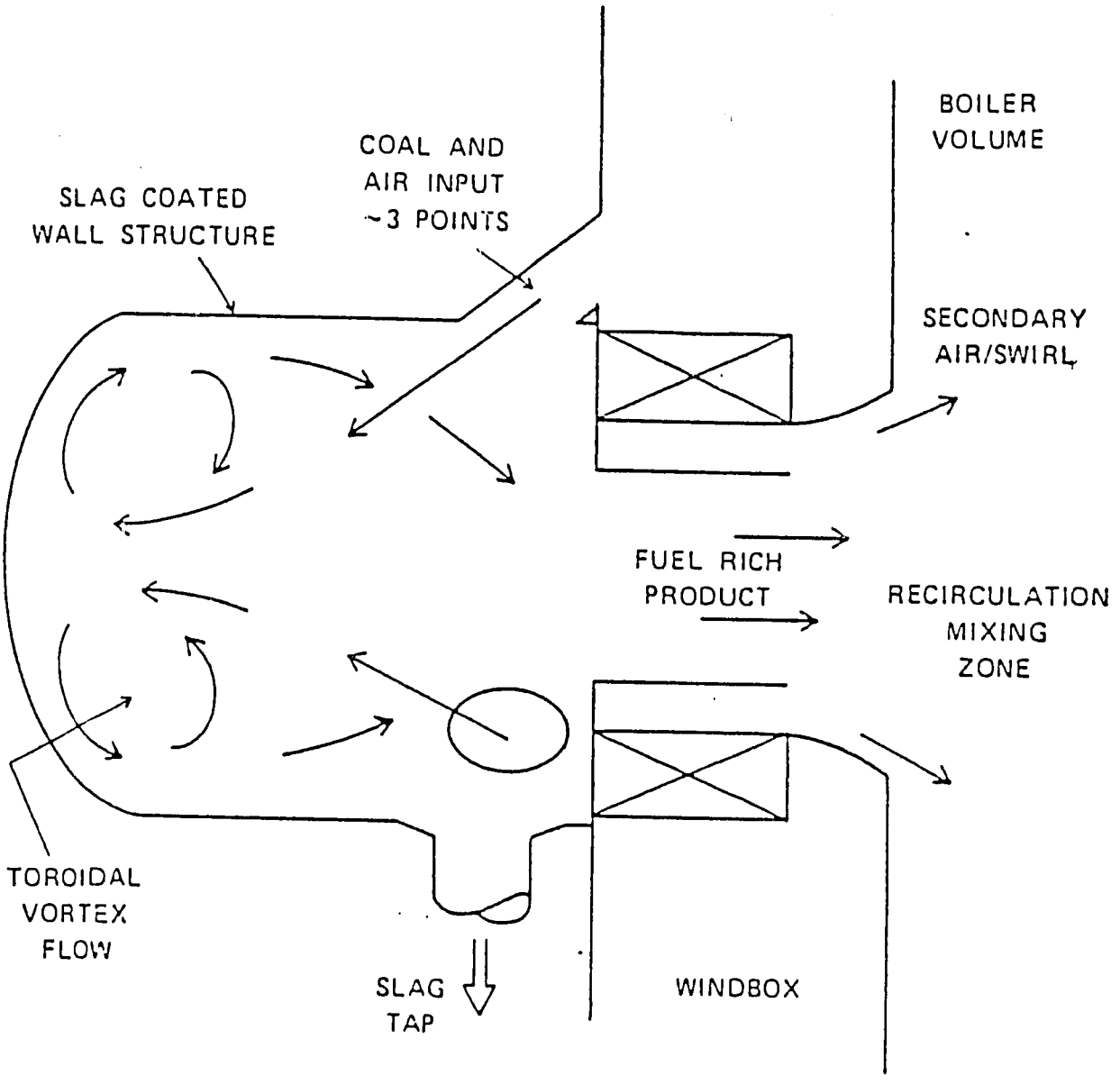
The AVCO combustor (Figure B-7) employs inertial particle separation from the flow field, using an unique toroidal vortex flow geometry. Mineral matter particles are impacted on the wall to form a steady-state flow of molten slag, which is removed from the combustor. This general design approach involves consideration of pressure drop, ash separation, combustion efficiency, heat loss, and pollutant emissions. The combustion products of the external combustor are discharged into the slag separator where more than 90% of the slag is inertially separated and collected. The hot-gas product of the external combustor system, rich in CO, is mixed with secondary air at the entrance to the boiler and the combustion is driven to completion in the boiler radiative heat-exchange furnace volume. Thus, the boiler furnace serves as the second combustor stage.

2.5 Management and Technical Consultants, Inc.

A similar technology of slagging combustor based on a different combustion principle is in a preliminary study stage of development. It is designed to fire coal in steam generators and other fired equipment. Under DOE sponsorship, Management and Technical Consultants, Inc. is developing preliminary designs for a subscale test facility of Pulsed Coal combustors fired with a coal-water slurry. The technology is similar to that of the propulsion system for the German V-1 rockets of World War II, based on Schmidt/Reynst patents. The principle of operation is illustrated in Figure B-8.

The principle has been applied to small oil, gas and gasoline fired hot water boilers, heaters and dryers. In the 1950's, a coal gasifier was built in Germany, and in the 1960's, a coal-fired lignite dryer was operated in the U.S. In Russia, pulse oil- and coal-fired burners for steam boilers were tested in the 1960's.

Current development is oriented to combustors which can be retrofitted to industrial and utility steam boilers and fired heaters, for the replacement of oil firing with coal fuels (coal-water slurries). The goal is to design combustors capable of complete carbon conversion and gas burnout, which are able to operate over a suitable load range, provide for rejection

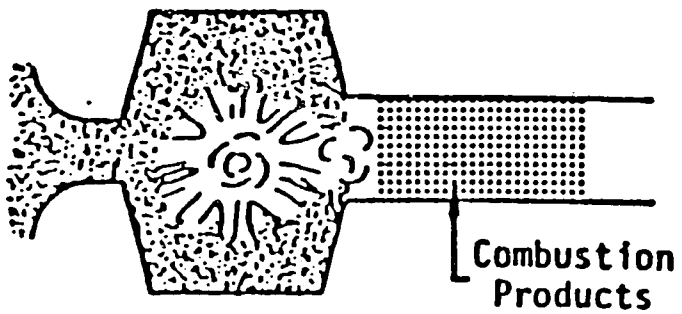


Retrofit Slagging Combustor Concept and General Flow Field Geometry.

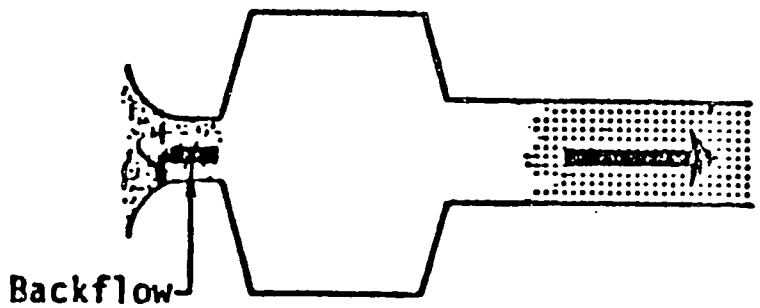
AVCO

Figure B-7

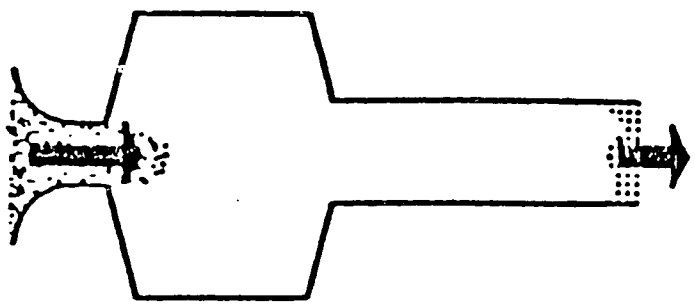
PULSE COMBUSTION PRINCIPLE OF OPERATION



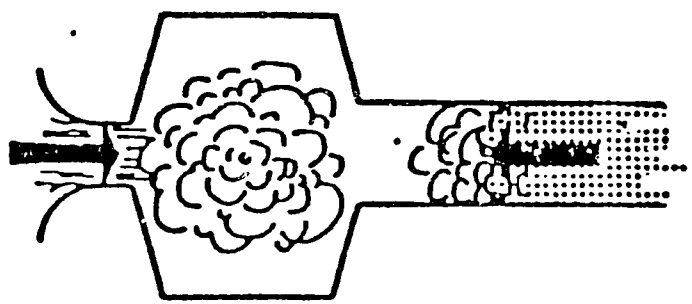
A. IGNITION AND COMBUSTION



B. EXPANSION



C. PURGE AND RECHARGE



D. RECHARGE AND COMPRESS

Figure B-8

of a substantial percent of ash within the combustor, and be able to control NO_x and SO_x emissions, with the prospect of low cost and maintenance.

Conceptual schematic diagrams of retrofit pulse combustors applied to utility and industrial boilers are shown in Figure B-9.

2.6 Babcock & Wilcox Co. Cyclone Furnace

For many years Babcock & Wilcox Co. built a single-stage combustor primarily for firing slagging low-fusion-temperature ash coals in large industrial and utility steam generators. The cyclone furnaces were integrated into the boiler furnace structure and water circulation circuits. The molten slag from the cyclones flowed to the floor of the main furnace for disposal in one or several large slag tanks. Figure B-10 shows a cyclone-fired utility steam generator.

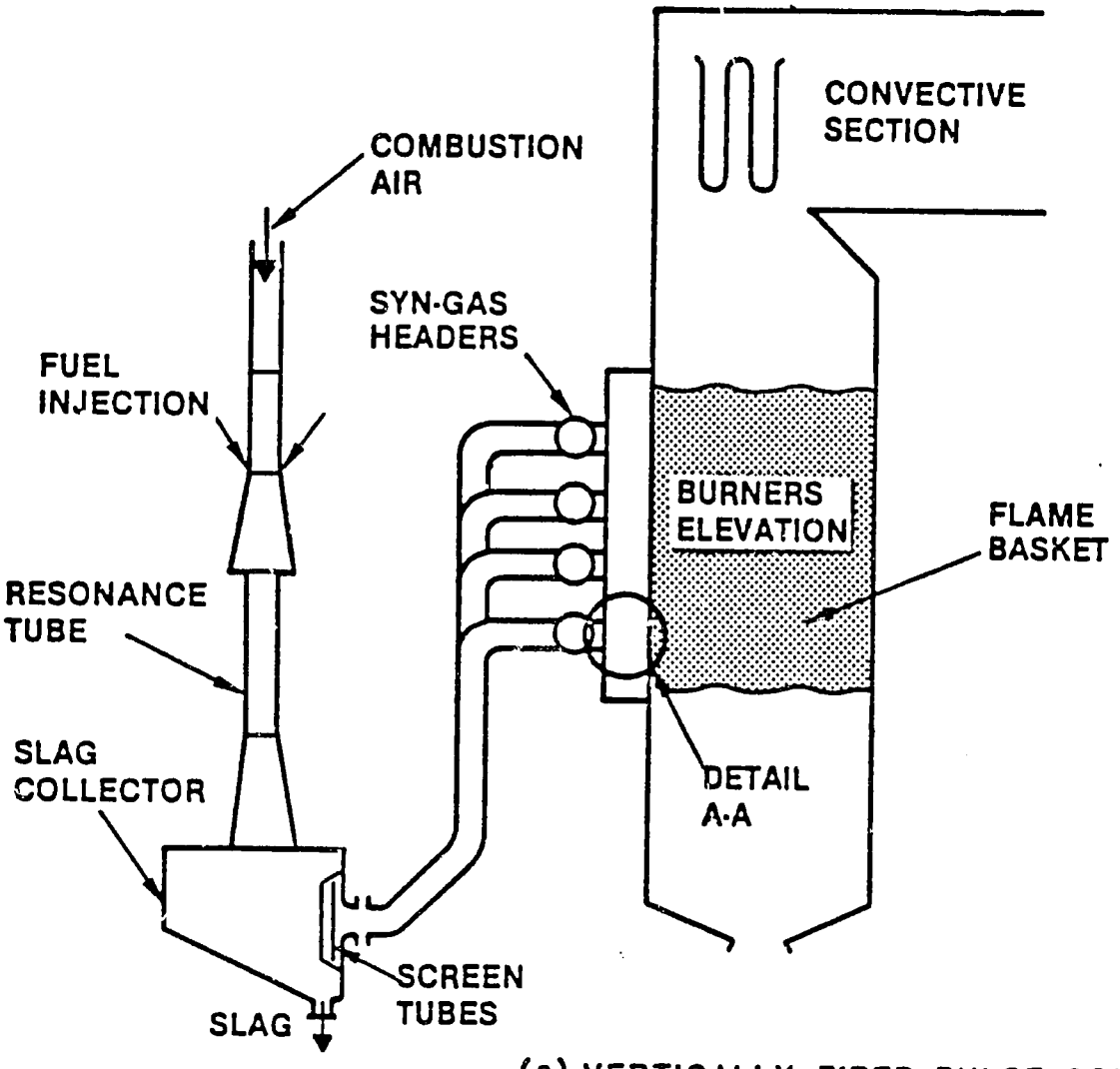
The cyclone furnace, Figure B-11, is a water-cooled horizontal cylinder in which fuel is fired, heat is released at extremely high rates, and combustion is completed. Its water-cooled surfaces are studded and covered with refractory over most of their area. Coal crushed in a simple crusher, so that approximately 95% will pass a 4-mesh screen, is introduced into the burner end of the cy clone. About 20% of the combustion air, termed primary air, also enters the burner tangentially and imparts a whirling motion to the incoming coal. Secondary air with a velocity of approximately 300 fps is admitted in the same direction tangentially at the roof of the main barrel of the cyclone and imparts a further whirling or centrifugal action to the coal particles. A small amount of air (up to about 5) is admitted at the center of the burner. This is known as "tertiary" air.

The combustibles are burned from the fuel at heat release rates of 450,000 to 800,000 BTU/cu.ft/hr., and gas temperatures exceeding 3000°F are developed. These temperatures are sufficiently high to melt the ash into the liquid slag, which forms a layer on the walls of the cyclone. The incoming coal particles (except for a few fines that are burned in suspension) are thrown to the walls by centrifugal force, held in the slag, and scrubbed by the high-velocity tangential secondary air. Thus the air required to burn the coal is quickly supplied, and the products of combustion are rapidly removed.

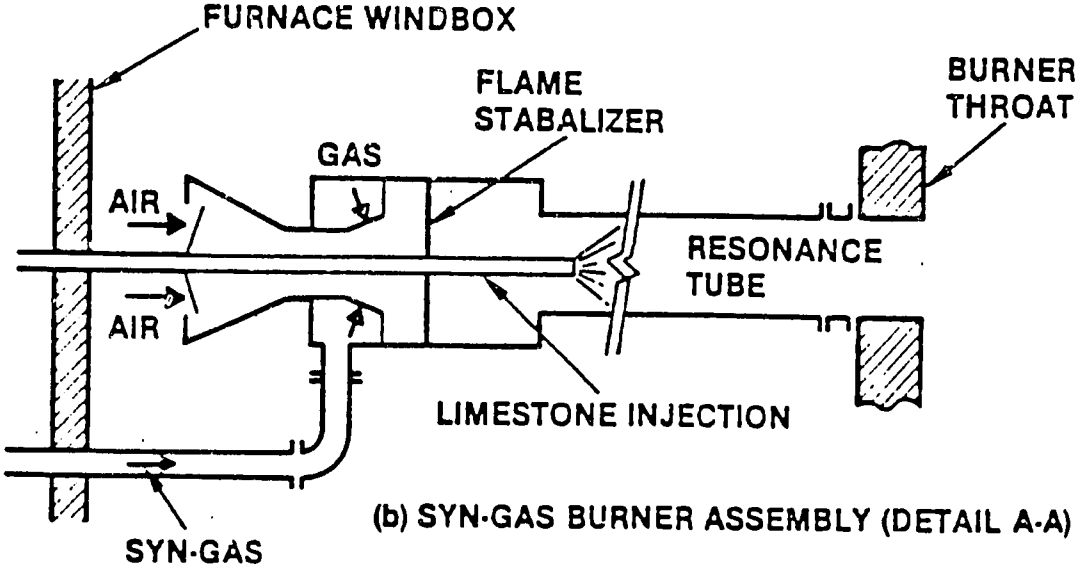
The volumetric heat release rate in the cyclone furnace is very high. However, there is only a small amount of surface in the cyclone, and this surface is partially insulated by the covering slag layer. Heat absorption rates range from 40,000 to 80,000 Btu/sq ft/hr. This combination of high heat release and low heat absorption assures the high temperatures necessary to complete combustion and to provide the desired liquid slag covering of the surface.

The gaseous products of combustion are discharged through the water-cooled re-entrant throat of the cyclone into the gas-cooling boiler furnace. Molten slag in excess of the thin layer retained on the walls

RETROFIT OF A PULSE COMBUSTOR TO A UTILITY BOILER



(a) VERTICALLY-FIRED PULSE COMBUSTOR RETROFIT



(b) SYN-GAS BURNER ASSEMBLY (DETAIL A-A)

Figure B-9

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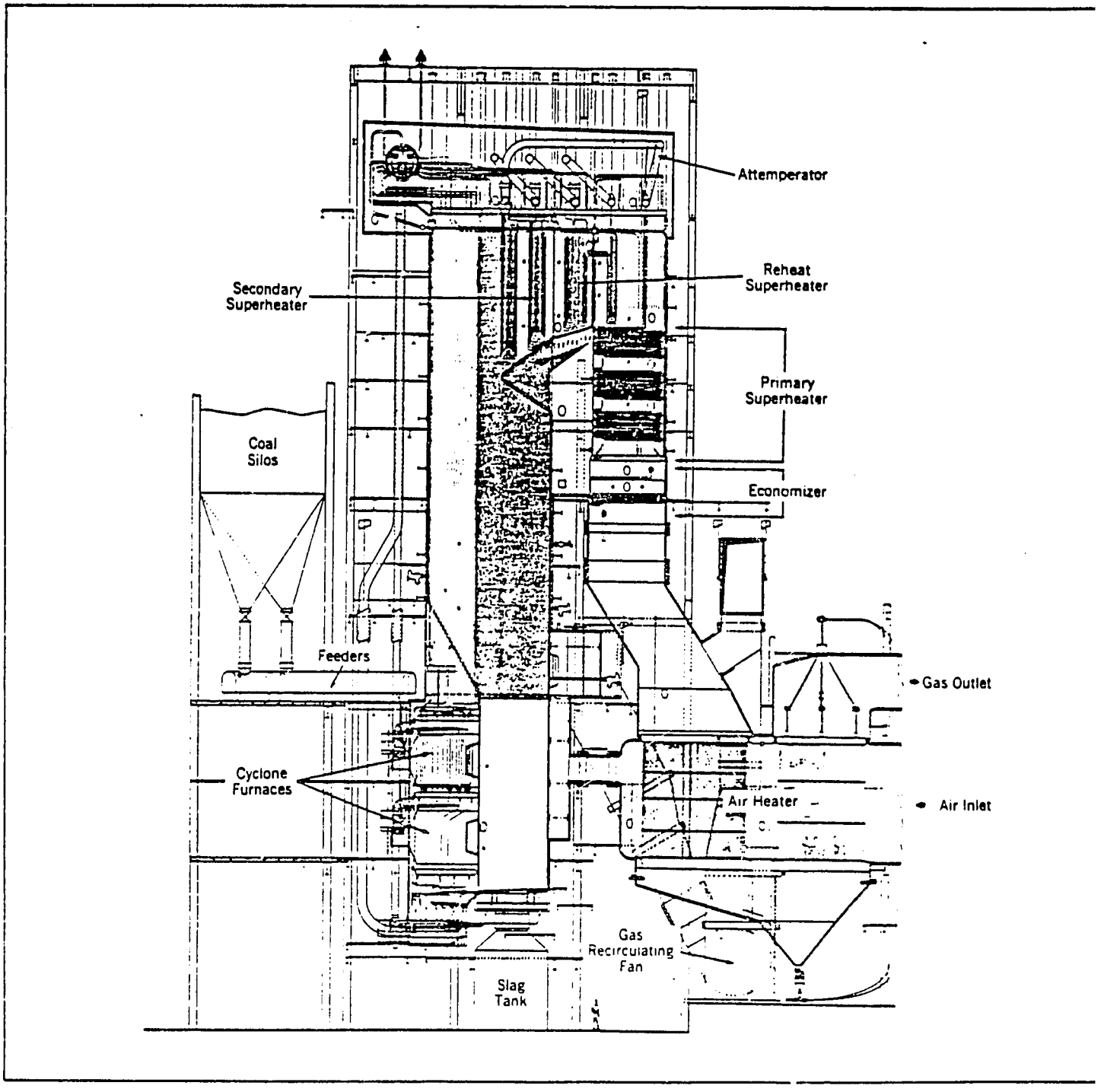
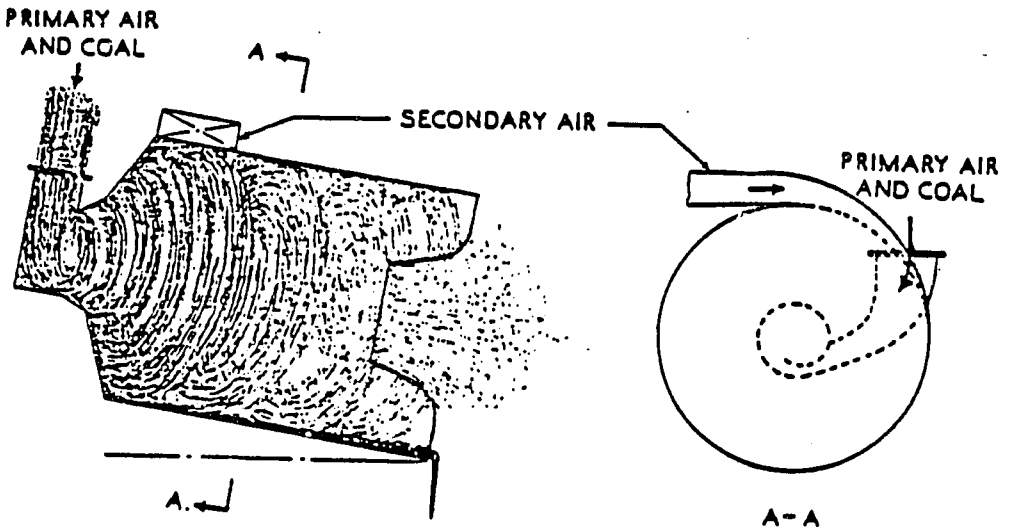
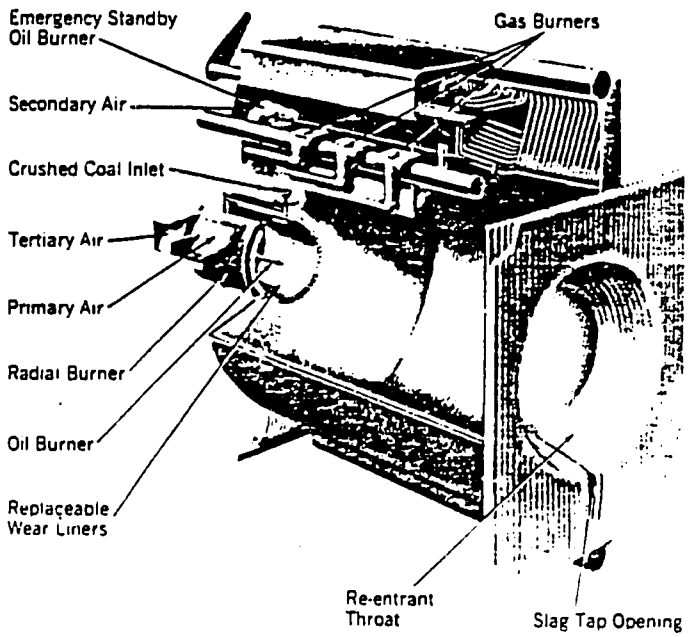


Radiant boiler with Cyclone Furnaces (one-wall)

Figure B-10



DIAGRAMMATIC PRESENTATION OF PRINCIPLES OF CYCLONE BURNER



The Cyclone Furnace, in the form of a horizontal cylinder, is completely water cooled by connection to the main boiler circulation. All combustion gases leave through the re-entrant throat at the rear. Molten slag drains from the bottom at the rear through a small opening into the adjacent boiler furnace.

Figure B-11

continually drains away from the burner end and discharges through the slag tap opening, shown in Figure B-11, to the boiler furnace, from which it is tapped into a slag tank, solidified, and disintegrated for disposal.

By this method of combustion, the fuel is burned quickly and completely into the small cyclone chamber, and the boiler furnace is used only for cooling the flue gases. Most of the ash is retained as a liquid slag (approximately 80%) and tapped into the slag tank under the boiler furnace. Thus, the quantity of fly ash is low.

The cyclone furnace is capable of successfully burning coals with low fusion temperatures. Coal-water slurries have been burned in test runs. The suitability of coals is dependent on the moisture, ash and volatile contents of the coal, together with the chemical composition of the ash. The volatile matter should be higher than 15%, on a dry basis, to obtain the required high combustion rate. The ash content should be a minimum of 6% to provide a proper slag coating in the cyclone and can be as high as 25% on a dry basis. A wide range of moisture content is permissible, depending on coal rank, secondary air temperature, and fuel preparation equipment that may include capacity for pre-drying the fuel.

An important criterion for establishing the suitability of coal for firing in the cyclone is the viscosity of the slag formed from the ash. Since satisfactory combustion of coal depends on the formation of a liquid slag layer in the cyclone, and since ash is removed from the cyclone and primary furnace in fluid form, the viscosity of the slag must permit slag flow at the temperatures experienced in the cy clone and primary furnace. Slag will just flow on a horizontal surface at a viscosity of 250 poises. The temperature at which this viscosity occurs (T_{250}) is used as the criterion to determine the suitability of a coal from this point of view.

In the cyclone furnace combustion is completed in a single stage at high temperatures at excess air conditions which produce NO_x quantities in excess of current permissible limits. Due to their inability to meet the present stringent NO_x emission limits, cyclone boilers are no longer built in the US.

3.0 DEVELOPMENT AND COMMERCIALIZATION

The staged slagging combustor developers have each performed at least 200 hours of coal-firing. TRW has performed the most testing, over 800 hours of coal-firing, with 7 different coals (both eastern and western) and has also fired highly loaded coal-water slurries (70% coal/30% water). Most of their testing has been at a scale of 10 MMBtu/hr, and they are now firing a 50 MMBtu/hr combustor. Rockwell began their testing with a 17 MMBtu/hr pressurized (6 atm.) unit and is now testing a 20 MMBtu/hr atmospheric burner. Rockwell has also fired both eastern and western coals, as well as coal-water slurry. Coal Tech derive their experimental data from tests performed on a 1 MMBtu/hr combustor, which is no longer operating. No testing is currently being performed by Coal Tech.

The developers are proposing industrial and/or utility retrofit demonstrations. Rockwell is proposing to retrofit three of the existing

nine burners on a 60 MW unit located near Edmonton, Alberta, Canada. Single-burner testing is scheduled for 1985, with multiple-burner testing to follow in 1986. TRW is actively pursuing a retrofit of a single combustor to a 30,000 lb/hr industrial boiler at a TRW plant in Cleveland. Fabrication and facility preparation is now under way, and long-duration testing (4000 hours) is expected in the second half of 1985. Coal Tech is proposing an industrial-boiler test, as well as a test of a single burner in Philadelphia Electric's 120 MW unit.

To date, none of these tests are in progress and, in fact, in most cases, no firm financial commitments or schedules have been established and little work has been done towards carrying out those for which dates were tentatively published. There are several areas that require development, confirmation and/or demonstration in actual long-term tests on existing or new boilers in order that this technology may qualify for utility use. Some of these factors, which include performance and integration issues, are discussed in the following paragraphs.

3.1 Performance (Air Pollution Control and Carbon Conversion)

The air pollutants controlled directly in the combustion process in these devices are NO_x and SO_x. NO_x is held at low levels by maintaining initial combustion at substoichiometric conditions. SO_x is controlled by injecting a sorbent (usually limestone) into the primary combustion zone. Although these devices are designed to remove 60 to 90% of ash in the combustor, this is not considered an air pollution control for particulates, since most regulations require the removal of 99+% of fly ash.

Care must be taken in design and operation to simultaneously achieve good carbon burnout and slag recovery as well as low NO_x/SO_x production. Also, most tests to date have been conducted in subscale test facilities, and there are often difficulties in simulating and/or measuring carbon burnout in subscale test facilities.

The NO_x emission goals of the developers have been well achieved in test firings. Carbon conversion goals have also been generally met, but simulation of full-scale carbon conversion is difficult in subscale facilities. Sulfur capture results have ranged from as low as 20% to as high as 95%. Best results were obtained when the sorbent (calcium) was already inherent in the coal such that no further calcium was added. TRW believes that additional sulfur capture will occur on the filter cake of a baghouse, and therefore the entire combustor, boiler, and baghouse system must be tested to determine final sulfur capture.

There are various levels of demonstration of slag removal goals among the developers. TRW has demonstrated their goal of 90% slag removal, as well as continuous operation of a slag tap at a scale of 10 MMBtu/hr and is now testing at 50 MMBtu/hr. Rockwell's initial experiments were done without a slag/fly ash separator or continuous slag removal. Slag was simply allowed to accumulate in a well inside the combustor. Rockwell has since tested a slag/fly ash separator at a scale of 17 MMBtu/hr and is now testing one with continuous slag removal at a scale of 25 MMBtu/hr; their

goal is 80% slag removal. Although Coal Tech has not tested their commercial combustor design, approximately 90% slag removal has been shown for the small-scale GE 1 MMBtu/hr combustor, which is similar to Coal Tech's design.

3.2 Mechanical Integration

The various combustor systems have significant size and mass which must be supported either independently of the boiler supports of in conjunction with them. In all designs, independent support has been proposed by the developers with either flexible "gun-mount" systems or floor-mounted arrangements with entry into the host boiler through a water seal. Although these methods appear feasible, their practicality has yet to be demonstrated. The slag-collection systems from the various combustor arrays also pose space constraints on the designs that have been proposed. At many oil-design boiler stations, available space, both in and around the boiler building, is very limited. Space limitations will increase difficulties in laying out the new systems required for retrofit, such as pulverizers, coal-storage bunkers, combustors, and slag-handling/storage equipment. Use of coal-water slurries would alleviate space requirements for coal storage and pulverizers.

3.3 Thermal Integration

Developers that use water cooling for their systems (TRW and Rockewell) indicate that 8-10% of the energy generated is transferred to the water. The integration of this load into the feed-water system could result in losses of both output power and efficiency; losses in the range of 2% were estimated by one developer. This aspect of the integration requires more design, equipment, and site-specific evaluation.

3.4 Coal- and Air-Supply and Control

All tests to date have been with single combustors where the flow of coal and air has been accurately measured and controlled. Control of air/fuel ratio is important because it affects emissions control and slag flow. Fuel and air-flow control on a large utility boiler with many burners will be more difficult because the distribution of fuel and air flow to each combustor and to the stages of each combustor will have to be controlled, in addition to the total flow of fuel and air. This is a more serious consideration for pulverized coal firing than for CWM fuel firing. In addition, limestone feed, if required for SO_x control, must also be metered to each combustor.

3.5 Operating Flexibility

Of interest in this area are startup and shutdown times and procedures (especially trip situations) as well as turndown. Systems containing refractory (Rockwell and Coal Tech) will have to make allowances during startup and shutdown to avoid fracturing the refractory. Subscale startup times on the order of 3-8 hours were mentioned, but the time required for a full-scale combustor will have to be determined from experience. Turndown

is limited primarily by considerations of maintaining slag flow. All developers are anticipating turndown in the range of 3/1 to 4/1, but actual values may depend on type of coal and on auxiliaries such as air-preheat temperature and, again, will have to be determined from full-scale testing.

3.6 Reliability

In applications where the combustors discharge through existing burner ports, a large number of combustors will be required for a utility boiler, and each will require a slag tap and a slag-handling system. There is concern that constant surveillance would be required to maintain a large number of combustors in reliable operation and that this would entail a sizable manpower requirement. It is suggested that good system reliability might be achieved by thorough instrumentation of each combustor to maintain good operating control and to alert operators to maintenance needs. Some of this instrumentation may need development work because of the severity of the environment within these combustors. Another reliability issue is material life, especially that of the liner of the combustor. Both refractory and water-cooled studded-metal walls are being pursued. Although developers have accumulated hundreds of hours of coal-firing experience, most individual tests are short, lasting for only about eight hours. All the developers have a goal of nominally one-year operation between major maintenance service; long-term firing will be needed to demonstrate this goal. Coal type will probably also have an effect on material life, as well as affecting performance and operation.

3.7 Coal Flexibility

Varying coal properties could potentially affect many aspects of combustor operations such as slag fluidity, sulfur capture, slag corrosivity, ash erosivity, combustor temperature, carbon burnout, and NO_x emissions. Combustor developers have performed short-term tests with several different types of coal including high-sulfur eastern and low-sulfur western coals. Nevertheless, considering the developing nature of the technology, it is felt that broad statements regarding coal suitability are not warranted and that the suitability of each specific coal should be demonstrated.

3.8 System Costs and Economics

At the present time, the developers' estimates of ultimate costs and economics are relatively unrefined, and this is to be expected at this stage of development. Also, different developers have concentrated on different applications. Even so, it is believed that this technology can be used to control SO_x and NO_x to levels near those currently achieved by post-combustion control (for example, flue-gas desulfurization (FGD) for SO_x control and selective catalytic reduction (SCR) for NO_x control) at costs ranging from one-third to one-tenth of post-combustion controls. As the technology develops, consistent and rigorous cost and economic analyses must be performed for each application.

4.0 CONCLUSION

The staged slagging coal combustor systems must be totally integrated with the boiler and plant operation and will have an impact on boiler availability. The combustion technology has been demonstrated adequately in sub-scale tests. With the planned full-scale, long-term, tests which are expected to be performed and completed within the next several years, sufficient operational data and experience will be available to reach a level of confidence and expertise to lead to the design and construction of a complete retrofit of a large oil-design boiler to fire pulverized coal or a coal-water slurry. This will allow retrofit of oil-fired boilers to coal with little or no derating of design capacity, while minimizing modification requirements. This may offer significant economic advantages when compared to conversion using normal coal firing technology and equipment. Also, the slagging combustors could be used for future new installations.

The economic benefits to be derived from two-stage combustor conversions are:

- Little or no derating of the plant; hence, no replacement energy costs
- Lower boiler modification costs than for standard pulverized coal conversion
- No equipment for NO_x removal necessary
- Slag easier and cheaper to dispose of than fly ash or bottom ash
- Potential for use of coal-water slurry as a fuel; hence, reduced coal handling and storage system costs
- Potential for removing sulfur during combustion, reducing the costs associated with sulfur removal

Staged slagging coal combustors have the potential of providing a technically attractive alternative for conversion of oil-designed boilers to coal or coal-water mix fuel firing. The SSCC technology is still under development and requires large scale demonstration before its cost attractiveness and technical practicality can be established. At the present pace of development, this technology could reach commercial applicability in 5-8 years.