FE-2363-4
Distribution Category UC-90g and UC-93

MHD ETF-150 MW PROGRESSIVE FACILITY REFERENCE CONCEPT

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Date Published - August,1979

PREPARED FOR THE
UNITED STATES DEPARTMENT OF ENERGY

Under Phase II Contract No. EF-77-C-01-2363

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1.0 INTRODUCTION

1.1 BACKGROUND AND SCOPE

This design study was performed as a follow-on to the previous MHD Engineering Test Facility (ETF) study, References (1) and (2), which suggested the developing of a progressive facility concept. The site of the facility, although not firmly established, is to be in the State of Montana, with the potential of using the present Component Development and Integration Facility Site. In its final evolved form, the facility will represent a pilot-scale, open cycle, coal fired combined MHD system, but will not include the steam turbine generator system. The size of the ETF must be such as to allow for extrapolation from component development programs that can be conducted in existing and planned MHD facilities, and also be extrapolatable to a practical size. A 150 MWt coal input to the MHD combustor is believed to be viable for this application as developed in Reference 1 and therefore stipulated as the basis for the present study.

The study reported herein was performed by the Advanced Energy Systems Division of Westinghouse Electric Corporation with support from previous studies and from services provided by subcontractors' contributions to the ETF studies already completed. Where necessary, scaling of components and adjustments for costs were made to match the current needs. For the purposes of determining the best approach and most logical path for the ETF progressive program plan, additional component design and costing were felt to be unnecessary. Therefore, the scope of this particular study emphasizes the impact of integrating previously conceived equipment and systems in various arrangements to provide the most attractive progressive facility path, to meet the objectives discussed below.

1.2 OBJECTIVES

The objectives of this study were to develop a progressive program plan for a 150 MWt MHD engineering test facility. The facility was to start with a minimal MHD power train system which utilized a proven separately fired air preheater with oxygen enhancement as needed. It was to be capable of progressive evolvement into a final configuration which included all of the pertinent systems necessary to demonstrate the open cycle MHD combined cycle plant in a 150 MWt size. Cost, risk, schedule, performance effects and component usefulness in various phases of the progressive plan were to be evaluated. The previous 150 MWt Reference ETF Design Study(1) results were to be utilized as a starting point for this study. Inasmuch as possible, current state-of-the-art components were to be used (as long as they did not compromise the performance or limit the ability to determine the potential of the MHD system). Direct or indirect preheat options were to be available in the final configuration. The flexibility to accommodate changes in components, substitute equipment and allow for uncertainties existing in developing equipments was to be provided. No steam driven generator was to be included although the required steam conditions necessary for such a bottoming plant were to be demonstrated. The system should in its final configuration utilize coal as its energy source, although oil or gas could be maintained as options for the separately fired air preheater combustor.

The results of this study were to provide guidance for and recommend the most logical plan by which the maximum information from plant design demonstration and operating performance could be obtained. Assessment of the various arrangements of the components and systems configurations was to provide guidance for the definition of priority development efforts needed for design and construction of the ETF.

2.0 SUMMARY AND CONCLUSIONS

A conceptual progressive 150 MWt ETF program plan has been defined that is capable of testing the MHD power train, its support systems and waste heat recovery systems. The principal power train components include the combustor, MHD generator (with "change out" channel), superconducting magnet, power conditioning system and preheaters. The progressive plan starts with the MHD power train utilizing a separately fired regenerative, state-of-the-art high temperature air preheater, supplemental oxygen, and a waste heat quench system. It evolves to reach the final facility configuration which includes all the pertinent MHD power plant systems and components with the exception of the steam turbine generator. Cost/risk/schedule tradeoffs, performance effects and component usefulness have been evaluated in the various phases of the progressive plan. The final objective of the study, to define a concept for a progressive facility that can provide a complete demonstration of an MHD power plant, with the exception of the steam turbine generator, has been met with a design approach that will permit either direct recuperative air preheat or an indirectly fired air preheater system. Although the concept was studied at the 150 MWt size, the approach appears valid at larger sizes that could eventually evolve for ETF.

The general conclusions from this study were that:

1. An effective and timely four step progressive ETF program plan is possible which meets the schedule guidelines, has low total cost and maximizes equipment usefulness.
2. The progressive plan permits continued utilization of earlier stage components and keeps open the options to revert to earlier configurations if desired. It keeps open the option of direct or indirect preheat even in the final configurations.

The basic approach to this study consisted of the following:

1. Establish for the final evolved facility, both in a direct and indirect fired mode the desired level of performance and the equipment sizes and requirements.

2. Establish an initial minimum power train demonstration facility using a separately fired metallic air preheater, oxygen injection and the equipment designed to accommodate the final conditions. The nozzle, channel and diffuser, although fixed in length, are reduced in cross section area to accommodate the lower level of preheat recommended for early configurations of the facilities.

3. Intermediate configurations between these two end points were defined and investigated.

The definition of five facility configurations resulting from this approach which were subjected to study are depicted in Figure 2-1.

Four development paths were evaluated in conjunction with these defined configurations. The four paths consisted of programs that initiated the facility with Configuration 1, 2, 3, and 4 respectively.

Table 2-1 presents the calculated performance of each configuration studied. As previously noted components are designed to the final requirements and then used off design at all other configurations. Temperatures and pressures in the combustor, and to the channel, are held constant throughout the program through the use of oxygen addition when preheat temperatures less than the final design objective are utilized in early configurations. It appears logical that between major configurations the MHD channel would be changed out. Thus a resizing of its area to accommodate the reduced flows of early configurations appears entirely practical. It is to be noted that in all configurations significant performance of the MHD system is achieved.

Plant layout schemes were investigated for each configuration and an arrangement arrived at which provides extreme flexibility for modifying the progressive plan, if necessary to accommodate unexpected development results. Figures 2-2 and 2-3 show the facility in Configuration 1 and 4 respectively. The key to flexibility was found in the use of a two section steam generator which allows easy interchange from indirect to direct fired configurations, and the overall plant arrangement which maintains the capability to revert to prior configurations with minor re-piping. Several attractive features of the plant arrangement are provided and include:

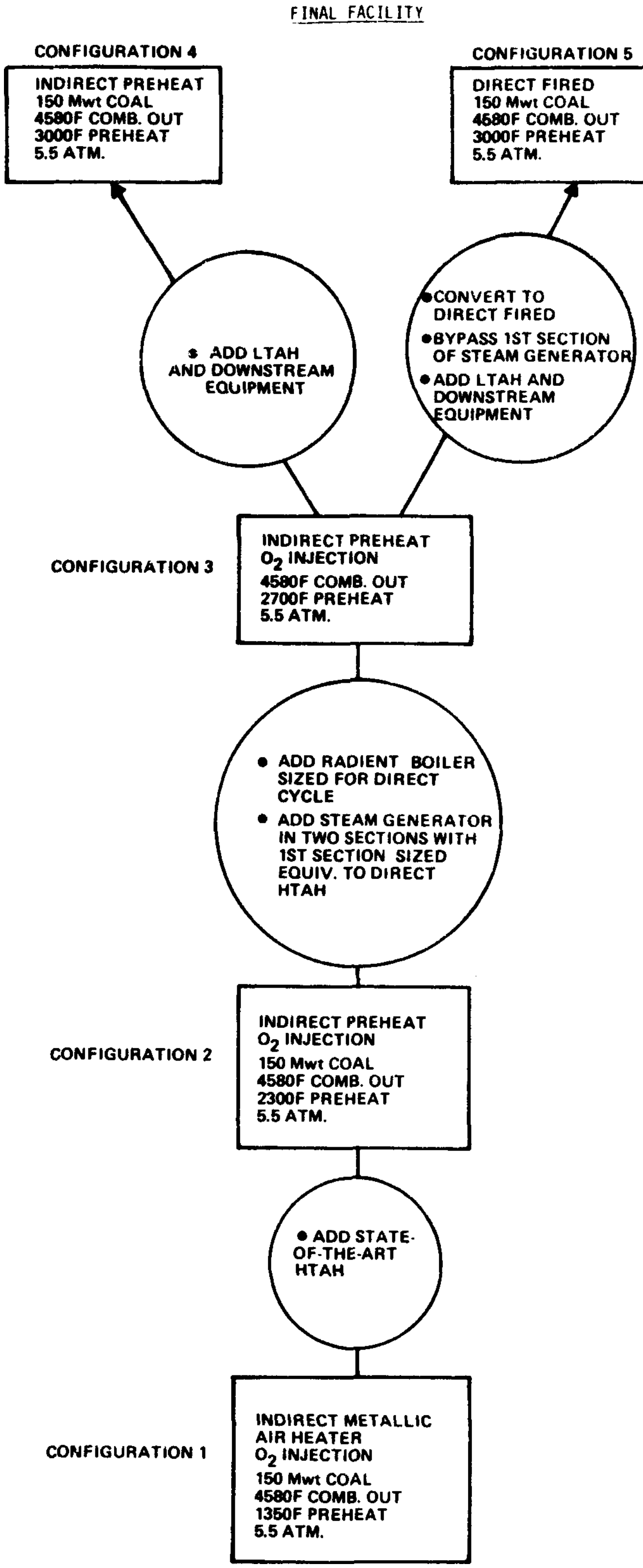

Figure 2-1. Definition of Configurations Studied

TABLE 2-1

PERFORMANCE PREDICTIONS*

	CONFIGURATION				
	1	2	3	4	5
Preheated Air Temperature	1005.0	1533.0	1755.0	1917.0	1917.0
Enrichment (%)	133.0	57.5	25.6	0.0	0.0
Seed Flow Rate	0.47	0.58	0.67	0.78	0.78
Combustor Exit Flow Rate	32.4	39.9	45.7	53.2	53.2
Combustor Exit Temperature	2800.0	2792.0	2800.0	2800.0	2800.0
Combustor Pressure	5.48	5.48	5.48	5.48	5.48
Diffuser Exit Temperature	2059	2093	2109	2127	2127
Diffuser Exit Pressure	0.88	0.88	0.82	0.82	0.82
Duct Geometry					
Inlet Area	0.08	0.11	0.12	0.14	0.14
Exit Area	0.6	0.76	0.88	1.0	1.0
Length	11.32	11.32	11.32	11.32	11.32
Heat Dissipation Rates					
Isolation Heat Exchanger Cooling Tower	53.5	53.8	15.4	13.8	22.9
Steam Generating System	---	---	122.3	135.8	76.0
Stack/Quench	88.2	108.0	15.0	15.7	19.9
Electrical Energy Input					
Pumps	0.01	0.01	0.8	1.1	0.6
Air Compressor	5.3	7.8	9.7	12.2	12.2
Thermal Energy Input					
Indirect Coal Drying	6.6	6.6	0.0	0.0	0.0
Indirect Air Preheating	10.0	33.4	29.3	46.2	0.0
Gross MHD Output	21.9	27.9	34.6	41.2	41.2
Enthalpy Extraction (%)	13.7	14.9	16.5	17.4	17.4
Overall Plant Efficiency (5)	10.3	10.9	13.4	14.2	18.9

*UNITS

Flow Rate - kg/s
Pressure - atm
Temperature - K
Length - m

Area - m^2
Energy, Heat Transfer Rates - MW
Velocity - m/s

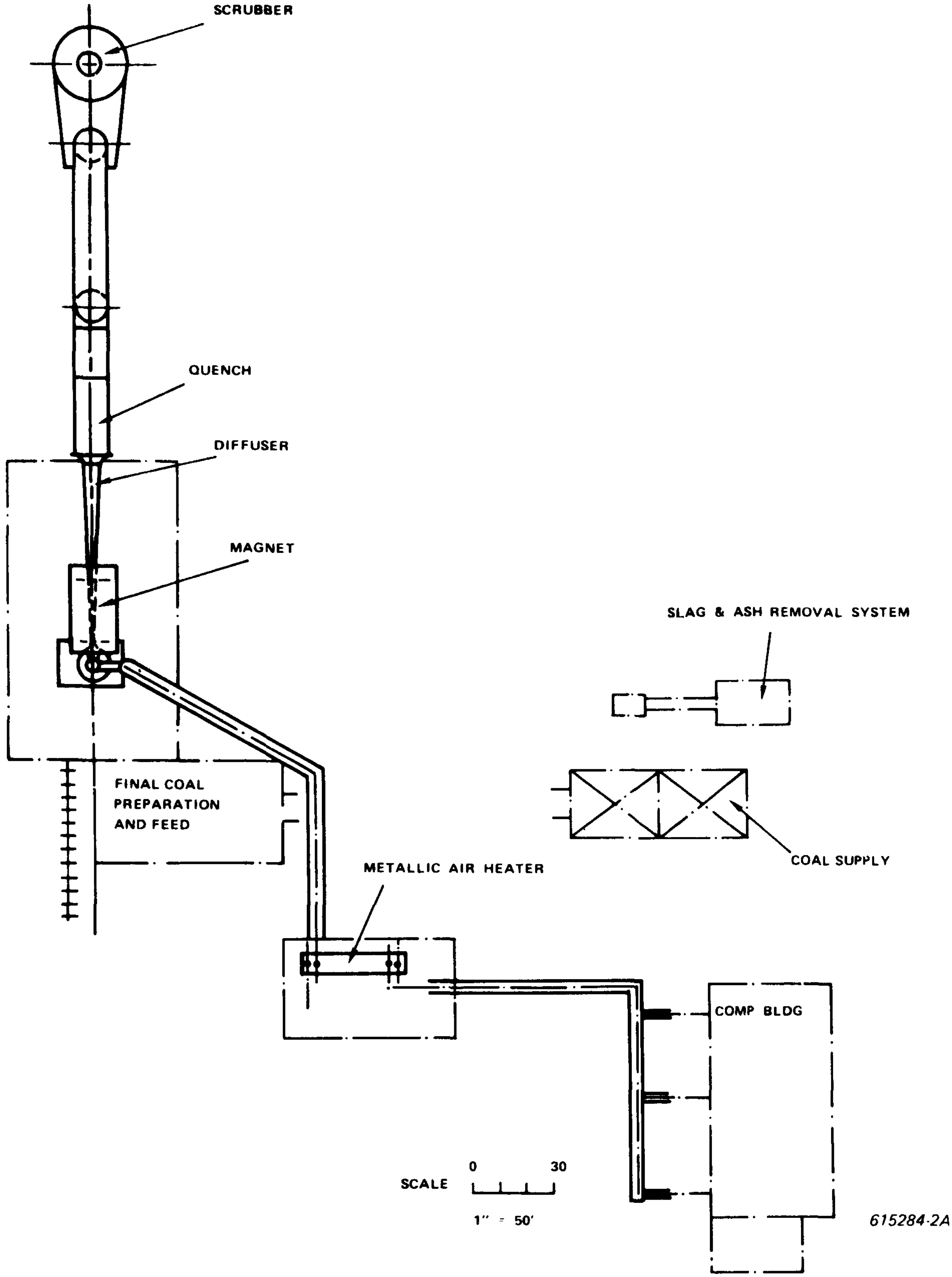

Figure 2-2. 150 MW ETF Plant Layout - Configuration 1

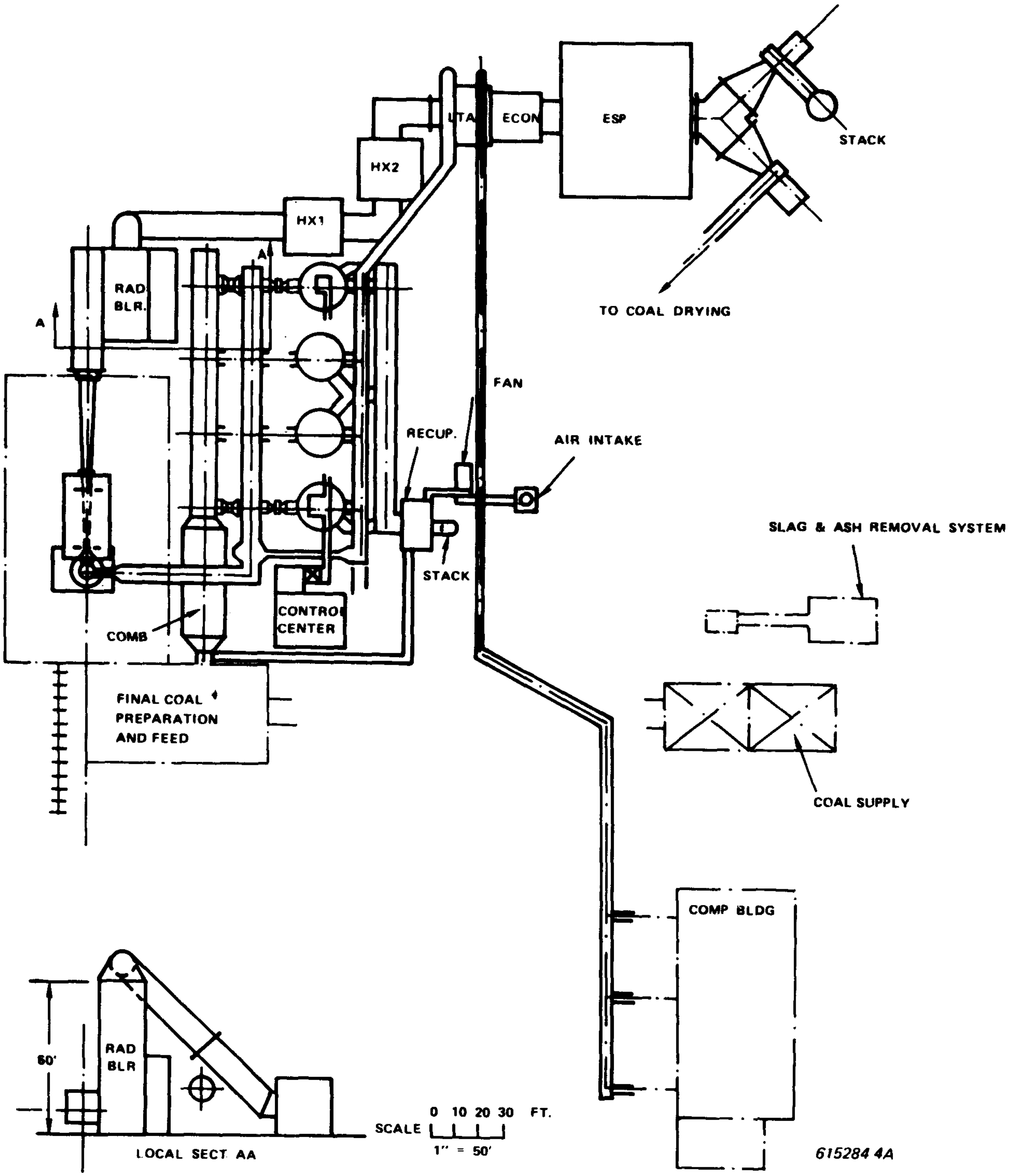

Figure 2-3. 150 MW ETF Plant Layout - Configuration 4 Final Indirectly Fired

- Keeping available the direct or indirect preheat options even in the final configurations.
- The ability to provide parallel or series MHD component cooling options with provision for optimizing coolant heat recovery as would be required for a steam plant.
- A separate MHD component cooling loop for minimal risk operation with an isolating heat exchanger, providing maximum probability of proper electrical isolation and minimal risk.
- Options which can be maintained throughout the progressive plan (such as quench system and either steam or motor driven compressors).
- Utilization of cooling tower options that would provide minimal cost and maximum flexibility.
- Adequate flexibility for change-out of key components, including the MHD channel.
- Modular channel configuration permitting change out of hot walls for lower flow rate O_2 enrichment conditions thus allowing matching other component requirements for minimal parametric variation.
- Making use of the same critical MHD power train equipment including the combustor, magnet and power conditioning system for all evolutionary steps.
- Non-interference with operation of the existing test facility while establishing the next generation arrangements.

For each of the four development paths selected, cost estimating was performed to determine the overall program costs. These costs included not only the equipment costs along a given path, but also the operational and staffing costs that differ due to the expanded requirements when a progressive plan involving a larger number of configurations is followed. Table 2-2 presents the costs for each of these paths.

Due to the unique approach taken on the utilization of components designed to the final configuration, and the solution for flexibility and plant arrangement, there is basically no equipment cost differential between paths 2, 3, and 4. Path 1 has a higher equipment cost since the separately fired metallic air preheater is a non-used item after Configuration 1, and because its use initially with a severely limited preheat temperature capability, forces a larger oxygen plant to be constructed. The differences in costs between Paths 2, 3 and 4 basically become the lengthened time of facility use, which requires additional cost for operation and staffing.

TABLE 2-2

ESTIMATED PROGRESSIVE PLAN COST*

	PATH 1	PATH 2	PATH 3	PATH 4
Configuration 1	$160M	--	--	--
Configuration 2	$ 20M	$160M	--	--
Configuration 3	$ 15M	$ 15M	$173M	--
Configuration 4	$ 98M	$ 98M	$ 98M	$270M
Total Equipment Costs	$293M	$273M	$271M	$270M
Additional Operation and Schedular Costs	$ 40M	$ 30M	$ 15M	$ 10M
Estimated Cost of Total Plan	$333M	$303M	$286M	$280

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* Mid 1978 dollars (no interest or escalation included)

A risk assessment methodology was developed and applied to each of the four selected development paths assuming that the end date for ETF demonstration in its final configuration was 1989. This methodology interacted the present component development program with the suggested facility program in a manner to assess the risk of major component inclusion in the facility at the time period demanded. A numerical system for risk evaluation was developed which can form a good basis for further development in risk analysis of this type.

The conclusions from this analysis showed the following, consistent with intuitive and judgemental evaluation.

- The lowest risk path, if the ETF is considered as a pilot scale demonstration, is Path 4. This allows development and demonstration of components prior to facility construction to meet the 1989 test date. Thus, high confidence exists in all components included in the facility.
- If the progressive path of ETF is viewed as a major systems developmental tool as well as a pilot scale demonstration, then Path 2 appears as most appropriate. The level of confidence in the final configuration in 1989 is better than in Path 4 since early experience will have been gained.
- Through use of the risk analysis technique, several changes were suggested to the configuration in Path 2 which will enhance the confidence of the program. These primarily involve a less ambitious set of objectives for the preheater development.
- The major development concerns to the progressive ETF facility are the coal fired combustor and its feed system and the coal fired (indirect) high temperature preheater and valves.
- Pacing component development programs for the ETF progressive plan in order of impact were found to be; the coal fired combustor and its feed system, the MHD generator, the radiant boiler and the high temperature heater valves.

The final recommended path is Path 2 and its schedule and costs are shown in Figure 2-4. The currently suggested ETF schedule from DOE sources shows test facility availability by mid 1989. A progressive program that could be carried out within the period prior to this date is therefore desired. To meet the 1989 test date with an indirectly fired configuration per Path 2 requires proceeding with the facility prior to full input from the magnet and power train development in the early configurations. Testing of the direct fired con-

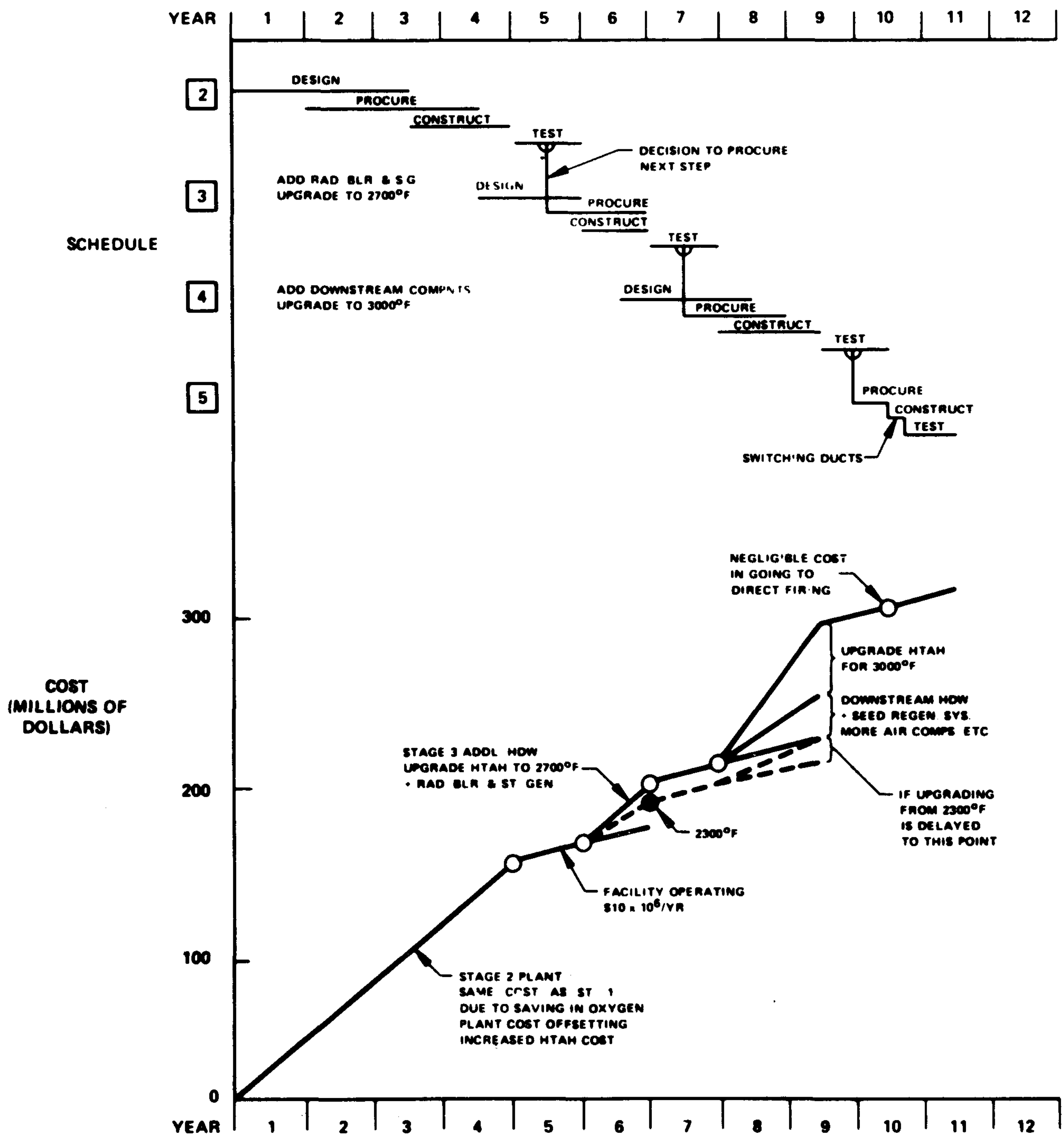


Figure 2-4. Recommended Progressive Plan for 150 MWt ETF

figurations would be expected to start in early 1991, assuming a reasonably expeditious shakedown of the indirectly fired final configuration. If initiation of the progressive path is delayed until 1982-83 to take advantage of further component development on the magnet and power train, then the indirectly fired final facility configuration testing would be delayed until mid 1991.

Recommendations for changes to the initial configurations of the facility along Path 2 as defined for the study have resulted from consideration of the risk/benefit evaluations performed. First, the state-of-the-art 1533K (2300^{0}F) air outlet temperature regenerative air preheater used in the initial facility (Configuration 2), should remain unchanged with its air outlet temperature limited to 1533K (2300^{0}F) throughout Configuration 3 when the radiant boiler, HX-1 and HX-2 components are incorporated. Upgrading of the preheater to slag (and later seed) resistant capability at higher outlet air temperature should be deferred until the final configuration testing stage. An air outlet temperature capability of 1755K (2700^{0}F) is judged at the present time to be a reasonable design goal for initial operation in the final configuration rather than the original goal of 1917K (3000^{0}F). It is recommended that initial operation of the complete system be in the indirect fired (oil or gas) mode to avoid potential valve sticking and checker flow passage clogging due to slag. After completion of testing in the indirect fired configuration, the transition to direct firing could be attempted. The direct fired final configuration is also recommended for operation with the preheater air outlet temperature limited to 1755K (2700^{0}F) until such time as the questions regarding slag and seed effects are satisfactorily resolved. Finally, the preheater air outlet temperature could be upgraded to 1917K (3000^{0}F) (or such lower temperature judged to be achievable at that time) and development of the direct fired final configuration continued at this condition.

It is recommended that test and development programs be conducted, in parallel with the ETF development program, to develop improved slag and seed resistant high temperature refractory materials for use in heater and valve thermal insulation and checker beds. At the present time it is not clear that air outlet temperatures significantly above 1755K (2700^{0}F) will be achievable without the use of prohibitively expensive zirconia unless such programs are pursued. Such materials development programs might allow some upgrading of the preheater air outlet temperature above 1755K (2700°F) late in the program if improved alternatives to the presently available magnesia-alumina spinels can be developed.

It is recommended that, if indirect firing of the preheater using oil or gas is considered undesirable throughout most of the development period, a separate coal fired preheater development program be pursued in parallel with the ETF development program. Oil or gas fired air preheating would then be terminated as soon as the reliability of the coal fired preheater could be adequately demonstrated.

3.0 STUDY BASIS

3.1 GUIDELINES

The guidelines established for this study were based upon the work accomplished in prior MHD ETF studies as reported in References 1 and 2. As recommended in Reference 1, the final configuration for the progressive plan should be a 150 MWt facility capable of demonstrating technology and performance necessary for extrapolating to a commercial size plant. With this configuration identified, a "backdown" plan to an initial, more readily achievable facility was to be established. This initial configuration would be based upon the separately fired state-of-the-art system discussed in Reference 1. Definition of these two end points and establishment of the most logical steps to progressively take from this initial facility to the final facility configuration are the subject of this study.

The overall guidelines established for this study are presented in Table 3-1. The effort emphasized establishing risk, cost and benefits of a progressive plan and the alternate paths which could be followed. Therefore, the best data available from existing studies on component designs were utilized and no detailed development of new specific requirements or specifications was deemed justified. Data obtained from the various contractor studies for the ETF were reviewed and the conclusions and recommendations that had been made assessed. On the basis of these assessments, the most logical equipment and components for the progressive facility study were selected. The general guidelines and requirements for the study were that the final facility be able to demonstrate the necessary technology in time to provide for application of a commercial system in the mid 1990s. Current technology capable of developing a minimal risk, maximum benefit path were to be established. Reasonable backoff positions and alternate paths were to be identifed. Recommendation for development effort and program planning were to be provided.

TABLE 3-1

OVERALL GUIDELINES

- Facility operation should be scheduled consistent with an early 1990 commercial plant decision.
- A combined MHD and steam generating capability should be demonstrated. This should include electric power from the MHD to an electric utility grid and steamflow conditions compatible to existing steam turbine generator bottoming systems.
- Demonstrate and resolve the major MHD combined cycle technological issues for commercial application.
- Utilize available proven (off-the-shelf if possible) equipment in non-developmental areas.
- Weigh risk and costs, and performance in arriving at a recommended facility plan.
- Maintain a logical relationship with on-going critical MHD component developments.
- Provide flexibility for direct or indirect air preheat in the final step without significant penalty.

3.2 STUDY LOGIC AND RATIONALE

The approach used in this study is depicted in Figure 3-1. As noted above, the final objective of this facility is the complete demonstration of a 150 MWt MHD plant, with the exception of the turbogenerator. The final configuration could be either a direct recuperatively heated air preheater system or an indirect fired system. The initial configuration was based on the 150 MWt ETF studied in Reference 1 utilizing a metallic separately fired preheater and oxygen injection.

The logic established for performing the study of a progressive series of facility configurations was as follows:

- As shown in Figure 3-2, the primary flow path is considered to consist of the MHD power train, a radiant boiler section, a high temperature direct fired air heater or, alternately, a steam generating section of equivalent heat extraction to the high temperature air heaters, a secondary steam generating section, and finally a downstream section.
- The desired levels of pressure, temperature and preheat to be demonstrated in the MHD power train were selected for the final facility configuration. This fixed the MHD generator length and magnet bore for all progressive configurations of the facility.
- All major equipment when designed for progressive configurations is designed to the final facility requirements thus requiring a one time design.
- For various facility configurations the MHD duct is designed to operate at the same inlet temperature. Oxygen addition is used as necessary to accomplish this. For each configuration the duct cross section is sized to also maintain a constant combustor pressure. Thus throughout the total series the duct is operated to the same levels of temperature and pressure at its inlet, and the flow rate will vary as a function of the degree of air preheat.

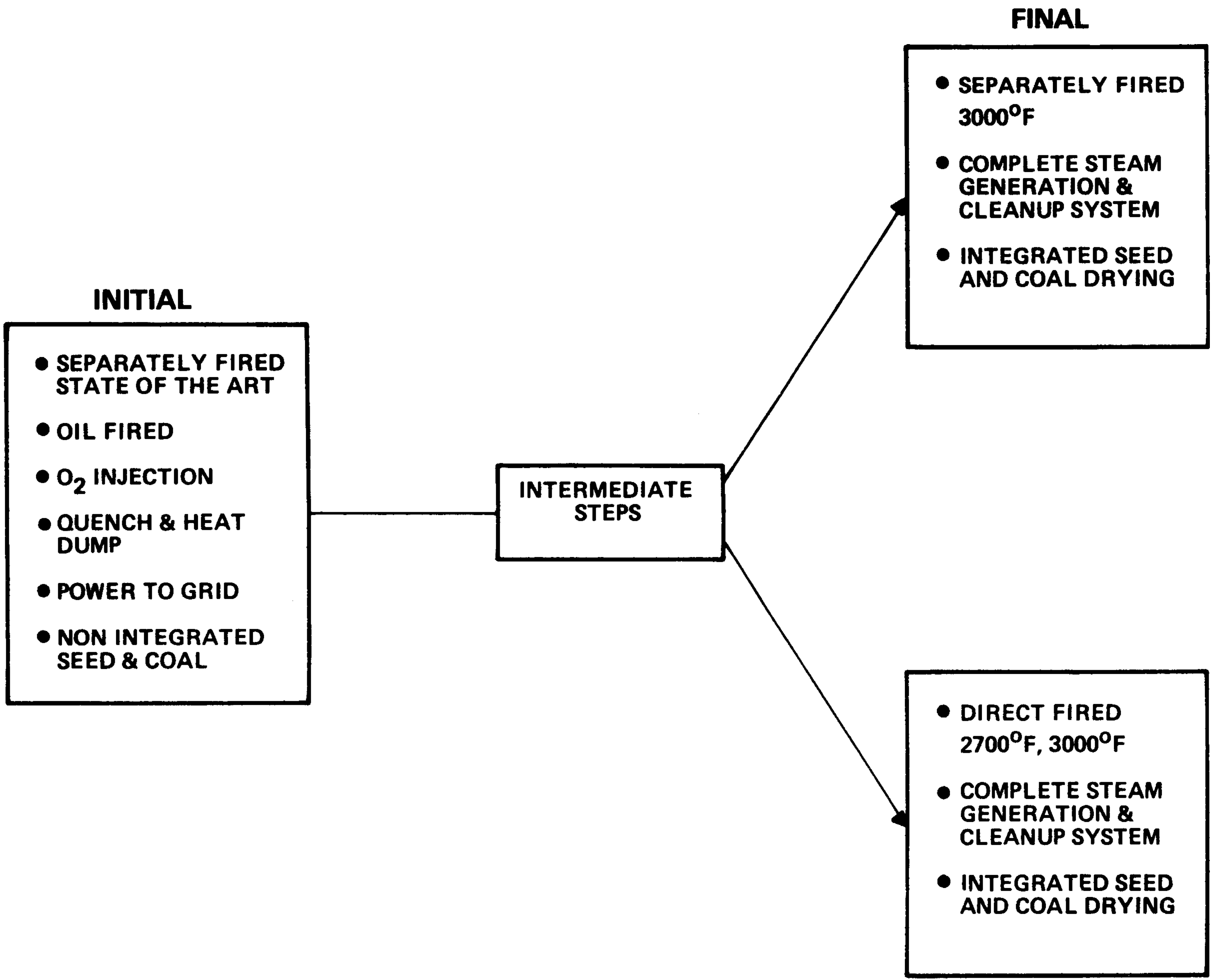


Figure 3-1. Study Logic

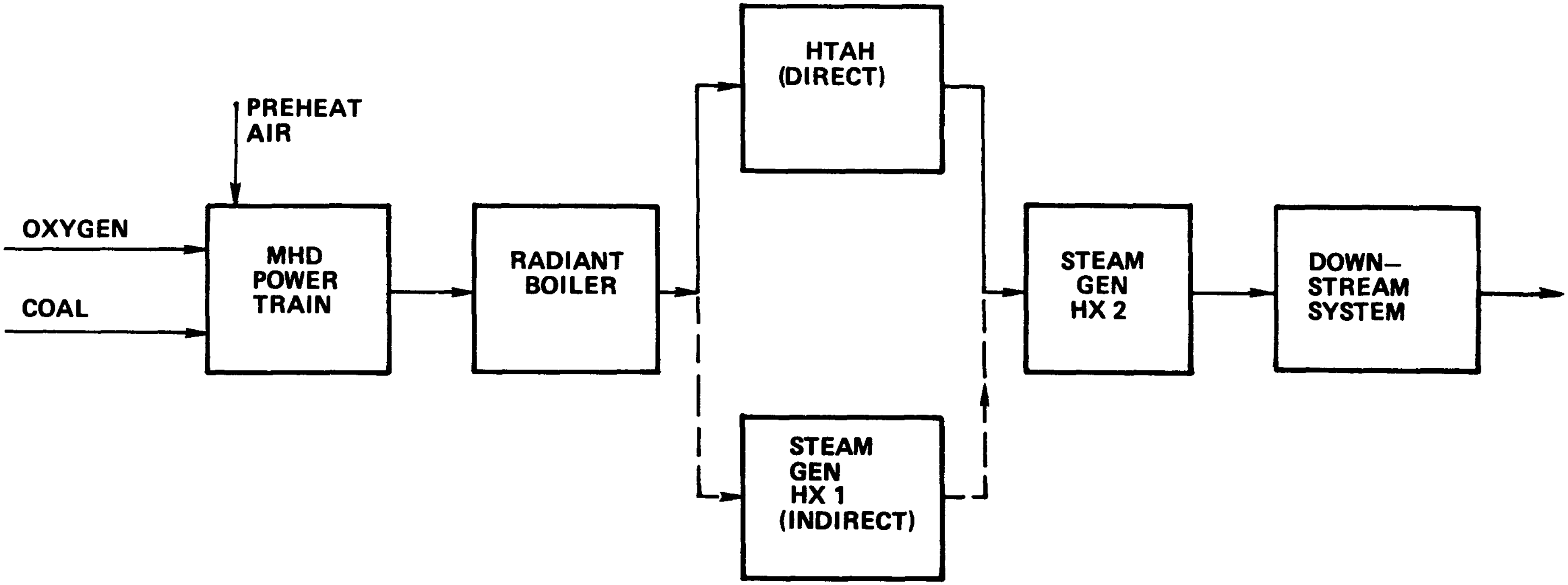


Figure 3-2. Primary Flow Path Configuration Logic

- The concept of two steam generating heat transfer sections downstream of the radiant boiler provides the flexibility to test in the direct or indirect fired mode by either excluding or including the first heat exchanger in the primary flow path.

A number of configurations including the intial and final ones were established as potential progressive configurations. The configurations defined for investigation utilizing the primary flow train building blocks shown in Figure 3-2 are as follows:

Configuration 1 - MHD power train with an exhaust quench system, separately oil fired state-of-the-art metallic preheater (1005K) and oxygen addition.

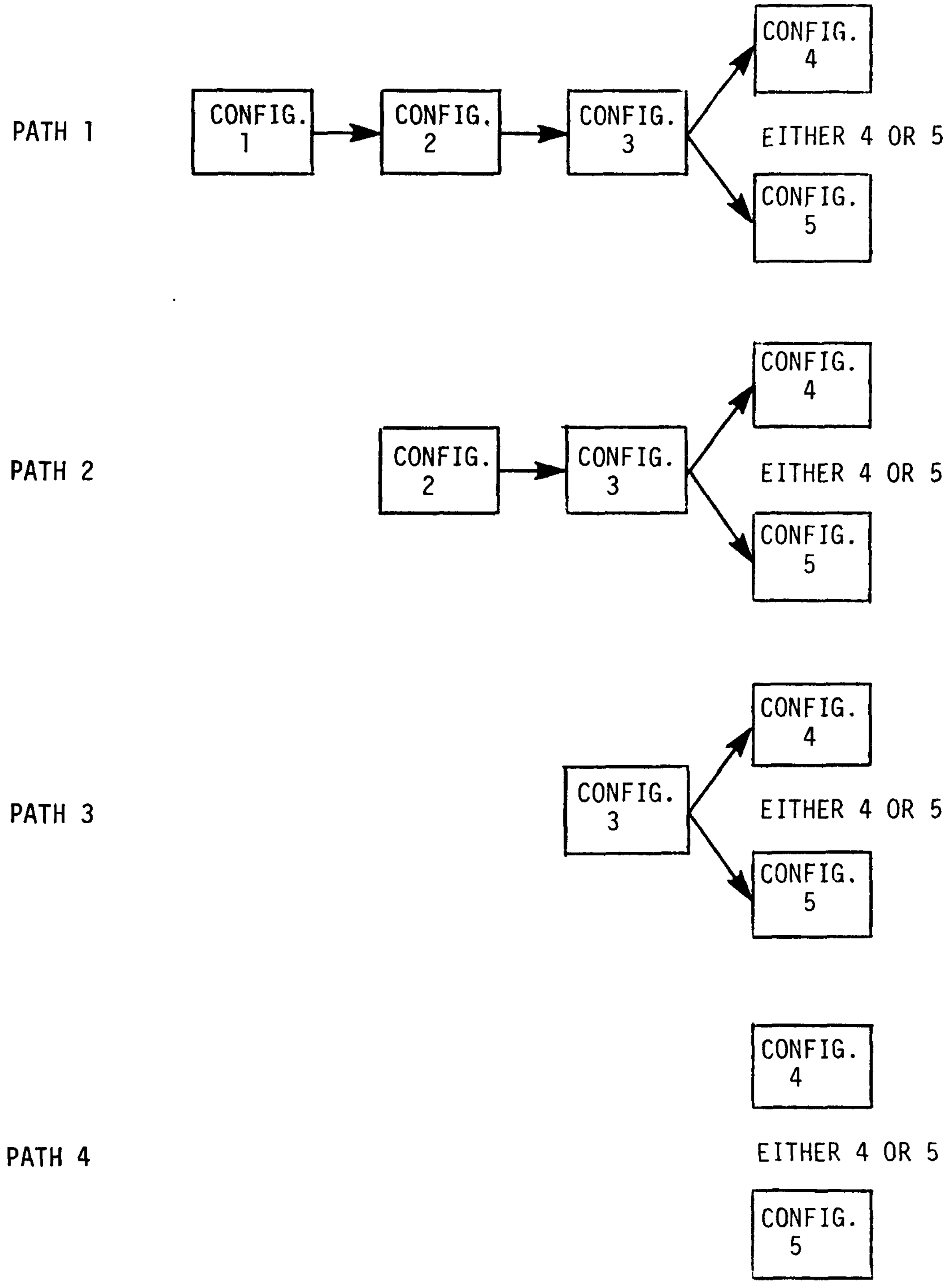
Configuration 2 - MHD power train with an exhaust quench system, a state-of-the-art (1533K) regenerative separate oil fired preheater and oxygen addition.

Configuration 3 - The same as Configuration 2 with the addition of the radiant boiler section, steam generating sections HX1 and HX2 and upgraded refractory beds (1755K) in the preheaters . Quench occurs downstream of HX2 and some oxygen injection is still utilized. Once this configuration is established the facility will be so arranged that an alternate mode of testing utilizing the heaters as direct fired units will be possible by repiping and bypassing HX1.

Configuration 4 - Final complete facility with an indirect fired configuration. Further upgraded preheater beds (1917K) with coal firing and no oxygen addition.

Configuration 5 - Final complete facility the same as Configuration 4 but with preheaters directed for direct firing at 1917K or 1755K.

With these configurations four development paths depicted below were defined for study relative to cost, schedule, and risk.



The last step in each path is the final configuration in either a direct or indirect fired configuration, the initial assumption being made that sufficient development will have been accomplished to be able to make that choice.

3.3 SITE AND FACILITY ASSUMPTIONS

The site is to be located in the State of Montana in accordance with the definition provided in Appendix A, "Description of a Hypothetical Site for an MHD Engineering Test Facility". The assumed facility requirements include provision for expanding the test system from the initial 150 MWt MHD power train and thermal waste quench system to a test facility capable of demonstrating all critical and major systems including seed regeneration. For this study, service resources and facilities equivalent to the Montana Test Facility at Butte, Montana are assumed available or capable of being obtained.

3.4 SYSTEM INTERFACE CONDITIONS, SPECIFICATIONS AND REQUIREMENTS

The interface state point conditions that were constrained or assumed for this study are identified in Table 3-2. The environmental emission requirements, the coal and seed system assumptions and the coal and ash analysis are given in Tables 3-3, 3-4 and 3-5 respectively. Tables 3-6 and 3-7 present the assumed magnet and power conditioning parameters. Some options for other than the stated conditions have been assessed and results are reported in the particular subsystem write-ups where these alternate conditions are discussed.

3.5 FACILITY DEMONSTRATION OBJECTIVES

The primary functional demonstration objectives for the facility and a listing of systems required for each are noted in Table 3-8. This list is not meant to be comprehensive, but does denote the type and order of plant demonstration desired in the ETF. The evolving plant has been defined to bring about the maximum potential for demonstrating these features with a compatible cost and risk.

TABLE 3-2

CONSTRAINED OR ASSUMED INTERFACING STATE POINT CONDITIONS

MHD Power Train Interfaces	Parameter Cond.
Ambient Temperature and Pressure	288K, 0.8atm
Coal Input Thermal Energy to Combustor	150 MW
Combustor Stoichimetry (overall)	0.95
Combustion Temperature	2800K
Single 6T max. SCMagnet Length*	11.3m
SCMagnet Warm Bore Outlet Diameter*	1.7m
Electrical Output to Grid voltage	60Hz,3ϕ,69kV
Diffuser Outlet Pressure	0.82atm
Radiant Boiler Outlet Temperature	2100K
Direct Heated Air Preheat Temperature (Design)	1917K
Combustion Gas Temperature, LTAH Inlet	1200K
Steam System Interfaces	
Steam Conditions	2400 psi/1000°F
Heat Reject System Interfaces	
Cooling Water Temperature (Cooling Tower)	297K
Emission Control	(meet NSPS Conditions-Table 3-3)

* Constrained on the basis of the dimensions desired for the final facility configuration-See Sections 4.1 and 4.2.

TABLE 3-3

NEW SOURCE PERFORMANCE STANDARDS (NSPS)

	NSPS	CURRENT STANDARD*	CHANGE
Particulate	0.03 #/10^6 Btu Input (13 ng/J) (a) With 99% reduction of uncontrolled emissions (b) Percent reduction would not apply to gaseous or liquid fuels fired alone (c) 10 percent opacity (six-minute) average)	0.1 #/10^6 Btu Input	(Down Factor of 3.3 Plus a,b, & c)
SO_2	1.2 #/10^6 Btu Input (520 ng/J) (a) With 85 reduction (b) 85% reduction would not apply if emissions are less than 0.2 #/10^6 Btu input	1.2 #/10^6 Btu Solid Fuel 0.8 Liquid Fuel 0.2 Gaseous Fuel	(Includes 85% Reduction Requirement)
NO_x	1. 0.8 #/10^6 Btu (340 ng/J) (a) With 65 percent reduction when using a cyclone furnace to fire North Dakota, South Dakota, or Montana lignites or more than 25 percent coal refuse	0.7#/10^6 Btu Solid Fuel	(Added Contingencies)
	2. 0.6 #/10^6 Btu (260 ng/J) (a) With 65 percent reduction for bituminous, certain lignites and other solid fuels		
	3. 0.5 #/10^6 Btu (220 ng/J) (a) With 65 percent reduction for subbituminous coals and 25 percent for low Btu synthetic gas		
	4. 0.3 #/10^6 Btu (130 ng/J) (a) With 65 percent reduction for liquid fuels	0.3#/10^6 Btu Liquid Fuel	
	5. 0.2 #/10^6 Btu (86 ng/J) (a) And Reduced 25 percent from uncontrolled levels for gaseous fuels except low Btu synthetic gas	0.2#/10^6 Btu Gaseous	

*Ref. NASA-CR 134948 Vol II

TABLE 3-4

COAL AND SEED SYSTEM ASSUMPTIONS

Coal Preparation and Feed System

Reference Coal	Montana Rosebud
Preparation Rate	Nominal rates equivalent to 150 MW operation range - provide constant weight flow rate over the pressure range specified for the combustor using 8 atm. as the reference design pressure.
Drying Capacity	Provide separately fired capability to dry coal to a total nominal moisture content of 5% by weight.
Sizing and Classifying	Provide capability to pulverize and size coal to pass 70% through 200 mesh.
Feed Rate Variation	Uniform to less than 1% variation in flow.
Injector System Pressure	1.5 times combustor pressure - min.
Duration	Continuous feed of prepared coal to the combustor for up to 500 hrs. of steady-state operation.
System Lifetime	15 years (Does not dictate that all components meet 15 year life if expedient to replace at earlier intervals).

Seed Feed System

Reference Material	K_2CO_3 in H_2O solution.(Initial)
Preparation Rate	To be supplied by Mfr. at whatever size designated for the experiment and stored in hoppers at the site.
Sizing, Classifying and Drying	System to keep K_2CO_3 powder dry at 233K (-40°F) dew point; Mfr. to supply sized particles to site.

TABLE 3-5

COAL AND ASH ANALYSIS

	Montana Rosebud
Proximate Analysis, Coal, As Received, (%)	
Moisture	22.7
Volatile Matter	29.4
Fixed Carbon	39.2
Ash	8.7
Ultimate Analysis, (%)	
Hydrogen	6.0
Carbon	52.1
Nitrogen	0.79
Oxygen	31.5
Ash Analysis, (%)	
SiO_2	37.6
Al_2O_3	17.3
Fe_2O_3	5.1
T_1O_2	0.7
P_2O_5	0.4
CaO	11.0
MgO	4.0
Na_2O	3.1
K_2O	0.5
SO_3	17.5
Sulfur	0.85
Heating Value, Wet, (Btu/lb)	8920
Heating Value, Dry, (Btu, lb)	11560
Coal Rank	Subbit B
Initial Deformation Temperature, (°F)	2190 ± 230
Softening Temperature, (°F)	2230 ± 240
Fluid Temperature, (°F)	2280 ± 240

TABLE 3-6

MAGNET SYSTEM DESIGN PARAMETERS

Nominal field, inlet	T	6
Nominal field, exit	T	4
Active length	m	11
Nominal warm bore, inlet dia.	m	0.8
Nominal warm bore, exit dia.	m	1.7
Superconductor		NbTi
Operating temperature	K	4.5
Current density, average overall	A/cm^2	1370
Ampere turns, front end	10^6 NI	18.7
Stored energy	MJ	690
Maximum field in winding	T	6.6
Charging time	Hours	6
Emergency discharge time	Minutes	3
Normal discharge time	Hours	1
Maximum discharge voltage	V	1000
Charging power supply voltage	V	10
Charging power supply max. current	A	9000
Heat load at 4.5K	Watts	145
at 80K	Watts	616
Cooldown time	Weeks	6 to 8
Cryoplant requirements at 4.5K	Watts	300
Helium storage (liquid)	Liters	10,000

TABLE 3-7

POWER CONDITIONING PARAMETERS

DESIGN PARAMETERS		SELECTED APPROACH
Selected Channel Configuration	-	• Segmented Faraday with 890 electrode pairs
Method of Electrical Pickup from Channel	-	• Consolidating electrode terminal pairs
Power Conditioning Concept	-	• Modular, 12 pulse inverters fed by consolidated terminal pairs
	-	• Harmonic filtering with static VAR generator
	-	• Power factor correcting before main breaker to grid
Final Output - Electrical Conditions	-	• 60 Hz,3 phase at 69 kV through main breaker to grid

TABLE 3-8

PRIMARY FUNCTIONAL DEMONSTRATIONS AND MAJOR MHD SYSTEMS REQUIRED

Primary Function Demonstration	System Requirements
1. Plasma Generation	• Flow medium and circulating system
	• Heat energy source - oxidizer and fuel
	• Ionizing media
	• Containment system
2. MHD Power Conversion to Electrical Output	• Generator system
	• Magnetic field
	• Electrode system
	• Working plasma flow control
	• Electric power loading control and conditioning
3. Waste Heat and Seed Recovery	• Steam generating heat exchangers
	• Recuperative preheaters and economizers
	• Seed quench and removal
	• Final heat rejection system
4. Effluent Emission Control	• Slag and seed recovery and disposal
	• No_x and SO_x control and particulate recovery and disposal
	• Seed make-up or regeneration

3.6 SYSTEMS DEFINITION

Several choices exist in developing the configuration evolution to reach the final ETF facility desired to demonstrate combined cycle operation. As discussed previously in the rationale for this study, the configuration have been derived by first defining the final configurations for the evolving plant design and then working backwards. The final plant configuration includes all the major components for demonstrating combined cycle operation with the exception of steam turbine generators and it provides the option of using either indirectly fired or directly fired air preheaters. Although the method of preheat does not impact the design, configuration, or performance of the major components of the MHD power train, it does impact the downstream components and waste heat utilization. To assess this impact, both versions of the final configurations (direct and indirect preheat) have been analyzed with preheat temperatures of 3000°F (1917K). The direct heated configuration with a lower 2700°F (1755K) preheat was also evaluated as an alternate design condition.

Configuration 1 utilized in this study has been derived from Reference 1. It provides a minimal MHD power train demonstration involving a separately fired metallic preheater, oxygen enrichment and quenching of all combustion gases as they emerge from the diffuser. The MHD components upstream of and including the diffuser are cooled by a separate water loop and cooling tower system that will find later application as the plant evolves toward the final configuration.

Configuration 2 would operate the plant with a higher preheat temperature using refractory heaters, 2300°F (1533K) versus 1350°F (1005K), while Configuration 3 and Configuration 4 will add elements of a steam generating, heat recovery system and then the downstream system to complete the system. The final configuration could also be a direct fired system defined as Configuration 5. Further details and descriptions of the systems for the progressive plant configuration selected for study are presented below.

CONFIGURATION 1

The initial system depicted in Figure 3-3 utilizes common MHD power train components (two-stage combustor, nozzle, MHD generator, diffuser, cryogenic magnet system and power conditioning equipment) and two major subsystems, 1) a liquid oxygen plant for enrichment purposes and 2) a low temperature, oil fired metallic air heater. The system does not recover waste heat and therefore the diffuser cooling system normally included in the steam generation plant will be coupled with the MHD component cooling loops. This arrangement defines the upper limit on the capacity of the MHD component cooling system and that system will therefore be applicable to all later steps in the evolving plant design. As shown in Figure 3-3, the MHD components are cooled in parallel and reject their heat through an isolation heat exchanger to the dry cooling tower loop; the remaining energy in the combustion gas stream is dumped to the quench system. Since no recuperative heat recovery is utilized, the quench system meeting the conditions of this base case configuration is of maximum size to meet all subsequent options. Although somewhat more costly than would be required with a recuperative system, the overall expense of the quench system is low compared with the other major components and the utilization of the largest system provides maximum heat rejection capability for use if needed in subsequent phases of the progressive plan.

CONFIGURATION 2

Figure 3-4 depicts a facility/configuration providing a high temperature air heater suitable for both indirect and direct firing with changeout of the brick checker heater elements but used in this configuration as indirect fired. This regenerative, oil fired system replaces the metallic air heater and produces higher preheat temperatures, 2300^{o}F (1533K), which lead to reductions in the quantities of oxygen required. In all other respects, this plant system is identical to Configuration 1.

CONFIGURATION 3

This arrangement, shown schematically in Figure 3-5, applies a radiant boiler and an associated steam feed and condensate system to Configuration 2. Two heat exchanger units are provided sized such that the first unit extracts an equivalent

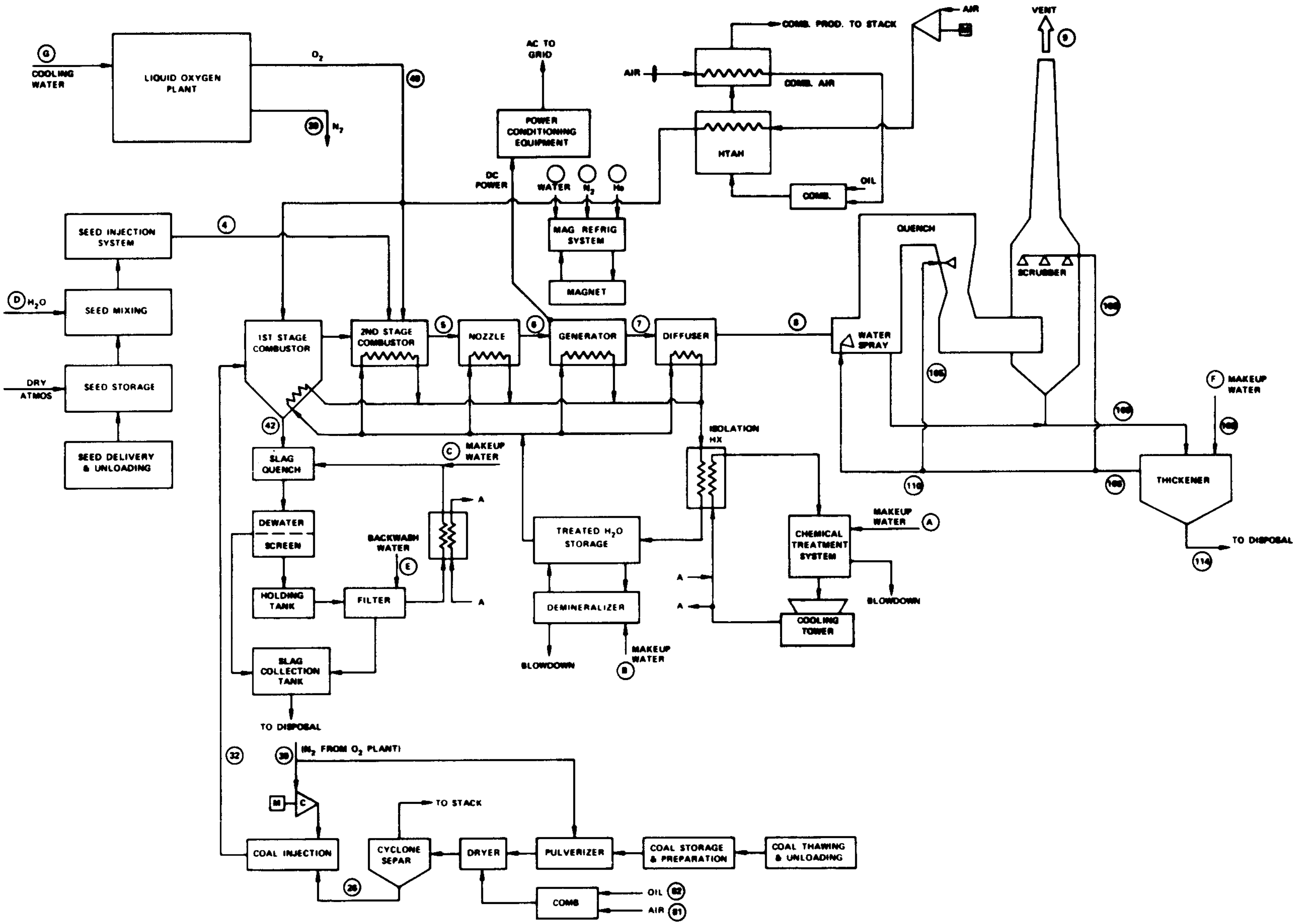


Figure 3-3. Configuration 1

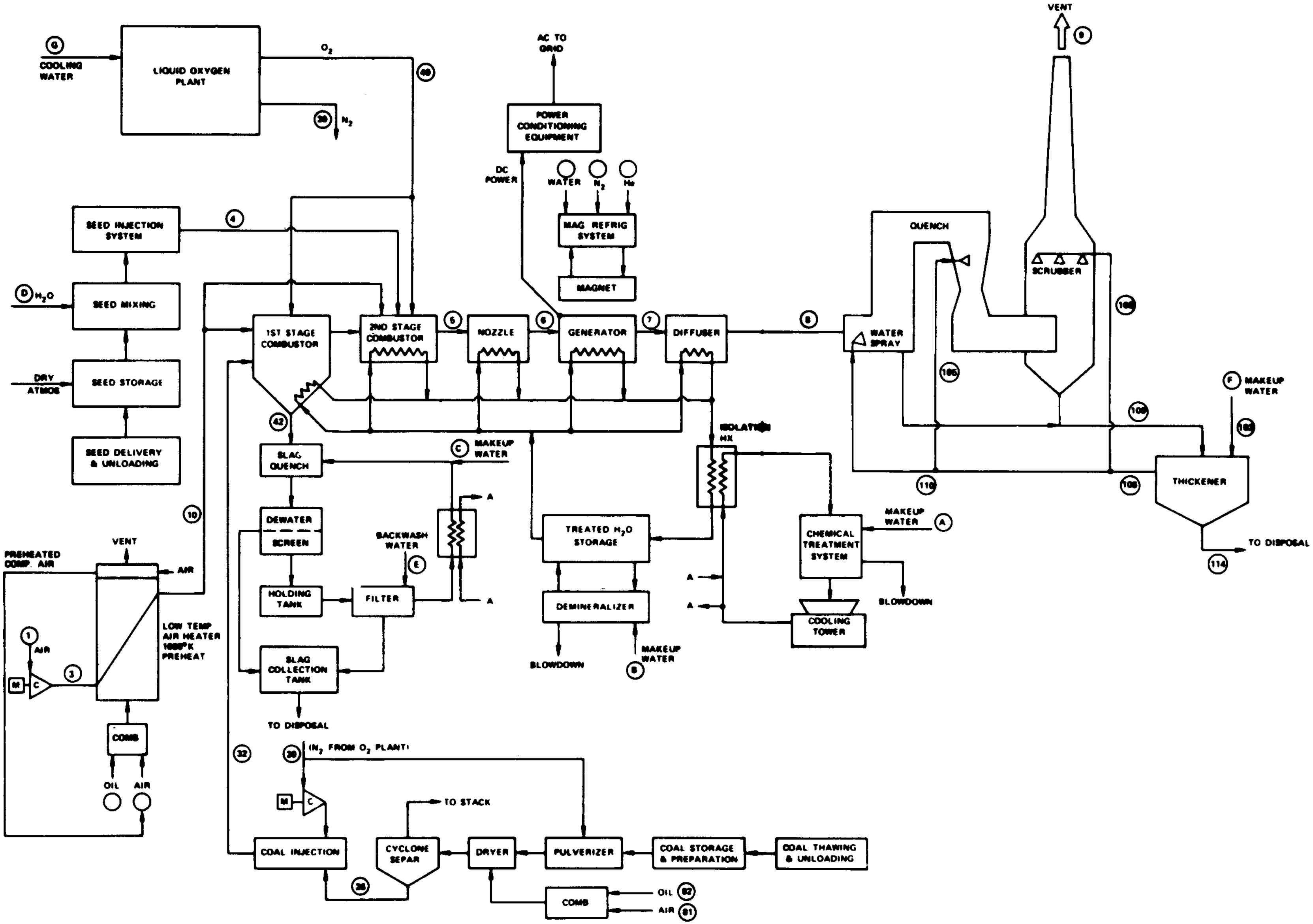


Figure 3-4. Configuration 2

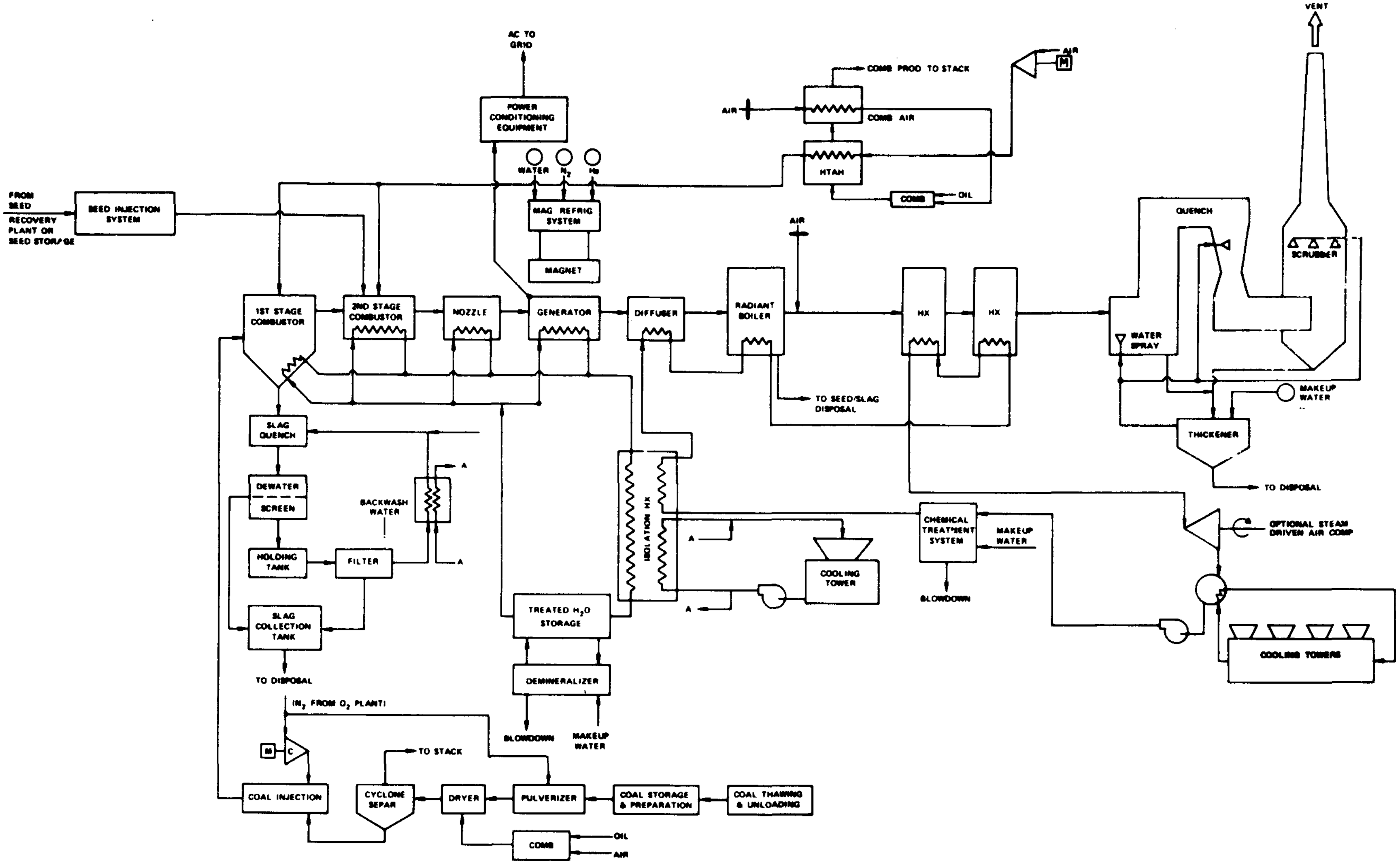


Figure 3-5. Configuration 3

amount of heat from the gas stream as would occur in direct fired heaters in the final configuration. This arrangement will also involve piping modifications to divert diffuser cooling to the new steam and feed system and the optional installation of a compressor turbine drive which will improve the overall plant efficiency. Steam will be produced at 2400 psia, 1000°F which will simulate typical utility steam conditions. An alternate arrangement of Configuration 3 allows flexibility for investigation of direct fired air heating. It is planned that air heater structurals will be common to direct and indirect configurations but that new internals will be installed anticipating the air temperatures and the gas environment to be encountered. The first of the two steam generating heat exchangers installed (HX1) would be made inactive and the gas passed through the preheaters instead. It is noted that plant operation with this approach incorporated will not be restricted to the direct fired mode and if difficulties arise related to seed or slag or, later, to the higher air temperatures, the system can revert easily to indirect firing by minor piping rearrangement and valve manipulations.

CONFIGURATIONS 4 AND 5

In the final configurations (Figures 3-6 and 3-7), the system will be equipped with a low temperature air heater, an economizer/ESP system and a stack to demonstrate full waste heat recovery. Heat exchanger technology allowing air preheat to 3000°F (1917K) is assumed to be an eventual objective, eliminating the need for oxygen enrichment.

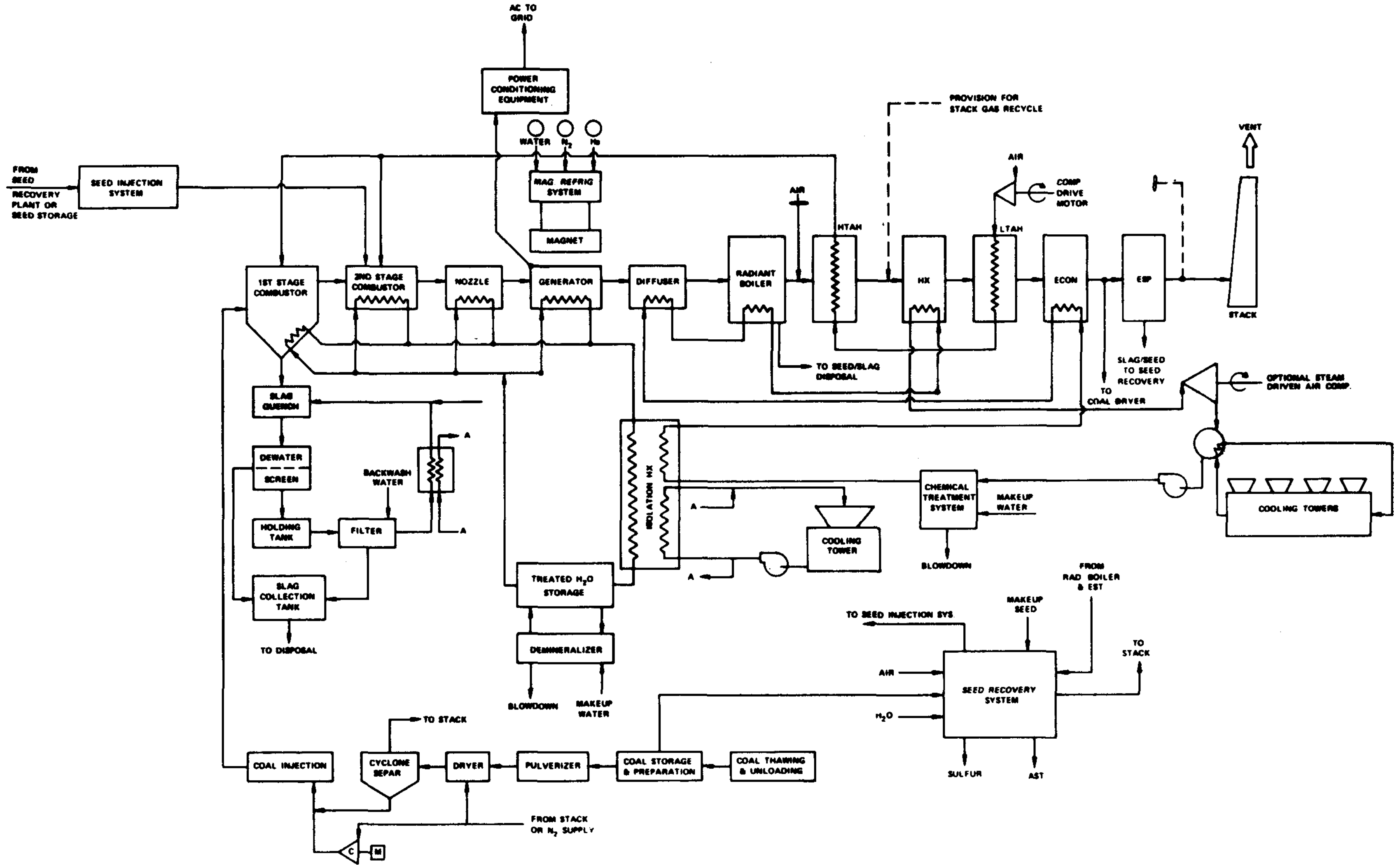


Figure 3-6. Configuration 4 - Final Indirect Fired

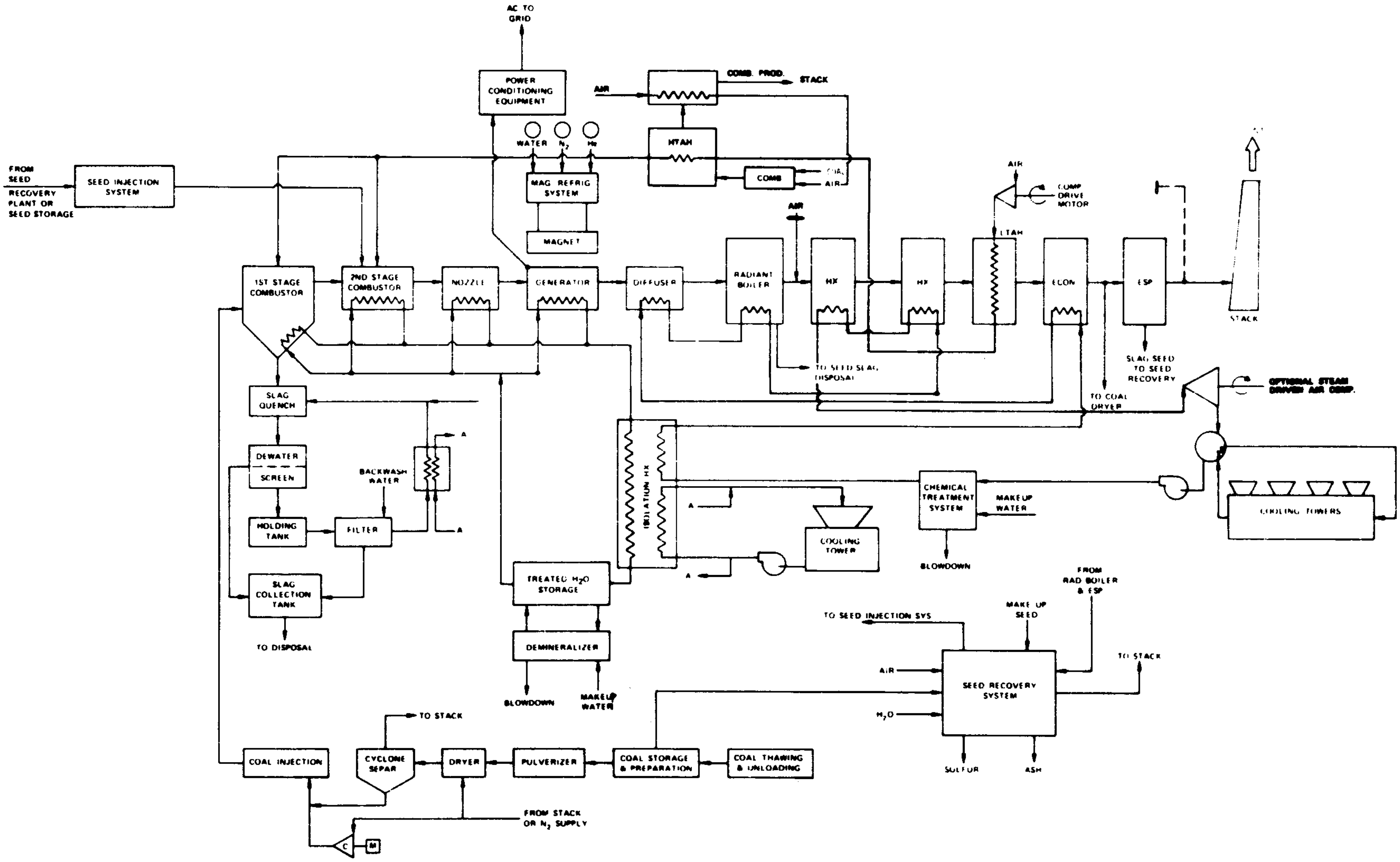


Figure 3-7. Configuration 5 - Final Direct Fired

4.0 SYSTEM ANALYSIS

This section presents the results of the system performance calculations for the configurations defined in Section 3.0, and the sensitivity of this performance to parameter variations.

4.1 BASIC PARAMETER AND CONFIGURATION CONSIDERATIONS

4.1.1 COMBUSTOR CONDITIONS

Key combustor parameters are dictated by the design conditions in the MHD channel and the downstream components. High performance of the MHD topping cycle requires a high energy extraction in the MHD duct. The key parameters that are involved in this requirement are establishing the conductivity levels in the plasma, a function of the plasma temperature and seed level, and the strength of the magnetic field and length of channel. Other parameters that affect significantly the performance of the channel are the electrodynamic characteristics which include the load factor, Hall parameter, size of the channel and its geometry. Relationships of these principal component parameters have been discussed in the scaling study of Reference 11.

System study tradeoffs of the combustor conditions, MHD power conversion conditions and downstream heat removal have established the general levels of the parameters for reasonable performance. The tradeoffs are principally constrained by the available technologies and seem to pivot upon the upper level of temperature that is possible. Although lower pressures are desired to enhance the conductivity of the fluid, the pressure levels are dictated by that pressure necessary to provide the flow through the system and the state point conditions that are required.

The very real limit that is imposed in the combustion process therefore becomes the combustor temperature that is possible. This limit comes from the amount of air preheat which is possible with existing preheater technology, the stoichiometry and combustion process, and the heat losses associated with the real device. Unless oxygen enrichment is used to enhance the combustion process, a combustion exit temperature of the order of 4400-4700°F exists for current technology preheaters. The lower temperature is that obtainable with indirect fired preheaters which currently permit temperatures on the order of 2300°F. The upper level is that developed with indirect preheaters with temperatures on the order of 2900°F. This temperature level is further reduced when a lower stoichiometry is developed to provide for the lowering of NO_x formation in the combustor. For the ETF conceptual design the overall combustor stoichiometry is assumed to be 0.95. Furthermore, for the control of ash carryover, the use of a two stage combustor with a first stage stoichiometry of 0.5 is desired. This is based upon permitting the first stage flame temperatures to provide good slag properties, low carbon loss and minimum formation of corrosive molten iron.

On the basis of established studies, a combustor exit temperature of approximately 2800 K (4580°F) is desired and is used for all configurations. This provides the MHD duct with a reasonable conductivity considering the other parameters as mentioned above. At this temperature level and with the current technology, a combustion pressure level of approximately 5.2 - 5.4 atmospheres is desired. A level of 5.4 was selected for this study.

4.1.2 SELECTION OF MHD CHANNEL CONDITIONS

The significant impact of design conditions which are assumed in the channel are indicated in Figures 4-1, 4-2 and 4-3. In Figure 4-1, the impact of the seed rate is observed. Above about 0.7 percent to 1.0 percent the increase in seed rate does not provide as significant an increase in conductivity as is obtained in increasing from 0.5 to 0.7. Since the cost of the seed and its recovery is a significant factor in the overall economics of the plant, the utilization of seed rates above 1.0 percent have not been found economical in previous studies. For this study with Montana Rosebud Coal a 0.7% seed rate has been utilized, consistent with sulfur control.

In Figure 4-2, the affect of pressure on conductivity is noted. The tradeoff

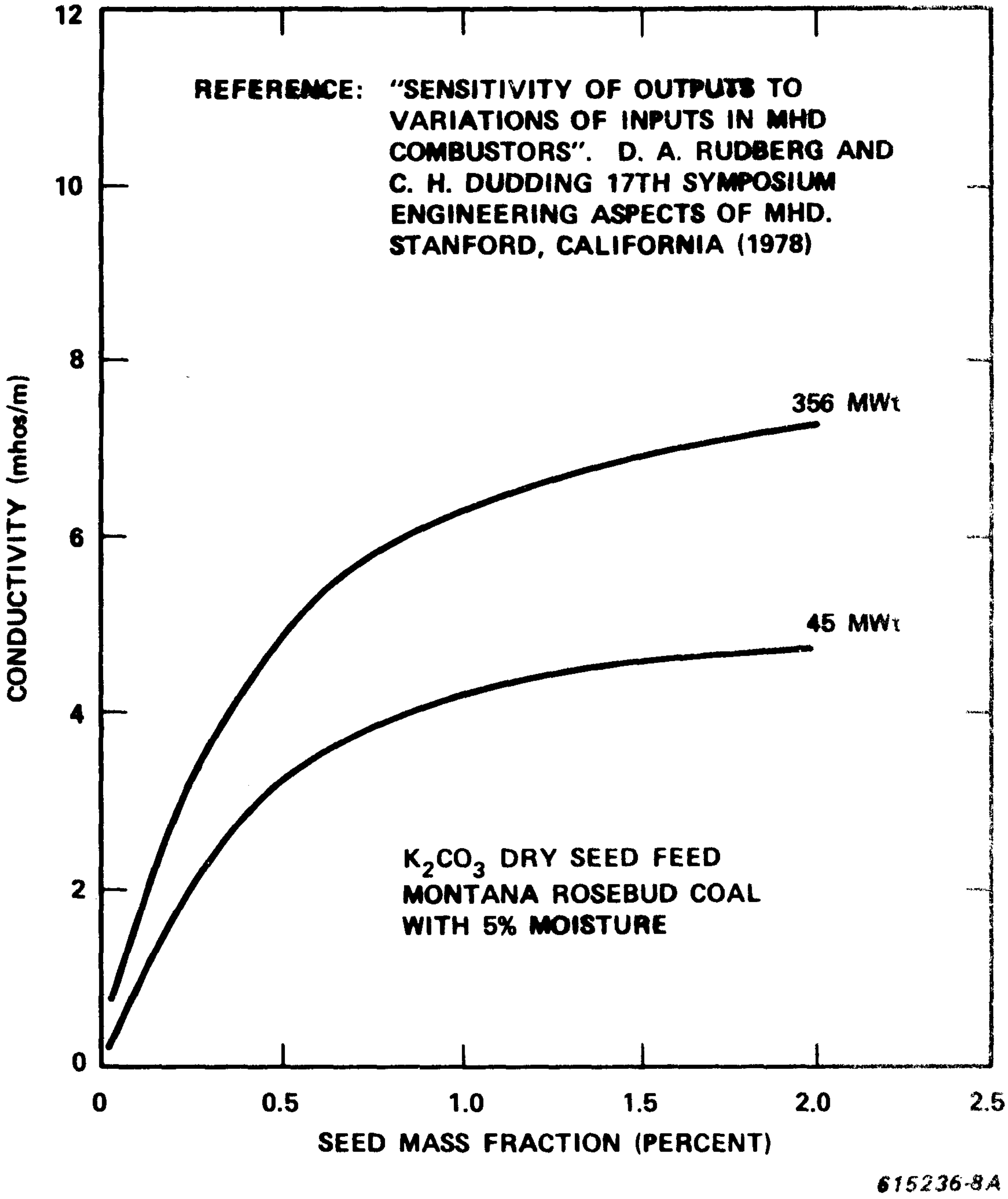


Figure 4-1. Non-Linear Effect of Seeding in Combustor and Sensitivity to Size

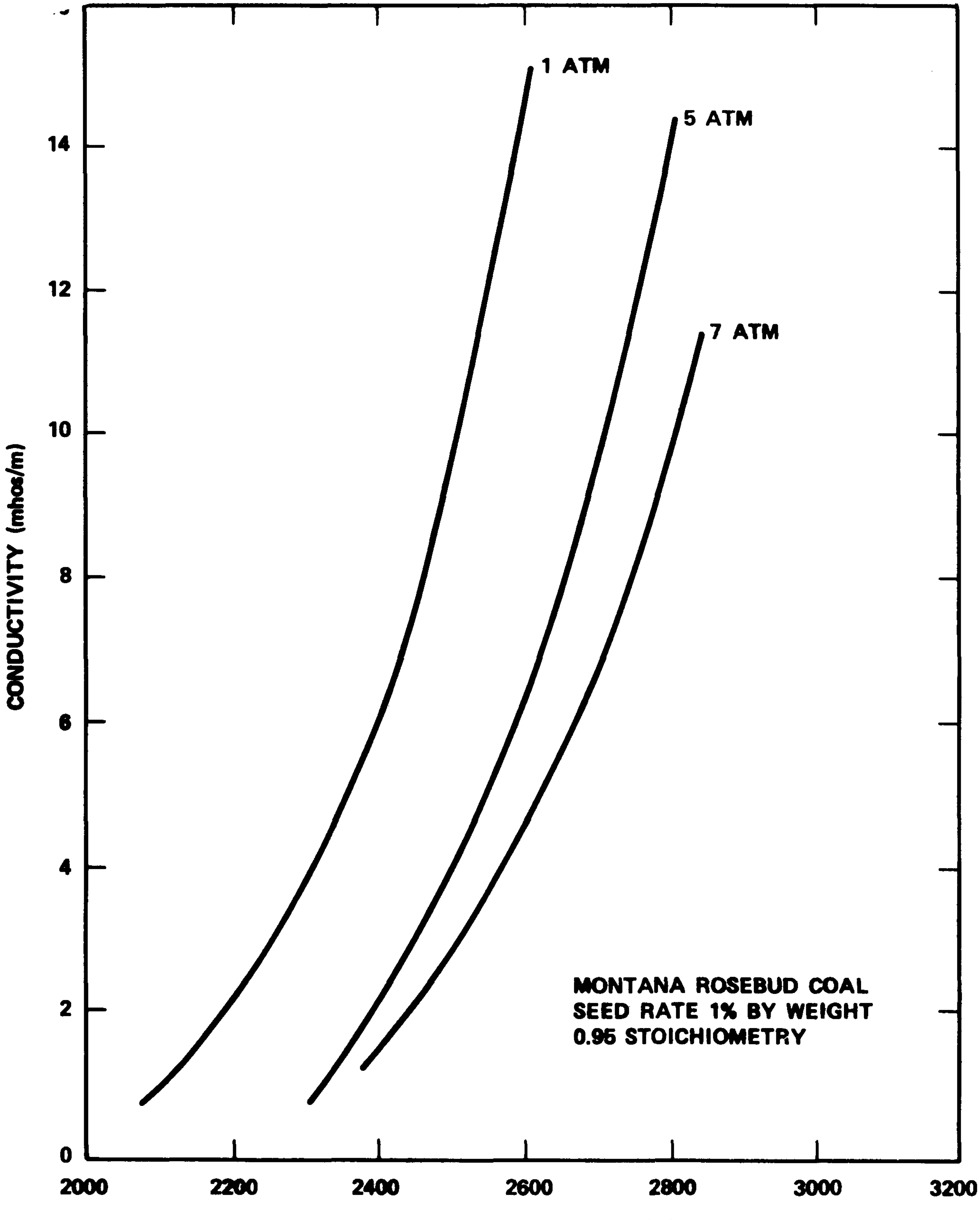


Figure 4-2. Impact of Temperature and Pressure on Plasma Conductivity

here is principally constrained by the required pressure conditions downstream and the desired performance in the heat transfer system. The lower pressure needed for higher conductivity is offset by the desired smaller component sizes and the exit pressure and pressure gradients necessary to provide flow through the system. Again, the desirable pressure drop in the channel is constrained by the geometry of the channel, a length factor which results in increased wall losses and pressure drops, and reduced performance because of lower temperatures and conductivity in the plasma. The impact of temperature on the conductivity is also noted in Figure 4-2. The very substantial improvement in conductivity with higher temperatures continues to press the designer to the highest temperatures that are compatible with existing experience and design precedence. As previously noted, for this study a maximum combustion temperature of 2800K at a pressure of 5.4 atmospheres has been selected. Figure 4-3 indicates the impact of the load parameter on the performance of the MHD channel. Control of this parameter will have a significant affect upon the enthalpy extraction and the overall efficiency of the MHD topping cycle. A load factor of about 0.7 to 0.8 is used for the ETF study.

4.1.3 SELECTION OF RADIANT BOILER CONDITIONS

The combustion product dynamics (both chemical and fluid characteristics) in the radiant boiler go beyond the effort level of this study. The general requirement for temperature range, rate of change and total residence time have been assumed as noted in Section 3. The concept selected is the Foster-Wheeler configuration as suggested in Reference 3. This has been scaled based upon the flow rate and scaling relationship for a residence time of 2.5 seconds and the required heat transfer. The principal constraint related to heat transfer has been that of maintaining the temperature level of the combustion gases above 2000 K. Matching the HTAH temperature requirements for configuration 3 and beyond has required the exit temperature to be maintained above 2090 K. However, the size and configuration of this unit required to best match the 2.5 second residence time as well as the low heat transfer requirements of early configurations has not been assessed in any depth. For the purpose of this study the feasibility, cost and spatial requirements are considered adequately defined. Engineering necessary to more completely develop this

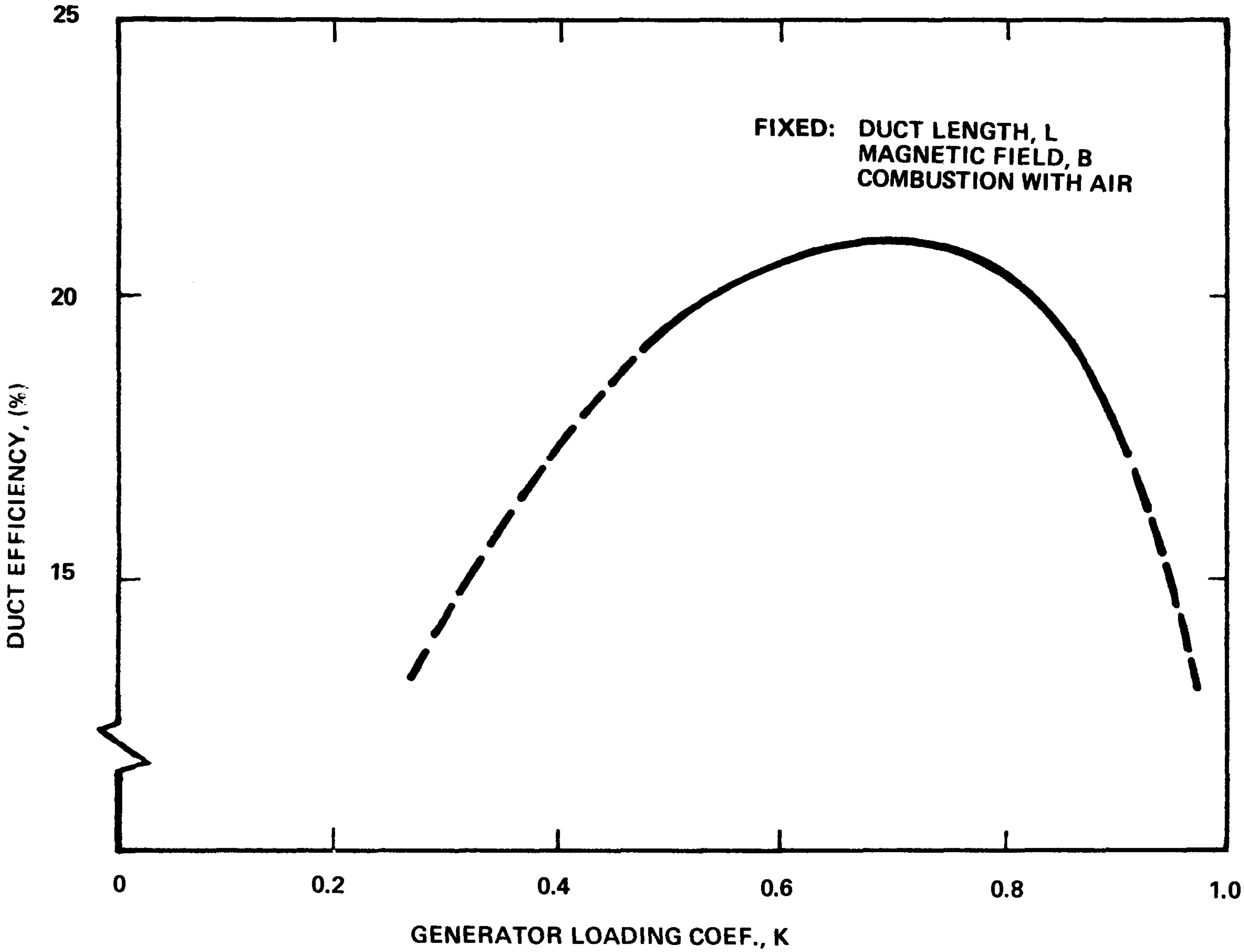


Figure 4-3. Affect of Power Load Factor

component design would not be justified until a more specific decision on the ETF reference system is made.

4.1.4 SELECTION OF DOWNSTREAM HEAT EXCHANGER CONDITIONS

The downstream heat exchangers have been sized very conservatively to assure capability in meeting the uncertainty factors in slag/sooting and heat transfer rates. The size has been based upon the earlier ETF study configurations(2) and the same factor of two margin in heat transfer over maximum heat transfer for most compact design has been maintained. Cost of these units may be reduced when more data are available that would suggest a higher heat transfer rate is justified. However, the lower value assumed (100% increase in surface over minimum) would provide a good margin for fouling effects and perhaps be closer to optimum for servicing schedule and clean out. The impact of these components on cost is relatively low and the additional spatial allowance required is consistent with adequate lay down and servicing area guidelines.

The control of heat transfer is easily maintained in these components by the cooling water flow conditions to meet the desired design steam conditions. However, the desired combustion gas temperatures entering the low temperature air heater (needed to obtain 1100 K preheat condition) will be a design constraint for the latter configurations of the progressive plan. By assessment of the performance of the heat exchange equipment in early testing, adjustments or heat exchanger modifications could be incorporated to assure the desired exit gas temperatures for inclusion of the LTAH.

4.1.5 COMPONENT COOLING OPTIONS

The objectives of a test program influence the selection of supporting subsystems toward more conservative design in order to assure maximum reliability in accomplishing the test article demonstrations. Although the major MHD power train component cooling system is in fact a part of the test article (the MHD power train system), the crucial nature of this cooling system as concluded in the failure mode event analysis (FMEA) study suggests the need to compromise the heat recovery and take additional performance penalty to assure reliability. At the same time, the more conservative approach can be configured to provide significant experimental data for future system design. The approach determined from assessment of the several design configurations listed in Table 4-1 is Option 5 shown on the table and provides the following advantages:

- flexibility to maintain component cooling conditions in remaining components if a failure develops in any one component's cooling loop
- capability to assess the best match of flow conditions for key components
- capability to assess the optional recovery of heat to match the steam bottoming plant

4.1.6 STEAM TURBINE COMPRESSOR DRIVE

The inclusion of a steam turbine compressor drive option with configuation 3, or subsequent steps provides a means to assess the interactions, cost and operating experience with this additional combined plant system. The question of best design approach for the steam source and selection of operating condition could be evaluated with this additional component provided. Also, some operating expense recovery could be realized. Since the major power requirement for compressor work is less than a third of the MHD electrical output, this advantage is not considered of significant consequence. However, upon assessment of the earlier steps, judgment as to the inclusion of a steam turbine compressor drive could be made. This option does not impact the assessment of the progressive plan path, however, and is left to later evaluation at this time. All performance calculations have been performed assuming electric motor drive.

TABLE 4-1

MAJOR MHD POWER TRAIN COMPONENT COOLING OPTIONS

	OPTION	ADVANTAGES	DISADVANTAGES
1.	Separate series cooling system with heat dump to cooling tower.	does not interfere with steam bottoming and minimizes interfacing	no heat recovery or capacity to operate if failure in any component cooling system
2.	Separate cooling system with parallel cooling loops for each major component with cooling tower.	as above and provides for protection of remaining components if one fails	no heat recovery, additional equipment
3.	Steam bottoming system directly coupled to MHD component cooling system with no separate cooling towers.	simplest and recovers waste heat	low reliability and steam bottoming plant performance penalty with full interfacing - also, must control chem. of all steam system water for elec. cond.
4.	Steam bottoming system indirectly coupled with cooling system as (3) above.	provides advantage of (3) above and reduces water chemistry problem	steam bottoming plant penalty and low reliability
5.	Steam bottoming system indirectly coupled, but with addition of cooling tower loop as (2) above	provides options for cooling system, heat recovery and advantages of (2) above minimal penalty in stringent coolant chemistry control necessary to hold dielectric properties for electrical isolation. provision for options in rejection of heat to match plant, also, if steam system shutdown or was lost as the heat sink, the cooling tower system could pick up the full cooling load.	more complex and costly system, consistent with maximum coolant temperatures compatible with the electrical isolation requirements on the cooling connections.

4.2 PERFORMANCE PREDICTIONS

Steady-state computer simulations of the selected configurations have been performed using a modular MHD systems code that is based upon the SYDSIMP program, Reference (4). SYDSIMP was developed by Westinghouse for general systems analysis and enables the simulation of systems whose components can be modeled mathematically and linked with one another by means of inputs and outputs to form the total system. The program is completely general and component modules can be arranged in any order to analyze arrangement effects on performance provided the input requirements for each module are satisfied. Major program input data for the present study are identified in Table 4-2 and it is noted that all thermodynamic and electrical properties of the combustion gas streams were determined based upon Reference (5).

The analysis model used for configurations 1 and 2 is shown in Figure 4-4. The model used for configurations 4 and 5 is shown in Figure 4-5. Plant performance predictions resulting from the study are presented in Table 4-3.

All computer simulations leading to Table 4-3 assumed Montana Rosebud coal having the as-received composition identified in Table 4-2. The dryer, heated by combustion gases or fired indirectly, was assumed to reduce the coal moisture content to 5% and resulted in a fuel temperature of 215°F (375 K) at the combustor inlet. As Table 4-2 indicates, the first and second combustor stages were supplied with sufficient oxygen to achieve a 0.95 stoichiometric condition at the combustor exit and for configurations 3, 4, and 5, secondary air was injected downstream to achieve a 1.05 stoichiometry at the radiant boiler. Gas temperatures at the radiant boiler exit were always restricted to values above 1900 K to ensure the required amount of NO_x decomposition.

The configuration simulations were forced to be identical in several respects to permit a more meaningful comparison of results. First of all, the coal energy input rate was held constant at 150 MW and the MHD duct length was fixed at the final configuration length of 11.32 m. This duct length resulted from the final configuration simulations (configurations 4 and 5) in which the combustor exit temperature was 2800 K which required a 1917 K air preheat

TABLE 4-2

PERFORMANCE ANALYSIS INPUT DATA

COAL DRYER

Coal -- Montana Rosebud

As-Received Analysis

	%
Carbon	52.1
Hydrogen	3.5
Sulfur	0.9
Oxygen	11.3
Mositure	22.7
Other Constituents	0.8
Temperature	300 K

Dryer Exit Conditions

Mositure	5.0
Temperature	375 K

Coal Specific Heat	1046 joules/kg-K
Higher Heating Value	2.687×10^7 joules/kg

COMBUSTOR

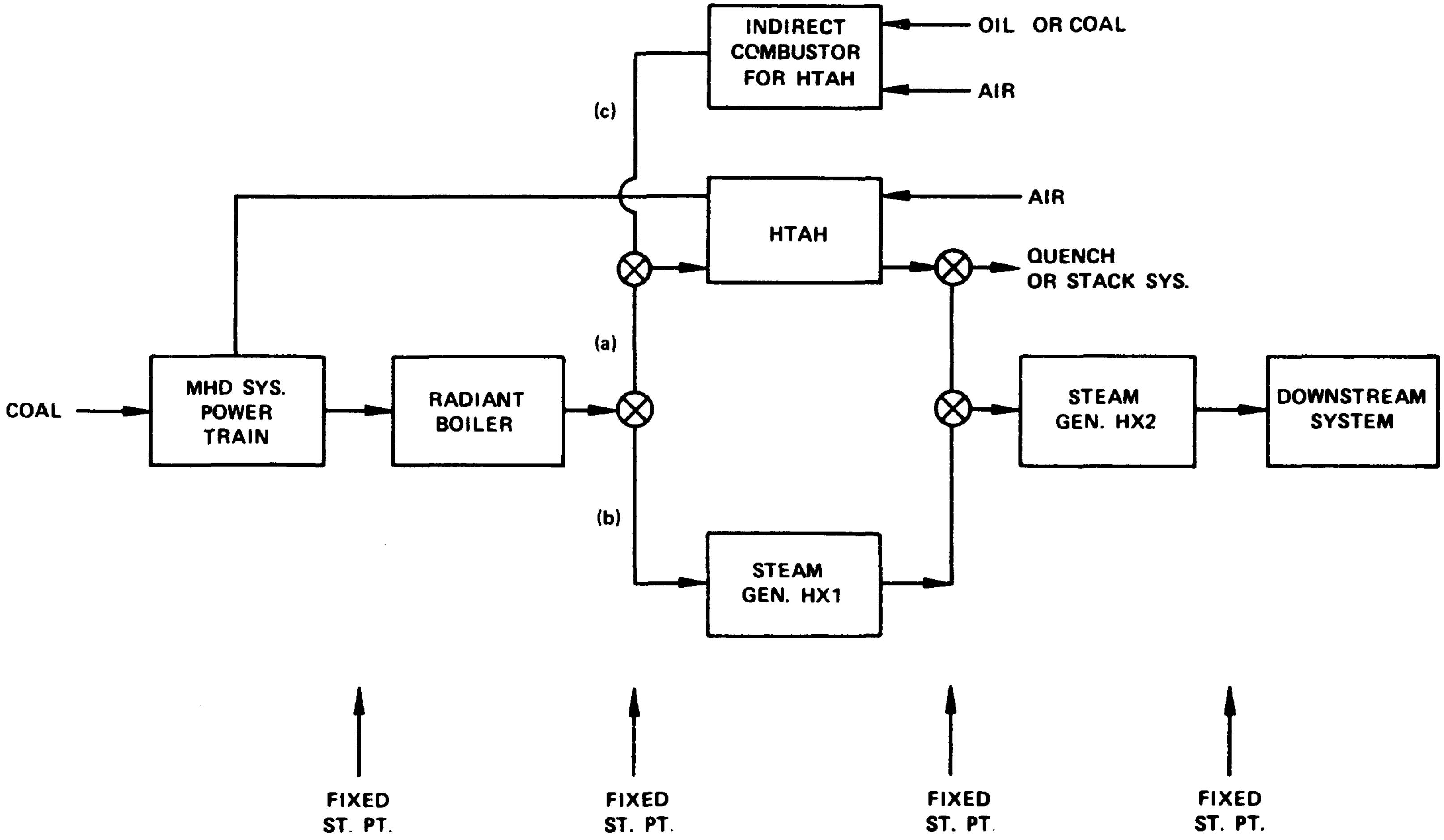
Coal Feed Rate	5.88 kg/s
Coal Energy	150 MW
Seeding Level	0.7%
$W_{K_2SO_4}/(W_{K_2SO_4} + W_{K_2CO_3})$	0.813
Slag Temperature	2000 K
Carrier Gas to Coal Ratio	0.10
Exit Stoichiometry	0.95
Stack Stoichiometry	1.05

MHD DUCT

Inlet Magnetic Field Strength (max)	6.0 tesla
Channel Aspect Ratio	2.0
Load Factor	0.75
Wall Temperature	1800 K
Friction Factor	0.005

TABLE 4-2 (Continued)

EFFICIENCIES	
Air Compressor	0.85
Pump	0.70
COMBUSTOR AIR INTAKE CONDITIONS	
Temperature	288.3 K
Pressure	0.787 atm



(a) DIRECTLY, RECUPERATIVELY HEATING AIR WITH MHD POWER TRAIN COMBUSTION GASES

(b), (c) INDIRECTLY HEATING HTAH AND ROUTING MHD POWER TRAIN COMBUSTION GASES THROUGH A STEAM GENERATOR MATCHED TO THE SAME HEAT REMOVAL AS REQUIRED BY THE HTAH.

Figure 4-4. Computer Model - Initial Configuration

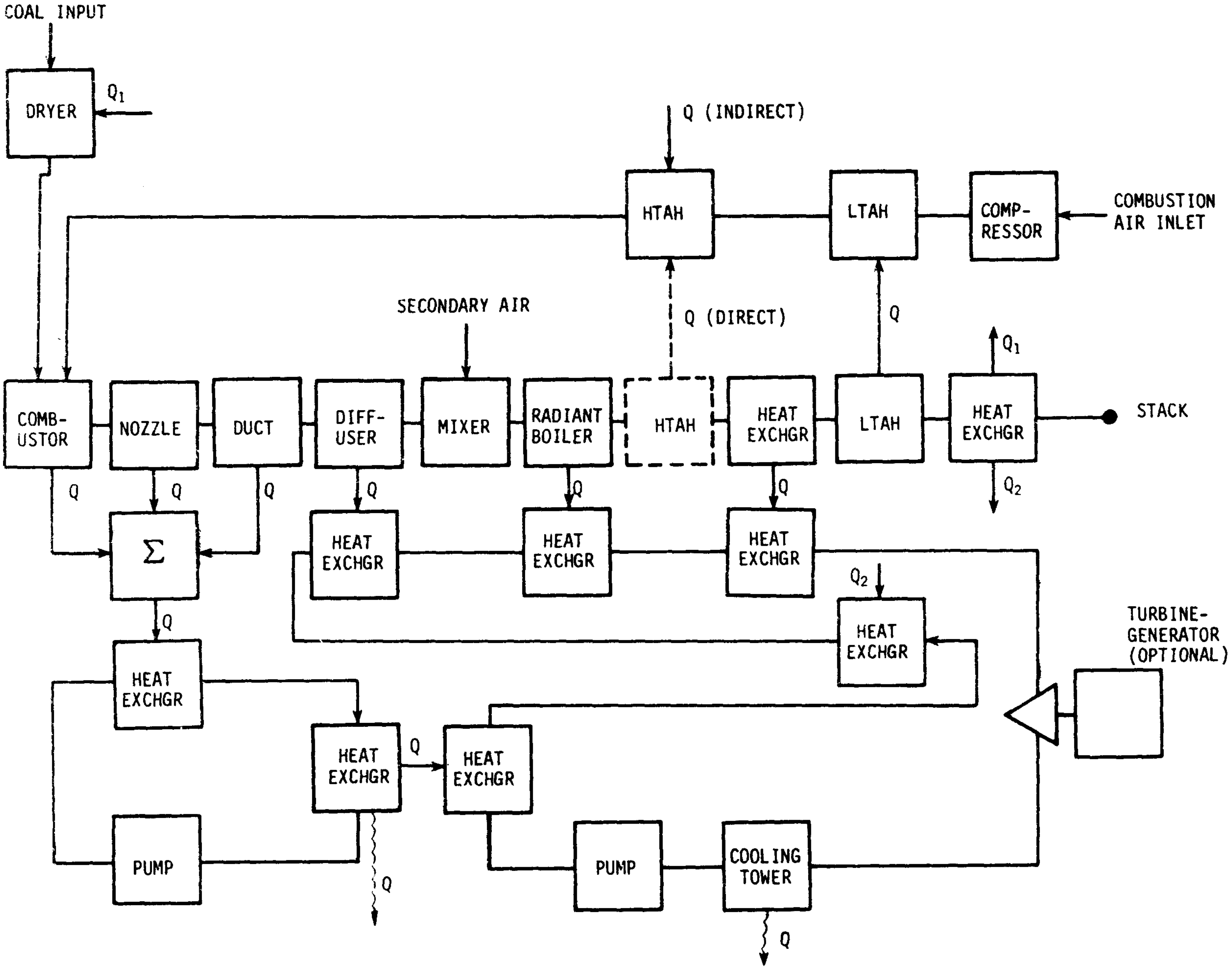


Figure 4-5. Computer Model - Final Configurations

TABLE 4-3

PERFORMANCE PREDICTIONS*

Configuration 1 - Quench, Air Preheat to 1005K (Metallic)
2 - Quench, Air Preheat to 1533 K (Regenerative)
3 - Steam Generating, Indirect Air Preheat to 1755K
4 - Final Configuration, Steam Generating, Indirect HTAH, Air Preheat to 1917K
5 - Final Configuration, Steam Generating, Direct HTAH, Air Preheat to 1917K

	CONFIGURATION				
	1	2	3	4	5
Preheated Air Flow Rate	19.9	29.5	37.0	46.5	46.5
Preheated Air Temperature	1005.0	1533.0	1755.0	1917.0	1917.0
Air Preheat Energy	14.4	40.0	60.3	85.2	85.2
Enrichment (%)	133.0	57.5	25.6	0.0	0.0
Pure Oxygen Flow Rate	6.1	3.9	2.2	0.0	0.0
Pure Oxygen Temperature	288.3	288.3	288.3	——	——
Seed Flow Rate	0.47	0.58	0.67	0.78	0.78
Secondary Air Flow Rate	0.0	0.0	4.9	4.9	4.9
Secondary Air Temperature	——	——	288.3	288.3	288.3
Secondary Air Pressure	——	——	0.82	0.82	0.82
Combustor Exit Flow Rate	32.4	39.9	45.7	53.2	53.2
Combustor Exit Temperature	2800.0	2792.0	2800.0	2800.0	2800.0
Combustor Pressure	5.48	5.48	5.48	5.48	5.48
Diffuser Exit Temperature	2059	2093	2109	2127	2127
Diffuser Exit Pressure	0.88	0.88	0.82	0.82	0.82
Duct Geometry					
Inlet Area	0.08	0.11	0.12	0.14	0.14
Exit Area	0.6	0.76	0.88	1.0	1.0
Length	11.32	11.32	11.32	11.32	11.32
Duct Inlet Velocity	825.0	825.0	825.0	825.0	825.0
Component Heat Transfer Rates					
Combustor	15.0	15.0	15.0	15.0	15.0
Nozzle	2.7	2.7	2.7	2.7	2.7
Duct	15.8	16.0	16.3	16.7	16.7
Diffuser	20.0	20.0	20.0	20.0	20.0
Radiant Boiler	——	——	13.9	8.6	13.2
High Temperature Air Heater	10.0	33.4	52.0	46.2	46.2
Low Temperature Air Heater	——	——	——	28.5	28.5
Heat Dissipation Rates					
Isolation Heat Exchanger Cooling Tower	53.5	53.8	15.4	13.8	22.9
Steam Generating System	——	——	104.9	135.8	75.0
Stack/Quench	88.8	108.0	55.7	16.3	40.8
Quench/Stack Inlet Conditions					
Flow Rate	32.4	39.9	50.6	58.0	58.0
Temperature	2059.0	2093.0	1200.0	425.0	425.0
Steam Conditions @ Turbine Inlet					
Flow Rate	——	——	32.3	41.9	23.5
Temperature	——	——	811.1	811.1	811.1
Pressure	——	——	163.3	163.3	163.3
Electrical Energy Input					
Pumps	0.01	0.01	0.8	1.1	0.6
Air Compressor	5.3	7.8	9.7	12.2	12.2
Thermal Energy Input					
Indirect Coal Drying	6.6	6.6	6.6	0.0	0.0
Indirect Air Preheating	10.0	33.4	52.0	46.2	0.0
Gross MHD Output	21.9	27.9	34.6	41.2	41.2
Enthalpy Extraction (%)	13.7	14.9	16.5	17.4	17.4
Overall Plant Efficiency (%)	10.3	10.9	13.4	14.2	18.3

*UNITS
Flow Rate - kg/s
Pressure - atm
Temperature - K
Length - m
Area m^2
Energy, Heat Transfer Rates - MW
Velocity - m/s

temperature with no O_2 enrichmant. This duct parameter was then assumed to establish the magnet design which was utilized in duct designs for earlier configurations in the plant evolution process. In the final configuration (configurations 4, and 5), it was also required that the diffuser exit pressure be held constant or nearly so to assure the satisfactory operation of the downstream gas train components.

The performance study predicts the occurrence of several expected trends that will develop as the plant configuration progresses from the initial to the final configuration. Of course, as the need for pure oxygen is phased out, the quantities of preheated air required will increase leading to larger compressor ratings. As Table 4-3 shows, the main compressor electrical input will rise from 5.3 MW in the initial configuration to 12.2 MW in the final configuration. Another result of the increased demand for combustion air and the discontinued use of oxygen addition will be the increased flow of combustion gases in the MHD duct. This will increase the MHD electrical output and this effect will override the increased compressor work and lead to net improvements in enthalpy extraction and overall efficiency as the plant evolves. It is noted that the final configuration data of Table 4-3 do not include the beneficial effects of an optional turbine/generator set to supply electrical energy to the air compressor and cooling water pumps. Calculations show that equipping the plant with that particular feature would increase the overall efficiency by two percentage points to 21%.

4.3 SYSTEM PARAMETER AND SENSITIVITY ANALYSES

To observe the effects of plant parameter variations on overall system performance and on the physical size of hardware, sensitivity studies have been performed using the plant computer model of Figure 4-5. The model, as the figure notes, represents the evolving plant in the final configuration and the sensitivity evaluations considered the plant to be in the indirect firing mode without the optional turbine/generator set. Thus, the heat rejection estimates produced by the study represent upper limits and are the values necessary for sizing the heat transfer hardware.

The sensitivity analysis was approached from two viewpoints. In the first case, the MHD duct design was variable and its cross section and length were allowed to vary in response to changes in certain independent variables while all duct electrical parameters, the inlet nozzle velocity and the diffuser exit pressure were held constant. The value of that analysis lies in its ability to show the response of component size and plant performance to changes in the important independent variables. That information, in turn, will allow components and plant parameters to be selected in the most appropriate and cost effective combination. In the second study, the duct physical dimensions were held fixed at values obtained during the first analysis and an off-design study was performed. The value of that work, of course, is that it identifies trade-offs and predicts the effects on plant performance of altering operating conditions once the plant physical design has been fixed. In each analysis, the coal energy input rate was held constant at 150 MW with no oxygen enrichment. Further, the diffuser exit pressure was also fixed at a value (0.82 atm) above atmospheric* pressure sufficient to assure the satisfactory operation of the downstream components without the need for induced draft. The values of other variables held constant throughout the study are identified in Table 4-2.

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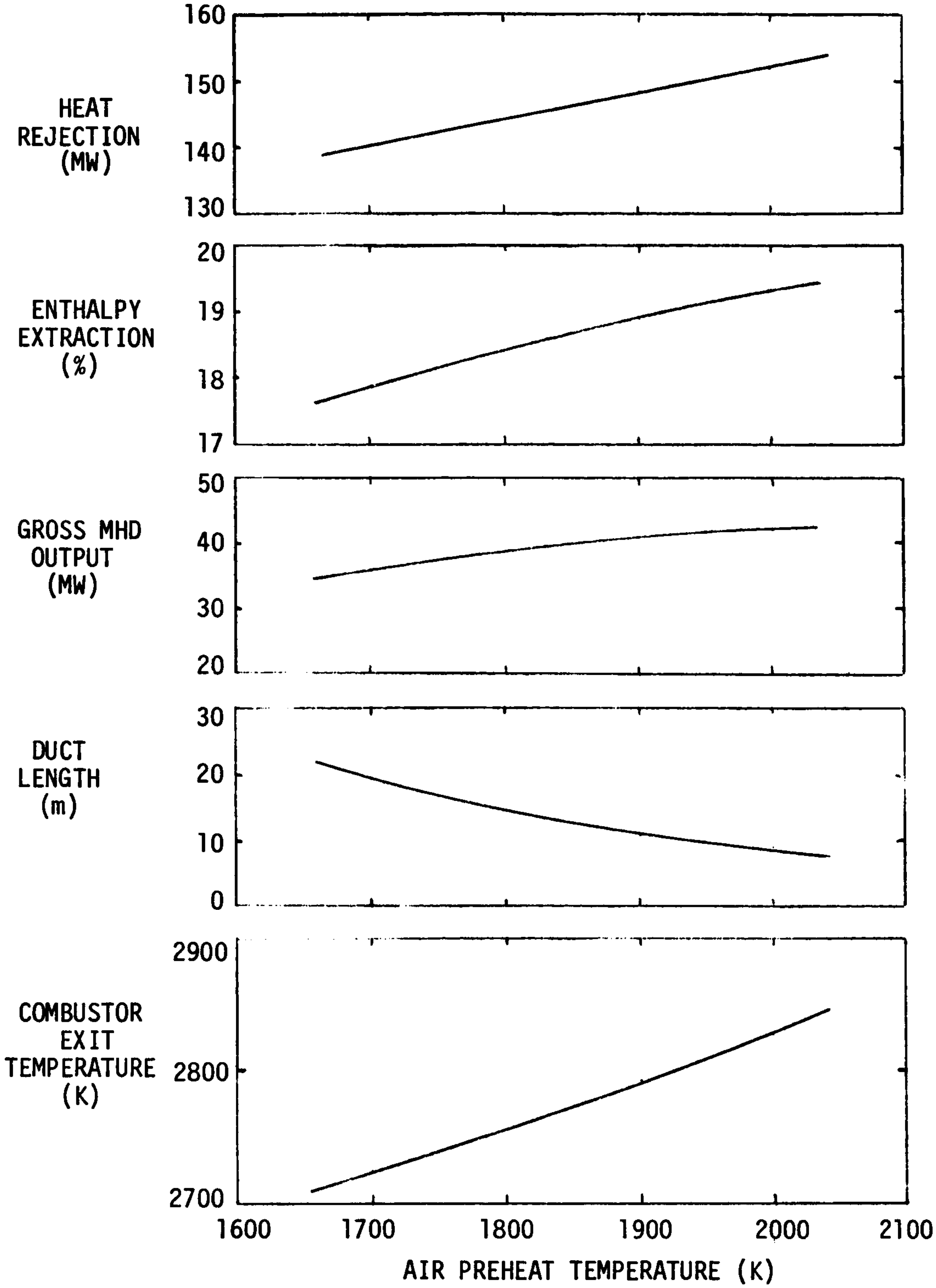
*Local atmospheric pressure in Butte, Montana = 0.79 atm.

4.3.1 VARIABLE DUCT DESIGN RESULTS

In this analysis, the four independent variables of interest were the air preheat temperature, combustor pressure, the MHD duct load factor and the combustor seeding level. In particular, the effects of these parameters on duct length, gross MHD output, enthalpy extraction and the plant heat rejection rate were sought. Duct length (and cross-section) is especially important since it impacts the design of the magnet system which is the single most costly item in the list of plant components. The benefit (i.e., the MHD electrical output) to be produced by the plant is of obvious interest, but equally important is enthalpy extraction which is a measure of the duct's ability to convert the net upstream influx of chemical and thermal energy to electrical energy. Finally, estimates of the plant's heat rejection rate and their sensitivity to variations in the major independent variables are also very important since they will determine the size of the required cooling tower system which also represents a major portion of the facility's physical plant and indicate the heat availability for steam bottoming plant application.

The predicted effects of varying the air preheat temperature are shown in Figure 4-6. Higher preheat temperatures give rise to higher plasma temperatures at the combustor exit which tend to improve the energy conversion performance of the MHD duct. These trends are predicted by the present analysis model as indicated in the Figure 4-6 plots of MHD output and enthalpy extraction. A third positive effect is the shortening of the MHD duct which is necessary to counter increases in gas steam specific volume and in the Lorentz force and to satisfy, in turn, the downstream pressure requirements at the diffuser exit. Thus, air preheat temperature is found to be an important design and optimizing parameter since increasing it can be used to significantly reduce duct size while simultaneously improving the duct's conversion performance. A negative effect of increasing air preheat temperature is the increasing heat rejection requirement. Since all of the incremental air preheat energy is not converted to electrical energy as the preheat temperature rises, the plant's heat rejection needs will also rise.



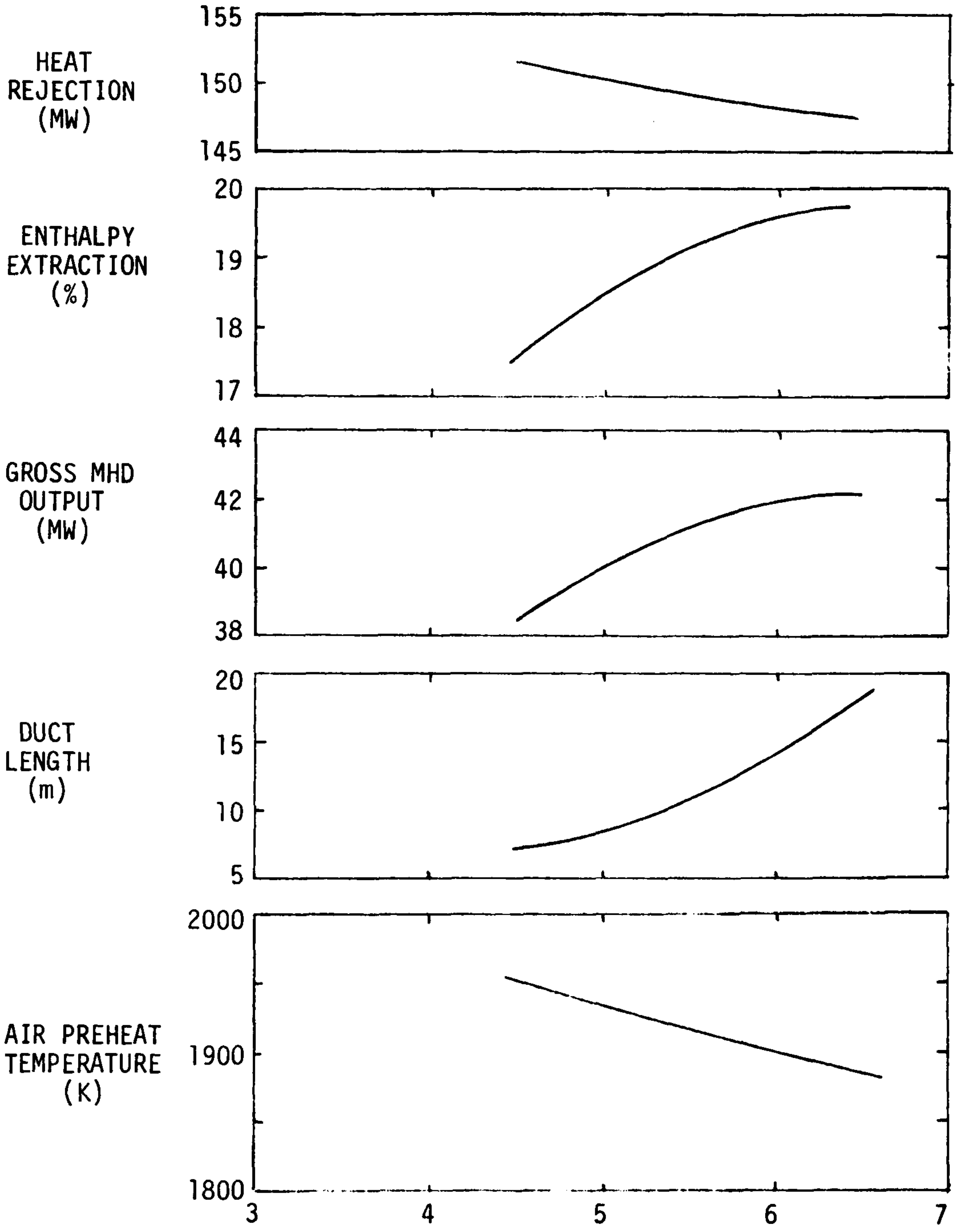
Final Configuration, Indirect HTAH
Coal Energy Input Rate — 150 MW
Enrichment — 0
Combustor Pressure — 5.48 atm
Diffuser Exit Pressure — 0.82 atm

Figure 4-6. Sensitivity to Preheat Temperature Variations -Variable MHD Duct Design-

Figure 4-7 illustrates the influence of combustor operating pressure on plant physical parameters and performance. While varying that parameter, the analysis fixed the combustor exit temperature at 2800 K and the inverse relationship between preheat temperature and combustor pressure reflects the fact that the air energy input to achieve that exit temperature is a sum of thermal and work of compression components. Thus, an increase in one component is compensated for by a decrease in the second. Figure 4-7 also indicates an improvement in the energy conversion performance of the duct with increasing combustor pressure and this is accomplished with slight decreases in the plant heat rejection rate. This improved performance is due in part directly to the higher operating pressure at the duct and also to the increased duct length which is needed, with the higher inlet pressures, to satisfy the constant pressure requirement downstream at the diffuser exit.

Predicted effects of varying the duct load factor are presented in Figure 4-8. As the figure shows, the MHD electrical output and enthalpy extraction initially increase rapidly with load factor but their plots eventually flatten and the optimum load factor value apparently lies in the vicinity of 0.70 to 0.75. Continuing to increase the load factor beyond 0.75 by significant amounts results in small improvements in duct performance but causes the duct length to increase rapidly. As the load factor rises, the Lorentz force opposing the gas flow decreases and, therefore, the added duct length is needed for pressure drop purposes to achieve the required pressure at the duct exit.

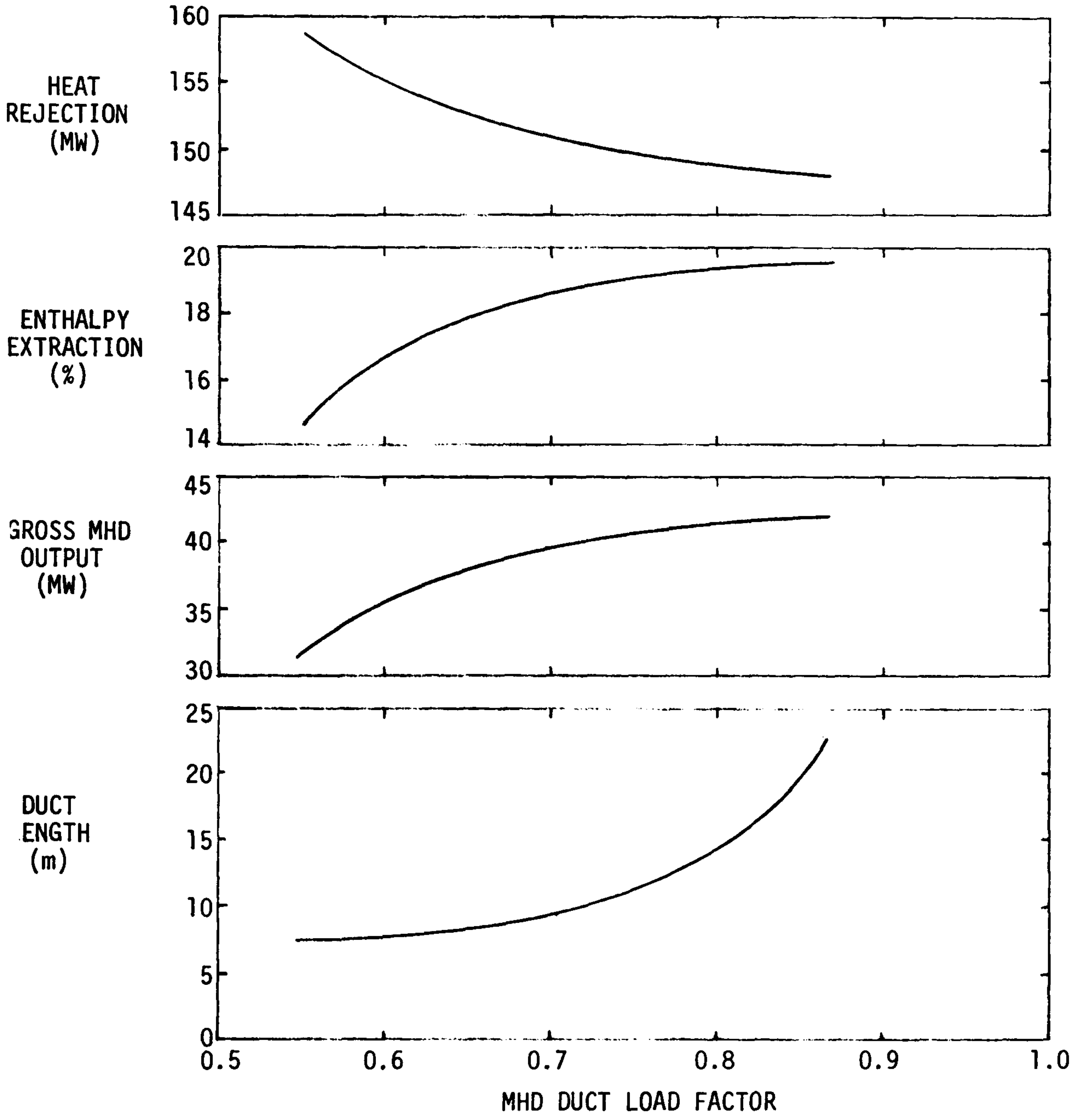
The effects of variable seeding were investigated through calculations performed at two seeding levels - 0.7% and 1.0%. A summary of results from this study are presented in Table 4-4. The dominant effects of varying the seed level pertain to the air preheat temperature and to the length of the MHD duct. By increasing the seed level, the duct length decreased by nearly 20% due to the increased Lorentz force on the gas stream. The Lorentz force assists the hydraulic flow resistance of the duct in establishing the required duct exit pressure and, consequently, a smaller duct length is required for that purpose as the Lorentz force rises. The air preheat temperature increased with the seeding level due to the increased flow of mass to the combustor. The study fixed the combustor exit temperature at 2800K regardless of the seeding level



COMBUSTOR PRESSURE (atm)

Final Configuration, Indirect HTAH
Coal Energy Input Rate – 150 MW
Enrichment – 0
Combustor Exit Temperature – 2800 K
Diffuser Exit Pressure – 0.82 atm

Figure 4-7. Sensitivity to Combustor Pressure Variations -Variable MHD Duct Design-



Final Configuration, Indirect HTAH
Coal Energy Input Rate – 150 MW
Enrichment – 0
Combustor Pressure – 5.48 atm
Combustor Exit Temperature – 2800 K
Diffuser Exit Pressure – 0.82 atm
Air Preheat Temperature – 1917 K

Figure 4-8. Sensitivity to Load Factor Variations -Variable MHD Duct Design-

TABLE 4-4: PERFORMANCE PREDICTIONS WITH VARIABLE SEEDING LEVEL -- VARIABLE DUCT DESIGN

Final Configuration, Indirect HTAH

Enrichment - 0
Combustor Pressure - 5.48 atm
Combustor Exit Temperature - 2800 K
Duct Inlet Velocity - 825 m/s
Diffuser Exit Pressure - 0.82 atm
Load Factor - 0.75

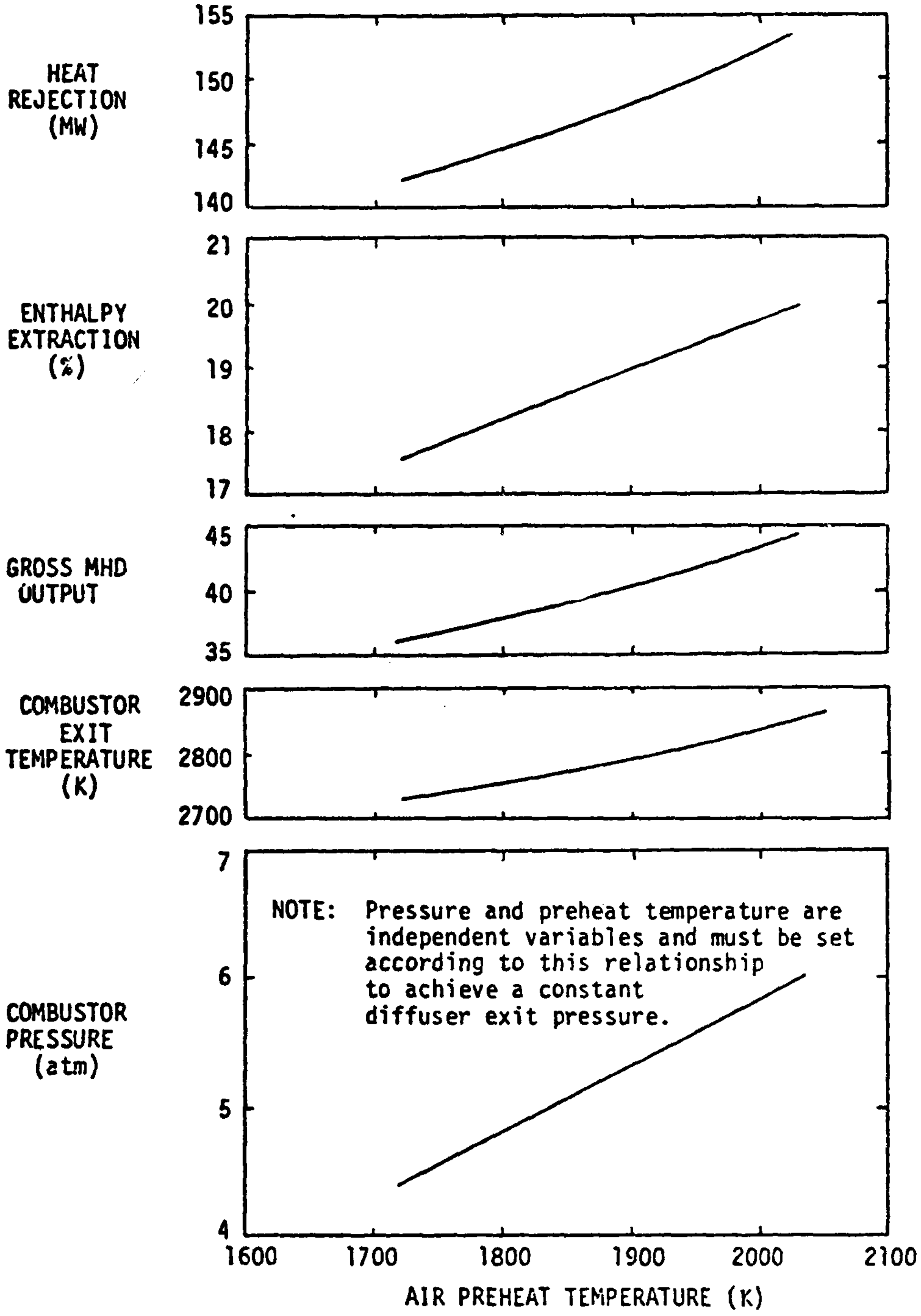
Seeding Level	0.7%	1.0
Air Flow Rate	46.5 kg/s	46.5
Air Preheat Temperature	1917 K	1963
Air Preheat Energy	85.1 MW	87.8
Flow Rate at Combustor Exit	53.2 kg/s	53.5
MHD Power Output	41.2 MW	42.0
Enthalpy Extraction	19.0%	19.2
Heat Rejection Rate	148.4 MW	150.6
Duct Length	11.32 m	9.42
Duct Inlet Area	0.14 m^2	0.14
Duct Exit Area	1.00 m^2	0.98

and, therefore, additional energy input to the combustor via a higher air preheat temperature was required to compensate for the increasing flow of cold, non-combustible seed. A reduction of 17% in channel length as shown in Table 4-4 might reduce the magnet cost approximately $6M. However, additional seed recovery and regeneration costs involved are substantial (> 43%) and the additonal uncertainty in seed effects, higher preheat temperature required and risk incurred make this option questionable at this time.

4.3.2 FIXED DUCT DESIGN ANALYSIS

The analysis of the fixed duct design involved variations in the same independent variables whose effects were examined in the variable duct study. Now, however, they were altered in combinations to maintain a fixed value of the diffuser exit pressure - air preheat temperature/combustor pressure and seeding level/load factor. The predicted effects of simultaneously increasing preheat temperature and combustor pressure are depicted in Figure 4-9. As discussed earlier, independent increases in these parameters do tend to improve the energy conversion performance of the duct and this tendency was experienced again in the fixed duct study as the figure indicates. While the conversion performance of the duct improves with increasing pressure and preheat temperature, the higher rates of thermal energy and work input required also give rise to a net increase in the system's heat rejection rate and this effect, too, is evident in Figure 4-9.

Plant performance calculations were obtained with two seed level and duct load factor combinations - 0.7%/0.75 and 1.0%/0.79, and the effects of varying those parameters in these combinations are found in Table 4-5. The most pronounced effect of increasing the seeding level involves the air preheat temperature which increased from 1917 to 1963 K to counter the increased mass flow to the combustor and still yield the required combustor outlet temperature of 2800 K. Increasing the seed level also increased the gross MHD electrical output a modest amount from 41.2 to 43.4 MW corresponding to an enthalpy extraction improvement from 19.0 to 19.8% and plant heat rejection requirements were predicted to increase by only 0.5 MW from 149.6 to 150.1 MW.



NOTE: Pressure and preheat temperature are independent variables and must be set according to this relationship to achieve a constant diffuser exit pressure.

Final Configuration, Indirect HTAH
Coal Energy Input Rate — 150 MW
Enrichment — 0
Diffuser Exit Pressure — 0.80 atm

Figure 4-9. Sensitivity to Preheat Temperature and Combustor Pressure Variations - Fixed MHD Duct Design -

TABLE 4-5: PERFORMANCE PREDICTIONS WITH VARIABLE SEEDING LEVEL -- FIXED DUCT DESIGN

Final Configuration, Indirect HTAH

Enrichment - 0
Combustor Pressure - 5.48 atm
Combustor Exit Temperature - 2800 K
MHD Duct Length - 11.32 m
Duct Inlet Area - 0.14 m^2
Duct Exit Area - 1.00 m^2
Duct Inlet Velocity - 825 m/s
Diffuser Exit Pressure - 0.83 atm

Seeding Level	0.7%	1.0
Load Factor	0.75	0.79
Air Flow Rate	46.5 kg/s	46.5
Air Preheat Temperature	1917 K	1963
Air Preheat Energy	85.1 MW	87.8
Flow Rate at Combustor Exit	53.2 kg/s	53.5
MHD Power Output	41.2 MW	43.4
Enthalpy Extraction	19.0%	19.8
Heat Rejection Rate	149.6 MW	150.1

5.0 PLANT ARRANGEMENT

The principal considerations in arranging the components for the MHD ETF progressive facility plan were:

- access to hot gas train major components
- diffuser removal for channel access
- personnel safety during operations
- close-coupled power conversion equipment
- close-coupled hot air and oxygen supply equipment
- spatial arrangement for upgrading system without major impact on operations
- concern for adequate space for maintenance, service operations and possible replacement

On the basis of making an economically attractive system a compact arrangement is usually desired. However, on the basis of cost of equipment, need for service and potential for possible replacement, it is not economical to make a compact arrangement, where this deters from adequate access. Since the need for access and potential replacement is greater for the ETF than in developed facilities, the arrangement selected has been based on access. The arrangements are assessed as having a reasonable compactness, but adequate spatial accommodation for ETF operation uncertainty and upgrading which is paramount.

The compromises that have been accepted in longer piping, less compact space utilization and minimal building multi-purpose use have permitted the flexibility desired in the 150 MWt ETF guidelines.

5.1 CONFIGURATION 1

An arrangement of the primary equipment to provide the first stage in the progressive development process is illustrated in Figure 5-1. The compressor outlet air is preheated to 1005K (1350°F) in a metallic air preheater prior to being delivered to the MHD combustor. Oxygen enrichment is employed to obtain the desired combustion temperature and a water quench system is used downstream of the diffuser. The overall site arrangement utilizing this power train is shown in Figure 5-2. This is the same arrangement as resulted from the previous Reference 1 ETF study.

This system represents a low capital cost investment plant capable of providing a development facility for the basic MHD train through to the diffuser outlet. A strong case can be made for such a system on the grounds that the MHD channel and its associated components, with their unprecendented combination of electrical, chemical, aerodynamic and mechanical problems, is logically the most appropriate subject for the initial development effort. This effort can best be concentrated on the basic MHD component developments if the downstream facility is a simple and reliable quench system rather than the more complex and expensive heat exchange components of a steam bottoming plant which, although more similar to conventional steam plant equipment than the MHD components, may require development effort as a result of the slag and seed laden gas throughput.

An additional advantage of deferring the addition of the steam bottoming plant and other downstream components to a later point in the MHD component development process, is that the design of the downstream components can then be based on observed performance characteristics of the MHD portion of the plant rather than on more theoretically ideal conditions which may not be achievable early in the program. This philosophy can be particularly beneficial when several steps of development are envisaged.

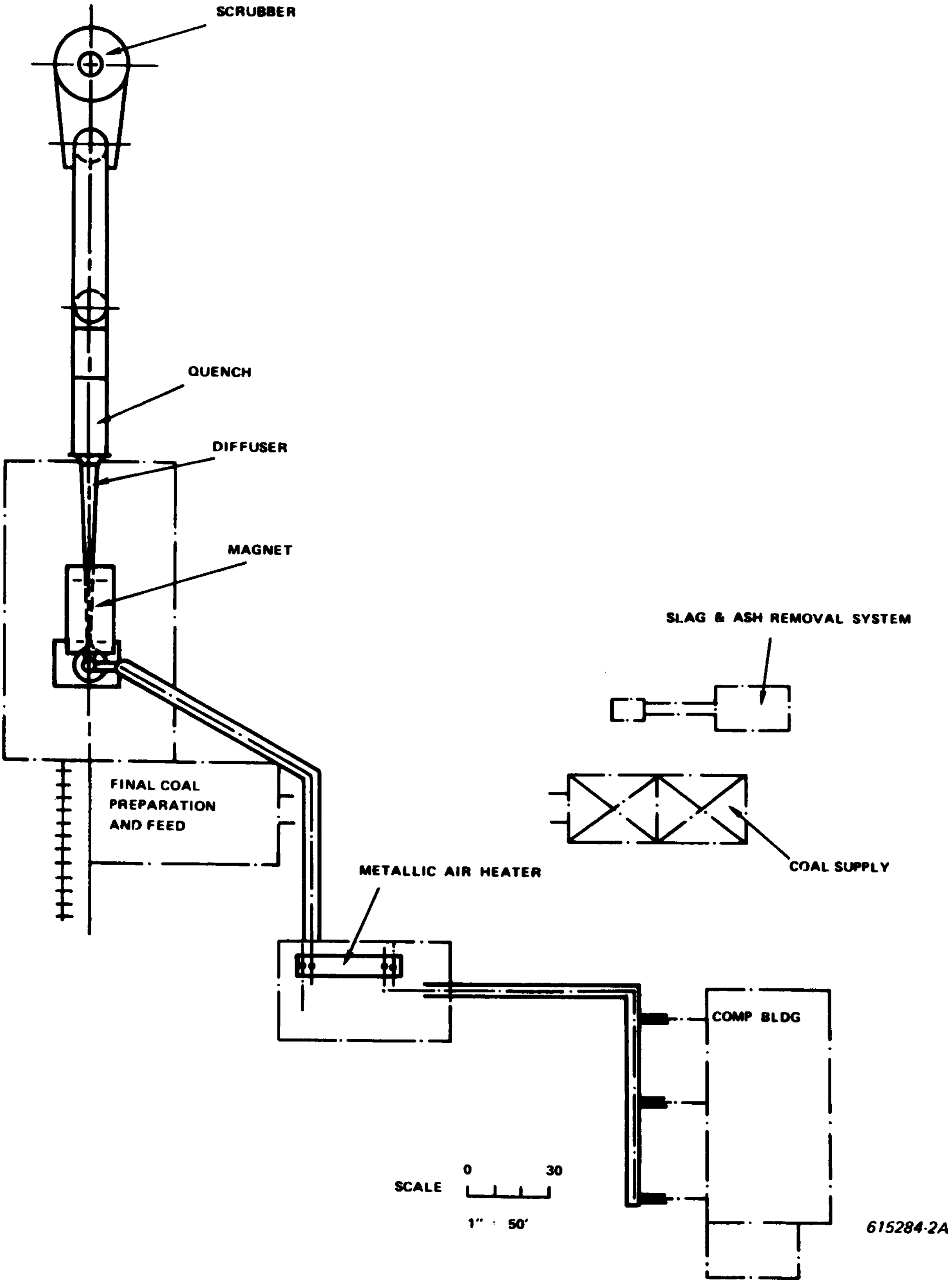


Figure 5-1. 150 MW ETF Plant Layout - Configuration 1

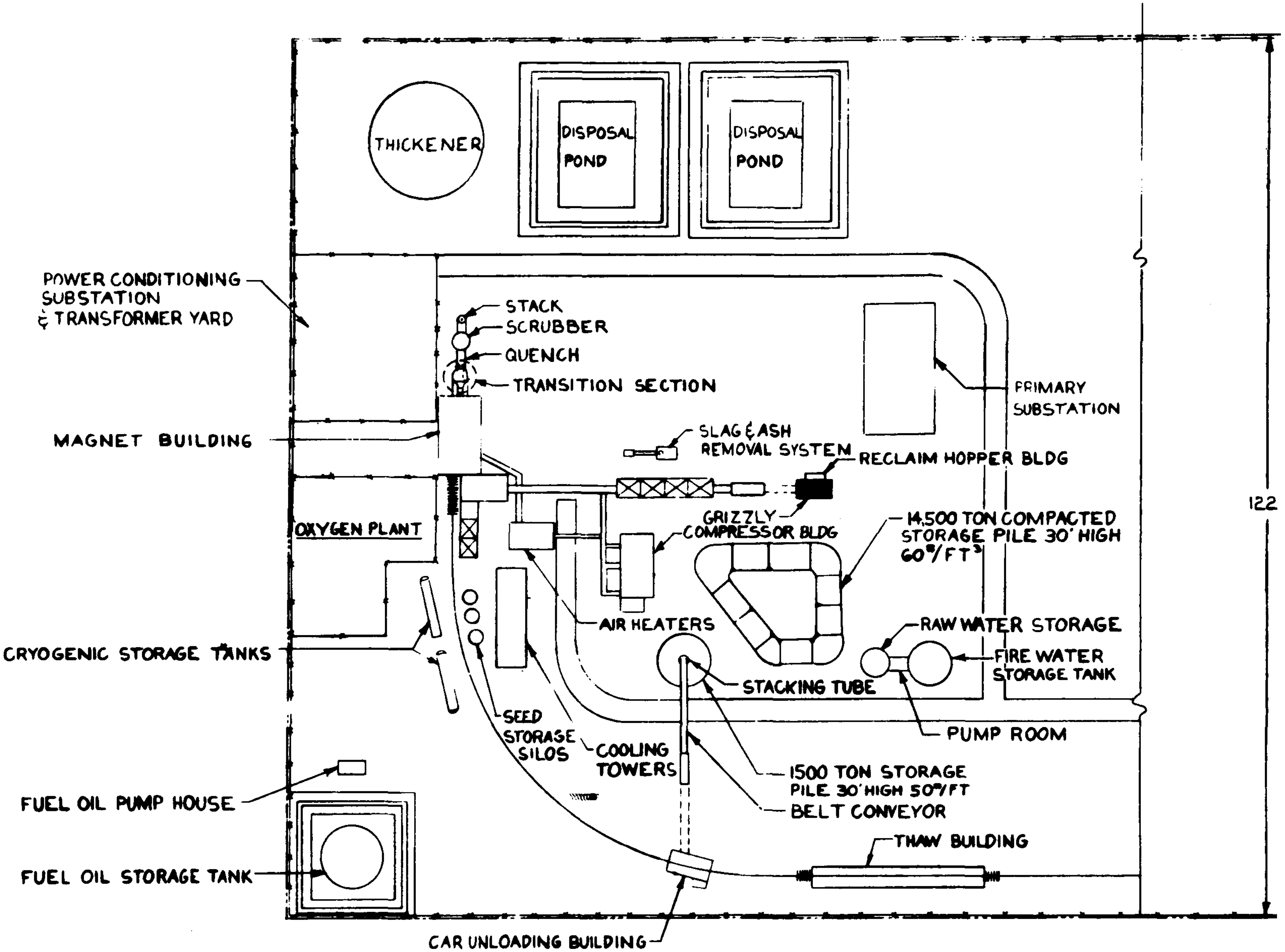


Figure 5-2. 150 MWt ETF Plant Arrangement - Configuration 1

5.2 CONFIGURATION 2

Configuration 2 is similar to Configuration 1 with the exception that the metallic air preheater is replaced by a regenerative preheater of the type used in steel mills to preheat blast furnace gas. Figure 5-3 illustrates the primary equipment arrangement.

The regenerative preheater or high temperature air heater (HTAH) has four vessels filled with thermal storage checkers. Although the capital cost of this type of heater is considerably higher than that of the metallic component, it is able to provide a substantially increased air preheater temperature and therefore reduces the oxygen enrichment required to achieve the required combustor outlet temperature. The reduced oxygen enrichment required, in turn, reduces the size of the on-site oxygen plant required, with a resulting reduction in capital and operating costs. As a result, the overall cost differential between the two arrangements is relatively insignificant. Moreover, the higher preheat temperature and reduced oxygen enrichment of the second arrangement results in gas properties in the MHD channel which are more closely representative of the final configuration and therefore preferable in an early development facility.

The high temperature regenerative air heater in its initial configuration is conservatively designed and well within the current state-of-the-art of steel plant blast heating. As such, a long life, approaching 25 years, of reliable operation would be expected under the relatively benign indirectly fired conditions contemplated during the initial phases of operation. The system is also capable of being upgraded to higher temperature and direct firing capability by the replacement of its ceramic checkers and insulation to suit the later steps of development. However, the significant expense involved in the refurbishment of the heater can be deferred until warranted by demonstrated successes in the earlier configurations.

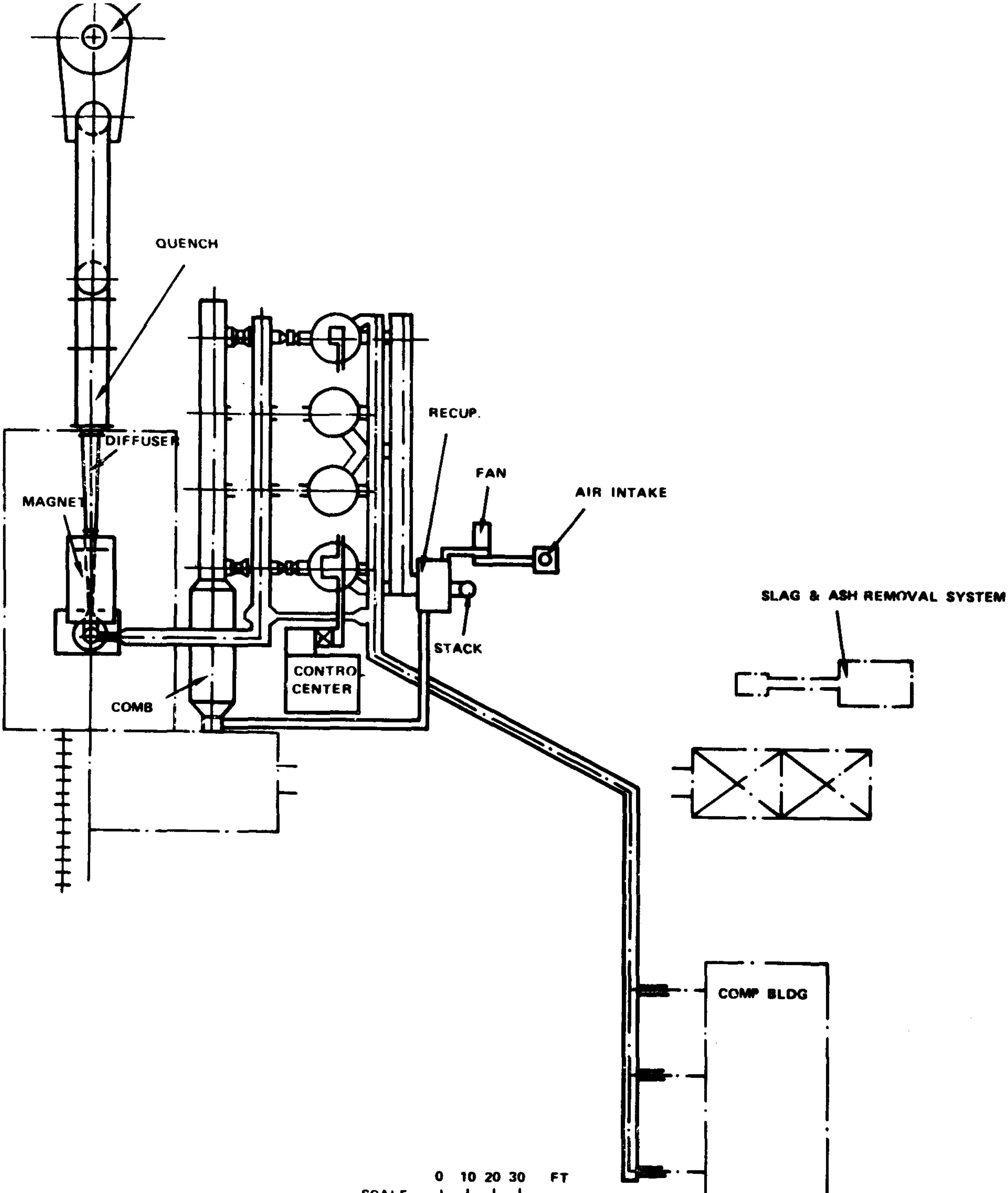


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Figure 5-3. 150 MW ETF Plant Layout - Configuration 2

5.3 CONFIGURATION 3

Configuration 3 consists of the addition of the radiant boiler and steam generators HX1 and HX2 to the previously described configuration and is illustrated in Figure 5-4.

In order to provide room for the radiant boiler, the upstream section of the quench system is disconnected from the diffuser outlet and rotated approximately 120° in azimuth about its connection with the inverted "U" shaped section. The relocated quench system is then repiped in its new location and serves the Configuration 3 plant.

The radiant boiler is then located at the diffuser outlet in the position previously occupied by the upstream section of the quench system. Refractory lined steel ducting is used to convey the hot gas from the radiant boiler outlet approximately 21 m above ground level to the HX1 steam generator. The location chosen for HX1 is conveniently near to the radiant boiler for minimizing ducting length but out of the way of subsequent development stage flow paths. A refractory lined steel elbow connects the outlet of HX1 with the inlet of HX2. The location of HX2 is chosen to be equally suitable for Configuration 3 and later stages of development. A ground rule used in planning the plant arrangements was that no dismantling and relocation of these heat exchangers should be required. A refractory lined elbow at the outlet of HX2 and a short length of refractory lined pipe convey the exhaust gases to the quench system. The plant is arranged such that direct as well as indirect firing can be easily accommodated if desired by a minor re-piping of the main gas duct.

In this system, the most critical downstream steam generating components are added to the MHD train while retaining the conservatively rated regenerative indirectly fired air heater and the highly reliable quench system. In this mode, the development effort can be concentrated on the operation of the radiant boiler, HX1 and HX2. An important part of this process will be the verification of the slag and seed deposition characteristics and the requirements

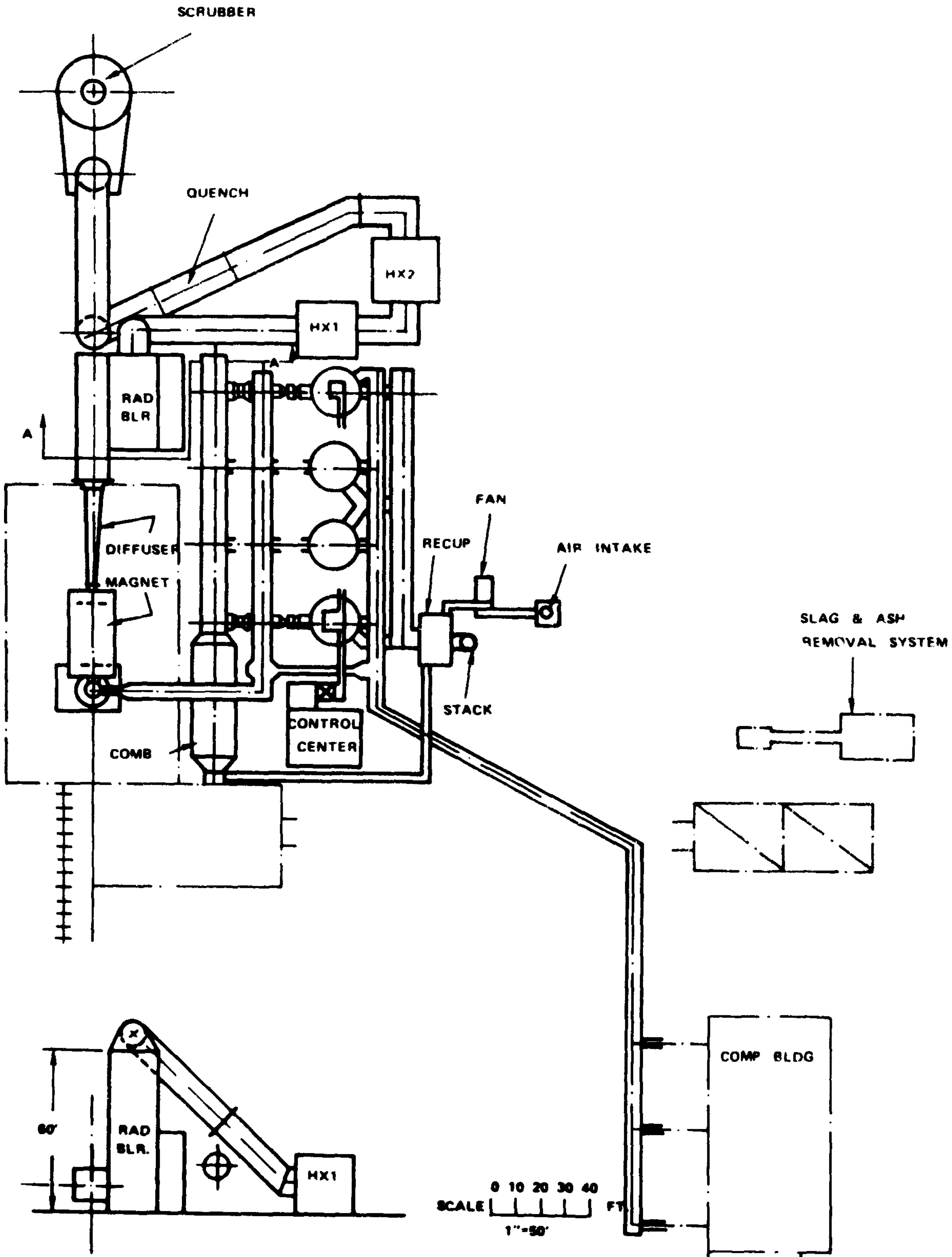

Figure 5-4. 150 MW ETF Plant Layout - Configuration 3

of the slag/seed removal and transport equipment. Since these characteristics affect the requirements of the downstream components and the seed recovery and regeneration system, which together constitute a significant cost increment, the inclusion of this intermediate development step could ultimately prove to be cost effective, in spite of its effect in delaying the approach to the final configuration. A favorable aspect of the interim step, from the standpoint of cost effectiveness, is the fact that the additional steam generator components added are also used, undisturbed, in the final indirectly fired configuration. Some reorientation of the quench system is required but most of the additional ducting components procured for the interim stage are also required in the later configurations and are thus cost effective.

Upgrading the HTAH does not appear to be warranted in this configuration. The adverse effect of higher temperature operation on reliability would be undesirable while the steam generator component are undergoing development testing.

5.4 CONFIGURATIONS 4 AND 5

Configurations 4 and 5 consist of adding the LTAH economizer, ESP and stack equipment to produce the final configuration. Configuration 4 is direct fired and Configuration 5 is indirect fired. The indirectly fired arrangement is illustrated in Figure 5-5. The directly fired arrangement is shown in Figure 5-6.

In progressing from the third to the indirectly fired fourth configuration, the refractory lined elbow downstream of HX2 is reoriented to mate with the inlet of the LTAH. The previously used quench system is then isolated from the system. The compressor outlet air is repiped to the LTAH tube side and from the LTAH to the HTAH air inlet manifold instead of directly from compressors to HTAH inlet manifold.

In changing from indirectly fired (Configuration 4) to directly fired (Configuration 5) the refractory lined steel elbow connecting HX1 and HX2 is replaced by a straight pipe connecting the inlet of HX2 with the HTAH outlet gas manifold. Also, the refractory lined pipe from the radiant boiler outlet to HX1 is reoriented and with the addition of a refractory lined elbow then supplies the HTAH inlet gas manifold. Provision must also be made for blanking the outlet gas manifold-to-recuperator and stack flow path and the air delivery line to the combustor of the HTAH.

No relocation of major pieces of equipment is required if it is desired to revert to indirect firing or to the earlier Configuration 3. All that is required is the reorientation of elbows and the substitution of some elements of the ducting system.

Upgrading of the HTAH from the state-of-the-art blast furnace technology envisaged in Configuration 2 can be effected by replacing internal checker and insulation materials by more refractory substitutes. Such changes can be made at any point in the development process. The originally supplied HTAH internals could be made to serve throughout into the Configuration 4

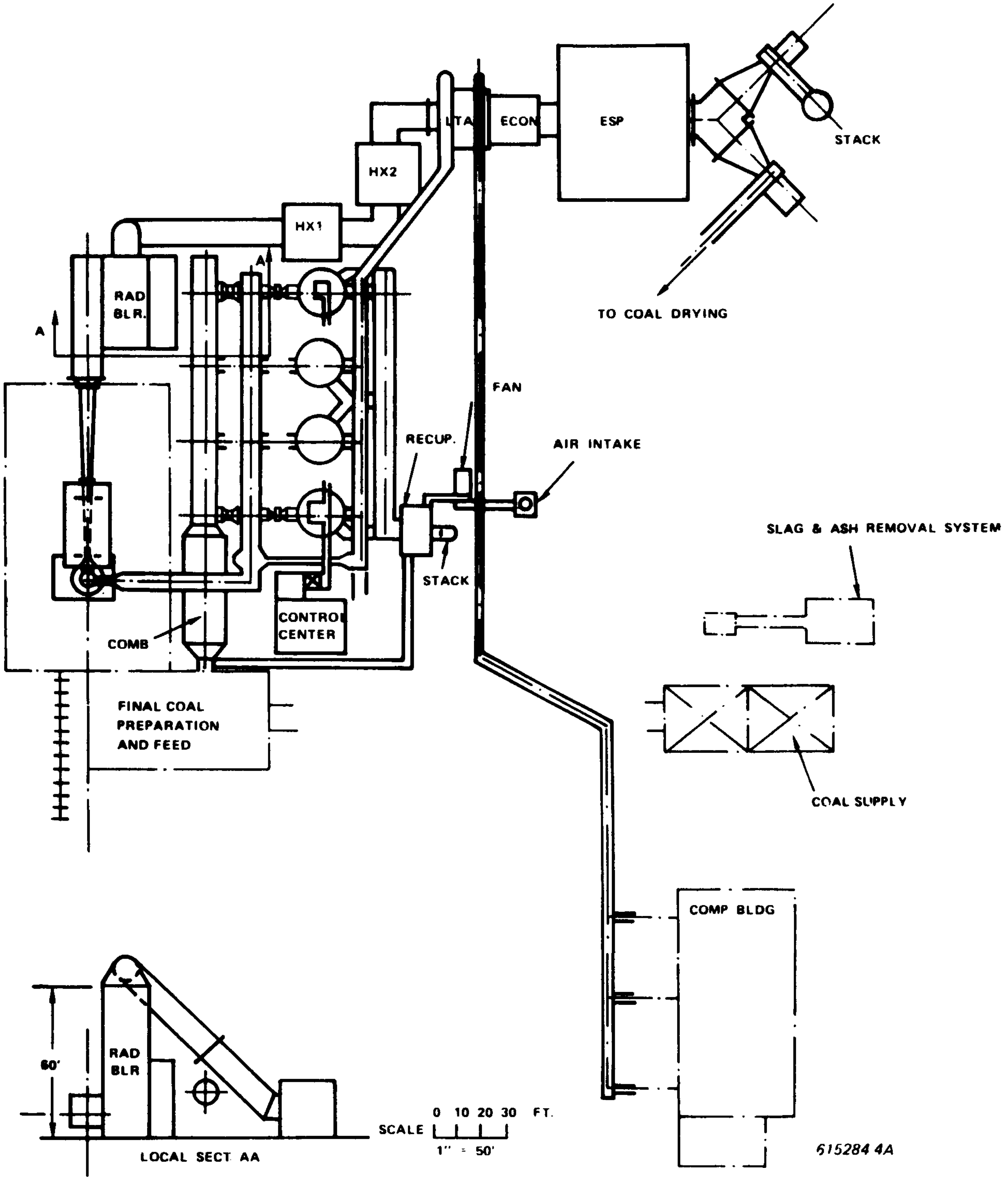

Figure 5-5. 150 MW ETF Plant Layout - Configuration 4 - Final Indirectly Fired

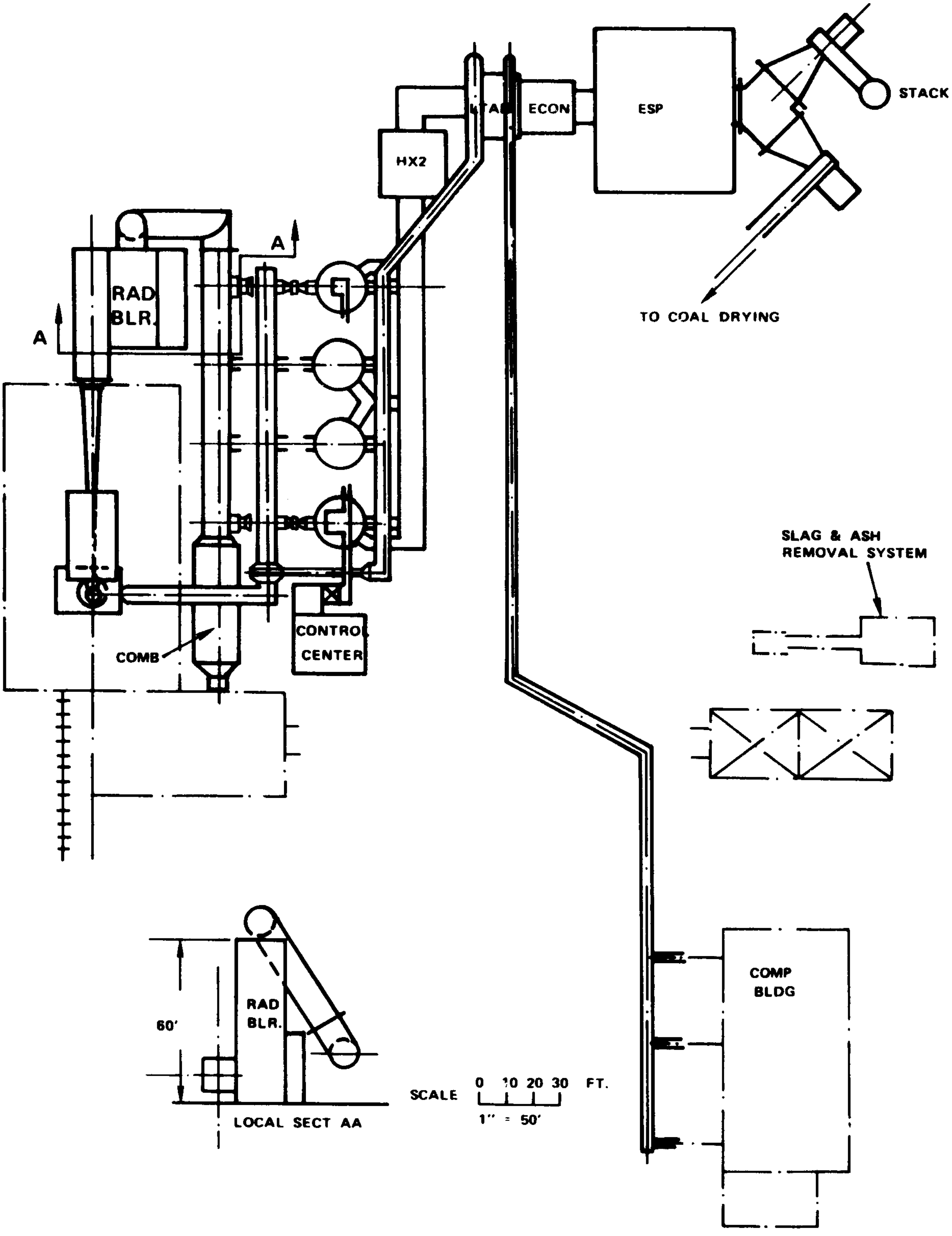

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Figure 5-6. 150 MW ETF Plant Layout - Configuration 5 - Final Direct Fired indirectly fired stage, assuming the outlet air temperature were suitably limited. Conversion to direct firing would, however, require the substitution of slag resistant refractories. As the HTAH air outlet temperature is increased, more temperature and corrosion resistant refractories are required resulting in a rapidly rising cost. At the 3000°F air temperature goal, a substantial quantity of extremely expensive zirconia refractories is expected to be required.

In the final configuration, with the provision of the downstream plant components, the operation of the auxiliary systems for seed regeneration, stack gas recirculation for coal drying and transport, etc. can be investigated. Since the system retains the flexibility to revert to an earlier development configuration at any time, difficulties encountered in the later stages are less constraining on the overall development program.

6.0 COSTING

The major emphasis of the costing effort of this study was to assess the cost impact of selecting various paths and progressive facility development concepts. Therefore, the principal effort has been in developing comparative costs and not in establishing detailed costing data. However, cost data have been assembled with some care to assure reasonable estimates and meaningful conclusions. The cost basis and approach to this assessment are developed in this section along with the comparative results.

6.1 COST BASIS

The estimated cost of equipment, materials, labor, and other associated and contingent costs have primarily been based on the work completed in the previous ETF studies.(1)(2) The estimates are organized in accordance with the modified FPC code of accounts as established by the DOE for the ETF capital cost estimates. These cost estimates include the design, procurement, fabrication and construction, installation, and other A&E costs on site. Also preliminary estimates of spare parts, operation expenses, and services are included. It should be noted however, that development costs for the critical components are not estimated or included. Costs of the critical components have been assumed consistent with prior ETF studies but are adjusted to this application.

6.1.1 TIME AND SCHEDULE BASIS

The estimated direct cost of equipment, materials and labor are based upon mid-year 1978 dollars as scaled from prior ETF studies (mid 1977 dollars) except where new vendors quotes and information have been made available. The impact of time during construction on both escalation of materials and labor costs and the interest during construction would be significant but has not been estimated since for path selection a current capital cost basis comparison is considered adequate. The additional impact of construction schedules and escalation on capital cost for the plant and operating periods would magnify the differences, but should be addressed as a separate study when more detailed plant design and schedule data are available.

6.1.2 MATERIAL AND LABOR COSTS BASIS

Material costs and labor data have been obtained from A&E experience as reported in earlier ETF studies and supporting references. Additional factors relating to the cost estimates as reported in the earlier ETF study are as follows:

- Land and Land Rights - This is not included in this study. The cost is not to be accounted against the ETF. In accordance, the cost of Account 310, Land and Land Rights, is not in the total estimate.

- Improvements to Site - The cost estimates for this account are based on the assumption that there is no significant difficulty in developing the site or expenses over and above the general grading and excavation necessary for good foundations. The cost of structures and site facilities are based on previous experience at approximately 50 percent for materials and 50 percent for installation.

- Construction Phasing and Planning - The escalation, interest during construction and development costs are highly speculative and are not included in this assessment.

- Installation Costs - These include the labor, field supervision, tools and associated expenses related to the particular piece of equipment and are itemized for each major account in the tables. Costs are proportioned per previous A&E experience. The installation cost would also include no overtime expenses, but insurance and taxes on labor are included.

- Indirect Costs - These have been estimated on the baais of 15 percent of the installed cost (materials plus installation costs) from previous A&E experience. The indirect costs consist of the following: Construction facilities, equipment and services, 10 percent, and contractors fees, 5 percent.

- Engineering Services - These have been based on a uniform percent of the material and labor costs for the A&E. Services and cost for those systems provided by the systems contractor are included in direct charges at 12%. For this study the Engineering Services of the A&E are averaged at eight percent of the total direct installation and contingency costs. This estimate includes the preliminary and final design, procurement and construction management as well as A&E fees, but does not include any basic conceptual design and development costs.

- Contingency Costs - The contingency costs on each account have been estimated on a uniform basis at three different rates. When applied to standard components readily available and fully developed, a five percent contingency has been used. A contingency of ten percent has been applied on other standard costs and those areas where some scaling of standard equipments have been required. A contingency of 20 percent has been applied to those items requiring some development costs.
- Other Owner Costs - The other owner cost have been estimated on a uniform basis at seven percent of the plant total capital cost. These include allowances for operator training, start-up costs, spare parts, excluding the major component spare parts costs, and other items common to large coal fired electrical utility plants.

Estimates of standard balance of plant equipments and subsystems have been based upon plant size, scaling from previous ETF studies and A&E experience. No effort has been made to determine specific item costs in these areas on the basis that the scaling factors are quite adequate for the lower impact that these BOP system costs have on the total system capital cost.

6.1.3 ESTIMATES OF MAJOR COMPONENT COSTS

The major component costs comprise a very large fraction of the total costs of the system. On this basis, the incorporation of those major power train equipments necessary to demonstrate the MHD power train will dominate the total cost. For the purpose of the costing study, it has been assumed that the combustor, nozzle, magnet/dewar, dc/ac inverter and control system, MHD generator and diffuser are installed in the initial step and with the exception of the MHD channel, the same components are maintained through the full path of the progressive program plan. Therefore, since costs are based on mid 1978 dollars, these major subsystems will not impact the choice of paths or progressive development other than having a major normalizing effect on the results. The cost of these major components is ~\$70M, as shown in Table 6-1. The other major components costs in the system introduced as a function of the progressive plan are the high temperature air heaters, emission and seed recovery subsystems and the radiant boiler.

TABLE 6-1

MAJOR EQUIPMENT DIRECT COST ESTIMATES*

Equipment	Cost (mid 1978 $1000
Coal Handling and Processing	3090
MHD Power Train Cooling	4250
Final Coal Proc. and Feed	8430
Combustor and Support	332
Nozzle	38
MHD Channel and Extension	1130
Diffuser	1595
Magnet System	45,200
Power Conditioning	5660
Fixed MHD Power Train Total	$69,725

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* Includes BOP and Installation.

As noted above, it has been assumed that the major components are designed for the final configuration and fitted into the facility to last throughout the sequence of progressive configuration steps. The only one of these components that would require changeout, and which the facility must be able to provide for, is the MHD generator channel. For the lower flows associated with the oxygen enhancement systems, the channels have a smaller flow cross-section, but are held to the same length and same power densities to provide as much as possible the same wall conditions for the staged development plan. The cost is assumed the same. The magnet/dewar bore is sized to accept the MHD channel in the final configuration and accommodate all the channels in the changes necessary to reach that particular configuration. The cost of each progressive path has been based upon estimates of the channel changeouts and cost of individual channels required.

Since the other major components in each path are the same, and the costs are basically the same, only the remaining progressive step equipment, operation and maintenance cost will be of significance. These have been estimated as a function of the number of configuration steps and operating time required. As noted earlier in Section 6.1.1, no adjustments have been made for any escalation or cost of monies for the different paths. Total capital cost of each path was generated by employing uniform standard procedures and rates for calculating direct and indirect costs as indicated in Section 6.1.2. The results are presented in the following section.

6.2 CAPITAL COST SUMMARY

The major objective of listing the capital costs of the progressive ETF plant was not only to assess the cost of the program, but also to obtain comparative costs of various configurations. To facilitate the visibility of the estimated cost, the modified code of accounts has been embodied in a cost account model which provides a systematic development of each account for summary and comparative purposes. This computer program includes the capacity to allocate predetermined distributions on the cost of the major items in the plant to delivered hardware, engineering, installation, etc. These distributions are developed arbitrarily but based on the type of equipment or system, and current quotes or estimates on similar type equipment. Flexibility exists for allocating the installed cost distribution, indirect cost and the contingency costs for each item in the account as well. This program therefore permits the direct comparison of a number of systems on the same costing basis and provides an expedient means to obtain a direct visible comparison of the impact of making changes of specific equipment or cost estimates. Since the program is developed to systematically handle the accounts, the impact of a change in a particular cost estimate or the cost distributions can be obtained with minimal effort.

The computer listing, assumptions, and input data that were used for the costing assessments of this study are presented in Appendix C.

A summary of the capital cost by major account is presented in Table 6-2 through Table 6-5 for Configurations 1 through 4. Configurations 5 has the same cost as Configuration 4 within the tolerances of this study. More detailed costing data according to specific account are presented in Appendix C.

6.3 OPERATION AND MAINTENANCE COST ESTIMATE

The assessment of the various paths to the final ETF configuration must include at least a cursory review of the operating and maintenance expenses to fully show the impact of the various paths. The estimate that is included here is based upon the following assumptions and ground rules:

- Operation of the ETF will be conducted in 500-hour increments for a 2000-hour per year total.
- Plant staffing will be in accordance with the schedule of personnel indicated in Table 6-6, as developed in Reference 1.
- The impact of staff buildup, escalation, and equipment change and maintenance programs is a function of the time of operation and will not be included.
- Fuel cost will be in accordance with the estimates as obtained from prior ETF referenced material. The fuel costs are associated with the coal and oil purchases, transportation, and handling as required by the operating schedule. These costs include procurement of replacements only, but not the initial plant cost estimate. The annual fuel cost shown in the table is based on Montana Rosebud coal purchased at the Western Energy Company quote of 6.5 dollars per ton plus 8.17 dollars per ton for

TABLE 6-2

150 MW ETF SUMMARY COSTS - CONFIGURATION 1

ACCOUNT NO.	DESCRIPTION	MATERIAL COST MJR. COMP.	MATERIAL COST BOP	INSTALL. COST	INDIR. COST	CONTIN.	TOTAL COST
311	STRUCTURES AND IMPROVEMENTS	258.52	3231.50	2972.98	930.67	646.50	8039.97
312	BOILER PLANT EQUIPMENT	4466.71	2644.23	6741.06	1407.79	1736.10	16995.89
314	TURBOGENERATOR UNITS	91.00	18.20	72.80	15.65	18.20	213.85
315	ACCESSORY ELECTRIC EQUIPMENT	127.28	1591.00	1463.72	458.21	318.20	3958.41
316	MISCELLANEOUS POWER PLANT EQUIP.	528.50	105.70	422.80	79.28	105.70	1241.98
317	MHD TOPPING CYCLE EQUIPMENT	59278.05	4859.25	14720.70	2936.99	15479.60	97274.59
318	RESEARCH EQUIPMENT	0.00	0.00	0.00	0.00	0.00	0.00
319	SIMULATION EQUIPMENT	0.00	0.00	0.00	0.00	0.00	0.00
350	TRANSMISSION PLANT EQUIPMENT	5816.44	705.66	1265.90	298.73	1524.60	9631.33
	SUBTOTALS	70566.50	13155.54	27679.96	6125.32	19828.70	137356.03
	ENGINEERING SERVICES *	8467.98	1052.44	2214.40		1586.50	13321.12
	OTHER COST **						9614.92
	TOTAL CONSTRUCTION COSTS ($1,000"S)	79034.48	14207.98	29694.36	6125.32	21415.00	160292.06

NOTES - (*) AT 8 PER CENT OF A AND E COSTS AND 12 PER CENT OF CONTRACTOR MAJOR EQUIPMENT COST
(**) AT 7 PER CENT OF TOTAL COSTS

ALL COSTS IN $1,000"S.
ALL COSTS 1978-1/2 DOLLARS.

TABLE 6-3

150 MW ETF SUMMARY COSTS - CONFIGURATION 2

ACCOUNT NO.	DESCRIPTION	MATERIAL COST MJR. COMP.	MATERIAL COST BOP	INSTALL. COST	INDIR. COST	CONTIN.	TOTAL COST
311	STRUCTURES AND IMPROVEMENTS	0.00	0.00	0.00	0.00	0.00	0.00
312	BOILER PLANT EQUIPMENT	0.00	0.00	0.00	0.00	0.00	0.00
314	TURBOGENERATOR UNITS	0.00	0.00	0.00	0.00	0.00	0.00
315	ACCESSORY ELECTRIC EQUIPMENT	0.00	0.00	0.00	0.00	0.00	0.00
316	MISCELLANEOUS POWER PLANT EQUIP.	0.00	0.00	0.00	0.00	0.00	0.00
317	MHD TOPPING CYCLE EQUIPMENT	5327.08	1755.30	5279.62	1055.24	2335.20	15752.44
318	RESEARCH EQUIPMENT	0.00	0.00	0.00	0.00	0.00	0.00
319	SIMULATION EQUIPMENT	0.00	0.00	0.00	0.00	0.00	0.00
350	TRANSMISSION PLANT EQUIPMENT	0.00	0.00	0.00	0.00	0.00	0.00
	SUBTOTALS	5327.08	1755.30	5279.62	1055.24	2335.20	15752.44
	ENGINEERING SERVICES *	639.25	140.42	422.37		186.82	1388.86
	OTHER COST **						1102.67
	TOTAL CONSTRUCTION COSTS ($1,000"S)	5966.33	1895.72	5701.99	1055.24	2522.02	18243.97

NOTES - (*) AT 8 PER CENT OF A AND E COSTS AND 12 PER CENT OF CONTRACTOR MAJOR EQUIPMENT COST
(**) AT 7 PER CENT OF TOTAL COSTS

ALL COSTS IN $1,000"S.
ALL COSTS 1978-1/2 DOLLARS.

TABLE 6-4

150 MW ETF SUMMARY COSTS - CONFIGURATION 3

ACCOUNT NO.	DESCRIPTION	MATERIAL COST MJR. COMP.	MATERIAL COST BOP	INSTALL. COST	INDIR. COST	CONTIN.	TOTAL COST
311	STRUCTURES AND IMPROVEMENTS	0.00	0.00	0.00	0.00	0.00	0.00
312	BOILER PLANT EQUIPMENT	3481.50	742.20	3117.30	578.93	1025.70	8945.62
314	TURBOGENERATOR UNITS	421.00	84.20	336.80	63.15	84.20	989.35
315	ACCESSORY ELECTRIC EQUIPMENT	0.00	0.00	0.00	0.00	0.00	0.00
316	MISCELLANEOUS POWER PLANT EQUIP.	0.00	0.00	0.00	0.00	0.00	0.00
317	MHD TOPPING CYCLE EQUIPMENT	822.88	702.80	731.32	215.12	324.70	2796.82
318	RESEARCH EQUIPMENT	0.00	0.00	0.00	0.00	0.00	0.00
319	SIMULATION EQUIPMENT	0.00	0.00	0.00	0.00	0.00	0.00
350	TRANSMISSION PLANT EQUIPMENT	0.00	0.00	0.00	0.00	0.00	0.00
	SUBTOTALS	4725.38	1529.20	4185.42	857.19	1434.60	12731.79
	ENGINEERING SERVICES *	567.05	122.34	334.83		114.77	1138.98
	OTHER COST **						891.23
	TOTAL CONSTRUCTION COSTS ($1,000"S)	5292.43	1651.54	4520.25	857.19	1549.37	14762.00

NOTES - (*) AT 8 PER CENT OF A AND E COSTS AND 12 PER CENT OF CONTRACTOR MAJOR EQUIPMENT COST
(**) AT 7 PER CENT OF TOTAL COSTS

ALL COSTS IN $1,000"S.
ALL COSTS 1978-1/2 DOLLARS.

TABLE 6-5

150 MW ETF SUMMARY COSTS - CONFIGURATION 4

ACCOUNT NO.	DESCRIPTION	MATERIAL COST MJR. COMP.	MATERIAL COST BOP	INSTALL. COST	INDIR. COST	CONTIN.	TOTAL COST
311.	STRUCTURES AND IMPROVEMENTS	0.00	0.00	0.00	0.00	0.00	0.00
312	BOILER PLANT EQUIPMENT	3446.38	1668.56	3642.06	796.59	875.70	10429.29
314	TURBOGENERATOR UNITS	0.00	0.00	0.00	0.00	0.00	0.00
315	ACCESSORY ELECTRIC EQUIPMENT	0.00	0.00	0.00	0.00	0.00	0.00
316	MISCELLANEOUS POWER PLANT EQUIP.	0.00	0.00	0.00	0.00	0.00	0.00
317	MHD TOPPING CYCLE EQUIPMENT	30201.25	5638.20	22865.55	4275.56	11303.00	74283.56
318	RESEARCH EQUIPMENT	0.00	0.00	0.00	0.00	0.00	0.00
319	SIMULATION EQUIPMENT	0.00	0.00	0.00	0.00	0.00	0.00
350	TRANSMISSION PLANT EQUIPMENT	0.00	0.00	0.00	0.00	0.00	0.00
	SUBTOTALS	33647.63	7306.76	26507.61	5072.16	12178.70	84712.86
	ENGINEERING SERVICES *	4037.72	584.54	2120.61		974.30	7717.16
	OTHER COST **						5929.90
	TOTAL CONSTRUCTION COSTS ($1,000"S)	37685.35	7891.30	28628.22	5072.16	13153.00	98359.92

NOTES - (*) AT 8 PER CENT OF A AND E COSTS AND 12 PER CENT OF CONTRACTOR MAJOR EQUIPMENT COST
(**) AT 7 PER CENT OF TOTAL COSTS

ALL COSTS IN $1,000"S.
ALL COSTS 1978-1/2 DOLLARS.

TABLE 6-6

ESTIMATED STAFF AND PAYROLL

<u>Facility Operation - Staffing</u>

Services provided by others (not costed)
- Contract Management
- Environmental Engineering
- Support Services

ETF Operations Additional Staffing
- Plant Operations
- Plant Engineering & Maintenance
- Test Engineering

<u>ETF Staffing Breakdown</u>

Plant Operations	
• Manager	1
• Secretary	1
• Supervisors	2
• Control Room Operators	3
• Equipment Operators	3
• Equipment Attendants	2
• Clerical & Services	14
	26
Plant Engineering & Maintenance	
• Manager	1
• Supervisors (Foreman)	4
• Engineer	11
• Draftsman	4
• Planner	1
• Craftsmen	39
- Mechanics	(8)
- Mechanics Helper	(8)
- Welder	(4)
- Machinist	(3)
- Electrician	(5)
- Electrician Helper	(5)
- Fab. & Instrum. Tech.	(6)
	60
Technical Support Group	
• Manager	1
• Supervisors	3
• Engineer	15
• Planner	1
• Computer Support	5
• Technician	6
	31
	117

Assuming 117 Staff with Average Salary $21,200/yr*	$2,480	($1000)
Fringe Benefits at 25 percent	$ 620	
TOTAL DIRECT LABOR - MID 1978	$3,100	

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*Mid 1977 Average Base Rate of $10.72/hr adjusted up by 10%

shipping adjusted from this 1977 value to mid-1978 dollars. The oil cost has been based on a Town Pump Incorporated quote of 34.75¢ per gallon. This also adjusted to the mid-1978 value. The seed cost has been based on a quote from the Diamond Shamrock Company of 17 dollars per hundred weight, plus $3.81 per hundred weight for shipping. This also has been adjusted to the mid-1978 dollar.

- Miscellaneous O&M costs includes such items as the training of staff and new personnel, requalifications, rental equipment, travel, licenses and fees, office supplies, and the upkeep and general maintenance of the operating equipment and vehicles. These charges have been assumed at a fixed percent of the non-varying O&M costs.

A summary of the estimated annual cost for the 150 MWt ETF operation and maintenance is shown in Table 6-7.

TABLE 6-7

SUMMARY OF ESTIMATED ANNUAL COSTS FOR 150 MWt ETF OPERATION AND MAINTENANCE*

ITEM	ANNUAL COST ($000)
1. Staff Payroll and Benefits	$3,100
2. Consumable Supplies and Equipment	720
3. Outside Support Services	
4. Miscellaneous	440
5. SUBTOTAL (Items 1 thru 4)	$4,260
6. General and Administrative (@15%)	640
7. Materials Make-up Purchases	---
8. Plant Liability Insurance and other Unclassified Costs	200
9. ETF ANNUAL DIRECT COSTS (Items 5 thru 8)	$5,100
10. Fuel Costs (for 2000 hours)	
- Coal	920
- Oil	800
11. Other Variables (Seed, Water, Helium, Treat. Chem.)	1,930
12. ETF ANNUAL VARIABLE COST	3,650
13. SUB-TOTAL ANNUAL COST OF OPERATION	8,750
14. Replacement of Channel and Instrumentation	1,250
15. TOTAL OPERATION ANNUAL COST (MID 1978 $)	$10,000

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* Estimate is presented prior to establishing ETF and plant operating and maintenance plans, based on 2000 hours run time at design conditions and staffing similar to that defined for ETF-2 (See Report FE2363-2)

6.4 PROGRESSIVE PATH COST EFFECTS

6.4.1 INCREMENTAL COSTS

Progressive paths 1, 2 and 3 as defined in Section 3.0 are illustrated in Figures 6-1, 6-2 and 6-3 respectively. Path 4 is simply the cost of the final configuration plus a year of test operation and is not depicted on a figure. Shown on each figure are the estimated time spans for design, procure, construct and test and the progressive build up of program costs.

Costs include an intial plant capital cost for Configuration 1 of $160,300,000, estimated from the costing presented in the accounts, Appendix C, and as shown in the Summary Table, Table 6-2. Also included is a yearly plant operating cost of $10,000,000 per year based on the estimate given in Table 6-7.

The incremental costs of components, piping, etc., added at each stage of development were estimated by scaling previously generated ETF component costs. These are itemized in Tables C-1 through C-4 of Appendix C.

It should be noted that the resulting cost estimates represent reasonably accurate present day estimates, but have been shown on the schedular charts without any allowance for inflation and escalation in the future. This omission would obviously result in gross underestimates of total projected costs with high escalation towards the end of the progressive development paths and the true impact of schedular adjustments or delays in such a condition is not visible. Nevertheless, on a comparative basis, the estimates are valid and useful in assessing the relative costs of the paths considered. An examination of this information will show a relative total program cost of 333 million, 303 million, 286 million and 280 million for Paths 1 through 4 respectively.

6.4.2 SCHEDULAR IMPACT

The schedular impact of the references paths are significant from the effects of both additional time (operation and construction costs) and type of equipment included. Even more, the schedular start date would have an effect that could wipe out the incremental cost impact if escalation rates now experienced

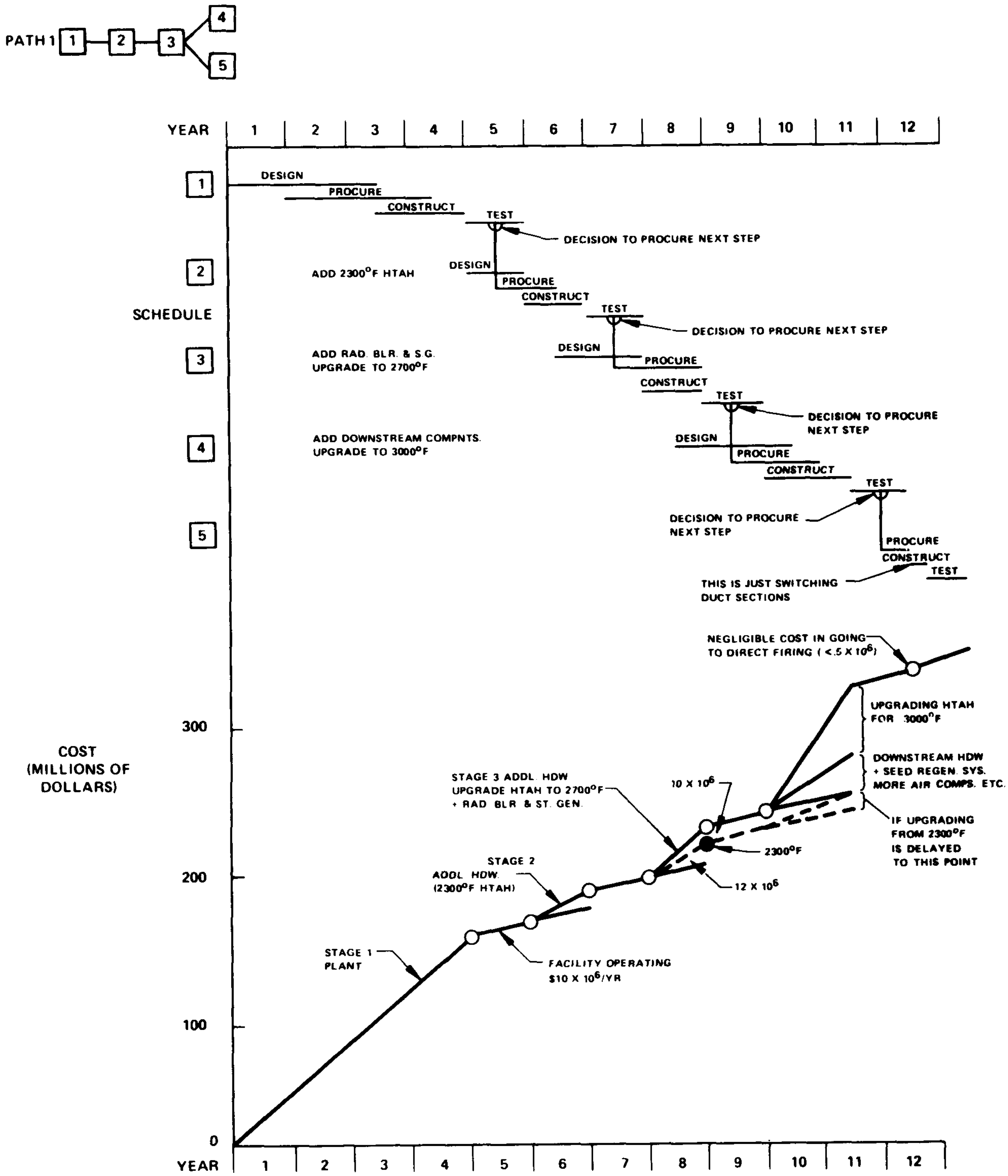

Figure 6-1. Progressive Program Path 1

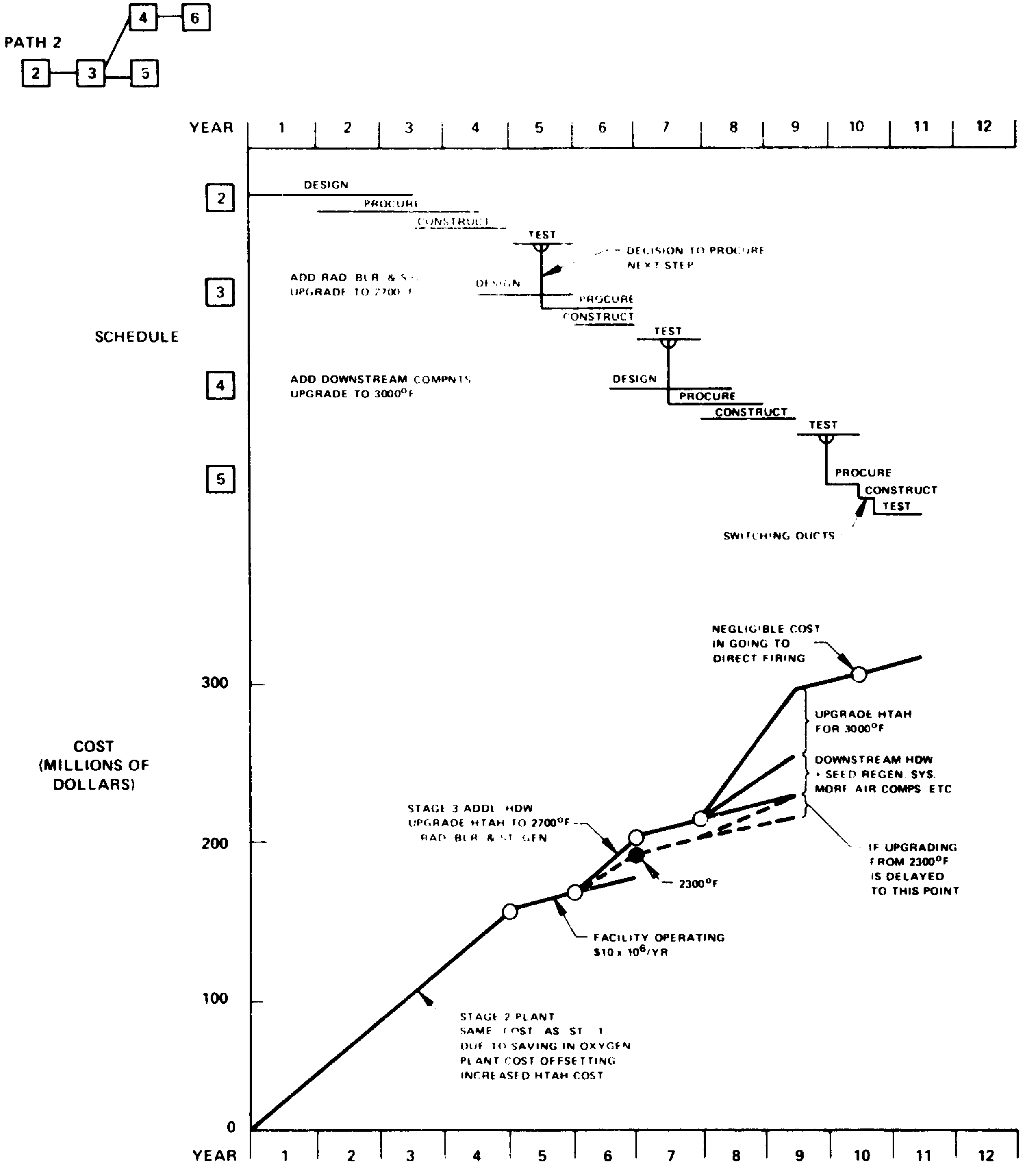

Figure 6-2. Progressive Program Path 2

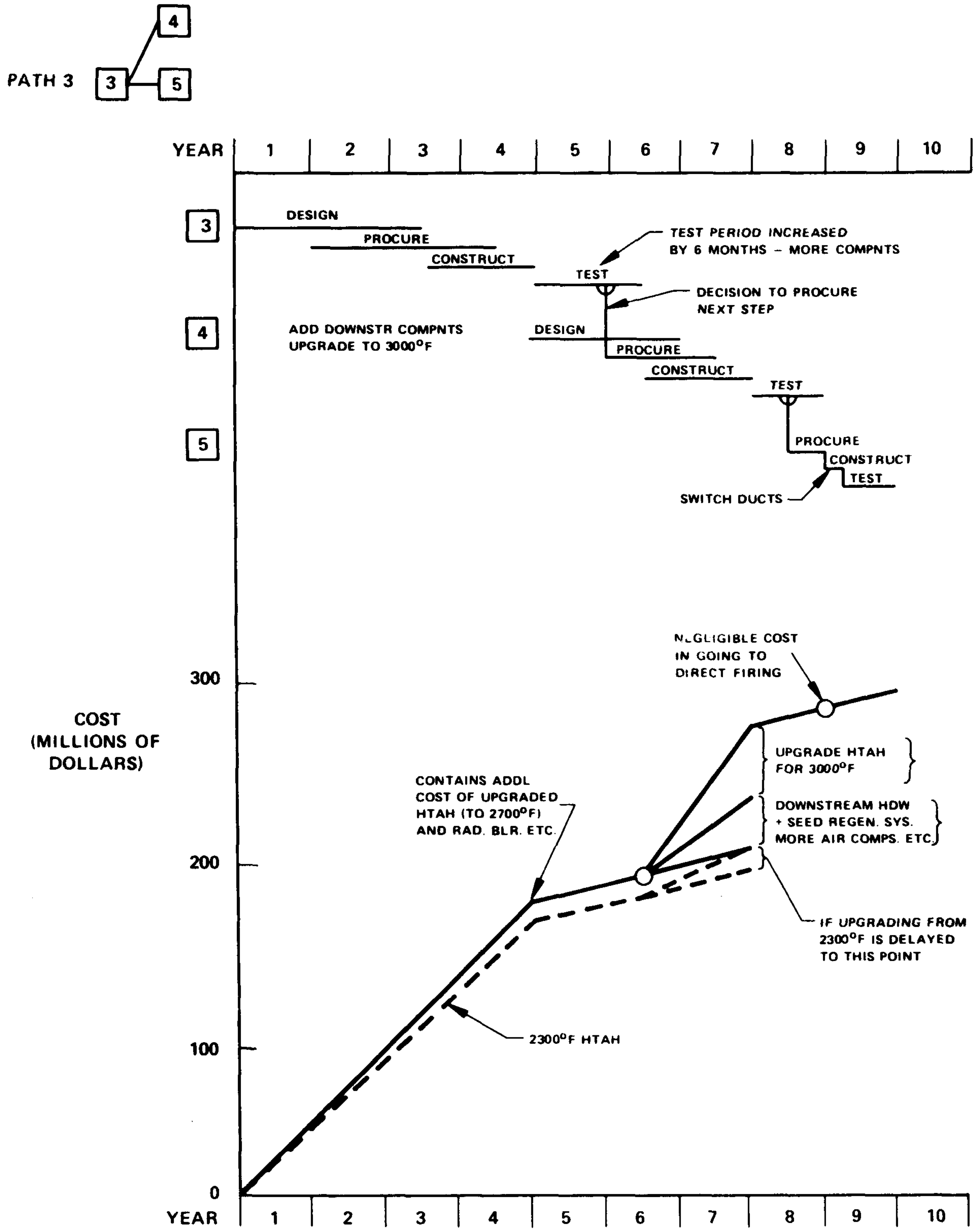

Figure 6-3. Progressive Program Path 3

were to continue. However, even without consideration or inclusion of escalation, the results show a cost advantage in reducing the schedular time and number of stages the progressive program uses. The data generated here must be interacted in a schedular manner with the planned development, and a risk/cost/benefit analysis performed in order to arrive at meaningful conclusions on the desired path. This assessment is performed in the following Sections.

7.0 PROGRESSIVE DEVELOPMENT PATH SELECTION

7.1 GENERAL CONSIDERATIONS FOR RISK ASSESSMENT

Several features and considerations have been included in the conceptual design efforts on the ETF Progressive Development Program. The more significant of these features and considerations are discussed below as a prelude to the effort on formalized risk analysis and development path selection. An understanding of these items is important to any subjective assessment.

7.1.1 OXYGEN ENRICHMENT

Significant design and operating flexibility will result from the inclusion of oxygen as a part of the system. The benefit would be found in the lower requirement on a high temperature air heater to obtain the desired temperatures and MHD performance. For the purpose of this study, a desired combustor temperature level of 2800K has been established and the amount of O_2 enrichment determined as a function of obtaining this temperature with the preheat temperatures and combustion conditions assumed. The design implications for both component and system equipment are significant. Early configurations can use a HTAH system as designed for the final configuration at "state-of-the-art" conditions thus avoiding major concerns of component life and plant availability.

This requirement of O_2 for ETF operation in any of the configurations considered is such that an on-site O_2 plant would be necessary. Consideration of trucking or transporting O_2 of the order of hundreds of tons per day, although feasible, would require a supplier to extend his own O_2 facilities. Suppliers have indicated(6) that this is not reasonable to them unless they can have a firm commitment for a large quantity of O_2 over a long period of time. The requirement of the on-site plant would result in a step-wise capital and operating cost penalty, but significant design flexibility and operating flexibility.

For purposes of this study, an on-site liquid oxygen plant utilizing the equipment and data for the earlier 150 MW ETF study is used.

7.1.2 HIGH TEMPERATURE AIR HEATER

A major consideration in the progressive 150 MW(t) ETF involves whether to use a metallic preheater and O_2 in the initial step or go to a higher temperature regenerative preheater with a lower O_2 requirement. The referenced initial base case 150 MW(t) ETF utilized an oil-fired metallic air preheater(1). This preheater provides combustion air at 1005K. Fuel economy is enchanced by recuperative preheating of the combustion air for the preheater combustor. The low air preheat temperature requires significant O_2 to obtain a 2800K combustor exit temperature.

The alternative preheater system considered uses current technology blast furnace regenerative air heaters. These regenerative heaters are similar to those designed and constructed by McKee Company. The oil-fired preheater air outlet temperatures available in current state-of-the-art stoves are in a range of 2300°F to 2700°F. Significant preheater life ($\sim$25 years) and much experience is available at 2300°F (1533K). Using this preheater system would significantly reduce the O_2 requirement. (State point calculations based upon the ETF reference design not utilizing O_2 enrichment requires a 1917K (3000°F) air preheater temperature). If this (1533K) preheater system were utilized instead of the lower temperature (1005K) metallic air heater system, approximately 23 MW additional thermal energy could be imparted to the air, reducing the oxygen requirement proportionately to 66% of the intial requirement. A comparison of the preheat temperatures, air heater equipment, relative risk, schedule, and oxygen enhancement requirements are presented in Table 7-1 for the two systems.

The conclusion as to which preheater approach is best for the ETF facility cannot be deduced from this table, however. The additional factor which must be assessed is the schedular and cost benefits which might be derived by maximizing the use of the same preheater equipment. The potential exists with the blast furnace regenerative air heater to use the same pressure vessel, ducting and valve equipment, requiring only changing the checkers for upgrading.

TABLE 7-1

COMPARISON OF OIL FIRED METALLIC AIR PREHEATER WITH OIL FIRED REGENERATIVE SYSTEM

ITEM	METALLIC PREHEATER	REGENERATIVE SYS.
Preheater Type	Oil Fired Ionic's Metallic Heater	McKee Blast Furnace Stove
Thermal Load per Module	10 MWt	23 MWt/Module(1)
Air Temperature	1350°F (1005 K)	2300°F (1533 K)
Duty	Continuous	40 min. cycled
Life	2 years	25 years
Material	St. Steel	Carbon Steel & Alumina Bricks
Dimensions		4 Units Each
Length	12.2 m	5.6 m
Width (dia.)	2.5 m	29 m
Height	1.52 m	
Service/Maint. or Replacement Allowance	(Neg. Except Replacement)	Valve seats replace ea. 2 yrs @ /yrs.
Oil Consumption	0.8 kg/s	1.68 kg/s
O_2 Enrichment Req't. for 2800 K Combustor Temp.	6.1 kg/s	3.9 kg/s
Equipment Cost ($1000)	300	6000

The potential to utilize the oil-fired regenerative air heater to 2700°F (1755K) has been proposed by McKee(7). Design modification and replacement of components to permit the extension of this capability another 200-300°F to 3000°F (1917K) has been pursued and appears reasonable assuming that the early design criteria for the system anticipates such a need.

7.1.3 CHANNEL CHANGEOUT

It is a basic assumption that channel lifetime and reliability will be major problems to be addressed in the ETF progressive development plan. Accordingly the channel is treated as an item for easy replacement. Thus the channels utilized in the facility can incorporate improvements as they are developed on the separate component development programs.

The channel is designed for rapid removal and replacement. Wiring from the channel electrodes is led, in conveniently sized groups, through non-metallic conduit to the channel outlet area where the many groups of wires are terminated in quickly separable connectors at panel boards located near the magnet dewar warm bore. The wiring is then run through non-metallic conduit containing similar groups of wires to the power conditioning plant. The connector male and female components are identified by the use of color and numerical codes to facilitate their rapid reconnection after the replacement of a channel assembly. Instrumentation wiring is handled in a similar manner using coded connectors. Coolant manifolds are equipped with quick-disconnect couplings.

As a result of such a highly organized layout of the electrical and coolant services, it is believed that it should be possible to remove and replace a channel assembly within a short period of time.

7.1.4 COMBUSTOR LIFE AND FAILURE

The combustor system in the ETF concept involves a significant amount of interfacing with other components. The concept of the ETF does not include a quick change for the combustor. Since the major mode of failure would be in the ceramic materials or specific equipments in the combustor and not the overall combustor system, the impact of the expected failure is somewhat different than that for the MHD duct. The penalty in time to replace the combustor system would well exceed that for the concept design for the MHD channel. However the cost of the combustor system does not suggest a major impact on the test system cost if this item were to fail and require replacement. The impact of any expected failure of the combustor on other items in the MHD power train can be minimized by early consideration in the design. To lessen the probability of slippage in the schedule, it is suggested that a substitute or spare combustor be made available for the ETF. The availability of a spare combustor would cost an additional half million dollars and would require downtime for replacement. However both of these effects would be minimized if the hardware were available for such a contingency.

7.1.5 SEED AND ASH RECOVERY AND CONTROL

Earlier studies(1) (2) (3) have suggested several options for seed and ash recovery and control. The approach suggested in the previous 150 MW ETF study(1) was to initially provide the seed over-the-fence and not try to recover. Costs for this approach during the initial phase of the demonstration testing would be reasonable with the low sulfur Montana Rosebud coal. With K_2CO_3 at \$0.458/kg(8) and K_2SO_4 at \$0.11/kg(9) the cost of seed for the initial testing would be \$330/hour as noted in Table 7-2. On the other hand, the cost of recovery would be significant. A recovery system sufficient to handle the final evolutionary facility seed rate would have a capital cost ~\$4.3M (mid 1978) and require ~\$600,000/year to operate. If the seed recovery system were sized at a fraction of the run usage rate and used for storage of the seed and slag slurry for processin between runs to permit higher seed rates during power runs the more expensive larger equipment cost could be reduced. For a half run rate recovery system, the cost would be reduced to ~\$2.9M, or approximately by a third, as noted in Table 7-2.

Compared to the facility cost and uncertainty, the conclusion suggested at this time would be to purchase seed for the initial two configurations and provide a fractional recovery system to demonstrate the seed recovery during the subsequent phases of the program.

TABLE 7-2

ALTERNATE SEED AND ASH RECOVERY AND CONTROL APPROACH COMPARISON

Approach	Make Up K_2SO_4 Rate kg/s	Make Up K_2CO_3 Rate kg/s	Seed Cost($)/hr	Oper. * Cost ($/yr)	Recove Sys. (
No recovery - purchase seed and disposal (initial)	0.38	0.10	330	660,000	-
(final)	0.64	0.15	520	1,040,000	-
Recovery system sized for final step	-	0.15	250	600,000	4,30
Fractional system sized for half final seed rate requirement	-	0.15	250	450,000	2,90

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*Based on 2,000 hrs. of MHD system operation, does not include disposal or handling cost.

Seed regeneration would presumeably be handled in the same way as recovery. That is to regenerate none of the seed in initial configurations and later install a fractional capacity plant.

7.2 RISK ANALYSIS

The development of any relative risk assessment at this stage of conceptual design evaluation must incorporate considerable subjective argument. Obviously the information necessary to proceed with a definitive, quantitative analysis is not available. Effort in past studies(1) (2) has defined the relative risk of some of the major components of MHD systems as found in Appendix E. Additional effort to identify the failure modes and effects in a combined open cycle MHD systems has been conducted on the earlier ETF configuration suggested by AVCO(10). The major objective of this study effort is to identify the progressive program path which provides the greatest probability of simultaneously meeting all mission objectives and the desired schedule. Although the input to the study is considerably subjective, a relative risk factor definition can and has been proposed and is utilized in the study to provide a decision tool for rating the approaches.

This section provides a definition of risk as used in this study, a discussion of the risk assessment methodology used, mission objectives as established for the risk assessment, and finally some numerical assessment of the selected development options using the assumed risk assessment relationships.

7.2.1 RISK DEFINITION

Risk may be defined as the product of the magnitude of an undesirable event and its frequency of occurrence. For a complex system such as an MHD power generation system there may exist many possible undesirable events, each having a greater or lesser consequence associated with its occurrence. The total risk associated with the existence of a system having a number of undesirable events is theoretically arrived at by performing a summation of the risks associated with each separate undesirable event.

7.2.2 RISK ASSESSMENT IN THE PROGRESSIVE DEVELOPMENT PROGRAM

To utilize the concepts noted above in assessing risks for proposed development plans for MHD engineering test facilities, it is required that the following be known:

1. A definition of what constitutes an undesirable event, and the specification of the units in which the consequences of such an undesirable event are to be measured;

2. A list of all possible undesirable events per the definition given in (1) above, their frequency of occurrence, and the consequence of each event.

For an MHD engineering test facility, as with any advanced technology system, neither all possible undesirable events nor all the consequences of known undesirable events can be anticipated. Nor can frequency of occurrence of the specified undesirable events be stated with accuracy. At best, projections of frequencies of occurrence for these events can be based on historical data for undesirable events occurring in previously developed systems or test facilities with similar configurations to the MHD engineering test facility option being assessed. However, the majority of components, subsystems, and system configurations proposed for the MHD engineering test facility progressive development program are innovative, untried concepts at this time. Therefore, the available "hard" data on frequencies of occurrence for undesirable events are severly limited in their application to the risk assessment process for an MHD combined power generation cycle.

For quantitative or semi-quantitative risk assessments of various advanced technologies, the establishment of risk levels is generally handled in terms of societal impact. That is, the units of risk are given in terms of an unacceptable societal consequence arising from the proposed application of the technology in question (e.g., deaths per unit time).

For assessment of MHD engineering test facility development option risks, the application of a risk measure reflecting societal consequences is obviously unjustified. Here, one is primarily concerned with demonstrating the technical feasibility of the MHD/steam combined cycle for electrical power production. The risks of using various proposed optional development paths should therefore reflect the ultimate consequence of failure to demonstrate feasibility by means of the progressive development program. In other words, risk is mission-related in the MHD engineering test facility progressive development program. An unaccep
able event is therefore any event which detracts from the capability of the syst
to achieve its specified mission objectives.

Risk, as defined for events occurring at a certain level in any option of the progressive development program under assessment, therefore includes both:

- The consequence of undesirable events upon the achievement of mission objectives forthe particular system configuration in which the facility is being operated when the event(s) occur, and
- The consequences of the undesirable events as related to the mission objectives at all subsequent stages of operation planned for the facility.

As an example, consider the risk associated with failures of the MHD duct itself during initial running in operation; the risk is greatly enhanced over the risk associated with the same duct failure during the end of the development program path, since a greater number of system mission objectives are voided due to the early failure, as opposed to a later failure of the duct. Here, for the purpose of this study the implicit assumption is made that the occurrence of an undesirable event results in immediate termination of facility operation and precludes the achievement of any subsequent mission objectives existing at the time of the failure.

7.2.3 RISK ASSESSMENT METHODOLOGY

It is desirable to assess the various development options numerically, in order to progress toward an objective risk assessment. Since a strictly quantitative risk assessment is precluded due to lack of data, a method of assigning objective numerical values to express comparative risk levels associated with the choice of specific development options must be provided.

Working from the definition of risk given previously in Section 7.2.1, that is

$$\text{RISK} = \left(\text{MAGNITUDE OF UNDESIRABLE EVENT}\right) \times \left(\text{FREQUENCY OF UNDESIRABLE EVENT}\right.$$

it can be seen that risk is given in units of consequences per unit time. The consequences have been defined in Section 7.2.2 as being related to the failure to achieve specified mission objectives. When operating the facility at any stage in a chosen development path within the progressive development program, it will be assumed that the occurrence of any failure invalidates not only the achievement of the objectives set for all subsequent stages of operation, but also the achievement of the objectives set for the stage at which the failure occurs. Thus, the expectation value of the magnitude of all undesirable events at a given stage can be seen to be proportional to the total number of mission objectives remaining at the beginning of operations (testing phase) at that stage, within the development path being assessed. Assigning symbols for each component in the risk definition statement.

$R = \langle C \rangle \times F$, where

$\langle C \rangle$ = Expectation value of the magnitude of all undesirable events, consequences/event,

F = Frequency of all undesirable events, event/time;

and R = Risk, consequences/time

Additionally, from the previous discussion on mission objectives,

$$\langle C \rangle \propto M$$

Where M = Number of mission objectives remaining at beginning of operation at any specified stage at which the assessment is being made.

Since some mission objectives are fulfilled at each stage of successful facility operation, the risk associated with each subsequent stage of operation changes. Also, the type and number of components within the specified stage operating system configuration varies, given the development path and stage at which operation occurs; this factor changes the numerical value of risk as well.

Some requirements which a numerical risk assessment scheme for the progressive development plan must address can be stated a priori. These are as follows:

a) A higher risk must be associated with the first-time operation of a specific systems configuration or component, as compared to its subsequent operation.

b) A higher risk must be associated with operation of a system configuration for which a greater number of mission objectives remain to be achieved, as compared to the same configuration for which a lesser number of objectives remain.

c) A higher risk must be associated with the utilization of components which cannot be considered fully developed, as opposed to proven components.

Item (b) in the list above has been addressed, since it has been stated previously that $\langle C \rangle$ (magnitude of undesirable event) is assumed proportional to the number of mission objectives remaining unfulfilled. Items (a) and (c) can be considered reasonable in light of the fact that a higher frequency of occurrence of undesirable events gives a higher risk; and that one may expect a higher frequency of undesirable events in a system using developmental components which have little actual operational time, as compared to a system which uses well-developed components, and has been operated for a lengthy period. Consideration of this fact leads to the functional relationship for any set of undesirable events occurring to a given item:

$$\begin{pmatrix}\text{FREQUENCY OF OCCURRENCE}\\ \text{OF UNDESIRABLE EVENTS}\\ \text{AT STAGE}\end{pmatrix} \propto \begin{pmatrix}\text{DEVELOPMENT}\\ \text{STATUS}\\ \text{AT STAGE}\end{pmatrix} \cdot \begin{pmatrix}\text{OPERATING}\\ \text{EXPERIENCE}\\ \text{AT STAGE}\end{pmatrix}$$

or

$F_{ij} \propto D_{ij}O_{ij}$ for the i^{th} item in stage j of a given evolutionary path

D_{ij} is assigned arbitrary numerical values, with higher values applied to the less-developed items; the same is true for O_{ij} with greater operating experience giving a lower value of O_{ij}. Hence, as the assigned values for D_{ij} and O_{ij} increase, signifying respectively a less-well developed and less experienced item, the frequency of occurrence of undesirable events F_{ij} for the item also increases.

The set of numerical values for the D_{ij}, O_{ij}, and M_i is arbitrarily assigned. For this report, the risk assessment will be done using the following numerical assignments.

D_{ij}: $D_{ij} = 5$, developmental item;

$D_{ij} = 2$, item partially developed;

$D_{ij} = 1$, item well-developed.

O_{ij}: O_{ij} = 10, no previous operating experience in facility;

O_{ij} = 2, one stage of operating experience;

O_{ij} = 1, two or more stages of operating experience.

M_j: The M_j will be integers representing the total number of mission objectives yet to be fulfilled at the beginning of testing of the facility at each stage of operation in the evolutionary path. To combine the M_i, O_{ij}, and D_{ij} in order to get the appropriate relative risk value, the following expression will be used for the j^{th} stage in evolutionary path m:

$$R_j^m = M_j^m \times \left(\sum_i D_{ij}^m \; O_{ij}^m \right),$$

where i - 1, 2. . . n signify the number of specifically considered components compromising the operating system under test in stage j of the selected path m. The mission objective multiplier M_j^m (representing the average consequence of the occurrence of all undesirable events in stage j of path m) is multiplied by the sum of the product of the development status indicator for each separately considered item i of stage j of path m and the operating experience indicator for each separately considered item (which sum of products represents the frequency of occurrence of all undesirable events in stage j of path m), in order to reflect the assumption made previously that an undesirable event occurring in any component used in a given stage precludes the subsequent achievement of the remaining objectives of the program. This assumption appears unduly harsh; however, there is currently no means of attaining a realistic projection of the consequences of individual failures upon the viability of the system and/or the concept underlying the facility. Some failures (undesirable events) can obviously be rectified easily and further system operation made possible. Other failures, which can occur as a result of as yet unforeseen difficulties, may be uncorrectable and result in the voiding of the entire MHD power generation concept. The application of such an assumption to the risk calculation will tend to penalize the development paths having a greater number of development stages. This fact should be born in mind when assessing the numerical values derived in the risk calculations.

7.2.4 MISSION OBJECTIVES FOR RELATIVE RISK ASSESSMENT

To utilize the risk assessment methodology discussed in Section 7.2.3, a listing of mission objectives for the MHD Engineering Test Facility broken down by component and development stage is required. The overall guidelines for the Progressive Development Program of the ETF are contained in Section 3.0. A major constraint for comparison of evolutionary paths of development leading to achievement of stated mission objectives is that successful ETF operation at the 150 MWt level be demonstrated by the early 1990's. This implies that operation of the facility to achieve all objectives proposed up to and including the final configuration should be planned to reach completion by FY 1989 at the latest.

The mission objectives to be considered in the risk assessment processes, rather than being derived from the general guidelines of Section 3.0 are taken from the major technical issues which must be demonstrated at each stage of development, if the viability of the combined-cycle MHD power generation process is to be demonstrated on or before the stated 1989 date. Since each stage of the evolutionary path is easily differentiated from all other stages by a simple listing of the major subsystems and components which are combined to form the MHD operating system for the stage, the mission objectives (technical objectives) to be used in the risk assessment process are listed in the following by subsystem or component (as required).

7.2.4.1 PROGRESSIVE DEVELOPMENT PROGRAM MISSION OBJECTIVES BY COMPONENT

Each component/subsystem has certain technical objectives listed, which it is hoped will be demonstrated by operation of the component or subsystem within the overall ETF configuration. These objectives are numbered in sequence for each component/subsystem in the following listings:

- MHD Generator (Channel, Nozzle, Diffuser)
    1. Demonstrate adequate thermodynamic, electrodynamic, and electrical performance.
    2. Demonstrate resistance to seed and slag effects on electrodes and sidewalls.

3. Demonstrate heat loss and cooling system performance.
4. Demonstrate structural and pressure boundary integrity.
5. Demonstrate adequate maintainability, serviceability, and reliability.
6. Demonstrate duct changeout procedures.

- Coal Combustor
  1. Demonstrate capability for production and maintenance of required plasma conditions with combustion stability.
  2. Demonstrate slag rejection capability.
  3. Demonstrate electrical isolation effectiveness.
  4. Demonstrate structural and pressure boundary integrity.
  5. Demonstrate heat losses and cooling system performance.
  6. Determine residual sulfur, NO_x, and particulate levels in plasma.
  7. Demonstrate feed systems.
  8. Demonstrate adequate maintainability, serviceability, reliability.
- Superconducting Magnet
  1. Demonstrate required field geometry and intensity.
  2. Demonstrate structural soundness.
  3. Demonstrate stability and magnet protective features.
  4. Demonstrate charging and discharging control.
  5. Demonstrate refrigeration/liquefication and vacuum system performance.
  6. Determine energy requirements for field maintenance.
  7. Determine duct changeout impact.
  8. Demonstrate adequate maintainability, serviceability,

- MHD Power Conditioning Equipment
  1. Demonstrate consolidation and inverter performance.
  2. Demonstrate high voltage and short circuit protection for channel.
  3. Demonstrate operation paralleled to ac grid (base load).
  4. Demonstrate power output to service plant hotel loads.
  5. Demonstrate acceptable reactivity control on ac gases.
  6. Determine power lead/electrode connector interface problems (duct changeout impacts).
  7. Demonstrate maintainability, serviceability, reliability.
- Component Cooling System
  1. Demonstrate adequate thermohydraulic performance.
  2. Demonstrate maintenance of water purity (conductivity control).
  3. Determine cooling line/connector interface problems on all hot gas system components.
  4. Demonstrate electrical isolation from all high-voltage equipment.
  5. Determine nominal makeup water requirements.
  6. Demonstrate adequate maintainability, serviceability, reliability.
- Hot Gas Quench System
  1. Demonstrate adequate quenching of duct exhaust gases.
  2. Scavenge seed, slag, and other impurities from duct exhaust to meet residual exhaust requirements.
  3. Provide acceptable gas dynamic exhaust characteristics for nozzle and gas/steam heat exchangers, as required.
- Cycle Air Compressors
  1. Demonstrate adequate capacity and control characteristics.
  2. Demonstrate induction motor prime mover acceptability.
  3. Demonstrate steam turbine prime mover acceptability.

4. Determine compressor power requirements.
5. Demonstrate maintainability, serviceability, reliability.

- Metallic Air Preheater - Indirect Firing Option
  1. Demonstrate 1005K preheat temperature for required air flow to combustor.
  2. Demonstrate pressure boundary integrity.

- Ceramic Air Preheater - Indirectly Fired
  1. Demonstrate clean fuel combustion system with preheat temperature for required air flow to combustor
  2. Demonstrate coal combustion system with final preheat temperature for required air flow to combustor.
  3. Demonstrate checker brick integrity at design condition operation.
  4. Demonstrate structural and pressure boundary soundness.
  5. Demonstrate vessel and ducting insulation performance; determine heat losses and leakage rates.
  6. Demonstrate high temperature air valve operation with coal fired gases.
  7. Demonstrate high temperature air valve operation at design temperatures.
  8. Demonstrate acceptable reheat/blowdown cycle performance.
  9. Demonstrate adequate temperature control of preheated air on blowdown.
  10. Demonstrate performance with LTAH at 1100K air outlet.
  11. Demonstrate reliability, maintainability, serviceability.
  12. Demonstrate slag removal and control.

- Ceramic Air Preheater - Direct Firing Option
  1. Demonstrate adequate fluid dynamic and thermodynamic performance at design preheat temperature.
  2. Determine heat losses and leakage rates.

3. Demonstrate duct and valve integrity and performance.
4. Demonstrate checker brick integrity at design conditions with coal fired, seeded exhaust gases.
5. Demonstrate freedom from undue detrimental effects from seed, slag, and ash in reheating exhaust gas streams.
6. Demonstrate performance with LTAH at 1100K air outlet.
7. Demonstrate reliability, serviceability, maintainability.

- Radiant Furnace; Heat Exchangers #1 and #2 (Heat Recover/Seed Recovery Subsystem)
    1. Demonstrate structural and pressure boundary integrity of components and connecting ducting.
    2. Demonstrate state point matching capability for proposed operational modes at all stages of development program.
    3. Demonstrate required thermodynamic performance; determine heat losses.
    4. Demonstrate seed and slag removal capabilities.
    5. Demonstrate steam raising and steam parameter control characteristics.
    6. Demonstrate adequate protection of heat transfer surfaces from hot gas and corrosive constituents.
    7. Demonstrate impurity burnout and NO_x control in exhaust gases.
    8. Demonstrate maintainability, reliability, serviceability.

- Feedwater, Condensate, Steam Systems
    1. Demonstrate required thermohydraulic performance of systems.
    2. Demonstrate boiler feedwater supply and recirculation control.
    3. Determine nominal makeup water requirements.
    4. Demonstrate heat recovery capability by steam generation.
    5. Provide power for steam turbine prime mover of cycle air compressor; demonstrate adequate control characteristics of turbine.

6. Demonstrate capability for feedwater purity control.

7. Demonstrate economizer performance and state point matching when used with LTAH and precipitator in exhaust duct.

8. Demonstrate system maintainability, serviceability, reliability.

- Seed Feeding System

  1. Demonstrate injection system performance and control characteristics.
  2. Determine optimum seed injection mixture and seed requirements.
  3. Demonstrate seed recovery in radiant furnace.
  4. Demonstrate seed recovery in electrostatic precipitator.
  5. Demonstrate sulfur control by use of seed.
  6. Demonstrate electrical isolation provision adequacy from combustor.
  7. Demonstrate maintainability, serviceability, reliability.

- Coal Handling, Processing, and Feeding

  1. Demonstrate adequacy of coal preparation and transport system.
  2. Determine coal drying requirements for various coal feedstocks.
  3. Demonstrate coal injection system performance and control characteristics.
  4. Demonstrate adequacy of electrical isolation provisions from combustor.
  5. Determine system power requirements.
  6. Demonstrate maintainability, serviceability, reliability.

- Oxygen Plant

  1. Demonstrate oxygen production capability and purity control.
  2. Demonstrate delivery and control adequacy to provide required combustor outlet plasma conditions at all air preheater temperatures.
  3. Demonstrate adequate maintainability, serviceability, reliability.

- Electrostatic Precipitator
    1. Determine power requirements.
    2. Demonstrate adequate particulate removal performance.
    3. Demonstrate maintainability, serviceability, reliability.
- Heat Rejection System
    1. Demonstrate heat rejection capability of cooling towers.
    2. Determine final stack conditions with Rankine Cycle heat recovery system in operation.
    3. Demonstrate adequate control of furnace draft.
    4. Support quenching system heat removal by cooling pond heat rejection.
    5. Determine nominal makeup water requirements.
    6. Determine system power requirements.
    7. Demonstrate maintainability, serviceability, reliability.

7.2.4.2 DEMONSTRATION OF MISSION OBJECTIVES BY CONFIGURATION

Each configuration in the Progressive Development Program makes use of a certain arrangement of the major components in order to obtain an operational MHD system; each component utilized is then required to demonstrate certain of the mission objectives assigned to it and listed in Section 7.2.4.1, in order to allow the program to be advanced to the next succeeding development stage. The configurations proposed for the ETF Progressive Development Program have been previously discussed in Section 3.0, 4.0 and 5.0 where the operating systems are described in terms of major components, subsystems, and process parameters.

The general risk assessment process requires a knowledge of mission objectives broken down by configuration. Since various optional paths beginning at differing configurations have been proposed, it is clear that certain mission objectives for a given component may be achieved at different configurations alon
different development paths. Thus, it is important to define the set of

optional development paths which are to be addressed by the analyst, in order to specify the mission objective requirements for each configuration within each path.

Three potential development paths for the facility to meet the operations schedule by (FY 1989) were defined in Section 3.0. These paths are as follows:

- Development Path 1 - Begin with Configuration 1, proceed through Configurations 2 and 3 to 4. Configuration 5 may be achieved after the 1989 end date. As outlined previously Configuration 4 could be bypassed. However, for this study it was assumed that the indirect fired case would be the final case prior to commercial application.
- Development Path 2 - Bypasses Configuration 1 altogether, by introducing both the minimal MHD power train equipment and regenerative air preheating in the initial operating systems configuration. Proceeds thereafter through Configuration 3 to Configuration 4. Configuration 5 may be added subsequently.
- Development Path 3 - This eliminates testing in both Configurations 1 and 2, introducing simultaneously the MHD power train, regenerative preheating, and steam bottoming plant components into the initial operating sytems configuration. Configuration 4 is achieved thereafter, with Configuration 5 being an available point for further development.

One additional path may be considered, although it cannot truly be called a development path - this path is one in which the ETF is initialy constructed to Configuration 4 specifications, with an option for achieving Configuration 5 in subsequent development. This path will be denoted as Development Path 4. Table 7-3 through 7-6 contain listings, by component and sequential number, of the specific objectives which are expected to be achieved at each configuration in each of the four development paths proposed above. This data were used in the risk comparison of Section 7.2.5 which follows:

7.2.5 RISK ASSESSMENT OF DEVELOPMENT LOGICS

Utilizing the four distinct development paths discussed previously, and observing the schedular constraint that the acceptable development program must provide for completion of all mission objectives through Configuration 4 by FY 1989, one may define certain development logics representing extremes with regard to schedule and risk. These logics are proposed and evaluated in this subsection.

TABLE 7-3

MHD-ETF
PROGRESSIVE DEVELOPMENT PLAN
MISSION OBJECTIVES DEMONSTRATED BY CONFIGURATION

DEVELOPMENT PATH 1

COMPONENT OR SUBSYSTEM	CONFIG. 1	CONFIG. 2	CONFIG. 3	CONFIG. 4	CONFIG. 5
MHD Generator	3,4			1, 2, 5, 6	
Coal Combustor	2, 3, 4, 5			1, 6, 7, 8	
Superconducting Magnet	1, 2, 3, 4, 5, 6			7, 8	
MHD Power Conditioning	1, 2, 3, 4 5			6, 7	
Component Cooling	1, 2, 4			3, 5, 6	
Hot Gas Quench	1, 2		3	3	
Cycle Air Compressors	1, 2		3, 4	5	
Metallic Air Preheater	1, 2				
Ceramic Air Preheater (Indirect Firing)		6, 7, 8, 11	2, 4, 9, 13	3, 5, 10, 14, 15	
Ceramic Air Preheater (Direct Firing)					1, 2, 3, 4, 5, 6, 7
Radiant Furnace, HX 1/2			1, 4, 5, 7	2, 3, 6	
Feedwater, Condensate, and Steam			2, 4, 5, 6	1, 3, 7, 8	
Seed Feeding	1, 2, 5, 6		3	4, 7	
Coal Handling Processing and Feeding	1, 3, 4, 5			2, 6	
Oxygen Plant	1		2, 3		
Electrostatic Precipitator			1, 2, 3		
Heat Rejection System	4, 6			1, 2, 3, 5, 7	

TABLE 7-4

MHD-ETF
PROGRESSIVE DEVELOPMENT PLAN
MISSION OBJECTIVES DEMONSTRATED BY CONFIGURATION

DEVELOPMENT PATH 2

COMPONENT OR SUBSYSTEM	CONFIG. 1	CONFIG. 2	CONFIG. 3	CONFIG. 4	CONFIG. 5
MHD Generator		3, 4		1, 2, 5, 6	
Coal Combustor		2, 3, 4, 5		1, 6, 7, 8	
Superconducting Magnet		1, 2, 3, 4, 5, 6		7, 8	
MHD Power Conditioning		1, 2, 3, 4, 5		6, 7	
Component Cooling		1, 2, 4		3, 5, 6	
Hot Gas Quench		1, 2	3		
Cycle Air Preheater		1, 6, 7, 8, 11, 12	2, 4, 9, 13	3, 5, 10, 14, 15	
Metallic Air Preheater					
Ceramic Air Preheater (Indirect Firing)		1, 6, 7, 8 11, 12	2, 4, 9, 13	3, 5, 10, 14 15	
Ceramic Air Preheater (Direct Firing)					1, 2, 3, 4, 5, 6, 7
Radiant Furnace HX 1/2			1, 4, 5, 7	2, 3, 6	
Feedwater, Condensate and Steam			2, 4, 5, 6	1, 3, 7, 8	
Seed Feeding		1, 2, 5, 6	3	4, 7	
Coal Handling, Processing and Feeding		1, 3, 4, 5		2, 6	
Oxygen Plant		1	2, 3		
Electrostatic Precipitator				1, 2, 3	
Heat Rejection System		4, 6		1, 2, 3, 5, 7	

TABLE 7-5

MHD-ETF
PROGRESSIVE DEVELOPMENT PLAN
MISSION OBJECTIVES DEMONSTRATED BY CONFIGURATION

DEVELOPMENT PATH 3

COMPONENT OR SUBSYSTEM	CONFIG. 1	CONFIG. 2	CONFIG. 3	CONFIG. 4	CONFIG. 5
MHD Generator			3, 4	1, 2, 5, 6	
Coal Combustor			2, 3, 4, 5	1, 6, 7, 8	
Superconducting Magnet			1, 2, 3, 4, 5, 6	7, 8	
MHD Power Conditioning			1, 2, 3, 4, 5	6, 7	
Component Cooling			1, 2, 4	3, 5, 6	
Hot Gas Quench			1, 2, 3		
Cycle Air Compressors			1, 2, 3, 4	5	
Ceramic Air Preheater (Indirect Firing)			(2, 4, 6, 7, 9 11, 12, 13)** (1,6,7,8,11, 12)*	(3, 5, 10, 14, 15)*** (2,4,9,13,15)**	
Ceramic Air Preheater (Direct Firing)					1, 2, 3, 4, 5, 6
Radiant Furnace, HX 1/2			1, 4, 5, 7	2, 3, 6	
Feedwater, Condensate and Steam			2, 4, 5, 6	1, 3, 7, 8	
Seed Feeding			1, 2, 3, 5, 6	4, 7	
Coal Handling, Processing and Feeding			1, 3, 4, 5	2, 6	
Oxygen Plant			1, 2, 3		
Electrostatic Precipitator				1, 2, 3	
Heat Rejection System			4, 6	1, 2, 3, 5, 7	

* Uses current blast furnace stove technology for 1533 K preheat.

**Upgraded refractory for 1755 K preheat.

***High Zirconia refractory for 1917 K preheat.

TABLE 7-6

MHD-ETF
PROGRESSIVE DEVELOPMENT PLAN
MISSION OBJECTIVES DEMONSTRATED BY CONFIGURATION

DEVELOPMENT PATH 4

COMPONENT OR SUBSYSTEM	CONFIG. 1	CONFIG. 2	CONFIG. 3	CONFIG. 4	CONFIG. 5
MHD Generator				1, 2, 3, 4 5, 6	
Coal Combustor				1, 2, 3, 4, 5, 6, 7, 8	
Superconducting Magnet				1, 2, 3, 4, 5, 6, 7, 8	
MHD Power Conditioning				1, 2, 3, 4, 5, 6, 7	
Component Cooling				1, 2, 3, 4, 5, 6	
Hot Gas Quench				1, 2, 3, 4, 5	
Cycle Air Compressors				(2, 4, 5, 7, 9, 11, 12, 13, 15)**	
Low Temp. Air Preheater					
Ceramic Air Preheater (Indirect Firing)				(3, 5,6, 7, 10, 11, 12, 14, 15)***	
Ceramic Air Preheater (Direct Firing)				1, 2, 3, 4, 5, 6, 7	
Radiant Furnace, HX 1/2				1, 2, 3, 4, 5, 6, 7, 8	
Feedwater, Condensate, and Steam				1, 2, 3, 4, 5, 6, 7, 8	
Seed Feeding				1, 2, 3, 4, 5, 6, 7	
Coal Handling, Process-and Feeding				1, 2, 3, 4, 5, 6	

**Upgraded refractory for 1755 K preheat.

*** High Zirconia refractory for 1917 K preheat.

7.2.5.1 SELECTION OF VIABLE DEVELOPMENT LOGICS

Acceptable development logics for the Progressive Development Program are clearly constrained by the requirement that whatever the path considered, it must provide for the achievement of all of the stated mission objectives through Configuration 4 by FY 1989 MHD window closure date. Each separate development path proposed has associated with it a schedule (development elapsed time) based upon reasonable assumptions as to the length of time required to design, procure, construct, and test the operating system configuration at each level within the path, and the coordination of testing at any stage with the design, procurement, and construction schedules for the succeeding stage of the facility as it evolves. The schedules for development elapsed times for Paths 1, 2, and 3 are discussed and defined in Section 6.4.1. The schedule for "Path 4" (i.e., building the facility immediately-to Configuration 4) is assumed to be similar to the Title I, II and III schedular proposals for the Engineering Test Facility in the current DOE MHD Development Logic.

As a means of applying the proposed risk assessment technique several development logics using the four development paths and their attendant schedules were postulated. A listing of these development logics is as follows:

- Path 1 with an immediate program start (Designated 1a)
- Path 1 with the program start constrained by the heat and seed recovery and magnet development program (Designated 1b)
- Path 2 with an immediate program start (Designated 2a)
- Path 2 with the program start initiated at a time to assure final configuration testing in 1989 (Designated 2b)
- Path 3 with an immediate program start and a final indirect fired preheater goal of 1755°K (Designated 3a)
- Path 3 with the program start constrained by the heat and seed recovery and magnet development program (Designated 3b)
- Path 3 with an immediate program start and a final indirect fired preheater goal of 1917°K (Designated 3c)
- Path 4 with an immediate program start (Designated 4a)
- Path 4 with the program start constrained by the heat and seed recovery and magnet development program (Designated 4b)

Development logic schedules have been graphically displayed in Figures 7-1 through 7-8, along with the development schedules for the Advanced MHD Power Train, Superconducting Magnet, and Heat Recovery/Seed Recovery systems which are currently being proposed by DOE in their MHD Program Development Logic. On the basis of the groundrule that the final configuration shall be demonstrated in 1989 it can be found by examination of the figures that the only viable logics are 2a, 2b, 3a, 3c, 4a, and 4b. Comparison of the schedule dates for the design phase at each configuration in each viable development option with the scheduled dates for independent major component development shown at the bottom of each applicable figure allows the determination of the appropriate value for the development status multiplier D_{ij} in the risk calculation expression (Section 7.2.3). If a component intended for use in a given state of the Progressive Development Program must be designed prior to the scheduled completion of its independent development program, as indicated by the limits noted on the figures, the component will be given a development status multiplier value of 5 for the risk assessment. If the component can be designed with input from the independent development program, the multiplier value is 2. After operation at two successive levels within a development option of the Progressive Development Program, the indicator value assigned reduces to 1. This procedure reflects the value of prior development of a component separately from the specific system in which it must operate, but also admits that complete development of components is not possible external to the specific operating system for which they are intended.

Where major components are not explicitly noted as having independent development programs on the appropriate figure, their development status multipliers are derived by means of the following procedure. Each component has previously been assigned a development status code letter (A, B, C, D) in the Westinghouse MHD ETF Conceptual Design Study(11). Using the code letter appropriate for the components as listed in that document, the value $D_{ij} = 2$ is given to components with C or D codes; $D_{ij} = 2$ is given to components with A or B codes. After two successive levels of operation in the Progressive Development Program, $D_{ij} = 1$ for all components.

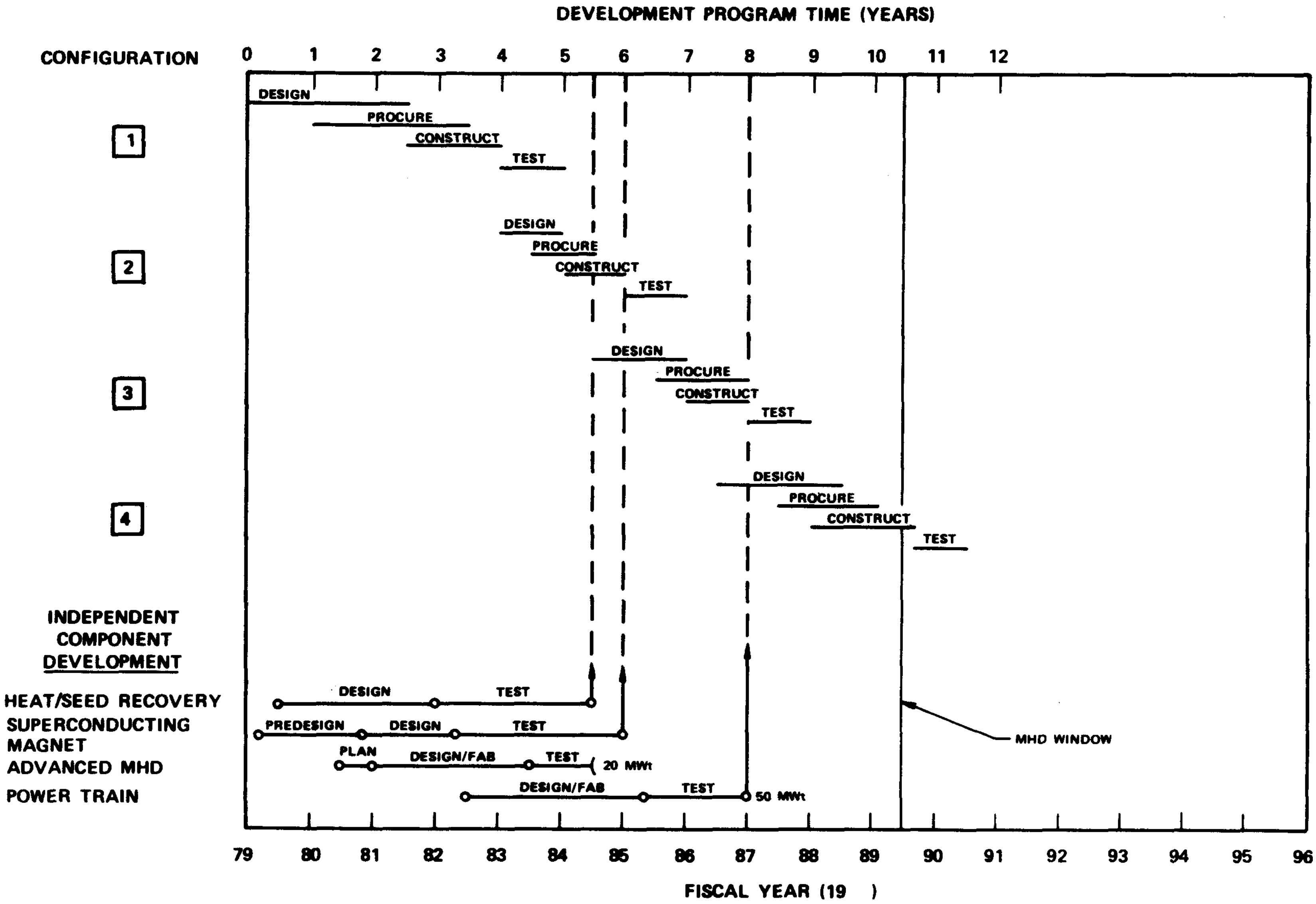

Figure 7-1. Development Logic 1a

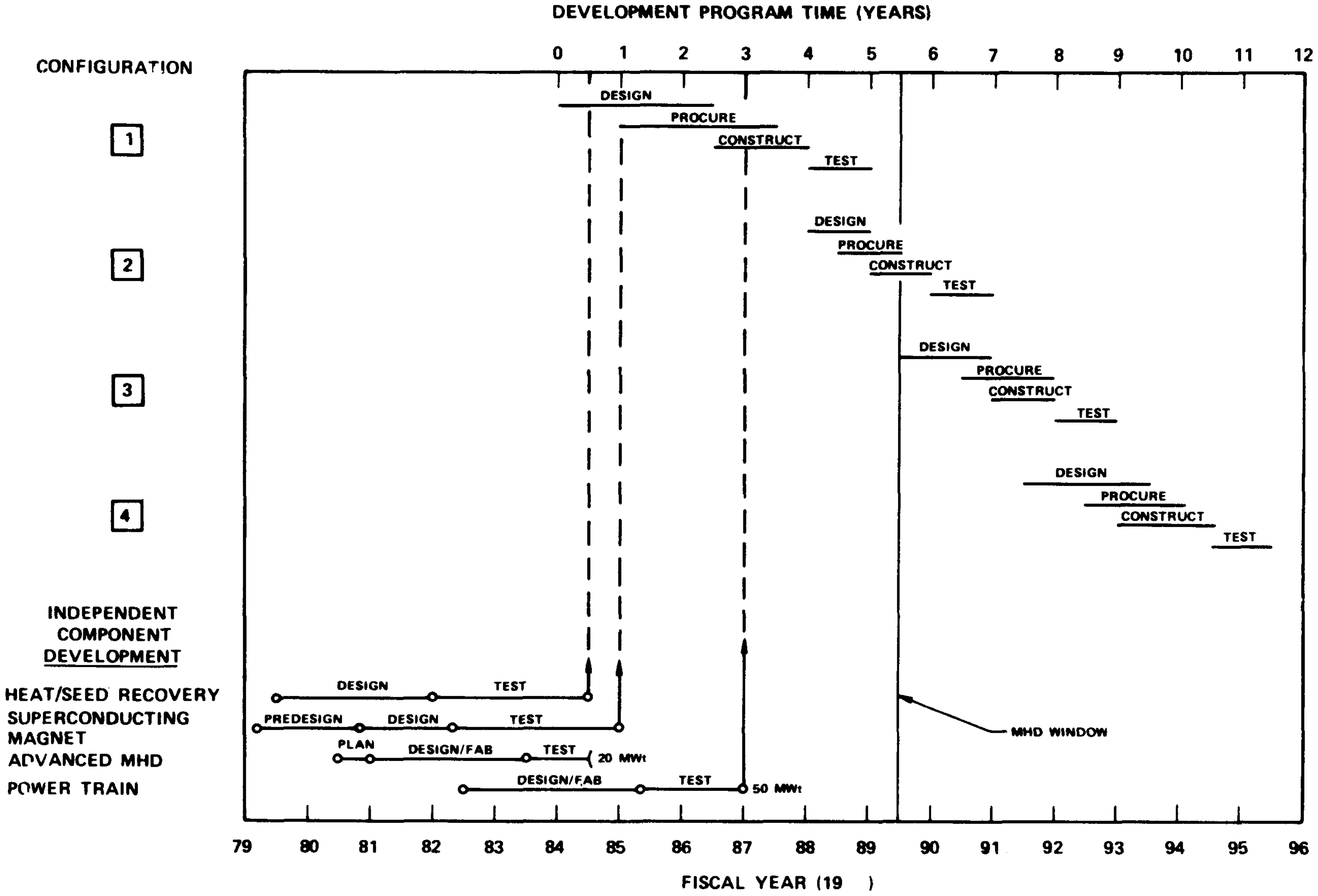

Figure 7-2. Development Logic 1b

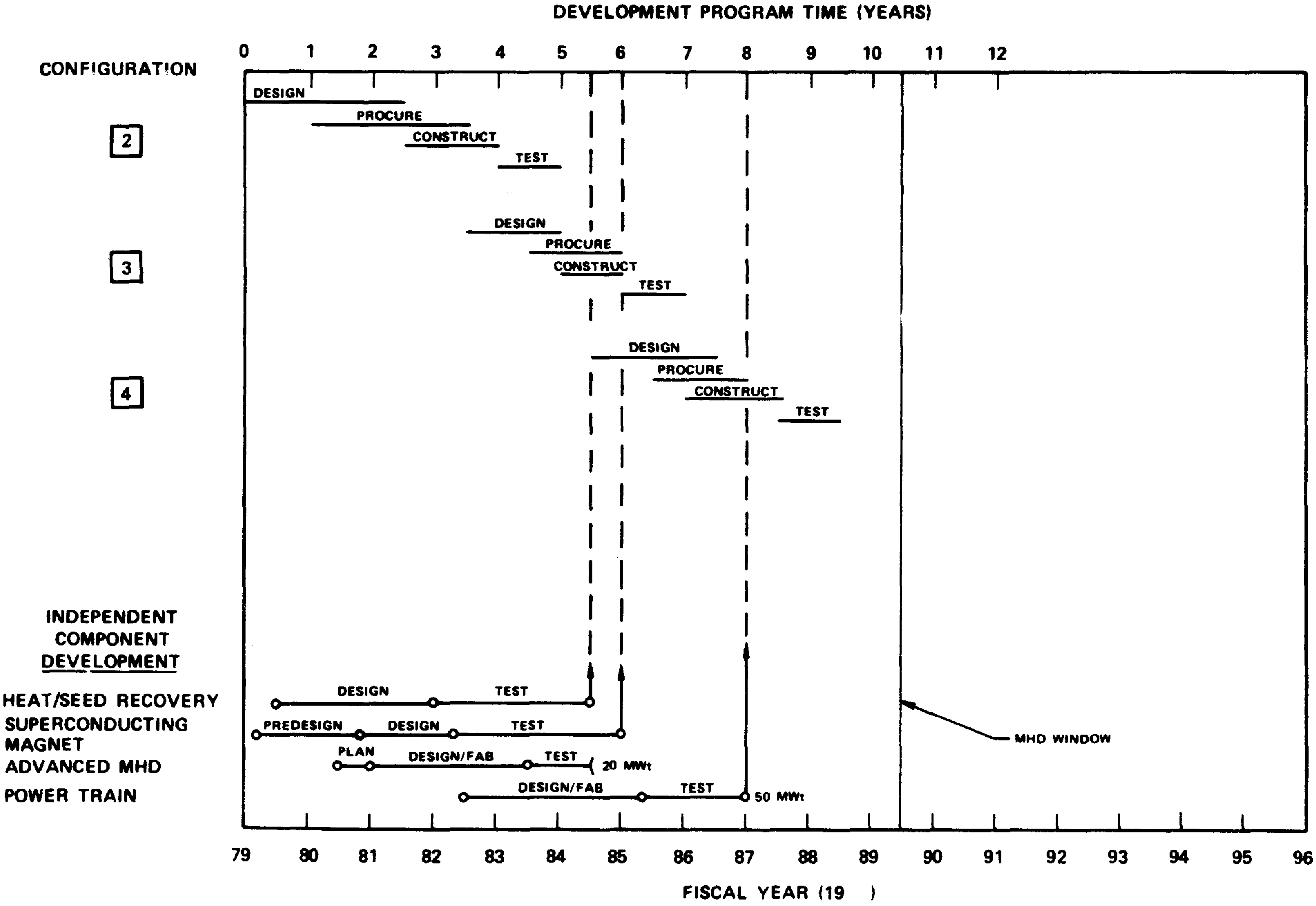

Figure 7-3. Development Logic 2a

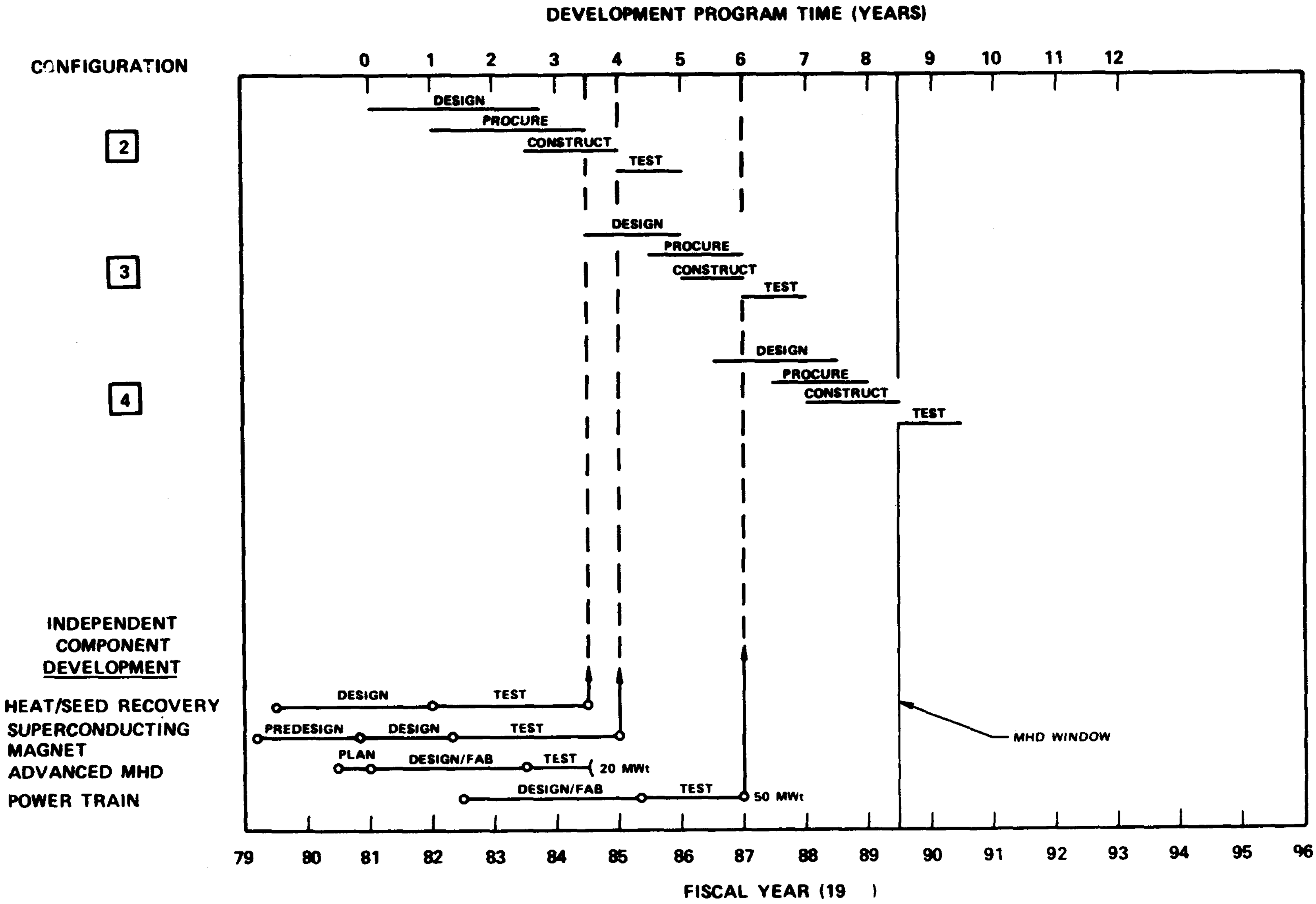

Figure 7-4. Development Logic 2b

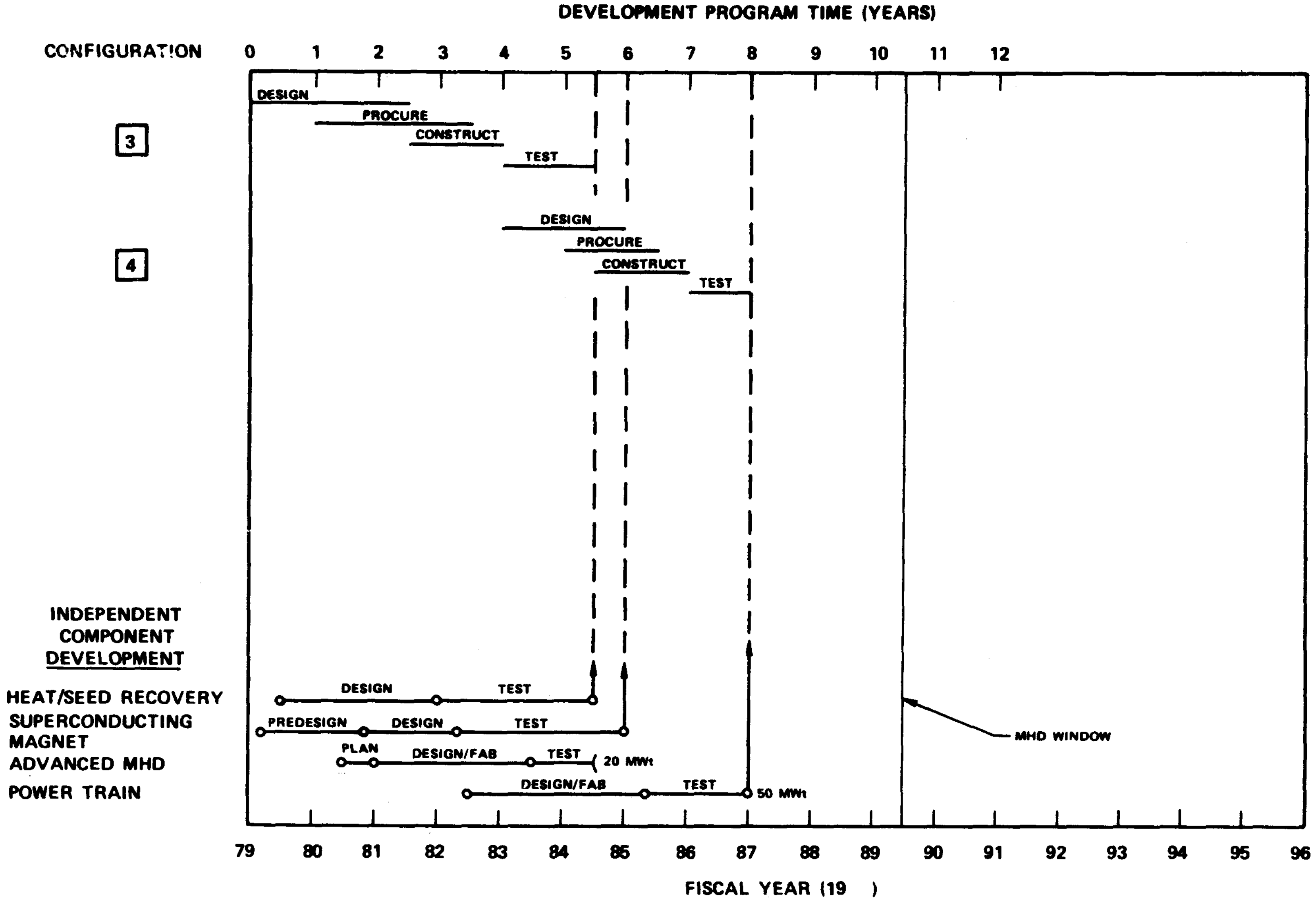

Figure 7-5. Development Logic 3a and 3c

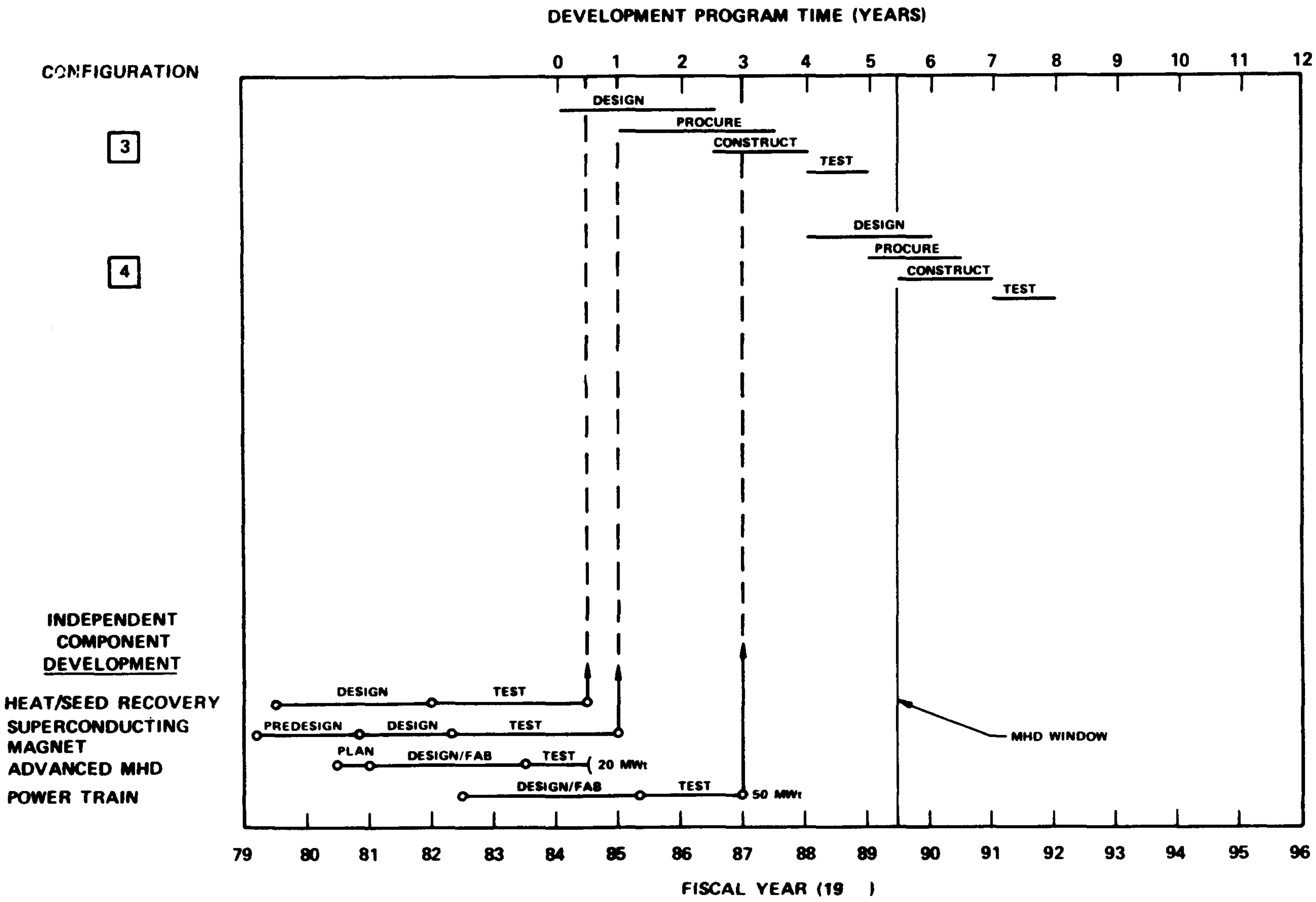

Figure 7-6 Development Logic 3b

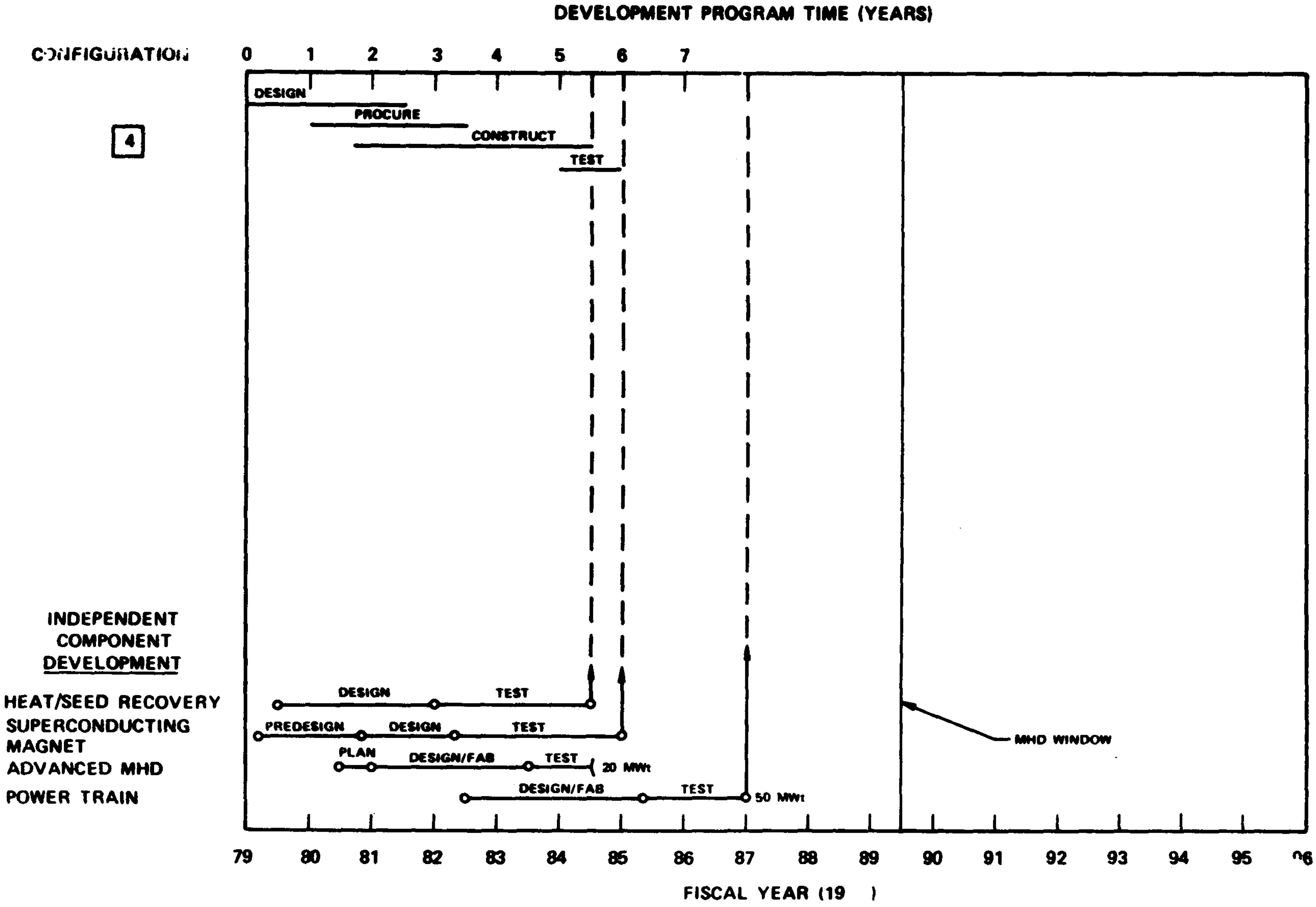

Figure 7-7. Development Logic 4a

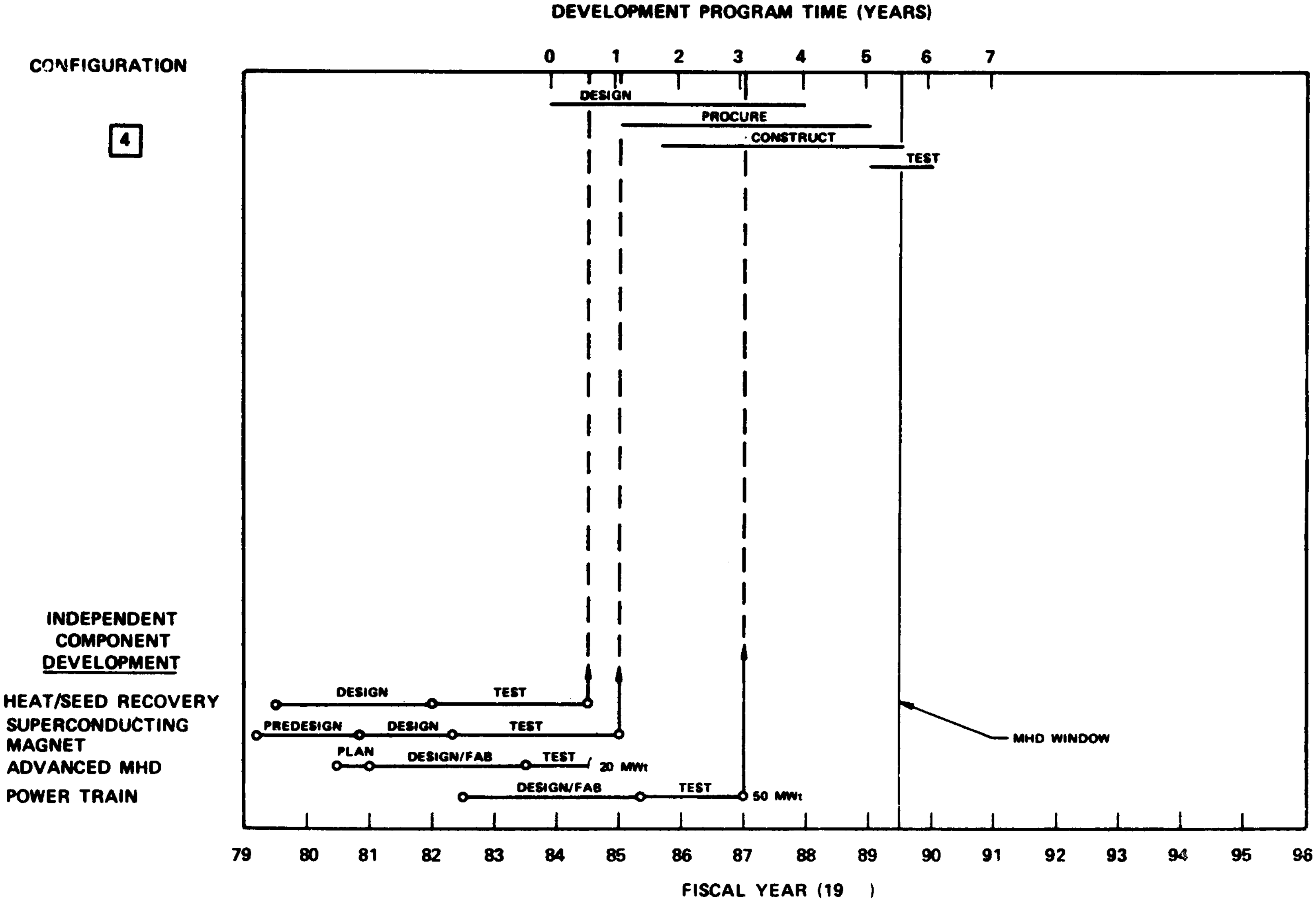

Figure 7-8. Development Logic 4b

7.2.5.2 NUMERICAL RISK ASSESSMENTS FOR VIABLE DEVELOPMENT LOGICS

Numerical risk assessments for the viable development logics previously identified (2a, 2b, 3a, 4a, and 4b) are performed in this subsection, utilizing the risk assessment methodology described in Section 7.2.3. The consequence multipliers Mj, development status multipliers Dij, and operational experience multipliers Oij for each component i of development stage j are valued as previously described. A complete listing of the numerical values assigned for these parameters (by development logic) is contained in Tables 7-7 through 7-12.

For purposes of selection of the appropriate development status multiplier, the vertical lines drawn from the time endpoints of (assumed) successful independent development programs for the Heat Recovery and Seed Recovery, Superconducting Magnet, and MHD Power Train schedule bars on Figures 7-1 through 7-8 are utilized. If an independent development program is completed (as noted by the vertical lines on each figure) prior to the midpoint of the design phase for a stage in any option of the Progressive Development Program where the independently developed component is to be introduced into the ETF operating system, then the development status multiplier for such a component is given a numerical value of 2. Otherwise, the value assigned is 5.

In this regard, it should be noted that only the successful development of the 50 MWt MHD power train in CDIF testing is assumed to provide substantive information for input to the design of the 150 MW power train of the ETF. Thus, any initial ETF design stage in the Progressive Development Program which begins prior to the assumed completion date of the 50 MWt power train testing at CDIF is assumed to require a numerical assignment of Dij = 5 for MHD power train components (i.e., channel, combustor, nozzle, diffuser, and power conditioning equipment).

The relative risk Rj for each stage j in each development logic m is calculated by using the derived relationship

$$\overset{m}{Rj} = \overset{m}{Mj} \cdot \left(\sum_{i=1}^{k} \overset{m}{Dij} \cdot \overset{m}{Oij} \right)$$

TABLE 7-7
PROGRESSIVE DEVELOPMENT PLAN
NUMERICAL DATA FOR RISK ASSESSMENT

DEVELOPMENT LOGIC 2a

COMPONENT OR SUBSYSTEM	CONFIG. 1			CONFIG. 2			CONFIG. 3			CONFIG. 4			CONFIG. 5		
	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}
MHD Generator				6	5	10	4	5	2	4	1	1	0	1	1
Coal Combustor				8	5	10	4	5	2	4	1	1	0	1	1
Superconducting Magnet				8	5	10	2	5	2	2	1	1	0	1	1
MHD Power Conditioning				7	5	10	2	5	2	2	1	1	0	1	1
Component Cooling				6	1	10	3	1	2	3	1	1	0	1	1
Hot Gas Quench				3	1	10	1	1	2	-	-	-	-	-	-
Cycle Air Compressor				5	1	10	3	1	2	1	1	1	0	1	1
Metallic Air Preheater				-	-	-	-	-	-	-	-	-	-	-	-
Ceramic Air Preheater (Indirect Firing)				11	2*	10	5	5**	2	2	5	1	-	-	-
Ceramic Air Preheater (Direct Firing)				-	-	-	-	-	-	-	-	-	7	5	10
Radiant Furnace, HX 1/2				-	-	-	7	2	10	3	2	2	0	1	1
Feedwater, Condensate, and Steam				-	-	-	8	1	10	4	1	2	0	1	1
Seed Feeding				7	5	10	3	5	2	2	1	1	0	1	1
Coal Handling, Processing and Feeding				6	5	10	2	5	2	2	1	1	0	1	1
Oxygen Plant				3	1	10	1	1	2	-	-	-	-	-	-
Electrostatic Precipirator				-	-	-	-	-	-	3	2	10	0	2	2
Heat Rejection Systems				7	1	10	5	1	2	5	1	1	0	1	1

*Uses current blast furnace stove technology for 1533K preheat.

**Upgraded refractory for higher preheat temperatures of 1755K and 1917K.

TABLE 7-8
PROGRESSIVE DEVELOPMENT PLAN
NUMERICAL DATA FOR RISK ASSESSMENT

DEVELOPMENT LOGIC 2b

COMPONENT OR SUBSYSTEM	CONFIG. 1			CONFIG. 2			CONFIG. 3			CONFIG. 4			CONFIG. 5		
	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}
MHD Generator				6	5	10	4	5	2	4	1	1	0	1	1
Coal Combustor				8	5	10	4	5	2	4	1	1	0	1	1
Superconducting Magnet				8	5	10	2	5	2	2	1	1	0	1	1
MHD Power Conditioning				7	5	10	2	5	2	2	1	1	0	1	1
Component Cooling				6	1	10	3	1	2	3	1	1	0	1	1
Hot Gas Quench				3	1	10	1	1	2	-	-	-	-	-	-
Cycle Air Compressor				5	1	10	3	1	2	1	1	1	0	1	1
Metallic Air Preheater				-	-	-	-	-	-	-	-	-	-	-	-
Ceramic Air Preheater (Indirect Firing)				13	2*	10	5	5**	10**	2	5	2	-	-	-
Ceramic Air Preheater (Direct Firing)				-	-	-	-	-	-	-	-	-	7	5	10
Radiant Furnace, HX 1/2				-	-	-	7	5	10	3	5	2	0	1	1
Feedwater, Condensate, and Steam				-	-	-	8	1	10	4	1	2	0	1	1
Seed Feeding				7	5	10	3	5	2	2	1	1	0	1	1
Coal Handling, Processing and Feeding				6	5	10	2	5	2	2	1	1	0	1	1
Oxygen Plant				3	1	10	1	1	2	-	-	-	-	-	-
Electrostatic Precipitator				-	-	-	-	-	-	3	2	10	0	2	2
Heat Rejection System				7	1	10	5	1	2	5	1	1	0	1	1

* Uses current blast furnace stove technology for 1533 K preheat.

** Upgraded refractory for higher preheat temperatures of 1755 K and 1917 K.

TABLE 7-9
PROGRESSIVE DEVELOPMENT PLAN NUMERICAL DATA FOR RISK ASSESSMENT

DEVELOPMENT LOGIC 3a

COMPONENT OR SUBSYSTEM	CONFIG. 1			CONFIG. 2			CONFIG. 3			CONFIG. 4			CONFIG. 5		
	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}
MHD Generator							6	5	10	4	5	2	0	1	1
Coal Combustor							8	5	10	4	5	2	0	1	1
Superconducting Magnet							8	2	10	2	2	2	0	1	1
MHD Power Conditioning							7	5	10	2	5	2	0	1	1
Component Cooling							6	1	10	3	1	2	0	1	1
Hot Gas Quench							3	1	10	-	-	-	-	-	-
Cycle Air Compressor							5	1	10	1	1	2	0	1	1
Metallic Air Preheater							-	-	-	-	-	-	-	-	-
Ceramic Air Preheater (Indirect Firing)							9	5*	10	2	5	2	-	-	-
Ceramic Air Preheater (Direct Firing)							-	-	-	-	-	-	7	5	10
Radiant Furnace, HX 1/2							7	2	10	3	2	2	0	1	1
Feedwater, Condensate and Steam							8	1	10	4	1	2	0	1	1
Seed Feeding							7	5	10	2	5	2	0	1	1
Coal Handling, Processing and Feeding							6	5	10	2	5	2	0	1	1
Oxygen Plant							3	1	10	-	-	-	-	-	-
Electrostatic Precipitator							-	-	-	3	2	10	0	2	2
Heat Rejection System							7	1	10	5	1	2	0	1	1

* Initial operation with upgraded refractory matrix.

TABLE 7-10

PROGRESSIVE DEVELOPMENT PLAN
NUMERICAL DATA FOR RISK ASSESSMENT

DEVELOPMENT LOGIC 3c

COMPONENT OR SUBSYSTEM	CONFIG. 1			CONFIG. 2			CONFIG. 3			CONFIG. 4			CONFIG. 5		
	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}
MHD Generator							6	5	10	4	5	2	0	1	1
Coal Combustor							8	5	10	4	5	2	0	1	1
Superconducting Magnet							8	5	10	2	5	2	0	1	1
MHD Power Conditioning							7	5	10	2	5	2	0	1	1
Component Cooling							6	1	10	3	1	2	0	1	1
Hot Gas Quench							3	1	10	-	-	-	-	-	-
Cycle Air Compressor							5	1	10	1	1	2	0	1	1
Metallic Air Preheater							-	-	-	-	-	-	-	-	-
Ceramic Air Preheater (Indirect Firing)							9	5*	10	2	5	2	-	-	-
Ceramic Air Preheater							-	-	-	-	-	-	7	5	10
Radiant Furnace, HX 1/2							7	5	10	3	5	2	0	1	1
Feedwater, Condensate and Steam							8	1	10	4	1	2	0	1	1
Seed Feeding							7	5	10	2	5	2	0	1	1
Coal Handling, Processing and Feeding							6	5	10	2	5	2	0	1	1
Oxygen Plant							3	1	10	-	-	-	-	-	-
Electrostatic Precipitator							-	-	-	3	2	10	0	2	2
Heat Rejection System							7	1	10	5	1	2	0	1	1

* Initial operation with upgraded refractory matrix.

TABLE 7-11

PROGRESSIVE DEVELOPMENT PLAN
NUMERICAL DATA FOR RISK ASSESSMENT

DEVELOPMENT LOGIC 4a

COMPONENT OR SUBSYSTEM	CONFIG. 1			CONFIG. 2			CONFIG. 3			CONFIG. 4			CONFIG. 5		
	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}
MHD Generator										6	5	10	0	5	2
Coal Combustor										8	5	10	0	5	2
Superconducting Magnet										8	2	10	0	2	2
MHD Power Conditioning										7	5	10	0	5	2
Component Cooling										6	1	10	0	1	2
Hot Gas Quench										-	-	-	-	-	-
Cycle Air Compressor										5	1	10	0	1	2
Metallic Air Preheater										-	-	-	-	-	-
Ceramic Air Preheater (Indirect Firing)										9	5*	10	-	-	-
Ceramic Air Preheater (Direct Firing)										-	-	-	7	5	10
Radiant Furnace, HX 1/2										7	2	10	0	2	2
Feedwater, Condensate and Steam										8	1	10	0	1	2
Seed Feeding										7	5	10	0	5	2
Coal Handling, Processing and Feeding										6	5	10	0	5	2
Oxygen Plant										-	-	-	-	-	-
Electrostatic Precipitator										3	5	10	0	5	2
Heat Rejection System										6	1	10	0	1	2

* Initial operation with upgraded refractory matrix.

TABLE 7-12

PROGRESSIVE DEVELOPMENT PLAN NUMERICAL DATA FOR RISK ASSESSMENT

DEVELOPMENT LOGIC 4b

COMPONENT OR SUBSYSTEM	CONFIG. 1			CONFIG. 2			CONFIG. 3			CONFIG. 4			CONFIG. 5		
	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}	M	D_{ij}	O_{ij}
MHD Generator										6	5	10	0	5	2
Coal Combustor										8	5	10	0	5	2
Superconducting Magnet										8	5	10	0	5	2
MHD Power Conditioning										7	5	10	0	5	2
Component Cooling										6	1	10	0	1	2
Hot Gas Quench										-	-	-	-	-	-
Cycle Air Compressor										5	1	10	0	1	2
Metallic Air Preheater										-	-	-	-	-	-
Ceramic Air Preheater (Indirect Firing)										9	5*	10	-	-	-
Ceramic Air Preheater (Direct Firing)										-	-	-	7	5	10
Radiant Furnace, HX 1/2										7	5	10	0	5	2
Feedwater, Condensate, and Steam										8	1	10	0	1	2
Seed Feeding										7	5	10	0	5	2
Coal Handling, Processing and Feeding										6	5	10	0	5	2
Oxygen Plant										-	-	-	-	-	-
Electrostatic Precipitator										3	2	10	0	2	2
Heat Rejection Systems										6	1	10	0	1	2

* Initial operation with upgraded refractory matrix

where k = total number of components in the operating system for the stage; the individual stage risk values (R_j's) are then combined by summing to identify the total risk of proceeding with the development logic R^m, as

$$R^m = \sum_{\text{all stages}} R_j^m$$

Table 7-13 contains the calculated values for R_j^m and R^m for each viable development logic. Note that the M_j for each stage j of a given development logic includes the M_j for any components not yet introduced into the operating system configuration, but which will be introduced in a subsequent stage. This procedure more correctly reflects the existence of all mission objectives for the entire system which must be met in order to demonstrate the technical feasibility of the concept. As an example, logic 2a does not include a radiant furnace, heat exchangers, steam system nor precipitator in its operating system configuration at Configuration 2 (the initial stage of development). However the 7, 8 and 3 mission objectives (respectively) which must be met by these systems/components at a later stage in the development program for the logic are counted in the mission objective total for Configuration 2. Thus, the total number of mission objectives voided by the occurrence of an undesirable event at Configuration 2 of Logic 2a will be $M_2^{2a} = 99$ rather than the $M_2^{2a} = 81$ which would be calculated on the basis of only those systems or components present in the operating system at Configuration 2.

Table 7-13 shows the following:

- Logic 4b (building the facility in its final configuration with design phase input only from successful independent development programs) has the least technical risk of the viable options.
- Logic 2a (building the facility in 3 progressive steps, beginning with Configuration 2 is the most risky of the viable options.
- Option 2b (building the facility in 3 progressive steps, beginning with Configuration 2 at a date sufficient to meet the 1989 window provides the least risk-intensive Configuration 4; this is important when considered in light of the Progressive Development Program. This can be interpreted to mean that more of the components of the final configuration have been successfully proven in previous testing. The system integration testing vital to proving the efficacy of the final

TABLE 7-13

COMPARATIVE RISK VALUES FOR VIABLE DEVELOPMENT LOGICS
ETF PROGRESSIVE DEVELOPMENT PROGRAM

Notes:

1) A *viable* logic permits the demonstration of a 150 MWt binary open-cycle MHD/steam power plant using indirect firing of oxidizer preheaters by FY 1989.
2) Configurations 1, 2, 3, and 4 are described in Section 3.0 of this report.
3) Development logics are numbered per Section 7.2.5.1 of this report.
4) Directly fired oxidizer preheaters can be added as a follow-on to Configuration 4 in each logic analyzed. The incremental risk for each logic is the same.
5) Values given by logic and configurations are R_j^m for each combination. "-" indicates configuration is not used in the logic.

Development Program Config.	Viable Development Logics					
	2a	2b	3a	3c	4a	4b
1	---	---	---	---	---	---
2	41580	41580	---	---	---	---
3	11600	9860	46550	47000	---	---
4	4920	4760	7440	7440	42840	39480
$R^m = \sum R_j^m$ all stages	$R^{2a}=58100$	$R^{2b}=56200$	$R^{3a}=53900$	$R^{3c}=54440$	$R^{4a}=42840$	$R^{4b}=39480$

configuration is therefore allotted a larger portion of the final configuration testing time available.

These considerations, and others concerning risks, costs, development time, benefits of various logic paths, etc. are used in the following section to define a Reference Development Logic for the Progressive Development Program.

7.3 SELECTION OF REFERENCE DEVELOPMENT LOGIC

The selection of an acceptable logic for the ETF Progressive Development Program is made on the basis of several factors. Included factors are risks, benefits, costs, and schedules. Each important factor is treated separately in the follow

7.3.1 RISKS

The use of relative risk values in the selection process must be guided by consideration of the methodology applied, and its limitations as an analytical tool. It is important to realize that the previously described risk assessment process, however numerically based, is essentially a subjective process. The sensitivity of the final results to the assumed numerical values for the parameters of the risk assessment relation will of course affect the validity of the conclusions drawn. However imperfect the method may be, it does provide a means of making visible the relative weighting of factors used in the assessment process for each development logic. Where disagreement exists as to relative values of the factors considered, it is a simple matter for one to recalculate the values using the modified weighting scheme desired.

A unilateral decision based only upon the comparison of risk values for the entire development program would indicate that an option bypassing the stagewise development of the MHD facility would be the desirable one; that is, either development logic 4a or 4b. It might also be argued that the most important consideration (and one that obviates the aforementioned tendency of the risk assessment methodology utilized herein to penalize development options having a greater number of stages) is minimization of the risk of the initial stage in any development option. The validity of this approach arises from the well-known tendency of complex systems to give high failure rates during their startup On this basis, acceptable development logics options are 2a, 2b, 4a, and 4b.

For this development program, the final stage (Configuration 4) in any of the development logics is admittedly the most important from the standpoint of effectively demonstrating the overall concept of an MHD/steam power generation facility. Thus, minimization of risk in the final Configuration appears to be a valid selection criterion as well. Development logics 2a and 2b are clearly the choice on this basis.

While granting that small differences in the calculated relative risk values are not extremely meaningful, it is apparent that a numerical rating system is useful only if the results are used in the manner for which the system was derived; that is, comparison of numerical values of risk to provide a choice on a numerical basis. Thus, noting that the three criteria previously used to select development logics have indicated that 2a, 2b, 4a, and 4b are effectively equal from the risk consideration standpoint, comparison of numerical values between logics of similar development progression allows a further elimination. Since a lower numerical value means a lower attendant risk, and on the basis of equivalance between 2a and 2b, and 4a and 4b, it appears that one may select either of the "late start" logics, that is 2b or 4b, as acceptable.

Logic 4b has a lower overall risk than logic 2b; logic 2b, on the other hand, minimizes the final stage risk level, while logic 4b minimizes the initial stage risk level.

7.3.2 BENEFITS

Having developed a "short list" of viable development logic candidates by use of the numerical risk assessment methodology, the benefits accruing from selection of various logics can be considered as well.

An obvious benefit of a longer development path is the extended development time available for the MHD power train components. The risk assessment methodology applied previously has been unable to totally assess the impact of other development programs on the selection of the appropriate development logic for the ETF. The working assumption made was that the independent development programs would be successful, providing useable data for ETF design on the dates indicated on Figures 7-1 through 7-8. This is the best which can be done in a static analysis of limited extent. As the Progressive Development Program develops, data (good <u>and</u> bad) from other development programs can be used in refining path selection and path selection criteria.

Hence, from the standpoint of benefits, one may select either 2a or 2b as the most advantageous, providing

- Longer development times for important equipments, and
- Enhanced ability to react to information developed in independent component development programs

From a numerical assessment basis, either 2a or 2b provides for the achievement of a greater number of mission objectives over the life of the program than do any of the alternative paths available.

7.3.3 COSTS

The costs along each of the development paths were evaluated in Section 6.0. Path 2 and 3 both result in an expense different by only 20 million dollars or seven percent (7%) of the total program costs. For Path 4 (i.e., immediate construction of the facility in Configuration 4) the approximate cost can be derived from the costs for Path 3, with the subtraction of the $15 million for operating costs as Configuration 3. Thus, the cost of Path 4 may be only as much as $35 million less than either of the longer paths. This difference seems insignificant when compared to the advantage of early testing with the MHD power train.

On this basis, it may be concluded that cost is not a major selection criterion for the plant concepts as derived in this study.

7.3.4 TIME AND SCHEDULAR CONSIDERATIONS

In selecting a reference progressive development option, proper consideration must be given to the independent MHD development programs presently underway and planned. Risk is obviously reduced if design input can be obtained from other programs. However, if the start of the ETF development program must be delayed to obtain the benefit of independent program results, the possibility that the MHD "window" may close prior to a demonstration of the ETF concept is increased. Both of these time factors have been addressed in the risk assessment phase of the report, either explicitly (for development status evaluations) or implicitly (by selection of logics as being "viable" only if they meet the 1989 date presently forseen as the MHD "window" closure date).

A further time factor which must be considered is the total testing time in the facility available for the development leading to the final configuration. Path 2 provides the greatest amount of testing time leading to Configuration 4 operation (2 years); Path 4 the least (no time prior to operation in Configuration 4).

7.3.5 FINAL SELECTION

On the basis of the foregoing discussions, it appears that the most reasonable development logic for the ETF Progressive Development Program is Logic 2b. This logic provides for delayed initiation of development in order to provide design input for Configuration 3 from the independent Heat Recovery/Seed Recovery and magnet development programs. The important considerations, in summary, which led to selection of this development option are listed below:

- Minimization of risk in final stage of operation;
- Provision for longest development testing time;
- Meets the MHD development window date of FY 1989 while maximizing design input from known component development programs;
- Provides the greatest number of benefits in terms of mission objectives achieved;
- Provides for extended time to react to adverse or advantageous results of independent development programs for vital components, if necessary.

The conclusion on development Logic 2b hinges on the continued viability of the assumptions made concerning the importance of meeting the FY 1989 end date, the requirement for maximizing input from other development programs, and the relative weights of the parameters used in the risk assessment process. The result of this selection process does appear to be consistent with the intuitive feeling as to which path would provide the greatest potential for success.

7.4 PRIORITY DEFINITION AND RISK AVERSION

With the identification of a viable development logic completed, the lower-level goals of priority definition and risk aversion within the chosen logic (and in the context of the assumptions leading to its choice) become important areas for evaluation. The process of risk assessment on a relative numerical basis again provides a means for quasi-objective evaluation of choices in these areas. The importance of the time constraint on achieving operational status in Configuration 4 could also be assessed numerically if a numerical definition of the impact of missing the mid-1989 window were available. Lacking such a definition, however, the second-level assessment process must be restricted to providing visibility for the effects of changing quantitative values assumed for the development status of the critical components in the risk calculations, to reflect the success/failure and schedule slippages of independent development programs. Some identification of the effects of selection of specific internal operating parameters may also be evaluated in numerical fashion (e.g., the logic for developing higher preheat temperatures).

Large risks are implied by the presence of the major developmental items in the ETF systems configuration, particularly in their initial operational stage. Under the assumption that the chosen development logic is 2b, as previously derive the risk assessment methodology may be used to characterize the effects on the calculated risk values R_j^{2b} for the j^{th} stage, and R^{2b} for the entire program caused by the inclusion of specified perturbations on the nominal development scheme. Some perturbations which can be expected to result in substantial changes in risk values for the selected logic are:

- Early development of specified critical items in the systems;
- Failure of scheduled development programs to achieve usable results;
- Modifications to the assumed stepwise increase in air preheat temperature, over the development program;
- Schedule slippages beyond the 1989 window date to allow utilization of independent development program results.

Increases or reductions in calculated risk due to the consideration of such perturbations are accompanied by changes in the benefits accruing at program completion. The accrued benefits are required to provide substantiating evidence as to the technical and economic feasibility of the combined cycle MHD/steam plant for electrical power generation.

7.4.1 REVIEW OF SELECTION BASIS

The basis upon which the selection of the development logic has been made includes the following elements:

- The relative risk associated with the use of the MHD power train components (combustor, nozzle, channel, diffuser, power conversion equipment) is derived from the relationship of the independent development program schedules for the components, and the proposed schedule for each development option.
- The superconducting magnet and its vital appurtenances have been developed to a degree that would make practicable the realistic initiation of magnet procurement activities on the dates required by each development program option schedule;
- Seed regeneration system design and demonstration is not considered to be a limiting item with regard to the Progressive Development Program, whatever the option chosen. Any MHD power train objectives related to seed and seed recovery can be met with a supply of seed "over the fence", although seed regeneration is acknowledged to be a necessary part of the ETF demonstration program.
- The risk/benefit tradeoffs in the development program have been implicitly considered in the assumed completion of the stated mission objectives and the relative risk values inherent in meeting these, within the selected development options.
- The established schedular constraint for the overall development program requires the availability of the Engineering Test Facility, operable in Configuration 4, by mid-1989.

The advanced technology components of the MHD/steam electrical power generation system whose accelerated (or delayed) development could perturb the selected development logic can be readily identified. These components are those which have a very great importance to the overall ETF objective (impact many mission objectives), comprise the non-conventional portions of the facility (MHD-process related), and are required to operate successfully in all progressive development configurations. This list includes:

- MHD generator (nozzle, channel, diffuser)
- Superconducting magnet
- Coal combustor
- Air preheat system
- MHD power conditioning equipment

Another item which carries great significance in the context under discussion, although not required to be provided in all stages of the development option selected, is the Heat Recovery-Seed Recovery equipment.

The magnet design has been previously identified as being eliminated from consideration in the perturbation analysis to be done. The MHD generator is considered as a unit in this assessment due to the complexity of performance-, structurally-, maintenance-, and operationally-related interactions among its constituent assemblies. The component of highest uncertainty in this assembly is the MHD channel itself.

The design approach assumed to be utilized for the facility is to provide a means whereby the channel itself can be changed out with minimal impact upon costs and system availability. It is likely that this approach is the one to be used in early commercialization of MHD in the future. On this basis, the overall significance of the MHD generator to the success or failure of the development program may be appreciated as lower than normally considered.

The secondary effect impact assessment may be then considered to cover effects associated only with the following components:

- Combustor
- Air preheat subsystem
- MHD power conditioning equipment
- Mid-1989 operating availability at Stage 4 configuration

7.4.1.1 RISK REDUCTION THROUGH EARLY DEVELOPMENT OF CRITICAL ITEMS

The critical items identified contribute significantly to the risks and benefits associated with the operation of the facility throughout the development program. If accelerated independent development programs were possible, and were capable of providing results which allowed inclusion of developed (not developmental) designs for these critical items in the original configuration of the ETF, then risks would be reduced significantly without a concomitant reduction in benefits (that is, all planned mission objectives could still be achieved). To identify candidate items for accelerated development, the numerical risk values for the assumed perturbations can be compared each to each, and to the base value of risk. The criteria for selection of such candidate items are: (1) Significant reduction in overall risk for the option; (2) Significant reduction in risk at final stage (Configuration 4); (3) Significant reduction in risk at initial stage (Configuration 2).

Accelerated development of the MHD Power Conditioning Subsystem, the Coal Combustor Subsystem and the air preheat subsystem will be investigated by the suggested technique.

For purposes of risk reduction calculations, the accelerated development of such items is indicated by a change in value of the development status multiplier (D_{ij}) from 5 to 2 for the initial stage of operation of the critical component. All other numerical values remain the same as assumed for the original risk calculations in Section 7.2.

The reference risk levels for logic 2b are (from Table 7-13):

$\underline{R^{2b} = 56{,}200 \text{ (Overall Risk)}}$

$R_2^{2b} = 41{,}580$ (Stage 2 Risk)

$R_3^{2b} = 9{,}860$ (Stage 3 Risk)

$R_4^{2b} = 4{,}760$ (Stage 4 Risk)

- Providing a developed MHD Power Conversion Subsystem for Configuration 2 (presumably the result of an accelerated development program, although this could be realized as well by a delay in the facility development program schedule) will result in the following values:

  R_2^{2b} (1) = 38610
  R_3^{2b} (1) = 9512
  R_4^{2b} = 4760

  R^{2b} (1) = 52882, a 6% risk decrement from the reference level of 56,200 for Logic 2b. For the initial operating stage, a 7% reduction in risk is achieved. No risk reduction accrues in the final operational stage (Configuration 4).

- For an accelerated combustor development program (or a delayed start to provide a developed component for Configuration 2) the risk reduction can be calculated from these values:

  R_2^{2b} (2) = 38610
  R_3^{2b} (2) = 9512
  R_4^{2b} (2) = 4760

  R^{2b} (2) = 52882, an identical 6% risk reduction is achieved overall. Stagewise risk reductions are also identical, for developed combustor introduction, to those for developed power conversion introduction.

- The development of the air preheat subsystem early in the overall ETF development schedule requires that at least two constituent areas be treated: high temperature valves and ceramic matrices.

There currently exists no known experience with long-term use of air preheat systems of the type proposed for the final ETF indirectly fired configuration at 2700°F (1755 K); virtually nothing is known concerning the viability of large-scale systems of this type at 3000°F (1917K). Even the mechanical thermal properties of the matrix materials proposed for the higher preheat must be determined.

Independent programs to accelerate the pace of development in the water-cooled valve and preheater ceramic areas appear necessary although unplanned at present. If such development programs are initiated and can provide usable results within the time frame necessary for the various ETF Progressive Development Program stage schedules, the calculated risk level for the selected development logic can be reduced.

Since the overall preheat system itself is necessarily proven only by operation within the ETF environment, the risk reduction in this case accrues from the combination of reduction in development status and number of objectives to be achieved. In particular, the objectives which can be demonstrated external to the ETF configuration are Nos. 4, 5, 8, 9, and 10 (of Section 7.2.4 under the subheading "Ceramic Air Preheater"). The risk reduction due to development status changes is of course operative only in Configurations 3 and 4, as Configuration 2 plans envision the use of state-of-the-art blast furnace stove technology at 2300°F (1533 K). Reduction in the number of mission objectives to be achieved reduces risk levels in all stages of the development program. Numerous development ploys for the air preheat system can be proposed to optimize risk reduction with independent accelerated development program. However, for illustrative purposes only the following will be considered:

<u>Configuration 2</u> - Uses blast furnace stove technology at 2300 K

<u>Configuration 3</u> - Uses upgraded refractory and water-cooled valves, developed to withstand 3000 K operation, but at 2700 K preheat

<u>Configuration 4</u> - Increases preheat to 3000 K. No system changes necessary in valve or ceramic matrix areas

The calculated risk levels resulting from assuming that valve and ceramic development programs have provided significant development for these items prior to their design for Configuration 3 application are as follows:

R_2^{2b} (3) = 39,900

R_3^{2b} (3) = 7,280

R_4^{2b} (3) = 2,847

R^{2b} (3) = 50,027; an 11% decrease in overall risk. This is accompanied by risk decreases in both the first and final configuration of the ETF development program. This result strongly indicates the advisability of planning and proceeding with an independent development program for both the high temperature air valves and the ceramic matrix materials to be utilized in the air preheat subsystem.

7.4.1.2 RISK AVERSION THROUGH PROGRAM LOGIC MODIFICATIONS

Aside from the reduction in risk levels predicted by assuming the accelerated independent development of ETF critical items, a risk reduction may also be effected within the selected development logic by allowing certain modifications to the original program development plan. This process may be termed risk aversion; it trades off risk reductions for mission objectives.

The risk aversion process is initiated by posing the question "What are the minimum performance levels at which the ETF concept can be said to have been acceptable demonstrated?" After such minimum levels have been defined and agreed upon, the development logic is modified to provide for achievement of these levels and for no more.

Certain deviations from the originally envisaged configuration of the facility have already been made for this study as a result of implicit risk aversion considerations.

- Deletion of the requirement for the direct firing for the high temperature oxidizer preheater as a part of the ETF feasibility demonstration;
- Deletion of the requirement that coal or coal gas be used for the firing of the ETF indirect high temperature air heaters;

- Deletion of the necessity for demonstrating electrial power generation from the bottoming plant by use of a turbine generator set.

A further risk aversion measure which can be considered is the modification to the original development plan in the area of air preheat temperature. Rather than insisting upon stepwise increases in air preheat temperature throughout the program's Configurations, achieving 3000°F (1533 K) in Configuration 4 through 2700°F (1755 K) in Configuration 3, it may be that a lower final air preheat temperature at Configuration 4 will provide the performance necessary to allow feasibility demonstration. The use of the lower preheat temperature will certainly reduce risk levels at the Configuration 4 operating point in the program.

Reference to the parametric evaluation of final preheat temperature for a fixed duct length with indirect air heater firing (Figure 4-9, this report) indicates that channel enthalphy extraction drops from 19 percent to 18 percent, while channel electrical power output is reduced from ~42 MW to ~37.5 MW by use of the 1775 K final preheat temperature in lieu of 1917 K as presently planned. This results in a 3 percent decrement in overall plant efficiency if the lower preheat temperature (no oxygen injection assumed) is adopted.

While the ETF final configuration must demonstrate potential for reaching efficiency levels in advance of those commonly achieved by an other type of coal-burning plant, these levels will not necessarily be achieved in Configuration 4, particularly with a 150 MWt thermal input. Thus, the 3 percent loss in efficiency due to utilization of lower air preheat temperature, while critical, is certainly not terminal for the program. These are calculated efficiency values of necessity; a more realistic evaluation of the acceptability of this particular risk aversion measure may be gained when more operating experience with combined cycle MHD/steam systems is available.

Granting that the reduction in final air preheat temperature Configuration 4 is conceivable, the risk reduction accruing from adopting a form of this risk aversion measure can be evaluated exactly as done previously.

One proposed plan modification could be to provide development of the ceramic matrix type indirect preheaters as follows:

- Configuration 2 - 2300°F (1533 K) blast furnace stove technology used, with oxygen injection to combustor.
- Configuration 3 - System configuration and operation remains identical to that in Configuration 2. Preheat temperature is 2300°F (1533 K).
- Configuration 4 - No oxygen injection utilized. LTAH in duct exhaust train plus upgraded refractory and high temperature air valves provide 2700°F (1755 K) preheat.

This development plan voids the necessity (hence the benefits) of demonstrating objectives 3, 5, 10, and 14 for the ceramic air preheat system (of Section 7.2.4). The risk levels for logic 2b resulting from the application of this approach are as follows:

R_2^{2b} (4) = 39,900

R_3^{2b} (4) = 6,696

R_4^{2b} (4) = 2,760

R^{2b} (4) = 49,356 With respect to the nominal risk level of 56,200 this results in a 12% reduction due to the risk aversion. Moreover, both the initial and final configuration individual risk levels are reduced.

Other program plan modifications leading to risk aversion may be assessed by use of similar techniques. Their risk reduction potential must of course be balanced against the minimum performance levels thought necessary to demonstrate the ETF concept successfully.

7.4.2 DEVELOPMENT PROGRAM RECOMMENDATIONS

The intent of reviewing the impact of certain events upon the risk level of the chosen development logic was to allow the delineation of specific program - related recommendations which can be presumed to have a positive effect upon the overall ETF progressive development.

hese recommendations (derived from the considerations made in the preceding ections) are as follows:

- Accelerated independent development programs are indicated for the following components:
  - Coal combustor
  - Ceramic materials for air preheater matrices
  - High temperature valves
  - Seed recovery furnace
  - Direct-fired high temperature air preheaters

hese items have been given in relative order of importance, first to last.

- Modifications to the development plan for the selected logic (2b) are proposed to enhance the chances for successful demonstration.
  - Defer the operation of preheaters at 2700°F (1755 K) until Configuration 4 is reached.
  - Defer utilization of seed regeneration during the early development of the facility.
  - While providing flexibility with regard to direct firing of high temperature air preheaters, utilize the indirectly-fired type burning a clean fuel (non-coal-derived) to at least the completion of Configuration 4 operations.

8.0 REFERENCES

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APPENDIX A

HYPOTHETICAL SITE DESCRIPTION

DESCRIPTION OF A HYPOTHETICAL SITE FOR AN MHD ENGINEERING TEST FACILITY

The hypothetical plant site described in this report has been established for use in the preparation of conceptual MHD power plant studies related to the design, construction, and operation of an MHD Engineering Test Facility (ETF). The hypothetical site described herein shall be used as the location for conceptual design of the conceptual facility.

Topography

The site is located in western Montana. The region is characterized by mountain ranges (elevation 8,000 - 10,000 feet asl.) separated by relatively wide (5 - 40 miles) flat valleys. The relief from valley to peak varies from 2,000 - 4,000 feet. The foothills located between the valleys and mountains are widely dissected by streams and consequently have strong local relief. The streams, most intermittent, leave the foothills and cut into the valley floors causing streamside relief of 5 - 50 feet. In contrast, streamless areas of the valley floors are quite flat and relatively large.

The valley in which the hypothetical site is located is generally oriented north-south, is relatively large and flat, is located approximately 10 miles east of Centertown, the nearest large city. The valley stretches 50 miles southward and is 8 - 10 miles wide in most places. A small stream, Rocky Creek, flows southward from near the center of the valley and enters Gold Creek which crosses the south end of the valley. Relatively flat areas of up to 500 acreas are found in the southern one-half of the valley, and it is in this vicinity that the hypothetical site is located. Gold Creek flows eastward across the southern end of the valley, then cuts through a small rise and enters the mountain valley to the east. Gold Creek is joined by several other streams to become the Pioneer River which generally flows east, eventually entering the Americana River and the Columbus Ocean.

Climatology

The site location has a continental climate. Cold winter temperatures are seasonally followed by substantially warmer summer tempertures. For example, in Centertown the mean normal temperature for January is near 15°F, while in July this temperature increases to about 62°F. Wintertime low temperatures often fall to -20°F to -40°F, while summertime highs often reach 80 to 90°F. Total precipitation is low, averaging about 20 inches per year. June is normally the wettest month, receiving 2.5 inches of precipitation. Water evaporation from Class A pans is estimated to be 35 inches per year with 80 percent of this evaporation occurring between May and October. Average relative humidity varies from summer daytime lows of 25 - 50 percent to year around nighttime heights of 60 - 70 percent.

Severe weather in the region includes summer thunderstorms (sometimes with damaging hail), strong winds, rare tornadoes, and sub-zero temperatures. Thunderstorms occur in the Centertown area approximately 35 times per year. Hailstorms are far less common, but do occur in most years.

Demography

Centertown is the largest population center in the vicinity of the hypothetical site with approximately 50,000 people.

During the 1960 - 1970 decade, the population of the general area declined. However, in recent years there has been a slight to moderate increase in population. Approximately 75 percent of the area population resides in Centertown with the balance in small towns and rural areas within 25 to 35 miles of Centertown.

Land Use

Land use within 50 miles of Centertown is strongly influenced by topography. The major population centers are all located in the valleys where year around access is possible. The major land use in the valleys of the region is agriculture, while in the mountains, conservation, recreation, and forestry are the major uses. Lesser uses in the valleys, including that of the hypothetical site, include industrialization and recreation, as well as livestock grazing. Irrigation is limited to relatively small acreages.

Current land value, in agricultural areas, is approximately $500 per acre for large tracts with 200+ acres of land.

Transportation Facilities

The hypothetical site location contains a well developed system composed of two railroads, airport, and federal and state highways. Daily jet flights are scheduled from the Centertown airport to major cities. The site is located adjacent to a major federal highway, and a major railroad line crosses the western edge of the site valley within five miles of the hypothetical site location.

Construction Work Force

The current labor situation in the Centertown area closely parallels other industrial regions of the country. Similarities include: 1) a low employment rate in the local construction industry, 2) ample skilled and experienced craftsmen available and qualified for all phases of industrial construction, 3) competitive contractors available who are highly competitive, and 4) an organizational structure of labor for training, testing, and certification of apprentices to the trades.

Utilities, Fuel, and Communications

Utility services for electric power fuel and communications are available at the hypothetical site. Natural gas supplies are questionable, however. Cave River is fifteen miles north of the hypothetical site location. Water for construction activities would be obtained by drilling 100 foot deep wells into the groundwater at the site.

Atmospheric Diffusion Properties

The meteorological investigations of the Centertown area have been at the regional levels and predominantly theoretical. In the general area of the hypothetical site, the effects of local topography may contribute to air pollution problems. The mountainous terrain surrounding the site and its valley is known to cause air flow channelization and inversion effects. Early morning inversions commonly occur in the valleys of western Montana during all months. However, they are more pronounced in fall and winter and have a longer duration.

In the vicinity of the hypothetical site, it has been found that calm wind periods account for early one-third of the observation during the morning and early afternoon and for one-fourth of all observations. The remainder of the time the wind blows from all sectors with a similar frequency of occurrence. Average wind speeds are approximately twenty miles per hour during unstable conditions and four miles per hour during stable conditions.

Geology and Seismology

The valley of the hypothetical site contans alluvial fill to depths of 500 feet or more. This alluvia is poorly sorted mixture, ranging from fine silty clay to boulders and conglomerates. The fill rests on an irregular bedrock surface of moderate relief.

The alluvial fill at the site presents no serious problems either for site preparation by grading or for construction of facilities.

The high permeability of the fill material will require lining or sealing of the liquid retaining and evaporating ponds.

The area is classified as a Class 3 in seismic risk.

Sewage Disposal

Disposal of sewage and waste water from the site, with the exception of streams with a high concentration of soluble potassium salts, will present no problems if they are treated to meet the Montana quality discharge standards.

APPENDIX B

MAJOR EQUIPMENT AND SUPPORT SYSTEMS DEFINITION

MAJOR EQUIPMENT AND SUPPORT SYSTEMS DEFINITION

Summary definitions of major equipment and support systems for the 150 MWt ETF Studies performed in this report are presented below. These definitions draw heavily on prior ETF Study efforts with scaling and modification as required for the particular case.

B-1 COMPONENT DESIGN ASSUMPTIONS

The major MHD power train components are described and concepts illustrated in this section to provide the basis for system assessment and cost/risk/benefit comparisons. These components have been selected on the basis of results of other ETF and MHD system studies (References 1, 2, 3).

COMBUSTOR

The two stage combustor is illustrated in Figure B-1. The first and second stages are mounted vertically in-line from a fiberglass insulating support cone since the combustor and nozzle float at channel inlet voltage; the channel outlet and downstream components being grounded. The complete assembly is mounted in a pit to place the outlet nozzle from the second stage in line with the channel inlet. Slag draining from the first stage combustor is quenched and crushed in a tank mounted below the assembly. The slag removal and quench water line are made of electrically insulating material and are provided in sufficient length to achieve the required pressure let-down together with an acceptably low current loss through the liquid.

The preheated air is supplied through individual pipes to the two stages from a single vertical supply pipe. A section of fiberglass duct is interposed between the steel ducting sections to provide electrical isolation. The fiberglass section is cooled by a stream of cooling air tapped from the compressor outlet and passed through a cooler. The fiberglass section is protected from radiation by means of water cooled cylindrical section supported inside it. The air for cooling the fiberglass section is fed into the annular space between the fiberglass duct and the water cooled radiation shield and is then

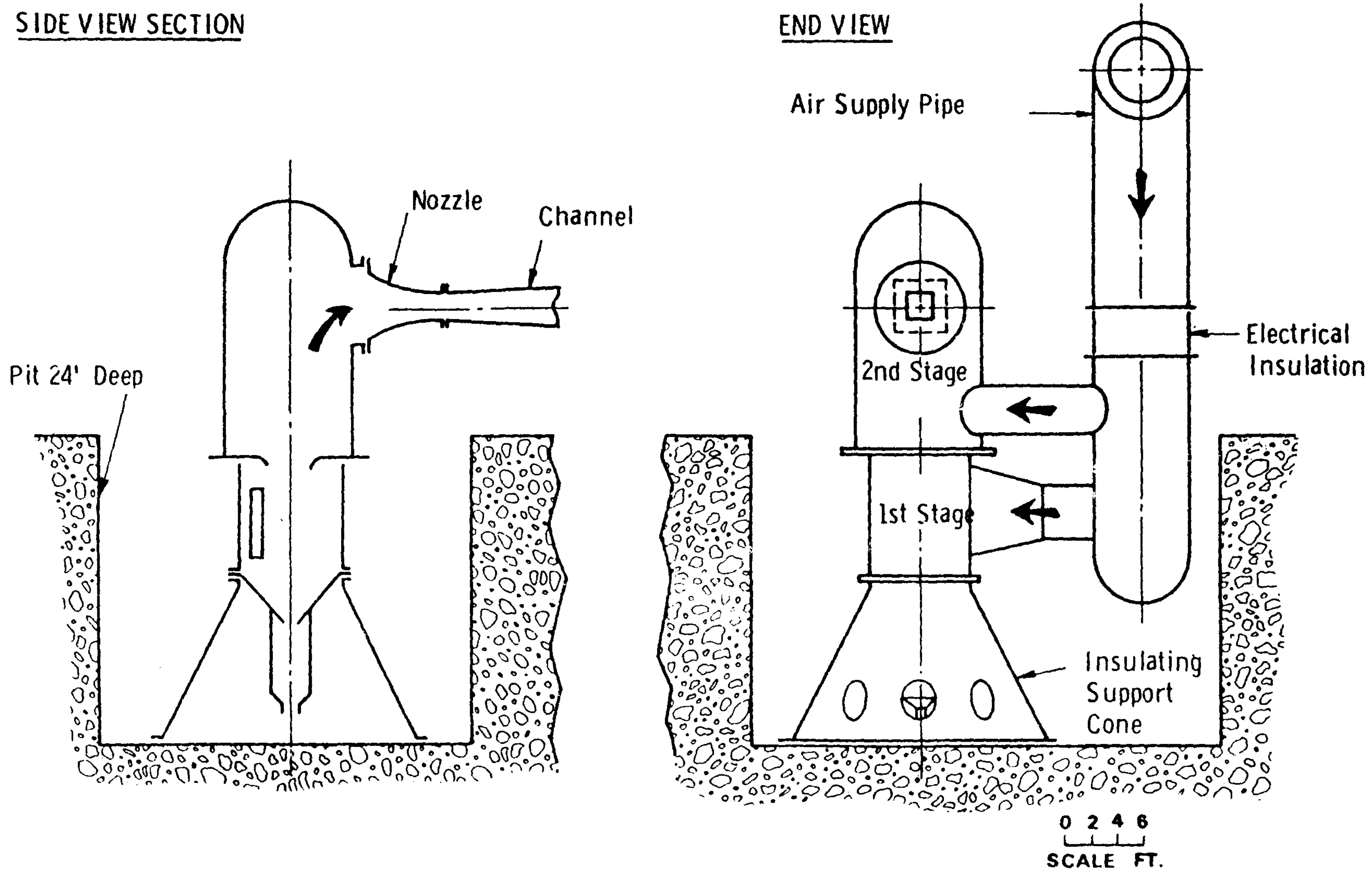

Figure B-1. 150 MW ETF Single Combustor Arrangement discharged into the hot gas flowing inside the duct. Since the amount of cool air required to maintain a satisfactory temperature at the fiberglass section is small, the effect on the combustor inlet temperature is small and easily compensated for.

The structure of the first stage combustor consists of a carbon steel casing lined with studded tubing and rammed refractory insulation. Harbison-Walker "Ruby-rammix" chrome oxide-alumina refractory is a possible candidate for this application since it has good resistance to slag corrosion effects. Water is circulated through the tubing to cool the structural assembly. The first stag is operated fuel-rich by restricting the air flow to 50 percent of stoichiometric. The preheated air is admitted tangentially through water cooled ports in the cylindrical section of the combustor. The coal is admitted through small ports inside the air ports. Pneumatic transport is used to convey the coal to the injection ports using cooling stack gas or nitrogen in non-metalli piping.

The second stage combustor receives relatively slag free combustion products passing upward through a central hole in a water-cooled baffle plate separatin the two stages. Second stage combustion air is admitted tangentially, in the opposite direction to that of the first stage, the flow rate being limited to achieve 95 percent stoichiometric combustion products. Seed is also injected through water cooled nozzles. Construction differs from that of the first stage in that a zirconia brick lining is used to insulate the chamber and minimize heat loss. The pressure vessel has an inner steel structural wall and an outer cooling jacket.

NOZZLE

The nozzle is illustrated in Figure B-2 and consists of a fabricated steel structure with integral cooling passages. Flame sprayed ceramic or other refractory insulating material is applied to the gas passage surfaces. The nozzle is bolted at its inlet end to a circular flanged penetration at the second stage combustor. At its outlet end the nozzle is bolted to the channel inlet flange and, during operation of the plant, supports the channel at this location.

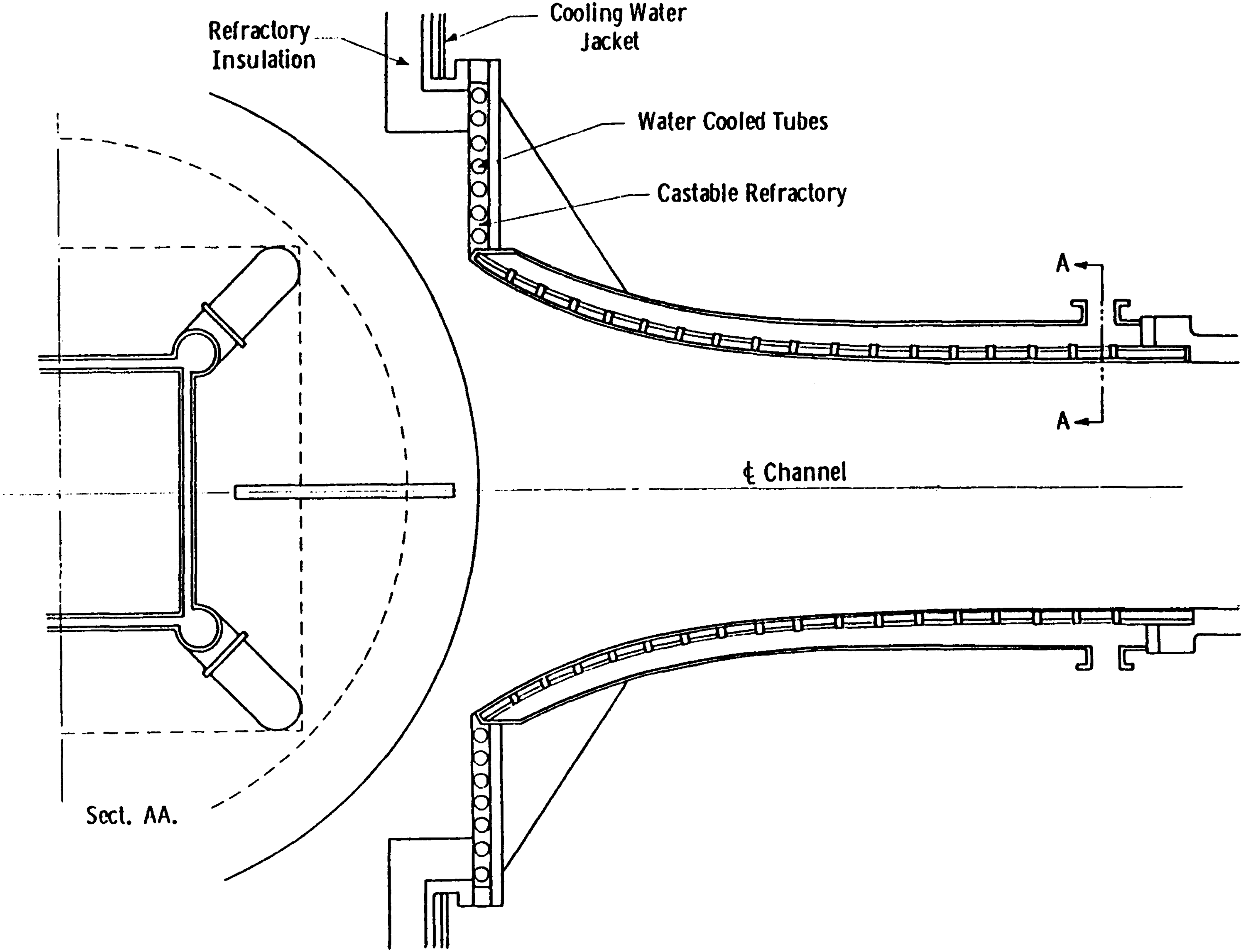

Figure B-2. Nozzle

CHANNEL

The channel is illustrated in Figure B-3 and consists of a rectangular section tapered fiberglass duct which serves as a pressure vessel and supports the water cooled electrodes. The duct is split on the horizontal centerline to allow access to the electrodes. The inlet end of the channel is equipped with a wheeled carriage which travels on rails supported in the bore of the magnet dewar during withdrawal of the channel for maintenance, etc. The diffuser must first be moved to the side to provide room for channel withdrawal. All electrical leads and water piping from the electrodes ar led to quick-disconnect couplings at the outlet of the channel.

CHANNEL OUTLET EXTENSION

The channel outlet extension provides a continuation of the flow duct from the channel, which terminates several feet inside the bore of the magnet dewar, to the diffuser inlet. The structure of the channel outlet extension is similar to the of the nozzle and is a steel plate fabrication having a similar arrangement of water cooling passages. The structure is supported on a wheeled undercarriage providing support for the channel as it is withdrawn from the magnet dewar. A sliding joint is provided at the interface with the diffuser inlet to accommodate axial thermal growth. Figure B-3 illustrates the channel outlet extension in its location at the channel outlet.

DIFFUSER

The diffuser is illustrated in Figure B-4. Its structure consists of a rectangular section carbon steel outer casing protected from the hot gas on the interior. The tubes are oriented laterally in the upper and lower walls and vertically in the sidewalls. An inlet header manifold runs along one of the lower corners of the duct and supplies the tubes with water at saturation temperature.

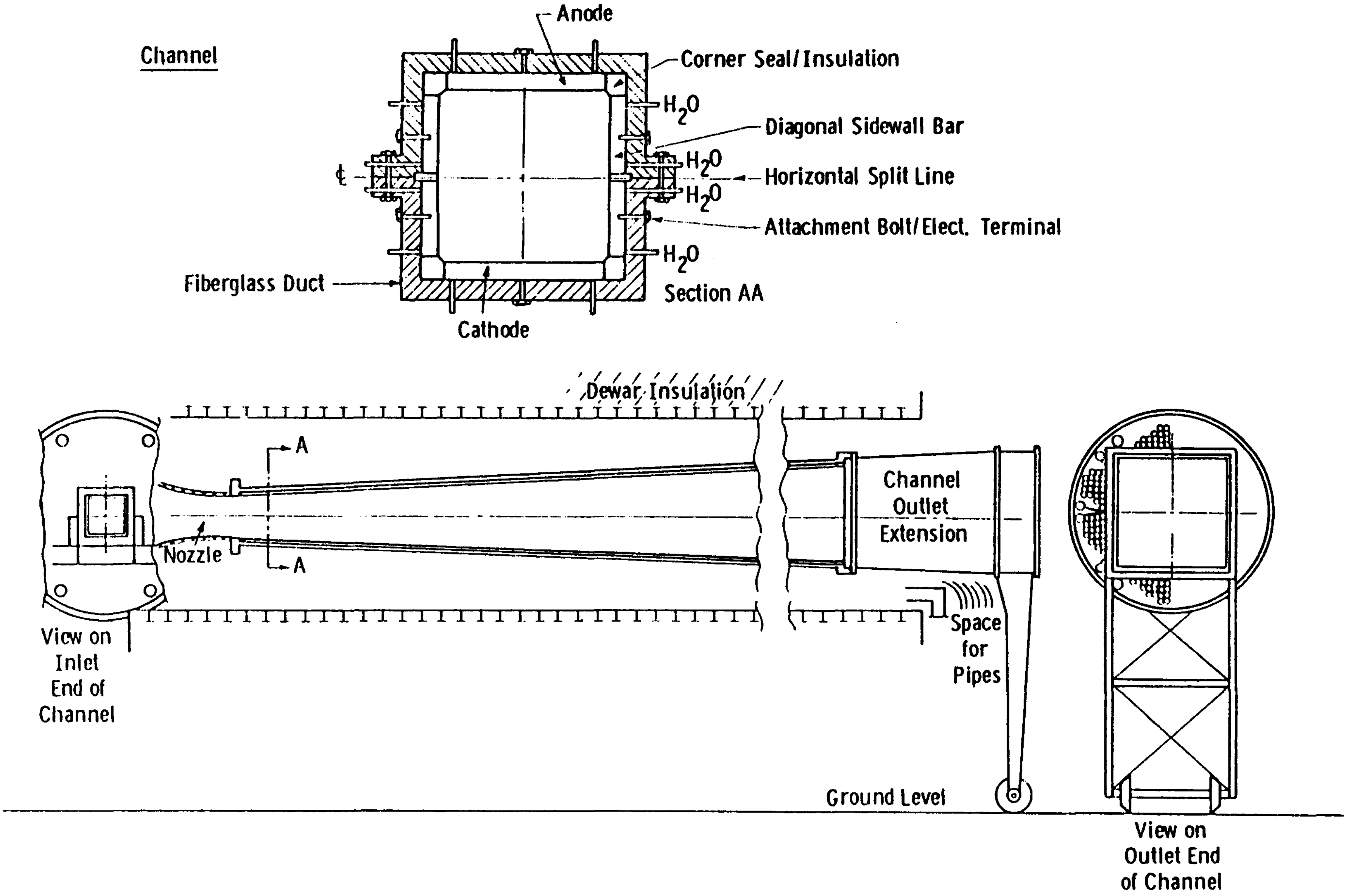

Figure B-3. Channel

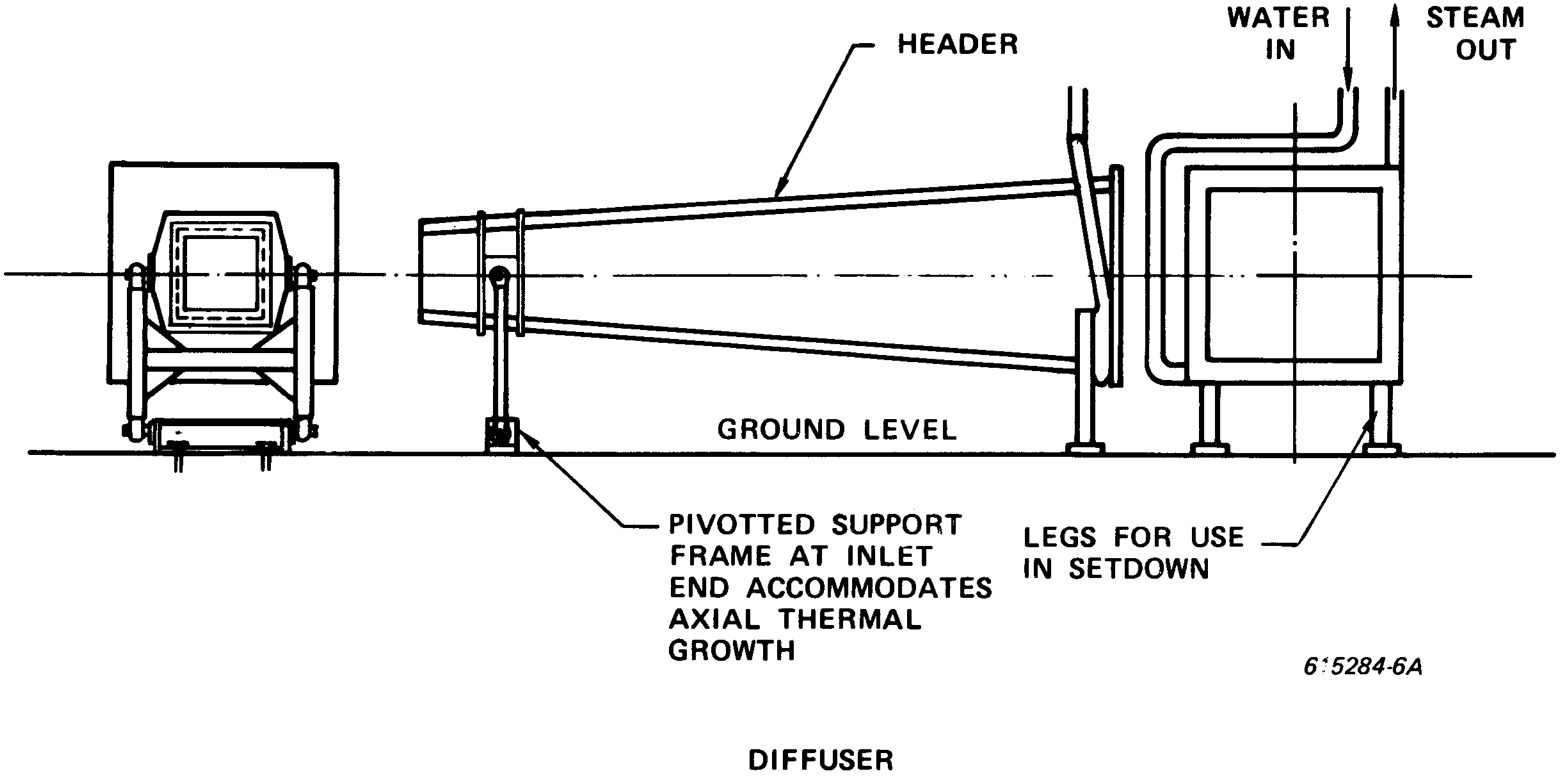

Figure B-4. Diffuser

RADIANT BOILER

The radiant boiler is a tall rectangular sectioned structure having flat carbon steel plate outer walls protected from the hot gas on their inner surfaces by a refractory-water cooled tubing arrangement similar to that employed in the diffuser walls. The radiant boiler is illustrated conceptually in Figure B-5 as defined by Foster Wheeler for the ETF study reported in Reference (3). The hot gas enters the radiant boiler from the diffuser via a square section spoiler duct running horizontally along one side. On the opposite side of the radiant boiler is a secondary cavity which can function as a combustion chamber to permit the operation of the bottoming steam plant while the MHD components are shut down.

SEPARATELY FIRED METALLIC AIR HEATER

The metallic air heater used in configuration 1 is the same as was derived in the previous 150 MWt facility of Reference (1). Figure B-6 illustrates this preheater and Table B-1 summarizes data obtained from a survey of potential heater suppliers.

HIGH TEMPERATURE AIR HEATER

The high temperature air heater is as illustrated in Figure B-7 similar in design to the McKee type hot blast stoves used in conjunction with steel industry blast furnaces. Four vessels are provided to allow uninterrupted flow using appropriate combination of vessels receiving and delivering heat. A single combustor is provided at the hot gas inlet manifold for use under the indirect firing conditions employed during earlier development. In this case the fuel gas from the radiant boiler is piped into the hot gas inlet manifold at the opposite end from the indirect fired combustor and is valved to the appropriate vessels for use in heating their ceramic checkers. After giving up its heat, the gas leaves the vessels and enters the hot gas outlet manifold from which it is piped to the steam generator (HX2). The remaining heater vessels, meanwhile receive high pressure air from the LTAH and transfer their stored heat to the air prior to its discharge into the air outlet manifold and delivery to the MHD combustor.

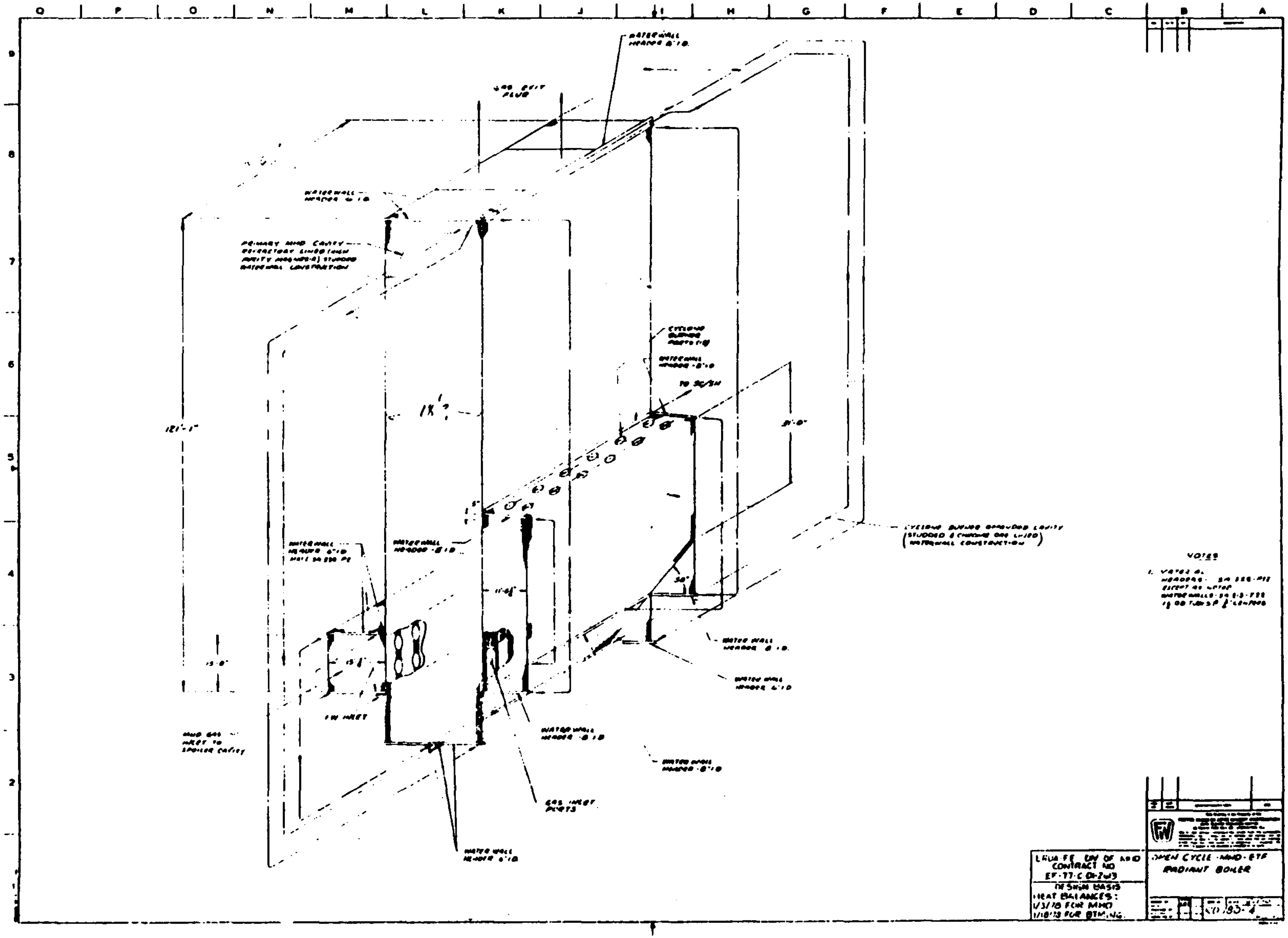

Figure B-5. Foster-Wheeler ETF Radiant Boiler Concept

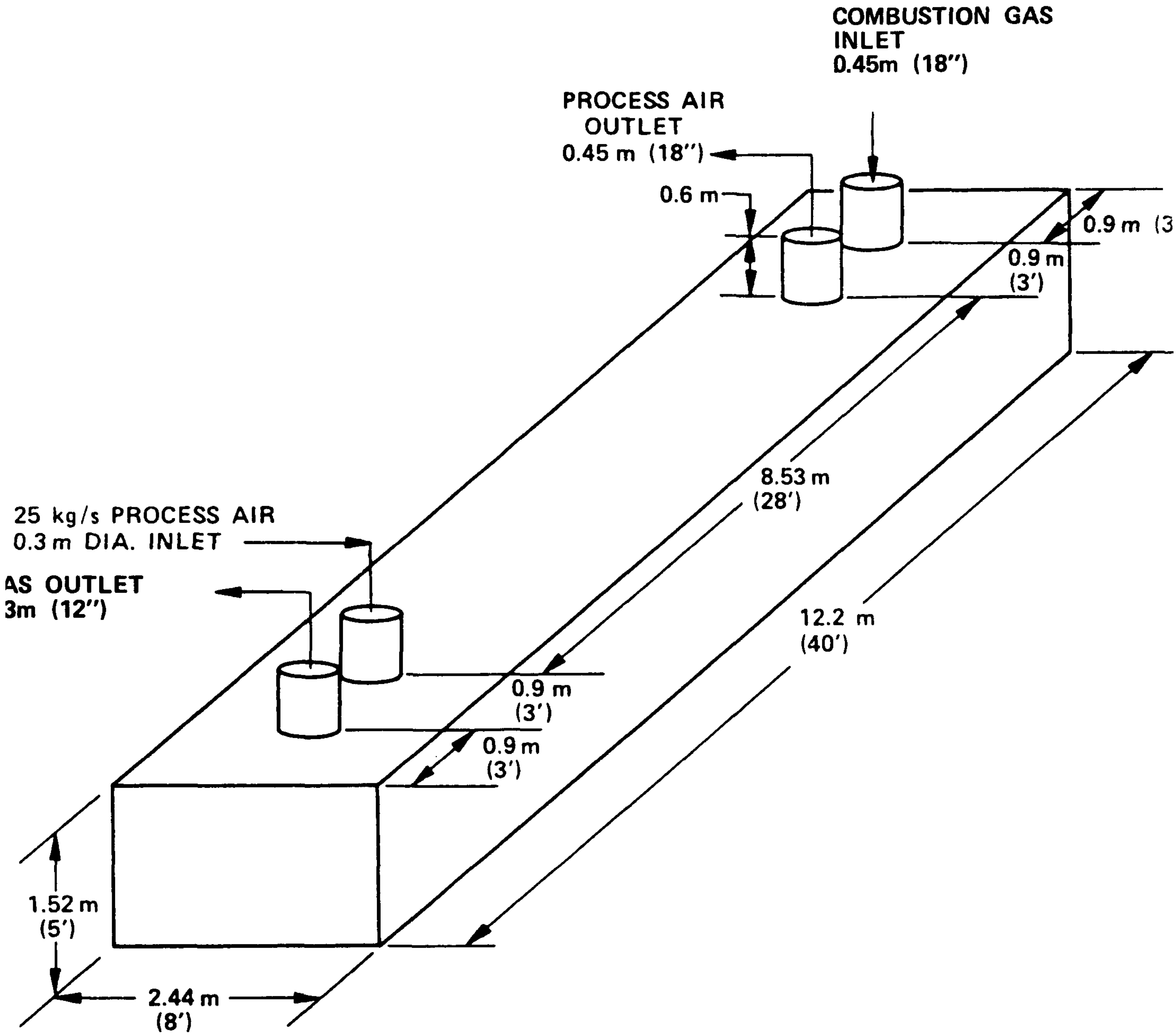

Figure B-6. Sketch of Metallic Air Heater

TABLE B-1: SUMMARY OF METALLIC AIR HEATER SURVEY

Bases:
- Oil-Fired Metallic Preheater
- Air Inlet at Atmospheric Pressure and 366 K temperature
- Output at 10 Atmos. (6 to 8 Atmos. Operating Conditions)
- Continuous Operation

Company:	Neandorfer Co	Trane Co	Ionics, Inc	Fluidyne	American Shack
Air Preheat Max. Temperature with Conventional Materials (300 Series SS)	1060 K (≤1450°F)	≤977 K (1200 - 1300°F)	1033 K (1400°F)	977 K (1200 - 1300°F)	1033 K (1400°F)
Cost* with Conventional Materials (300 Series SS)	(not quoted)	<$15,000/ 10^6 B/Hr	$7,500/ 10^6 B/Hr	$5,000 to $10,000/ 10^6 B/Hr	$10,000/ 10^6 B/Hr
Air Preheat Max. Temperature with Superalloys	(not quoted)	≤1200 K (1600 - 1700°F)	≤1255 K (1650 - 1800°F)	≤1144 K (1400 - 1600°F)	≤1200 K (1700°F)
Cost* with Superalloys	(not quoted)	---	$22,500/ 10^6 B/Hr	$25,000/ 10^6 B/Hr	(not quoted)

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*Includes controls and combustor.

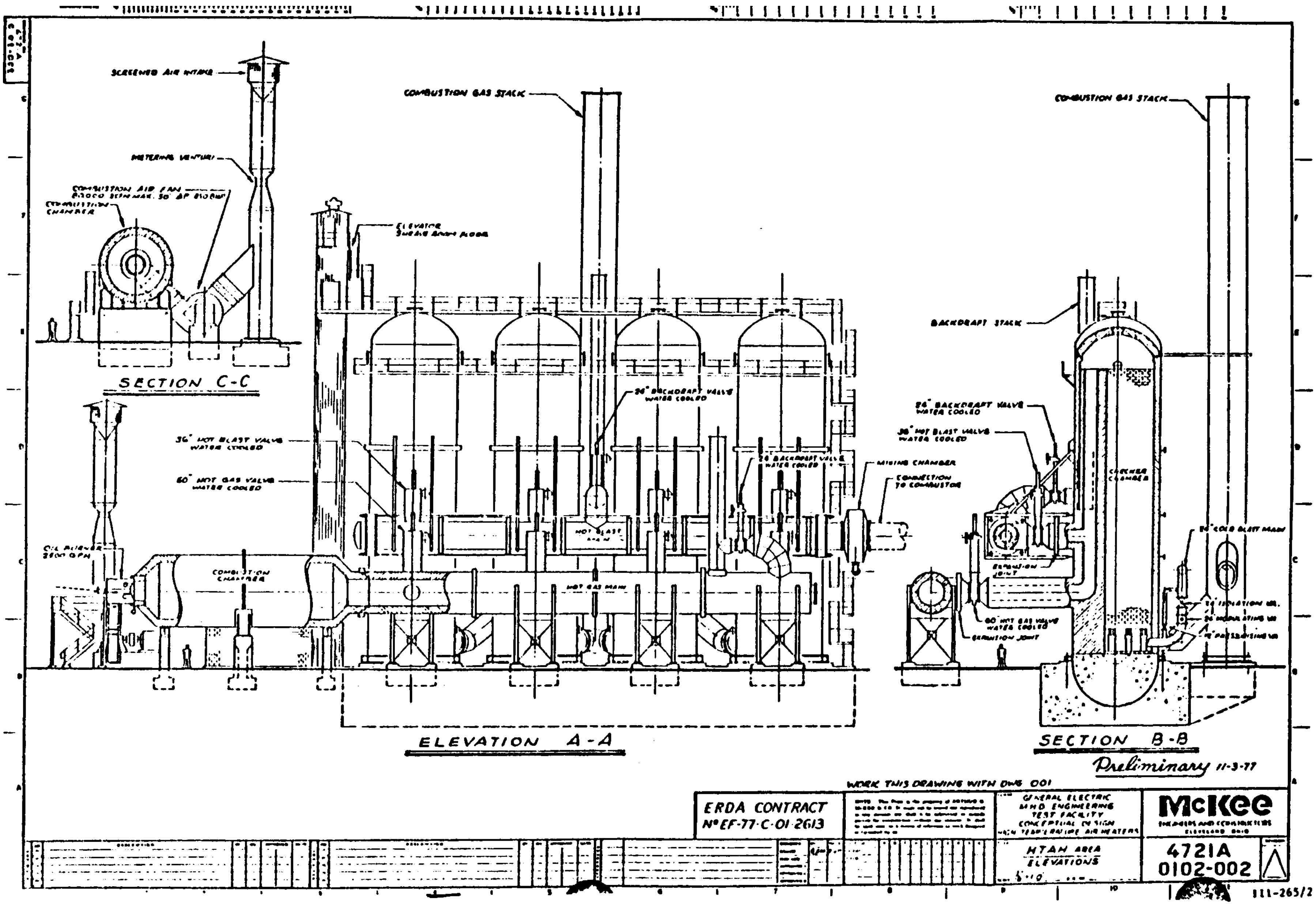


Figure B-7. McKee Type HTAH Concept Used in Study

The ceramic checkers and the refractory materials used to insulate the manifolds and pipes are upgraded in the final direct fired heater in order to provide the increased corrosion and temperature resistance required in order to provide the increased corrosion and temperature resistance required in the high temperature slag and seed environment. This requires the replacement of the low alumina ceramics, originally installed in the HTAH for use in the earlier development steps at 2300°F air outlet temperature in an indirectly fired mode, with fused grain magnesia-alumina spinel and, in the highest temperature locations, with zirconia checkers and insulation. The HTAH is required to cycle more rapidly to provide the higher 1755K (2700°F and 1920K (2900°F) air outlet temperatures required in the final directly fired configuration in order to transfer the increased quantities of heat involved.

STEAM GENERATORS (HX1) and (HX2)

The steam generators are of a conventional design employing multiple banks of water cooled tubing in a vertical pendant configuration. A simple straight refractory lined steel duct connects the generators to interfacing equipment.

LOW TEMPERATURE AIR HEATER

This component will be introduced in Configurations 4 and 5. The low temperature air heater in similar fashion to the steam generators employs multiple banks of vertical tubing in a pendant arrangement. Gas from the steam generator outlet enter the LTAH via a refractory lined elbow which is reoriented to suite the final plant from its previous position in the earlier development step. High pressure air from the compressors is admitted to the inside of the tubes via an arrangement of larger diameter manifold pipes. After traversing the pendant tubing flow path the heated high pressure air is ducted to the HTAH air inlet manifold. Gas leaving the shell side of the LTAH enters the economizer directly. This component is scaled from the earlier ETF-3 Final Configuration, Reference (2).

ECONOMIZER

This component will be introduced in Configurations 4 and 5. The economizer is of conventional pendant vertical tubing design similar in concept to the steam generator. Upon leaving the economizer the gas enters the electrostatic precipitator.

ELECTROSTATIC PRECIPITATOR

This component will be introduced in Configurations 4 and 5. The precipitators are of conventional design, but must incorporate provision for extracting the seed and ash for pneumatic transport to the seed processing systems. This component has been scaled from the earlier ETF-3 Final Configuration, Reference (2).

DRAFT BLOWERS AND STACK

The final configuration is considered to incorporate an integrated coal drying system. The clean gas from the electrostatic precipitators is divided into two streams. One of the streams is exhausted to the stack via a forced draft blower which, augments the thermal draft of the stack. The other stream is fed through another forced draft blower to the coal drying facility.

B-2 SUPPORT SYSTEMS DESCRIPTIONS

The major support systems involved in the configurations studied are briefly discussed in the following paragraphs.

COAL HANDLING, PROCESSING AND FEEDING

The requirements for the coal handling, processing and feeding are defined and major components are identified in Reference (1). This system is common to all of the progressive stages of the ETF and has been assumed as defined in Reference (1).

AIR SUPPLY SYSTEM

The air supply system for the ETF evolves from the oxygen enriched initial phase to the fully recuperative option of the final phase. As discussed and shown in Reference (1), the air compressors are sized to 1/2 capacity each and provide the pressure head necessary to drive the primary combustion air through the air heating systems equivalent to the final configuration. The air compressors are induction motor driven and include a third air compressor system as a standby. Options for a steam driven air compressor are provided. To provide the required combustion temperature in the intial configuration, an oxygen plant capable of supplying up to 550 tons of oxygen per day would be located on site. The rationale for providing the on-site storage has been developed in Reference (1).

SEED FEED SYSTEM

The seed system has been designed to provide a reliable continuous flow of potassium carbonate and water with the ratio of the mix by weight as follows:

K_2CO_3 - 67%
H_2O - 33%
Resin - Trace Only

This mix is a homogeneous concentrated slurry that can be supplied under pressure to the combustion system. An over-the-fence supply of the carbonate would be used in the initial configurations. Modifications of this system to be compatible with the direction of the seed regeneration development is expected as the final facility configuration is approached.

MHD OUTPUT POWER CONDITIONING

The power conditioning for the MHD output is based upon the systems concept defined in Reference (1). This system includes the equipment and arrangements schematically shown in Figure B-8 .

QUENCH SYSTEM

The hot gas leaving the diffuser is cleaned and cooled in a quench and scrubber system using direct water sprays. The system is similar to the CDIF system presently under construction and is discussed in Reference (1). Figure B-9 taken from Reference (1) illustrates the quench system conceptually.

The quench section consists of ceramic-lined 3.66 meter (12 feet) diameter steel pipe constructed in the shape of an inverted "U". The inlet end of this pipe is connected directly to the exit of the diffuser. Spray nozzles are located immediately downstream of the inlet, at the throat of the venturi scrubber and at the entrance to the scrubber stalls. A total of 10,854 gpm of water is required for the sprays. However, only 7.9 percent, 858 gpm, is lost up the stack as a steam plume. The remainder of the spray water is collected and recycled.

Water containing particulates (flyash) and dissolved seed is collected from the scrubber and the inlet to the inverted "U" piping. Particulates are removed by settling in a thickener. Makeup water, 858 gpm, is added and the water recycled. A blowdown from the thickener is pumped to the evaporation ponds.

HEAT REJECTION SYSTEM

The heat rejection system is comprised of the MHD power train cooling water heat rejection system and the combustion gas waste heat rejection system.

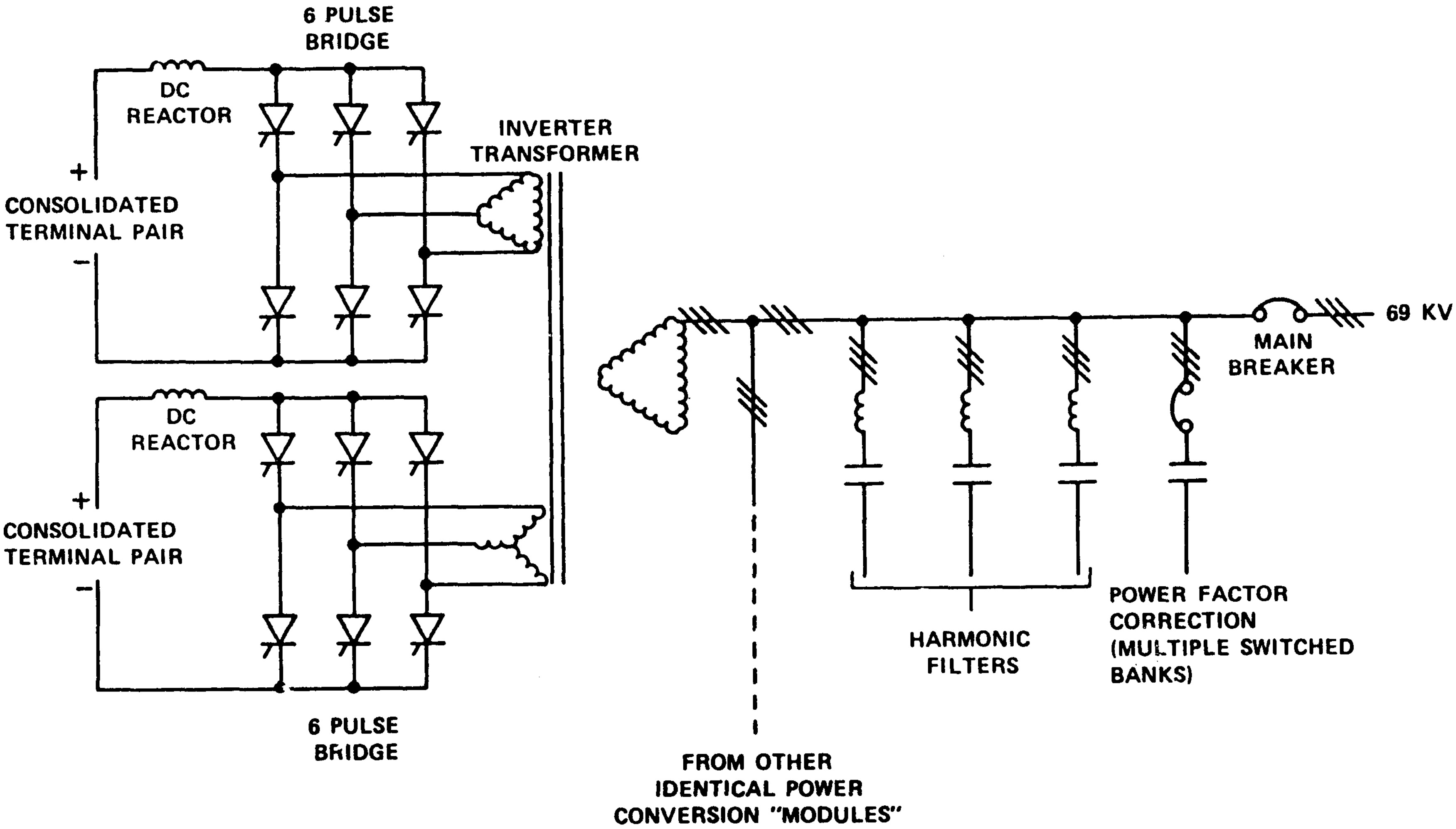
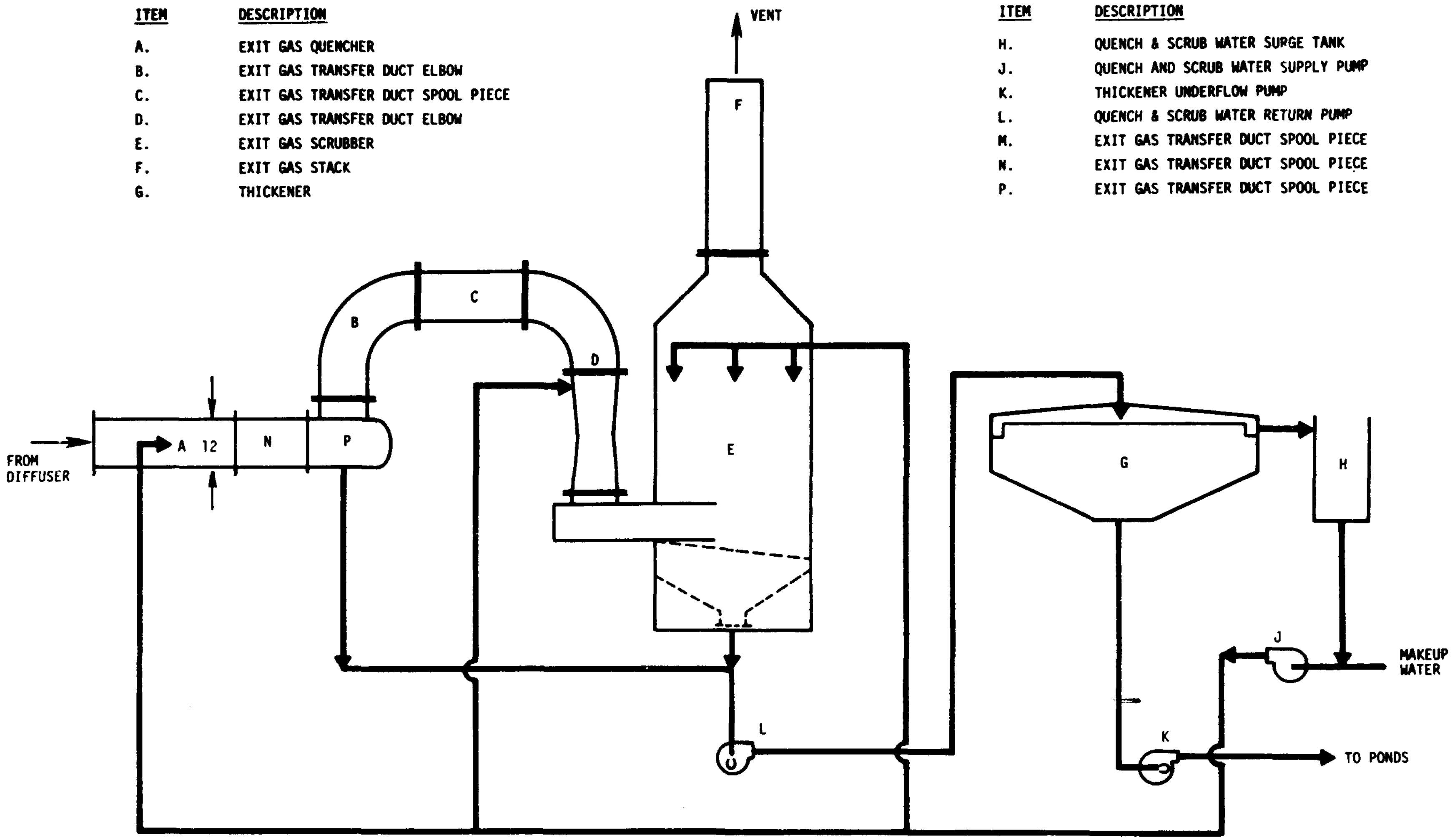


Figure B-8. 1 Module 12-Pulse Inverter Fed by Two Consolidated Terminal Pairs, Plus Harmonic Filtering and Power Factor Correction Common to All Inverters



ITEM	DESCRIPTION
A.	EXIT GAS QUENCHER
B.	EXIT GAS TRANSFER DUCT ELBOW
C.	EXIT GAS TRANSFER DUCT SPOOL PIECE
D.	EXIT GAS TRANSFER DUCT ELBOW
E.	EXIT GAS SCRUBBER
F.	EXIT GAS STACK
G.	THICKENER

ITEM	DESCRIPTION
H.	QUENCH & SCRUB WATER SURGE TANK
J.	QUENCH AND SCRUB WATER SUPPLY PUMP
K.	THICKENER UNDERFLOW PUMP
L.	QUENCH & SCRUB WATER RETURN PUMP
M.	EXIT GAS TRANSFER DUCT SPOOL PIECE
N.	EXIT GAS TRANSFER DUCT SPOOL PIECE
P.	EXIT GAS TRANSFER DUCT SPOOL PIECE

Figure B-9. 150 MWt ETF Quench System

The former is made up of an isolation heat exchanger and cooling loop which rejects the heat to the air in a mechanical wet, wet-dry or dry cooling tower. For the purpose of this study, a mechanical dry cooling tower has been assumed. The combustion gas waste heat when quenched has its heat rejected to the atmosphere through the stack and an evaporation cooling pond. When steam is generated the steam energy is rejected in a condensor to a cooling tower.

CLEAN FUEL AND AUXILIARY STEAM SYSTEM

The unloading fuel oil facility, oil storage and supply, and the auxiliary steam generation system are treated as a complete system. A rail tank car and two tank truck unleading positions are provided to permit the simultaneous unloading of the vehicles to a 50,000 barrel storage tank. Unloading pumps are provided at each unloading position for the transfer of fuel oil to the storage tank. A fuel oil heater, operated by steam from the auxiliary steam generation system, is provided in the storage tank for the supply of fuel oil in cold weather. A fuel oil delivery pump with a 100 percent capacity pump for stand-by delivers fuel oil from storage through two parallel replaceable fuel oil filters to the auxiliary boiler, the railroad car thawing shed heaters and the MHD air preheater. Fuel oil delivered to the auxiliary boiler is used to produce steam for station and water heating. Steam can also be supplied from the auxiliary boiler for storage tank heating in cold weather.

ELECTRICAL EQUIPMENT

A 66 kV, three phase, 3 wire overhead transmission line conveys electrical power to the plant as required or receives power from the MHD channel electrical conditioning system. Transformers and switchgear supply 13.8 kV, 4.16 kV and 480 V three phase power to the electric motors dirving the various pumps and air compressors of the plant and also 110 V single phase power for lighting, instrument power supplies and other miscellaneous uses. Two 1000 kVA, 4160 V standby diesel generators are provided to supply emergency electrical power to the plant, in the event of a power failure.

SEWAGE AND WASTE HANDLING

Sewage and waste water from the plant are drained to an on-site sewage treatment plant.

The slag slurry mixture is pumped to a settling/disposal pond. Recirculation pumps are used to transport the water from the settling pond to a head tank for recirculation back to the hydraulic jet pumps of the slag slurry. Makeup water from the raw water supply is added to the head tank as required. Ash from seed regeneration in the latter configurations is mixed with the slag slurry.

FLUE GAS DESULFURIZATION SCRUBBER

The potential use of a coal fired indirect high temperature air preheater system will require the desulfurization of the combustion gases. The design of the combustion system for the indirectly fired air preheater will incorporate a recuperative air preheat system which will remove energy and reduce heat loss from this system. Downstream of this a separate ESP unit and scrubber would be incorporated ahead of the common stack.

This preheat combustion gas system will be approximately 40 percent the size of the main combustion gas effluent system. The incorporation of the additional ESP and scrubber would take place at the time that coal fired indirect air preheater system was incorporated.

References

1. Report FE-2363-3, "MHD ETF 150 MW Reference Design and Cost Report", Westinghouse Electric Corporation, Advanced Energy Systems Division, July 1, 1978.
2. Report FE-2363-2, "MHD ETF Conceptual Design", Volume III, Definition of Concepts, Westinghouse Electric Corporation, Advanced Energy Systems Division, April 1978.
3. Report FE-2613-6, "MHD-ETF Program Final Report," Volume III, Program Implementation, General Electric Space Division, for U. S. Department of Energy, Division of MHD, March 1978.

APPENDIX C

COST ESTIMATES

The cost estimates for the first four configurations used in assessing the progressive plan for the 150 MW MHD ETF are presented in the tables of this Appendix. These data are presented in the modified FTS code of accounts as previously defined for ETF use. The costs are presented in mid-1978 dollars. The breakdown of costs between major component, BOP and installation, indirect costs and contingency based upon the relationships presented in Table C-1. Estimated costs by account for Configurations 1 through 4 are given in Tables C-2 to C-5. The results are believed to represent a reasonable comparative picture of the costs of the progressive steps in the program.

For purposes of this comparison, all of the assumed costs of major equipments and systems are unchanged regardless of the year of scheduled plant constructio Since the experienced inflation rates would result in considerable escalation, the costs of those increments added at later dates in the schedule would be significantly larger than indicated in the tables.

TABLE C-1

DIRECT COSTING FACTORS BASED ON EQUIPMENT TYPE

SYSTEM	DESCRIPTION	EQUIP.	B.O.P.	INSTALL.	TOTAL DIRECT	CONTIN.
TYPE A	FIELD/SITE CONSTRUCTION AND STD. EQUIP. ERECTION	.3400	.1300	.5300	1.0000	.1000
TYPE B	MAJOR EQUIP - FIELD ERECTION	.5000	.1000	.4000	1.0000	.1000
TYPE C	MAJOR COMP. SYSTEM FIELD FABRICATION	.4500	.1000	.4500	1.0000	.2000
TYPE D	SPECIAL - DEV. EQUIP. ERECTION	.7800	.0700	.1500	1.0000	.2000
TYPE E	B.O.P. SYSTEM - INSTALL.	.0400	.5000	.4600	1.0000	.1000
TYPE F	MAJOR EQUIP. LITTLE INSTALL. NO B.O.P.	.9000	.0000	.1000	1.0000	.2000
TYPE G	MAJOR B.O.P., NO EQUIP. LITTLE INSTALL.	.0000	.9000	.1000	1.0000	.1000

TABLE C-2

150 MW - ETF CONFIGURATION 1
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
311	STRUCTURES AND IMPROVEMENTS	259.	3232.	2973.	931.	646.	8040.
311.1	IMPROVEMENTS TO SITE	45.	569.	523.	164.	114.	1414.
311.1.1	AREA LIGHTING	4.	50.	46.	14.	10.	123.
311.2	MAIN BUILDING	43.	540.	497.	156.	108.	1344.
311.3	STEAM TURBINE BUILDING	0.	0.	0.	0.	0.	0.
311.4	COAL BUNKER AND PROCESSING	15.	187.	172.	54.	37.	464.
311.5	SERVICE BUILDINGS						
311.5.1	OFFICE BUILDING						
311.5.2	SHOP BUILDING	22.	279.	257.	80.	56.	694.
311.5.3	WAREHOUSE						
311.5.4	MAINTENANCE BUILDING						
311.6	OTHER BUILDINGS						
311.6.1	WATER TREATMENT BLDG.						0.
311.6.2	SEED SYSTEM BLDG.	13.	158.	145.	46.	32.	393.
311.6.3	MHD CRYOGENIC BLDG.						
311.6.4	ACCESSORY BUILDING	100.	1248.	1148.	359.	250.	3104.
311.7	COMPRESSOR BUILDING	16.	203.	186.	58.	41.	504.

TABLE C-2 (Cont'd)

150 MW - ETF CONFIGURATION 1
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
312	BOILER PLANT EQUIPMENT	4467.	2644.	6741.	1408.	1736.	16996.
312.1	COAL HANDLING AND PROCESSING	1390.	309.	1390.	255.	618.	3962.
312.1.1	COAL UNLOADING STATION						
312.1.2	RAILROAD SIDING						
312.1.3	SCALES						
312.1.4	THAW SHED						
312.1.5	TRACK HOPPER (S)						
312.1.6	CAR PULLER						
312.1.7	OUTLET FEEDERS						
312.1.8	STOCKPILE CONVEYOR SYSTEM						
312.1.9	COAL SAMPLER						
312.1.10	F.E.L.						
312.1.11	CONVEYORS						
312.1.12	FEEDERS						
312.1.13	CHUTES						
312.1.14	GATES						
312.1.15	MAGNETIC SEPARATOR						
312.1.16	CRUSHER						
312.1.17	MECHANICAL DUST COLLECTOR						
312.1.18	FEEDER						
312.1.19	CONVEYOR						
312.1.20	COAL BUNKERS						
312.1.21	COAL TRANSFER SYSTEM						
312.2	SLAG AND ASH HANDLING EQUIPMENT						
312.2.1	COMBUSTOR SLAG REMOVAL AND DISPOSAL	59.	13.	59.	11.	26.	169.
312.2.2	HEAT EXCHANGER SYS.	51.	20.	80.	15.	15.	180.
312.2.3	ASH AND WASTE DISP. SYS. - SEP.	57.	13.	57.	10.	25.	162.
312.2.4	MAIN ASH DISPOSAL	73.	16.	73.	13.	32.	208.

TABLE C-2 (Con't)

150 MW - ETF CONFIGURATION 1
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
312.3	RADIANT BOILER SYSTEM						
312.3.1	RADIANT BOILER	0.	0.	0.	0.	0.	0.
312.3.2	PULVERIZER, MOTOR AND GRINDER						
312.3.3	CONTROLS, VALVES AND INTEG. SEP.	0.	0.	0.	0.	0.	0.
312.4	STEAM GENERATOR SECTION						
312.4.1	ECONOMIZER NO. 1						
312.4.2	ECONOMIZER NO. 2	0.	0.	0.	0.	0.	0.
312.4.3	SUPERHEATER (HX - 1)	0.	0.	0.	0.	0.	0.
312.4.4	PREHEATER (HX - 2)	0.	0.	0.	0.	0.	0.
312.4.5	SECONDARY AIR INJECTION SYS. AND FAN	0.	0.	0.	0.	0.	0.
312.4.6	MIXER COMBUSTOR CHAMBER	0.	0.	0.	0.	0.	0.
312.4.7	COMBUSTOR COOLING HEAT EXCHANGER						
312.4.8	MHD GENERATOR COOLING HEAT EXCHANGER	1032.	394.	1608.	300.	303.	3638.
312.4.9	DIFFUSER COOLING HEAT EXCHANGER						
312.4.10	PIPES, VALVES AND PUMPS	915.	350.	1426.	266.	269.	3225.
312.4.11	ASSOC. INSTRUMENTATION AND CONTR.	4.	52.	47.	15.	10.	128.
312.5	EFFLUENT CONTROL						
312.5.1	ELECTROSTATIC PRECIPITATOR	0.	0.	0.	0.	0.	0.
312.5.2	INDUCED DRAFT FAN	0.	0.	0.	0.	0.	0.
312.5.3	STACK	6.	75.	69.	22.	15.	187.
312.5.4	INSTRUMENTATION AND CONTROLS	0.	0.	0.	0.	0.	0.
312.5.5	QUENCH SYS.	96.	1198.	1102.	345.	240.	2979.
312.5.6	REVISED PIPING	0.	0.	0.	0.	0.	0.
312.6	AUXILIARY BOILER SYSTEM	118.	45.	163.	54.	35.	415.
312.7	OTHER BOILER PLANT SYSTEMS						
312.7.1	CONDENSATE SYSTEM						
312.7.2	CONDENSATE STORAGE TANK	55.	11.	44.	8.	11.	129.
312.7.3	CONDENSATE TRANSFER PUMP						

TABLE C-2 (Cont'd)

150 MW - ETF CONFIGURATION 1
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
312.7.4	L.P. FEEDWATER HEATER	0.	0.	0.	0.	0.	0.
312.7.5	FEEDWATER CHEMICAL SYSTEM	0.	0.	0.	0.	0.	0.
312.7.6	FEEDWATER PUMP AND MOTOR	0.	0.	0.	0.	0.	0.
312.7.7	AMMONIA AND HYDRAZINE	4.	2.	6.	1.	1.	14.
312.7.8	EQUIPMENT INSULATION	8.	3.	15.	2.	2.	29.
312.7.9	PIPING VALVES AND HANGERS	0.	0.	0.	0.	0.	0.
312.7.10	PLANT AIR	53.	20.	62.	15.	16.	186.
312.7.11	WATER DEMINERALIZER	85.	33.	135.	25.	25.	300.
312.7.12	RAW WATER STORAGE						
312.7.13	WATER TRANSFER PUMPS	462.	92.	370.	69.	92.	1086.
312.7.14	WATER FEED PUMPS						
312.7.15	TREATED WATER STORAGE TANKS						

TABLE C-2 (Cont'd)

150 MW - ETF CONFIGURATION 1
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
314	TURBOGENERATOR UNITS	91.	18.	73.	14.	18.	214.
314.1.1	STEAM TURBINE GENERATOR AND AUX.	0.	0.	0.	0.	0.	0.
314.1.2	D.F.M. FLUID PART OF 314.1.1	0.	0.	0.	0.	0.	0.
314.1.3	LUBE OIL STORAGE TANK	0.	0.	0.	0.	0.	0.
314.1.4	LUBE OIL PURIFIER	0.	0.	0.	0.	0.	0.
314.2	CONDENSER AND AUXILIARIES						
314.2.1	CONDENSER	0.	0.	0.	0.	0.	0.
314.2.2	CONDENSER VACUUM PUMPS	0.	0.	0.	0.	0.	0.
314.3.1	CIRCULATING WATER SYSTEM	0.	0.	0.	0.	0.	0.
314.3.2	COOLING TOWERS	91.	18.	73.	14.	18.	214.
314.4	STEAM PIPING SYSTEMS						
314.4.1	MAIN STEAM PIPING	0.	0.	0.	0.	0.	0.
314.4.2	REHEAT SUPPLU PIPING	0.	0.	0.	0.	0.	0.
314.4.3	REHEAT RETURN PIPING	0.	0.	0.	0.	0.	0.
314.4.4	EXTRACTION STEAM PIPING	0.	0.	0.	0.	0.	0.
314.4.5	BYPASS STEAM PIPING	0.	0.	0.	0.	0.	0.
314.5	OTHER TURBINE PLANT EQUIPMENT						
314.5.1	TURBINE BUILDING SUMP PUMPS	0.	0.	0.	0.	0.	0.
314.5.2	FIRE DETECTION	0.	0.	0.	0.	0.	0.
314.5.3	FIRE PROTECTION	0.	0.	0.	0.	0.	0.
314.5.4	TURBINE HALL CRANE	0.	0.	0.	0.	0.	0.
314.5.5	TURBINE HALL MISC. HOIST	0.	0.	0.	0.	0.	0.

TABLE C-2 (Cont'd)

150 MW - ETF CONFIGURATION 1
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
315	ACCESSORY ELECTRIC EQUIPMENT	127.	1591.	1464.	458.	318.	3958.
315.1	GENERATOR ACCESSORY EQUIPMENT						
315.1.1	ISO PHASE BUS DUCT						
315.1.2	D.E.H. FLUID						
315.1.3	GENERATOR PROTECTIVE RELAY						
315.2	MEDIUM VOLTAGE SWITCHGEAR						
315.3	LOW VOLTAGE SWITCHGEAR	127.	1591.	1464.	458.	318.	3958.
315.4	POWER CENTER TRANSFORMER						
315.5	M.C.C.						
315.6	BATTERIES AND CHARGER SYSTEM						
315.7	D.C. DISTRIBUTION PANELS						
315.8	POWER AND CONTROL CABLES						
315.9	INSTRUMENTATION AND CONTROL						
315.10	EMERGENCY DIESEL GENERATOR						
315.11	AUXILARY POWER TRANSFORMER						

TABLE C-2 (Cont'd)

150 MW - ETF CONFIGURATION 1
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
316.	MISCELLANEOUS POWER PLANT EQUIP.	529.	106.	425.	79.	106.	1242.
316.1	FIRE PROTECTION						
316.2	FIRE DETECTION						
316.3	HVAC						
316.4	LIGHTING SYSTEM						
316.5	PLANT GASES						
316.6	SAMPLING SYSTEM						
316.7	NO. 2 FUEL OIL STORAGE TANKS						
316.8	NO. 2 FUEL OIL TRANSFER PUMPS	529.	106.	425.	79.	106.	1242.
316.9	NO. 2 FUEL OIL FEED PUMPS						
316.10	NO. 2 FUEL OIL UNLOADING STATION						
316.11	MAINTENANCE EQUIPMENT						
316.12	INSTRUMENT STATIONS						
316.12.1	ASSOCIATED VALVES						
316.12.2	ASSOCIATED PIPING						

TABLE C-2 (Cont'd)

150 MW - ETF CONFIGURATION 1
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
317	MHD TOPPING CYCLE EQUIPMENT	59278.	4859.	14721.	2937.	15480.	97275.
317.1	COMBUSTION EQUIPMENT						
317.1.1	COAL PULVERIZER						
317.1.2	STACK GAS BLOWER						
317.1.3	COAL DRYER	7587.	0.	843.	126.	1686.	10242.
317.1.4	MECHANICAL DUST COLLECTOR						
317.1.5	COAL INJECTION SYSTEM						
317.1.6	TWO STAGE COMBUSTOR	144.	32.	144.	26.	64.	409.
317.1.7	INSULATING SUPPORT CONE	7.	1.	5.	1.	1.	15.
317.2	MHD GENERATOR SUBSYSTEM						
317.2.1	NOZZLE	17.	4.	17.	3.	8.	49.
317.2.2	GENERATOR CHANNEL	772.	69.	149.	33.	198.	1221.
317.2.3	CHANNEL OUTLET EXTENSION	63.	14.	63.	12.	28.	181.
317.2.4	DIFFUSER	1244.	112.	239.	53.	319.	1967.
317.3	MAGNET SYSTEM	35256.	3164.	6780.	1492.	9040.	55732.
317.4	INVERTERS AND ELECTRODE CONTROL						
317.4.1	MHD POWER CONDITIONING	(included in acc't 350)					
317.5	OXIDIZER PREHEATER SUBSYSTEM						
317.5.1	MAIN GAS PIPES	19.	243.	223.	70.	49.	603.
317.5.2	HTAH AND VALVES						
317.5.3	HTAH MANIFOLD	0.	0.	0.	0.	0.	0.
317.5.4	HTAH VALVE COOLANT EXCH. AND H2O CIRC						
317.5.5	LTAH	268.	54.	214.	40.	54.	629.
317.5.6	TRANSPORT GAS BOOSTER	0.	0.	0.	0.	0.	0.
317.5.7	COMBUSTOR AIR COMP. AND DRIVES	4156.	924.	4156.	762.	1847.	11844.
317.5.8	AIR COMP. TURBINE DRIVE STEAM COMP	0.	0.	0.	0.	0.	0.
317.5.9	PREHEATER AIR SUPPLY SYSTEM	(included in acc't 317.5)					
317.5.10	PREHEATER AIR HEAT						

TABLE C-2 (Cont'd)

150 MW - ETF CONFIGURATION 1
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
317.5.11	PREHEATER COMBUSTOR	(included in acc't 317.5)					
317.5.12	ASSOC. INSTRUMENTATION AND CONT.	944.	189.	755.	142.	189.	2217.
317.6	SEED SUBSYSTEM	234.	21.	45.	10.	60.	370.
317.6.1	SEED UNLOAD., ST. AND TR. TO PREP.						
317.6.2	SEED PREPARATION						
317.6.3	SEED INJECTION SYSTEM						
317.6.4	SEED REGENERATION						
317.7	OTHER MHD TOPPING CYCLE SUPT. EQUIP.						
317.7.1	COAL/GAS SEPARATOR	0.	0.	0.	0.	0.	0.
317.7.2	OXYGEN PLANT	8415.	0.	935.	140.	1870.	11360.
317.7.3	HELIUM MAKE - UP	0.	0.	0.	0.	0.	0.
317.7.4	NITROGEN UNLOADING	0.	0.	0.	0.	0.	0.
317.7.5	MHD COMPONENT COOLING SYS.	153.	34.	153.	28.	68.	436.
317.8	MISC. MHD TOPPING CYC. SUP. EQUIP.	0.	0.	0.	0.	0.	0.

TABLE C-2 (Cont'd)

150 MW - ETF CONFIGURATION 1
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
518	RESEARCH EQUIPMENT						
518.1	INSTRUMENTED GENERAL CHANNEL	0.	0.	0.	0.	0.	0.

TABLE C-2 (Cont'd)

150 MW - ETF CONFIGURATION 1
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
319	SIMULATION EQUIPMENT						
319.1	STEAM PLANT SIMULATOR EQUIP.	0.	0.	0.	0.	0.	0.

TABLE C-2 (Cont'd)

150 MW - ETF CONFIGURATION 1
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
350	TRANSMISSION PLANT EQUIPMENT	5816.	706.	1286.	299.	1525.	9631.
350.1	MAIN POWER TRANSFORMERS	1387.	124.	267.	59.	356.	2192.
350.2	STATION AUXILIARY TRANSFORMER						
350.3	UNIT AUXILIARY TRANSFORMER						
350.4	TRANSFORMER OIL						
350.5	SWITCHYARD STRUCTURAL CONST.	15.	185.	170.	55.	37.	460.
350.6	MHD POWER CONDITIONING	4415.	396.	849.	187.	1132.	6979.

TABLE C-2 (Cont'd)

150 MW - ETF CONFIGURATION 1
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MATERIAL COST MJR. COMP.	MATERIAL COST BOP	INSTALL. COST	INDIR. COST	CONTIN.	TOTAL COST
311	STRUCTURES AND IMPROVEMENTS	259.	3232.	2973.	931.	646.	8040.
312	BOILER PLANT EQUIPMENT	4467.	2644.	6741.	1408.	1736.	16996.
314	TURBOGENERATOR UNITS	94.	18.	75.	14.	18.	214.
315	ACCESSORY ELECTRIC EQUIPMENT	127.	1591.	1464.	456.	316.	3958.
316	MISCELLANEOUS POWER PLANT EQUIP.	520.	106.	425.	79.	106.	1242.
317	MHD TOPPING CYCLE EQUIPMENT	59278.	4859.	14721.	2937.	15480.	97275.
318	RESEARCH EQUIPMENT	0.	0.	0.	0.	0.	0.
319	SIMULATION EQUIPMENT	0.	0.	0.	0.	0.	0.
350	TRANSMISSION PLANT EQUIPMENT	5816.	706.	1286.	299.	1525.	9631.
	SUBTOTALS	70566.	13156.	27660.	6125.	19829.	137356.
	ENGINEERING SERVICES *	8468.	1052.	2214.		1586.	13321.
	OTHER COST **						9615.
	TOTAL CONSTRUCTION COSTS ($1,000"S)	79034.	14208.	29894.	6125.	21415.	160292.

NOTES - (*) AT 6 PER CENT OF A AND E COSTS AND 12 PER CENT OF CONTRACTOR MAJOR EQUIPMENT COST
(**) AT 7 PER CENT OF TOTAL COSTS

ALL COSTS IN $1,000"S.
ALL COSTS 1978-1/2 DOLLARS.

TABLE C-3

150 MW - ETF CONFIGURATION 2
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
311	STRUCTURES AND IMPROVEMENTS						
311.1	IMPROVEMENTS TO SITE	0.	0.	0.	0.	0.	0.
311.1.1	AREA LIGHTING	0.	0.	0.	0.	0.	0.
311.2	MAIN BUILDING	0.	0.	0.	0.	0.	0.
311.3	STEAM TURBINE BUILDING	0.	0.	0.	0.	0.	0.
311.4	COAL BUNKER AND PROCESSING	0.	0.	0.	0.	0.	0.
311.5	SERVICE BUILDINGS						
311.5.1	OFFICE BUILDING	0.	0	0.	0.	0.	0.
311.5.2	SHOP BUILDING						
311.5.3	WAREHOUSE						
311.5.4	MAINTENANCE BUILDING						
311.6	OTHER BUILDINGS						
311.6.1	WATER TREATMENT BLDG.	0.	0.	0.	0.	0.	0.
311.6.2	SEED SYSTEM BLDG.						
311.6.3	MHD CRYOGENIC BLDG.						
311.6.4	ACCESSORY BUILDING	0.	0.	0.	0.	0.	0.
311.7	COMPRESSOR BUILDING	0.	0.	0.	0.	0.	0.

TABLE C-3 (Cont'd)

150 MW - ETF CONFIGURATION 2
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
312	BOILER PLANT EQUIPMENT						
312.1	COAL HANDLING AND PROCESSING	0.	0.	0.	0.	0.	0.
312.1.1	COAL UNLOADING STATION						
312.1.2	RAILROAD SIDING						
312.1.3	SCALES						
312.1.4	THAW SHED						
312.1.5	TRACK HOPPER (S)						
312.1.6	CAR PULLER						
312.1.7	OUTLET FEEDERS						
312.1.8	STOCKPILE CONVEYOR SYSTEM						
312.1.9	COAL SAMPLER						
312.1.10	F.E.L.						
312.1.11	CONVEYORS						
312.1.12	FEEDERS						
312.1.13	CHUTES						
312.1.14	GATES						
312.1.15	MAGNETIC SEPARATOR						
312.1.16	CRUSHER						
312.1.17	MECHANICAL DUST COLLECTOR						
312.1.18	FEEDER						
312.1.19	CONVEYOR						
312.1.20	COAL BUNKERS						
312.1.21	COAL TRANSFER SYSTEM						
312.2	SLAG AND ASH HANDLING EQUIPMENT						
312.2.1	COMBUSTOR SLAG REMOVAL AND DISPOSAL	0.	0.	0.	0.	0.	0.
312.2.2	HEAT EXCHANGER SYS.	0.	0.	0.	0.	0.	0.
312.2.3	ASH AND WASTE DISP. SYS. - SEP.	0.	0.	0.	0.	0.	0.
312.2.4	MAIN ASH DISPOSAL	0.	0.	0.	0.	0.	0.

TABLE C-3 (Cont'd)

150 MW - ETF CONFIGURATION 2
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
312.3	RADIANT BOILER SYSTEM						
312.3.1	RADIANT BOILER	0.	0.	0.	0.	0.	0.
312.3.2	PULVERIZER, MOTOR AND GRINDER	0.	0.	0.	0.	0.	0.
312.3.3	CONTROLS, VALVES AND INTEG. SEP.						
312.4	STEAM GENERATOR SECTION						
312.4.1	ECONOMIZER NO. 1						
312.4.2	ECONOMIZER NO. 2						
312.4.3	SUPERHEATER (HX - 1)	0.	0.	0.	0.	0.	0.
312.4.4	PREHEATER (HX - 2)	0.	0.	0.	0.	0.	0.
312.4.5	SECONDARY AIR INJECTION SYS. AND FAN	0.	0.	0.	0.	0.	0.
312.4.6	MIXER COMBUSTOR CHAMBER	0.	0.	0.	0.	0.	0.
312.4.7	COMBUSTOR COOLING HEAT EXCHANGER						
312.4.8	MHD GENERATOR COOLING HEAT EXCHANGER	0.	0.	0.	0.	0.	0.
312.4.9	DIFFUSER COOLING HEAT EXCHANGER						
312.4.10	PIPES, VALVES AND PUMPS	0.	0.	0.	0.	0.	0.
312.4.11	ASSOC. INSTRUMENTATION AND CONTR.	0.	0.	0.	0.	0.	0.
312.5	EFFLUENT CONTROL						
312.5.1	ELECTROSTATIC PRECIPITATOR	0.	0.	0.	0.	0.	0.
312.5.2	INDUCED DRAFT FAN	0.	0.	0.	0.	0.	0.
312.5.3	STACK	0.	0.	0.	0.	0.	0.
312.5.4	INSTRUMENTATION AND CONTROLS	0.	0.	0.	0.	0.	0.
312.5.5	QUENCH SYS.	0.	0.	0.	0.	0.	0.
312.5.6	REVISED PIPING	0.	0.	0.	0.	0.	0.
312.6	AUXILIARY BOILER SYSTEM	0.	0.	0.	0.	0.	0.
312.7	OTHER BOILER PLANT SYSTEMS						
312.7.1	CONDENSATE SYSTEM						
312.7.2	CONDENSATE STORAGE TANK	0.	0.	0.	0.	0.	0.
312.7.3	CONDENSATE TRANSFER PUMP						

TABLE C-3 (Cont'd)

150 MW - ETF CONFIGURATION 2
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
312.7.4	L.P. FEEDWATER HEATER	0.	0.	0.	0.	0.	0.
312.7.5	FEEDWATER CHEMICAL SYSTEM	0.	0.	0.	0.	0.	0.
312.7.6	FEEDWATER PUMP AND MOTOR	0.	0.	0.	0.	0.	0.
312.7.7	AMMONIA AND HYDRAZINE	0.	0.	0.	0.	0.	0.
312.7.8	EQUIPMENT INSULATION	0.	0.	0.	0.	0.	0.
312.7.9	PIPING VALVES AND HANGERS	0.	0.	0.	0.	0.	0.
312.7.10	PLANT AIR	0.	0.	0.	0.	0.	0.
312.7.11	WATER DEMINERALIZER	0.	0.	0.	0.	0.	0.
312.7.12	RAW WATER STORAGE	0.	0.	0.	0.	0.	0.
312.7.13	WATER TRANSFER PUMPS						
312.7.14	WATER FEED PUMPS						
312.7.15	TREATED WATER STORAGE TANKS						

TABLE C-3 (Cont'd)

150 MW - ETF CONFIGURATION 2
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
314	TURBOGENERATOR UNITS						
314.1.1	STEAM TURBINE GENERATOR AND AUX.	0.	0.	0.	0.	0.	0.
314.1.2	D.E.H. FLUID PART OF 314.1.1	0.	0.	0.	0.	0.	0.
314.1.3	LUBE OIL STORAGE TANK	0.	0.	0.	0.	0.	0.
314.1.4	LUBE OIL PURIFIER	0.	0.	0.	0.	0.	0.
314.2	CONDENSER AND AUXILIARIES						
314.2.1	CONDENSER	0.	0.	0.	0.	0.	0.
314.2.2	CONDENSER VACUUM PUMPS	0.	0.	0.	0.	0.	0.
314.3.1	CIRCULATING WATER SYSTEM	0.	0.	0.	0.	0.	0.
314.3.2	COOLING TOWERS	0.	0.	0.	0.	0.	0.
314.4	STEAM PIPING SYSTEMS						
314.4.1	MAIN STEAM PIPING	0.	0.	0.	0.	0.	0.
314.4.2	REHEAT SUPPLY PIPING	0.	0.	0.	0.	0.	0.
314.4.3	REHEAT RETURN PIPING	0.	0.	0.	0.	0.	0.
314.4.4	EXTRACTION STEAM PIPING	0.	0.	0.	0.	0.	0.
314.4.5	BYPASS STEAM PIPING	0.	0.	0.	0.	0.	0.
314.5	OTHER TURBINE PLANT EQUIPMENT						
314.5.1	TURBINE BUILDING SUMP PUMPS	0.	0.	0.	0.	0.	0.
314.5.2	FIRE DETECTION	0.	0.	0.	0.	0.	0.
314.5.3	FIRE PROTECTION	0.	0.	0.	0.	0.	0.
314.5.4	TURBINE HALL CRANE	0.	0.	0.	0.	0.	0.
314.5.5	TURBINE HALL MISC. HOIST	0.	0.	0.	0.	0.	0.

TABLE C-3 (Cont'd)

150 MW - ETF CONFIGURATION 2
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
315	ACCESSORY ELECTRIC EQUIPMENT						
315.1	GENERATOR ACCESSORY EQUIPMENT	0.	0.	0.	0.	0.	0.
315.1.1	ISO PHASE BUS DUCT						
315.1.2	D.E.H. FLUID						
315.1.3	GENERATOR PROTECTIVE RELAY						
315.2	MEDIUM VOLTAGE SWITCHGEAR						
315.3	LOW VOLTAGE SWITCHGEAR						
315.4	POWER CENTER TRANSFORMER						
315.5	M.C.C.						
315.6	BATTERIES AND CHARGER SYSTEM						
315.7	D.C. DISTRIBUTION PANELS						
315.8	POWER AND CONTROL CABLES						
315.9	INSTRUMENTATOR AND CONTROL						
315.10	EMERGENCY DIESEL GENERATOR						
315.11	AUXILARY POWER TRANSFORMER						

TABLE C-3 (Cont'd)

150 MW - ETF CONFIGURATION 2
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
316	MISCELLANEOUS POWER PLANT EQUIP.						
316.1	FIRE PROTECTION	0.	0.	0.	0.	0.	0.
316.2	FIRE DETECTION						
316.3	HVAC						
316.4	LIGHTING SYSTEM						
316.5	PLANT GASES						
316.6	SAMPLING SYSTEM						
316.7	NO. 2 FUEL OIL STORAGE TANKS						
316.8	NO. 2 FUEL OIL TRANSFER PUMPS						
316.9	NO. 2 FUEL OIL FEED PUMPS						
316.10	NO. 2 FUEL OIL UNLOADING STATION						
316.11	MAINTENANCE EQUIPMENT						
316.12	INSTRUMENT STATIONS						
316.12.1	ASSOCIATED VALVES						
316.12.2	ASSOCIATED PIPING						

TABLE C-3 (Cont'd)

150 MW - ETF CONFIGURATION 2
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
317	MHD TOPPING CYCLE EQUIPMENT	5327.	1755.	5280.	1055.	2335.	15752.
317.1	COMBUSTION EQUIPMENT	0.	0.	0.	0.	0.	0.
317.1.1	COAL PULVERIZER						
317.1.2	STACK GAS BLOWER						
317.1.3	COAL DRYER						
317.1.4	MECHANICAL DUST COLLECTOR						
317.1.5	COAL INJECTION SYSTEM						
317.1.6	TWO STAGE COMBUSTOR	0.	0.	0.	0.	0.	0.
317.1.7	INSULATING SUPPORT CONE	0.	0.	0.	0.	0.	0.
317.2	MHD GENERATOR SUBSYSTEM						
317.2.1	NOZZLE	0.	0.	0.	0.	0.	0.
317.2.2	GENERATOR CHANNEL	772.	69.	149.	33.	198.	1221.
317.2.3	CHANNEL OUTLET EXTENSION	0.	0.	0.	0.	0.	0.
317.2.4	DIFFUSER	0.	0.	0.	0.	0.	0.
317.3	MAGNET SYSTEM	0.	0.	0.	0.	0.	0.
317.4	INVERTERS AND ELECTRODE CONTROL	(included in acc't 350)					
317.4.1	MHD POWER CONDITIONING						
317.5	OXIDIZER PREHEATER SUBSYSTEM						
317.5.1	MAIN GAS PIPES	55.	686.	631.	198.	137.	1707.
317.5.2	HTAH AND VALVES	3240.	720.	3240.	594.	1440.	9234.
317.5.3	HTAH MANIFOLD						
317.5.4	HTAH VALVE COOLANT EXCH. AND H2O CIRC						
317.5.5	LTAH	0.	0.	0.	0.	0.	0.
317.5.6	TRANSPORT GAS BOOSTER	0.	0.	0.	0.	0.	0.
317.5.7	COMBUSTOR AIR COMP. AND DRIVES	1260.	280.	1260.	231.	560.	3591.
317.5.8	AIR COMP. TURBINE DRIVE STEAM COMP.	0.	0.	0.	0.	0.	0.
317.5.9	PREHEATER AIR SUPPLY SYSTEM	(included in acc't 317.5)					
317.5.10	PREHEATER AIR HEAT						

TABLE C-3 (Cont'd)

150 MW - ETF CONFIGURATION 2
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
317.5.11	PREHEATER COMBUSTOR	(included in acc't 317.5)					
317.5.12	ASSOC. INSTRUMENTATION AND CONT.	0.	0.	0.	0.	0.	0.
317.6	SEED SUBSYSTEM						
317.6.1	SEED UNLOAD., ST. AND TR. TO PREP.						
317.6.2	SEED PREPARATION	0.	0.	0.	0.	0.	0.
317.6.3	SEED INJECTION SYSTEM					0.	0.
317.6.4	SEED REGENERATION					0.	0.
317.7	OTHER MHD TOPPING CYCLE SUPT. EQUIP.					0.	0.
317.7.1	COAL/GAS SEPARATOR	0.	0.	0.	0.	0.	0.
317.7.2	OXYGEN PLANT	0.	0.	0.	0.	0.	0.
317.7.3	HELIUM MAKE - UP	0.	0.	0.	0.	0.	0.
317.7.4	NITROGEN UNLOADING	0.	0.	0.	0.	0.	0.
317.7.5	MHD COMPONENT COOLING SYS.	0.	0.	0.	0.	0.	0.
317.8	MISC. MHD TOPPING CYC. SUP. EQUIP.	0.	0.	0.	0.	0.	0.

TABLE C-3 (Cont'd)

150 MW - ETF CONFIGURATION 2
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
318	RESEARCH EQUIPMENT						
318.1	INSTRUMENTED GENERAL CHANNEL	0.	0.	0.	0.	0.	0.

TABLE C-3 (Cont'd)

150 MW - ETF CONFIGURATION 2
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
319	SIMULATION EQUIPMENT						
319.1	STEAM PLANT SIMULATOR EQUIP.	0.	0.	0.	0.	0.	0.

TABLE C-3 (Cont'd)

150 MW - ETF CONFIGURATION 2
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
550	TRANSMISSION PLANT EQUIPMENT						
550.1	MAIN POWER TRANSFORMERS	0.	0.	0.	0.	0.	0.
550.2	STATION AUXILIARY TRANSFORMER						
550.3	UNIT AUXILIARY TRANSFORMER						
550.4	TRANSFORMER OIL						
550.5	SWITCHYARD STRUCTURAL CONST	0.	0.	0.	0.	0.	0.
550.6	MHD POWER CONDITIONING	0.	0.	0.	0.	0.	0.

TABLE C-3 (Cont'd)

150 MW - ETF CONFIGURATION 2
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MATERIAL COST MJR. COMP.	MATERIAL COST BUP	INSTALL. COST	INDIR. COST	CONTIN.	TOTAL COST
311	STRUCTURES AND IMPROVEMENTS	0.	0.	0.	0.	0.	0.
312	BOILER PLANT EQUIPMENT	0.	0.	0.	0.	0.	0.
314	TURBOGENERATOR UNITS	0.	0.	0.	0.	0.	0.
315	ACCESSORY ELECTRIC EQUIPMENT	0.	0.	0.	0.	0.	0.
316	MISCELLANEOUS POWER PLANT EQUIP.	0.	0.	0.	0.	0.	0.
317	MHD TOPPING CYCLE EQUIPMENT	5327.	1755.	5280.	1055.	2335.	15752.
318	RESEARCH EQUIPMENT	0.	0.	0.	0.	0.	0.
319	SIMULATION EQUIPMENT	0.	0.	0.	0.	0.	0.
350	TRANSMISSION PLANT EQUIPMENT	0.	0.	0.	0.	0.	0.
	SUBTOTALS	5327.	1755.	5280.	1055.	2335.	15752.
	ENGINEERING SERVICES *	639.	140.	422.		187.	1389.
	OTHER COST **						1103.
	TOTAL CONSTRUCTION COSTS ($1,000"S)	5966.	1896.	5702.	1055.	2522.	18244.

NOTES - (*) AT 8 PER CENT OF A AND E COSTS AND 12 PER CENT OF CONTRACTOR MAJOR EQUIPMENT COST
(**) AT 7 PER CENT OF TOTAL COSTS

ALL COSTS IN $1,000"S.
ALL COSTS 1978-1/2 DOLLARS.

TABLE C-4

150 MW - ETF CONFIGURATION 3
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
311	STRUCTURES AND IMPROVEMENTS						
311.1	IMPROVEMENTS TO SITE	0.	0.	0.	0.	0.	0.
311.1.1	AREA LIGHTING	0.	0.	0.	0.	0.	0.
311.2	MAIN BUILDING	0.	0.	0.	0.	0.	0.
311.3	STEAM TURBINE BUILDING	0.	0.	0.	0.	0.	0.
311.4	COAL BUNKER AND PROCESSING	0.	0.	0.	0.	0.	0.
311.5	SERVICE BUILDINGS						
311.5.1	OFFICE BUILDING	0.	0.	0.	0.	0.	0
311.5.2	SHOP BUILDING						
311.5.3	WAREHOUSE						
311.5.4	MAINTENANCE BUILDING						
311.6	OTHER BUILDINGS						
311.6.1	WATER TREATMENT BLDG.	0.	0.	0.	0.	0.	0.
311.6.2	SEED SYSTEM BLDG.						
311.6.3	MHD CRYOGENIC BLDG.						
311.6.4	ACCESSORY BUILDING	0.	0.	0.	0.	0.	0.
311.7	COMPRESSOR BUILDING	0.	0.	0.	0.	0.	0.

TABLE C-4 (Cont'd)

150 MW - ETF CONFIGURATION 3
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
312.	BOILER PLANT EQUIPMENT	3482.	742.	3117.	579.	1026.	8946.
312.1	COAL HANDLING AND PROCESSING	0.	0.	0.	0.	0.	0.
312.1.1	COAL UNLOADING STATION						
312.1.2	RAILROAD SIDING						
312.1.3	SCALES						
312.1.4	THAW SHED						
312.1.5	TRACK HOPPER (S)						
312.1.6	CAR PULLER						
312.1.7	OUTLET FEEDERS						
312.1.8	STOCKPILE CONVEYOR SYSTEM						
312.1.9	COAL SAMPLER						
312.1.10	F.E.L.						
312.1.11	CONVEYORS						
312.1.12	FEEDERS						
312.1.13	CHUTES						
312.1.14	GATES						
312.1.15	MAGNETIC SEPARATOR						
312.1.16	CRUSHER						
312.1.17	MECHANICAL DUST COLLECTOR						
312.1.18	FEEDER						
312.1.19	CONVEYOR						
312.1.20	COAL BUNKERS						
312.1.21	COAL TRANSFER SYSTEM						
312.2	SLAG AND ASH HANDLING EQUIPMENT						
312.2.1	COMBUSTOR SLAG REMOVAL AND DISPOSAL	0.	0.	0.	0.	0.	0.
312.2.2	HEAT EXCHANGER SYS.	0.	0.	0.	0.	0.	0.
312.2.3	ASH AND WASTE DISP. SYS. - SEP.	0.	0.	0.	0.	0.	0.
312.2.4	MAIN ASH DISPOSAL	0.	0.	0.	0.	0.	0.

TABLE C-4 (Cont'd)

150 MW - ETF CONFIGURATION 3
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
312.3	RADIANT BOILER SYSTEM						
312.3.1	RADIANT BOILER	1312.	292.	1312.	241.	583.	3740.
312.3.2	PULVERIZER, MOTOR AND GRINDER	729.	146.	583.	109.	146.	1713.
312.3.3	CONTROLS, VALVES AND INTEG. SEP.						
312.4	STEAM GENERATOR SECTION						
312.4.1	ECONOMIZER NO. 1	0.	0.	0.	0.	0.	0.
312.4.2	ECONOMIZER NO. 2						
312.4.3	SUPERHEATER (HX = 1)	544.	109.	435.	82.	109.	1277.
312.4.4	PREHEATER (HX = 2)	805.	161.	644.	121.	161.	1892.
312.4.5	SECONDARY AIR INJECTION SYS. AND FAN	0.	0.	0.	0.	0.	0.
312.4.6	MIXER COMBUSTOR CHAMBER	0.	0.	0.	0.	0.	0.
312.4.7	COMBUSTOR COOLING HEAT EXCHANGER	0.	0.	0.	0.	0.	0.
312.4.8	MHD GENERATOR COOLING HEAT EXCHANGER						
312.4.9	DIFFUSER COOLING HEAT EXCHANGER						
312.4.10	PIPES, VALVES AND PUMPS	0.	0.	0.	0.	0.	0.
312.4.11	ASSOC. INSTRUMENTATION AND CONTR.	0.	0.	0.	0.	0.	0.
312.5	EFFLUENT CONTROL						
312.5.1	ELECTROSTATIC PRECIPITATOR	0.	0.	0.	0.	0.	0.
312.5.2	INDUCED DRAFT FAN	0.	0.	0.	0.	0.	0.
312.5.3	STACK	0.	0.	0.	0.	0.	0.
312.5.4	INSTRUMENTATION AND CONTROLS	0.	0.	0.	0.	0.	0.
312.5.5	QUENCH SYS.	0.	0.	0.	0.	0.	0.
312.5.6	REVISED PIPING	92.	35.	143.	27.	27.	324.
312.6	AUXILIARY BOILER SYSTEM	0.	0.	0.	0.	0.	0.
312.7	OTHER BOILER PLANT SYSTEMS						
312.7.1	CONDENSATE SYSTEM	0.	0.	0.	0.	0.	0.
312.7.2	CONDENSATE STORAGE TANK						
312.7.3	CONDENSATE TRANSFER PUMP						

TABLE C-4 (Cont'd)

150 MW - ETF CONFIGURATION 3
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
312.7.4	L.P. FEEDWATER HEATER	0.	0.	0.	0.	0.	0.
312.7.5	FEEDWATER CHEMICAL SYSTEM	0.	0.	0.	0.	0.	0.
312.7.6	FEEDWATER PUMP AND MOTOR	0.	0.	0.	0.	0.	0.
312.7.7	AMMONIA AND HYDROZINE	0.	0.	0.	0.	0.	0.
312.7.8	EQUIPMENT INSULATION	0.	0.	0.	0.	0.	0.
312.7.9	PIPING VALVES AND HANGERS	0.	0.	0.	0.	0.	0.
312.7.10	PLANT AIR	0.	0.	0.	0.	0.	0.
312.7.11	WATER DEMINERALIZER	0.	0.	0.	0.	0.	0.
312.7.12	RAW WATER STORAGE	0.	0.	0.	0.	0.	0.
312.7.13	WATER TRANSFER PUMPS						
312.7.14	WATER FEED PUMPS						
312.7.15	TREATED WATER STORAGE TANKS						

TABLE C-4 (Cont'd)

150 MW - ETF CONFIGURATION 3
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
314	TURBOGENERATOR UNITS	421.	84.	337.	63.	84.	989.
314.1.1	STEAM TURBINE GENERATOR AND AUX.	0.	0.	0.	0.	0.	0.
314.1.2	D.E.H. FLUID PART OF 314.1.1	0.	0.	0.	0.	0.	0.
314.1.3	LUBE OIL STORAGE TANK	0.	0.	0.	0.	0.	0.
314.1.4	LUBE OIL PURIFIER	0.	0.	0.	0.	0.	0.
314.2	CONDENSER AND AUXILIARIES						
314.2.1	CONDENSER	0.	0.	0.	0.	0.	0.
314.2.2	CONDENSER VACUUM PUMPS	0.	0.	0.	0.	0.	0.
314.3.1	CIRCULATING WATER SYSTEM	0.	0.	0.	0.	0.	0.
314.3.2	COOLING TOWERS	421.	84.	337.	63.	84.	989.
314.4	STEAM PIPING SYSTEMS						
314.4.1	MAIN STEAM PIPING	0.	0.	0.	0.	0.	0.
314.4.2	REHEAT SUPPLU PIPING	0.	0.	0.	0.	0.	0.
314.4.3	REHEAT RETURN PIPING	0.	0.	0.	0.	0.	0.
314.4.4	EXTRACTION STEAM PIPING	0.	0.	0.	0.	0.	0.
314.4.5	BYPASS STEAM PIPING	0.	0.	0.	0.	0.	0.
314.5	OTHER TURBINE PLANT EQUIPMENT						
314.5.1	TURBINE BUILDING SUMP PUMPS	0.	0.	0.	0.	0.	0.
314.5.2	FIRE DETECTION	0.	0.	0.	0.	0.	0.
314.5.3	FIRE PROTECTION						
314.5.4	TURBINE HALL CRANE						
314.5.5	TURBINE HALL MISC. HOIST						

TABLE C-4 (Cont'd)

150 MW - ETF CONFIGURATION 3
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
315	ACCESSORY ELECTRIC EQUIPMENT	0.	0.	0.	0.	0.	0.
315.1	GENERATOR ACCESSORY EQUIPMENT						
315.1.1	ISO PHASE BUS DUCT						
315.1.2	D.E.H. FLUID						
315.1.3	GENERATOR PROTECTIVE RELAY						
315.2	MEDIUM VOLTAGE SWITCHGEAR						
315.3	LOW VOLTAGE SWITCHGEAR						
315.4	POWER CENTER TRANSFORMER						
315.5	M.C.C.						
315.6	BATTERIES AND CHARGER SYSTEM						
315.7	D.C. DISTRIBUTION PANELS						
315.8	POWER AND CONTROL CABLES						
315.9	INSTRUMENTATOR AND CONTROL						
315.10	EMERGENCY DIESEL GENERATOR						
315.11	AUXILARY POWER TRANSFORMER						

TABLE C-4 (Cont'd)

150 MW - ETF CONFIGURATION 3
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
316	MISCELLANEOUS POWER PLANT EQUIP.						
316.1	FIRE PROTECTION	0.	0.	0.	0.	0.	0.
316.2	FIRE DETECTION						
316.3	HVAC						
316.4	LIGHTING SYSTEM						
316.5	PLANT GASES						
316.6	SAMPLING SYSTEM						
316.7	NO. 2 FUEL OIL STORAGE TANKS						
316.8	NO. 2 FUEL OIL TRANSFER PUMPS						
316.9	NO. 2 FUEL OIL FEED PUMPS						
316.10	NO. 2 FUEL OIL UNLOADING STATION						
316.11	MAINTENANCE EQUIPMENT						
316.12	INSTRUMENT STATIONS						
316.12.1	ASSOCIATED VALVES						
316.12.2	ASSOCIATED PIPING						

TABLE C-4 (Cont'd)

150 MW - ETF CONFIGURATION 3
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
317	MHD TOPPING CYCLE EQUIPMENT	823.	703.	731.	215.	325.	2797.
317.1	COMBUSTION EQUIPMENT	0.	0.	0.	0.	0.	0.
317.1.1	COAL PULVERIZER						
317.1.2	STACK GAS BLOWER						
317.1.3	COAL DRYER						
317.1.4	MECHANICAL DUST COLLECTOR						
317.1.5	COAL INJECTION SYSTEM						
317.1.6	TWO STAGE COMBUSTOR	0.	0.	0.	0.	0.	0.
317.1.7	INSULATING SUPPORT CONE	0.	0.	0.	0.	0.	0.
317.2	MHD GENERATOR SUBSYSTEM						
317.2.1	NOZZLE	0.	0.	0.	0.	0.	0.
317.2.2	GENERATOR CHANNEL	772.	69.	149.	33.	198.	1221.
317.2.3	CHANNEL OUTLET EXTENSION	0.	0.	0.	0.	0.	0.
317.2.4	DIFFUSER	0.	0.	0.	0.	0.	0.
317.3	MAGNET SYSTEM	0.	0.	0.	0.	0.	0.
317.4	INVERTERS AND ELECTRODE CONTROL	(included in acc't 350)					
317.4.1	MHD POWER CONDITIONING						
317.5	OXIDIZER PREHEATER SUBSYSTEM						
317.5.1	MAIN GAS PIPES	51.	634.	583.	182.	127.	1576.
317.5.2	HTAH AND VALVES	0.	0.	0.	0.	0.	0.
317.5.3	HTAH MANIFOLD						
317.5.4	HTAH VALVE COOLANT EXCH. AND H2O CIRC						
317.5.5	LTAH	0.	0.	0.	0.	0.	0.
317.5.6	TRANSPORT GAS BOOSTER	0.	0.	0.	0.	0.	0.
317.5.7	COMBUSTOR AIR COMP. AND DRIVES	0.	0.	0.	0.	0.	0.
317.5.8	AIR COMP. TURBINE DRIVE STEAM COMP.	0.	0.	0.	0.	0.	0.
317.5.9	PREHEATER AIR SUPPLY SYSTEM	(included in acc't 317.5)					
317.5.10	PREHEATER AIR HEAT						

TABLE C-4 (Cont'd)

150 MW - ETF CONFIGURATION 3
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
317.5.11	PREHEATER COMBUSTOR	(included in acc't 317.5)					
317.5.12	ASSOC. INSTRUMENTATION AND CONT.	0.	0.	0.	0.	0.	0.
317.6	SEED SUBSYSTEM						
317.6.1	SEED UNLOAD., ST. AND TR. TO PREP.	0.	0.	0.	0.	0.	0.
317.6.2	SEED PREPARATION						
317.6.3	SEED INJECTION SYSTEM						
317.6.4	SEED REGENERATION						
317.7	OTHER MHD TOPPING CYCLE SUPT. EQUIP.						
317.7.1	COAL/GAS SEPARATOR	0.	0.	0.	0.	0.	0.
317.7.2	OXYGEN PLANT	0.	0.	0.	0.	0.	0.
317.7.3	HELIUM MAKE - UP	0.	0.	0.	0.	0.	0.
317.7.4	NITROGEN UNLOADING	0.	0.	0.	0.	0.	0.
317.7.5	MHD COMPONENT COOLING SYS.	0.	0.	0.	0.	0.	0.
317.8	MISC. MHD TOPPING CYC. SUP. EQUIP.	0.	0.	0.	0.	0.	0.

TABLE C-4 (Cont'd)

150 MW - ETF CONFIGURATION 3
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
318	RESEARCH EQUIPMENT						
318.1	INSTRUMENTED GENERAL CHANNEL	0.	0.	0.	0.	0.	0.

TABLE C-4 (Cont'd)

150 MW - ETF CONFIGURATION 3
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
319	SIMULATION EQUIPMENT						
319.1	STEAM PLANT SIMULATOR EQUIP.	0.	0.	0.	0.	0.	0.

TABLE C-4 (Cont'd)

150 MW - ETF CONFIGURATION 3
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
350	TRANSMISSION PLANT EQUIPMENT						
350.1	MAIN POWER TRANSFORMERS	0.	0.	0.	0.	0.	0.
350.2	STATION AUXILIARY TRANSFORMER						
350.3	UNIT AUXILIARY TRANSFORMER						
350.4	TRANSFORMER OIL						
350.5	SWITCHYARD STRUCTURAL CONST.	0.	0.	0.	0.	0.	0.
350.6	MHD POWER CONDITIONING	0.	0.	0.	0.	0.	0.

TABLE C-4 (Cont'd)

150 MW - ETF CONFIGURATION 3
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MATERIAL COST MJR. COMP.	MATERIAL COST BOP	INSTALL. COST	INDIR. COST	CONTIN.	TOTAL COST
311	STRUCTURES AND IMPROVEMENTS	0.	0.	0.	0.	0.	0.
312	BOILER PLANT EQUIPMENT	3482.	742.	3117.	579.	[illegible]	8946.
314	TURBOGENERATOR UNITS	421.	84.	337.	63.	84.	989.
315	ACCESSORY ELECTRIC EQUIPMENT	0.	0.	0.	0.	0.	0
316	MISCELLANEOUS POWER PLANT EQUIP.	0.	0.	0.	0.	0.	0
317	MHD TOPPING CYCLE EQUIPMENT	823.	703.	731.	215.	325.	2797.
318	RESEARCH EQUIPMENT	0.	0.	0.	0.	0.	0.
319	SIMULATION EQUIPMENT	0.	0.	0.	0.	0.	0.
350	TRANSMISSION PLANT EQUIPMENT	0.	0.	0.	0.	0.	0.
	SUBTOTALS	4725.	1529.	4185.	857.	1435.	12732.
	ENGINEERING SERVICES *	567.	122.	335.		115.	1139.
	OTHER COST **						891.
	TOTAL CONSTRUCTION COSTS ($1,000"S)	5292.	1652.	4520.	857.	1549.	14762.

NOTES - (*) AT 8 PER CENT OF A AND E COSTS AND 12 PER CENT OF CONTRACTOR MAJOR EQUIPMENT COST
(**) AT 7 PER CENT OF TOTAL COSTS

ALL COSTS IN $1,000"S.
ALL COSTS 1978-1/2 DOLLARS.

TABLE C-5

150 MW - ETF CONFIGURATION 4
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
311	STRUCTURES AND IMPROVEMENTS						
311.1	IMPROVEMENTS TO SITE	0.	0.	0.	0.	0.	0.
311.1.1	AREA LIGHTING	0.	0.	0.	0.	0.	0.
311.2	MAIN BUILDING	0.	0.	0.	0.	0.	0.
311.3	STEAM TURBINE BUILDING	0.	0.	0.	0.	0.	0.
311.4	COAL BUNKER AND PROCESSING	0.	0.	0.	0.	0.	0.
311.5	SERVICE BUILDINGS						
311.5.1	OFFICE BUILDING						
311.5.2	SHOP BUILDING	0.	0.	0.	0.	0.	0.
311.5.3	WAREHOUSE						
311.5.4	MAINTENANCE BUILDING						
311.6	OTHER BUILDINGS						
311.6.1	WATER TREATMENT BLDG.						
311.6.2	SEED SYSTEM BLDG.	0.	0.	0.	0.	0.	0.
311.6.3	MHD CRYOGENIC BLDG.						
311.6.4	ACCESSORY BUILDING	0.	0.	0.	0.	0.	0.
311.7	COMPRESSOR BUILDING	0.	0.	0.	0.	0.	0.

TABLE C-5 (Cont'd)

150 MW - ETF CONFIGURATION 4
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
312	BOILER PLANT EQUIPMENT	3446.	1669.	3642.	797.	876.	10429.
312.1	COAL HANDLING AND PROCESSING	0.	0.	0.	0.	0.	0.
312.1.1	COAL UNLOADING STATION						
312.1.2	RAILROAD SIDING						
312.1.3	SCALES						
312.1.4	THAW SHED						
312.1.5	TRACK HOPPER (S)						
312.1.6	CAR PULLER						
312.1.7	OUTLET FEEDERS						
312.1.8	STOCKPILE CONVEYOR SYSTEM						
312.1.9	COAL SAMPLER						
312.1.10	F.E.L.						
312.1.11	CONVEYORS						
312.1.12	FEEDERS						
312.1.13	CHUTES						
312.1.14	GATES						
312.1.15	MAGNETIC SEPARATOR						
312.1.16	CRUSHER						
312.1.17	MECHANICAL DUST COLLECTOR						
312.1.18	FEEDER						
312.1.19	CONVEYOR						
312.1.20	COAL BUNKERS						
312.1.21	COAL TRANSFER SYSTEM						
312.2	SLAG AND ASH HANDLING EQUIPMENT						
312.2.1	COMBUSTOR SLAG REMOVAL AND DISPOSAL	0.	0.	0.	0.	0.	0.
312.2.2	HEAT EXCHANGER SYS.	0.	0.	0.	0.	0.	0.
312.2.3	ASH AND WASTE DISP. SYS. - SEP.	0.	0.	0.	0.	0.	0.
312.2.4	MAIN ASH DISPOSAL	0.	0.	0.	0.	0.	0.

TABLE C-5 (Cont'd)

150 MW - ETF CONFIGURATION 4
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
312.3	RADIANT BOILER SYSTEM						
312.3.1	RADIANT BOILER	0.	0.	0.	0.	0.	0.
312.3.2	PULVERIZER, MOTOR AND GRINDER						
312.3.3	CONTROLS, VALVES AND INTEG. SEP.	0.	0.	0.	0.	0.	0.
312.4	STEAM GENERATOR SECTION						
312.4.1	ECONOMIZER NO. 1						
312.4.2	ECONOMIZER NO. 2	0.	0.	0.	0.	0.	0.
312.4.3	SUPERHEATER (HX = 1)	0.	0.	0.	0.	0.	0.
312.4.4	PREHEATER (HX = 2)	0.	0.	0.	0.	0.	0.
312.4.5	SECONDARY AIR INJECTION SYS. AND FAN	69.	15.	61.	11.	12.	158.
312.4.6	MIXER COMBUSTOR CHAMBER	0.	0.	0.	0.	0.	0.
312.4.7	COMBUSTOR COOLING HEAT EXCHANGER						
312.4.8	MHD GENERATOR COOLING HEAT EXCHANGER	0.	0.	0.	0.	0.	0.
312.4.9	DIFFUSER COOLING HEAT EXCHANGER						
312.4.10	PIPES, VALVES AND PUMPS	0.	0.	0.	0.	0.	0.
312.4.11	ASSOC. INSTRUMENTATION AND CONTR.	0.	0.	0.	0.	0.	0.
312.5	EFFLUENT CONTROL						
312.5.1	ELECTROSTATIC PRECIPITATOR	2350.	470.	1880.	353.	470.	5523.
312.5.2	INDUCED DRAFT FAN	205.	41.	164.	31.	41.	462.
312.5.3	STACK	79.	985.	906.	284.	197.	2451.
312.5.4	INSTRUMENTATION AND CONTROLS	16.	6.	25.	5.	5.	56.
312.5.5	QUENCH SYS.	0.	0.	0.	0.	0.	0.
312.5.6	REVISED PIPING	0.	0.	0.	0.	0.	0.
312.6	AUXILIARY BOILER SYSTEM	0.	0.	0.	0.	0.	0.
312.7	OTHER BOILER PLANT SYSTEMS						
312.7.1	CONDENSATE SYSTEM						
312.7.2	CONDENSATE STORAGE TANK	0.	0.	0.	0.	0.	0.
312.7.3	CONDENSATE TRANSFER PUMP						

TABLE C-5 (Cont'd)

150 MW - ETF CONFIGURATION 4
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
312.7.4	L.P. FEEDWATER HEATER	0.	0.	0.	0.	0.	0
312.7.5	FEEDWATER CHEMICAL SYSTEM	0.	0.	0.	0.	0.	0
312.7.6	FEEDWATER PUMP AND MOTOR	0.	0.	0.	0.	0.	0
312.7.7	AMMONIA AND HYDROZINE	0.	0.	0.	0.	0.	0
312.7.8	EQUIPMENT INSULATION	0.	0.	0.	0.	0.	0
312.7.9	PIPING VALVES AND HANGERS	0.	0.	0.	0.	0.	0
312.7.10	PLANT AIR	0.	0.	0.	0.	0.	0
312.7.11	WATER DEMINERALIZER	0.	0.	0.	0.	0.	0
312.7.12	RAW WATER STORAGE	0.	0.	0.	0.	0.	0.
312.7.13	WATER TRANSFER PUMPS						
312.7.14	WATER FEED PUMPS						
312.7.15	TREATED WATER STORAGE TANKS						

TABLE C-5 (Cont'd)

150 MW - ETF CONFIGURATION 4
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
314	TURBOGENERATOR UNITS						
314.1.1	STEAM TURBINE GENERATOR AND AUX.	0.	0.	0.	0.	0.	0.
314.1.2	D.E.H. FLUID PART OF 314.1.1	0.	0.	0.	0.	0.	0.
314.1.3	LUBE OIL STORAGE TANK	0.	0.	0.	0.	0.	0.
314.1.4	LUBE OIL PURIFIER	0.	0.	0.	0.	0.	0.
314.2	CONDENSER AND AUXILIARIES						
314.2.1	CONDENSER	0.	0.	0.	0.	0.	0.
314.2.2	CONDENSER VACUUM PUMPS	0.	0.	0.	0.	0.	0.
314.3.1	CIRCULATING WATER SYSTEM	0.	0.	0.	0.	0.	0.
314.3.2	COOLING TOWERS	0.	0.	0.	0.	0.	0.
314.4	STEAM PIPING SYSTEMS						
314.4.1	MAIN STEAM PIPING	0.	0.	0.	0.	0.	0.
314.4.2	REHEAT SUPPLU PIPING	0.	0.	0.	0.	0.	0.
314.4.3	REHEAT RETURN PIPING	0.	0.	0.	0.	0.	0.
314.4.4	EXTRACTION STEAM PIPING	0.	0.	0.	0.	0.	0.
314.4.5	BYPASS STEAM PIPING	0.	0.	0.	0.	0.	0.
314.5	OTHER TURBINE PLANT EQUIPMENT						
314.5.1	TURBINE BUILDING SUMP PUMPS	0.	0.	0.	0.	0.	0.
314.5.2	FIRE DETECTION	0.	0.	0.	0.	0.	0.
314.5.3	FIRE PROTECTION	0.	0.	0.	0.	0.	0.
314.5.4	TURBINE HALL CRANE	0.	0.	0.	0.	0.	0.
314.5.5	TURBINE HALL MISC. HOIST	0.	0.	0.	0.	0.	0.

TABLE C-5 (Cont'd)

150 MW - ETF CONFIGURATION 4
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
315	ACCESSORY ELECTRIC EQUIPMENT						
315.1	GENERATOR ACCESSORY EQUIPMENT	0.	0.	0.	0.	0.	0
315.1.1	ISO PHASE BUS DUCT						
315.1.2	D.E.H. FLUID						
315.1.3	GENERATOR PROTECTIVE RELAY						
315.2	MEDIUM VOLTAGE SWITCHGEAR						
315.3	LOW VOLTAGE SWITCHGEAR						
315.4	POWER CENTER TRANSFORMER						
315.5	M.C.C.						
315.6	BATTERIES AND CHARGER SYSTEM						
315.7	D.C. DISTRIBUTION PANELS						
315.8	POWER AND CONTROL CABLES						
315.9	INSTRUMENTATOR AND CONTROL						
315.10	EMERGENCY DIESEL GENERATOR						
315.11	AUXILARY POWER TRANSFORMER						

TABLE C-5 (Cont'd)

150 MW - ETF CONFIGURATION 4
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
316	MISCELLANEOUS POWER PLANT EQUIP.						
316.1	FIRE PROTECTION	0.	0.	0.	0.	0.	0.
316.2	FIRE DETECTION						
316.3	HVAC						
316.4	LIGHTING SYSTEM						
316.5	PLANT GASES						
316.6	SAMPLING SYSTEM						
316.7	NO. 2 FUEL OIL STORAGE TANKS						
316.8	NO. 2 FUEL OIL TRANSFER PUMPS						
316.9	NO. 2 FUEL OIL FEED PUMPS						
316.10	NO. 2 FUEL OIL UNLOADING STATION						
316.11	MAINTENANCE EQUIPMENT						
316.12	INSTRUMENT STATIONS						
316.12.1	ASSOCIATED VALVES						
316.12.2	ASSOCIATED PIPING						

TABLE C-5 (Cont'd)

150 MW - ETF CONFIGURATION 4
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
317	MHD TOPPING CYCLE EQUIPMENT	30201.	5538.	22866.	4276.	11303.	74284.
317.1	COMBUSTION EQUIPMENT						
317.1.1	COAL PULVERIZER	0.	0.	0.	0.	0.	0.
317.1.2	STACK GAS BLOWER						
317.1.3	COAL DRYER						
317.1.4	MECHANICAL DUST COLLECTOR						
317.1.5	COAL INJECTION SYSTEM						
317.1.6	TWO STAGE COMBUSTOR	0.	0.	0.	0.	0.	0.
317.1.7	INSULATING SUPPORT CONE	0.	0.	0.	0.	0.	0.
317.2	MHD GENERATOR SUBSYSTEM						
317.2.1	NOZZLE	0.	0.	0.	0.	0.	0.
317.2.2	GENERATOR CHANNEL	772.	69.	149.	33.	198.	1221.
317.2.3	CHANNEL OUTLET EXTENSION	0.	0.	0.	0.	0.	0.
317.2.4	DIFFUSER	0.	0.	0.	0.	0.	0.
317.3	MAGNET SYSTEM	0.	0.	0.	0.	0.	0.
317.4	INVERTERS AND ELECTRODE CONTROL	(included in acc't 350)					
317.4.1	MHD POWER CONDITIONING						
317.5	OXIDIZER PREHEATER, SUBSYSTEM						
317.5.1	MAIN GAS PIPES	15.	190.	175.	55.	38.	473.
317.5.2	HTAH AND VALVES	18000.	4000.	18000.	3300.	8000.	51300.
317.5.3	HTAH MANIFOLD						
317.5.4	HTAH VALVE COOLANT EXCH. AND H2O CIRC						
317.5.5	LTAH	2000.	400.	1600.	300.	400.	4700.
317.5.6	TRANSPORT GAS BOOSTER	209.	47.	209.	38.	93.	596.
317.5.7	COMBUSTOR AIR COMP. AND DRIVES	1260.	280.	1260.	231.	560.	3591.
317.5.8	AIR COMP. TURBINE DRIVE STEAM COMP.	0.	0.	0.	0.	0.	0.
317.5.9	PREHEATER AIR SUPPLY SYSTEM	(included in acc't 317.5)					
317.5.10	PREHEATER AIR HEAT						

TABLE C-5 (Cont'd)

150 MW - ETF CONFIGURATION 4
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
317.5.11	PREHEATER COMBUSTOR	(included in acc't 317.5)					
317.5.12	ASSOC. INSTRUMENTATION AND CONT.	0.	0.	0.	0.	0.	0.
317.6	SEED SUBSYSTEM						
317.6.1	SEED UNLOAD., ST. AND TR. TO PREP.						
317.6.2	SEED PREPARATION	0.	0.	0.	0.	0.	0.
317.6.3	SEED INJECTION SYSTEM						
317.6.4	SEED REGENERATION						
317.7	OTHER MHD TOPPING CYCLE SUPT. EQUIP.						
317.7.1	COAL/GAS SEPARATOR	675.	0.	75.	11.	150.	911.
317.7.2	OXYGEN PLANT	0.	0.	0.	0.	0.	0.
317.7.3	HELIUM MAKE - UP	0.	0.	0.	0.	0.	0.
317.7.4	NITROGEN UNLOADING	0.	0.	0.	0.	0.	0.
317.7.5	MHD COMPONENT COOLING SYS.	0.	0.	0.	0.	0.	0.
317.8	MISC. MHD TOPPING CYC. SUP. EQUIP.	0.	0.	0.	0.	0.	0.

TABLE C-5 (Cont'd)

150 MW - ETF CONFIGURATION 4
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
318	RESEARCH EQUIPMENT						
318.1	INSTRUMENTED GENERAL CHANNEL	0.	0.	0.	0.	0.	0.

TABLE C-5 (Cont'd)

150 MW - ETF CONFIGURATION 4
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
319	SIMULATION EQUIPMENT						
319.1	STEAM PLANT SIMULATOR EQUIP.	0.	0.	0.	0.	0.	0.

TABLE C-5 (Cont'd)

150 MW - ETF CONFIGURATION 4
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MJR. COMP.	BOP	INSTALL.	INDIR.	CONTIN.	TOTAL COST
350	TRANSMISSION PLANT EQUIPMENT						
350.1.	MAIN POWER TRANSFORMERS	0.	0.	0.	0.	0.	0.
350.2	STATION AUXILIARY TRANSFORMER						
350.3	UNIT AUXILIARY TRANSFORMER						
350.4	TRANSFORMER OIL						
350.5	SWITCHYARD STRUCTURAL CONST.	0.	0.	0.	0.	0.	0.
350.6	MHD POWER CONDITIONING	0.	0.	0.	0.	0.	0.

TABLE C-5 (Cont'd)

150 MW - ETF CONFIGURATION 4
ESTIMATED COST BY ACCOUNT ($000)

ACCOUNT NO.	DESCRIPTION	MATERIAL COST MJR. COMP.	MATERIAL COST BOP	INSTALL. COST	INDIR. COST	CONTIN.	TOTAL COST
311	STRUCTURES AND IMPROVEMENTS	0.	0.	0.	0.	0.	0.
312	BOILER PLANT EQUIPMENT	3446.	1669.	3642.	797.	876.	10429.
314	TURBOGENERATOR UNITS	0.	0.	0.	0.	0.	0.
315	ACCESSORY ELECTRIC EQUIPMENT	0.	0.	0.	0.	0.	0.
316	MISCELLANEOUS POWER PLANT EQUIP.	0.	0.	0.	0.	0.	0.
317	MHD TOPPING CYCLE EQUIPMENT	30201.	5638.	22866.	4276.	11303.	74284.
318	RESEARCH EQUIPMENT	0.	0.	0.	0.	0.	0.
319	SIMULATION EQUIPMENT	0.	0.	0.	0.	0.	0.
350	TRANSMISSION PLANT EQUIPMENT	0.	0.	0.	0.	0.	0.
	SUBTOTALS	33648.	7307.	26508.	5072.	12179.	84713.
	ENGINEERING SERVICES *	4038.	585.	2121.		974.	7717.
	OTHER COST **						5930.
	TOTAL CONSTRUCTION COSTS ($1,000"S)	37685.	7891.	28628.	5072.	13153.	98360.

NOTES - (*) AT 8 PER CENT OF A AND E COSTS AND 12 PER CENT OF CONTRACTOR MAJOR EQUIPMENT COST
(**) AT 7 PER CENT OF TOTAL COSTS

ALL COSTS IN $1,000"S.
ALL COSTS 1978-1/2 DOLLARS.

APPENDIX D

PERFORMANCE ANALYSIS DATA

The statepoint data calculated for each of the configurations used in assessment of the progressive program plan for the 150 MW thermal MHD-ETF are presented in this Appendix. These data are tabulated in the format given by DOE for the ETF study.

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 1

```
OVERALL SYSTEM PERFORMANCE ....

COAL INPUT (MWT)                                      150.00
REFERENCE COAL                                      M. ROSEBUD
OPERATING MODE
PLANT LIFE (YEARS)
NET POWER OUTPUT (MWE)                                15.780
GROSS MHD POWER (MWE)                                 21.941
GROSS STEAM POWER (MWE)                               0.
MHD ENTHALPY EXTRACTION (PCT)                         13.272
PLANT EFFICIENCY (PCT)                                10.519
STEAM CYCLE EFFICIENCY (PCT)                                  -1
PLANT CAPITAL COST ($1000)                           160292.
REFERENCE ATMOSPHERE
  PRESSURE (ATM)                                      .78695
  DRY BULB TEMPERATURE (DEG K)                        288.30
  RELATIVE HUMIDITY (PCT)                             40.000
STEAM CONDITIONS
  MAIN TURBINE THROTTLE PRESSURE (ATM)                        -1
  MAIN TURBINE THROTTLE TEMPERATURE (DEG K)             NA    -1
  REHEAT TEMPERATURE (DEG K)                                  -1

POWER CONSUMPTION
  COMPRESSOR POWER                                    5.2757
  RECIR. PUMP POWER                                   0.
  SEC. AIR BLOWER                                     0.
  DRAFT FAN POWER                                     0.
  ELECTRO PRECIP POWER                                0.
  COOLING TWR CIRC PUMP                               0.
  COAL HANDLING AND PROCESSING                        .66036
  MHD MAGNET POWER                                   2.48815E-02
  SEED HANDLING                                       0.
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 1 (Cont'd)

```
COAL HANDLING AND PROCESSING

RAW COAL SIZE (TOP SIZE AS DELIVERED, IN)          2.0000
RAW COAL MOISTURE CONTENT (MAX PCT H2O)            22.700
RAW COAL HHV (J/KG)                               2.07705E+07
RAW COAL FLOW RATE (KG/S)                          7.2220
COAL TO COMBUSTOR (MESH)                          200
MOISTUTURE CONTENT (PCT)                           5.0000
COAL FLOW RATE TO COMB. (KG/S)                     5.8764
TRANSPORT MEDIUM
  MECHANISM                                       INERT GAS
  RATIO                                           1.00000E-01
DRYING MEDIUM
  FLOW RATE (KG/S)                                          -1 )
  TEMPERATURE IN (DEG K)                                    -1 } (6.58 MWt HEAT TO DRY)
  TEMPERATURE OUT (DEG K)                                   -1 )
POWER REQUIREMENT (MWE)                            .66036
COST($1000) (ACCT. 312.1)
COST($1000) (ACCT. 317.1--5, 317.7.1)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 1 (Cont'd)

```
OXIDIZER SUPPLY ....

OXYGEN PLANT ....
AMOUNT OF O2 ENRICHMENT (PCT)                      133.00
O2 FLOW RATE (KG/S)                                6.1004
COST($1000) (ACCT. 317.7.2)                        13837.

MAIN AIR COMPRESSOR
  TYPE OF COMPRESSOR                             AXIAL FLOW
  TYPE OF INTERCOOLING                              NO
  RATED INLET PRESSURE (ATM)                       .78695
  RATED DISCHARGE PRESSURE (ATM)                   5.6510
  INLET TEMPERATURE (DEG K)                        288.30
  RELATIVE HUMIDITY (PCT)                          40.000
  ACTUAL FLOW (KG/S)                               19.945
  ADIABATIC EFFICIENCY (PCT)                       83.000
  SHAFT POWER (MWE)                                5.2757
  LUBE SYSTEM POWER (MWE)                          0.03
OXIDIZER PREHEAT TEMPERATURE (DEG K)               1005.0
COST($1000) (ACCT. 317.5.7)                             ,


SECONDARY AIR INJECTIVE
  LOCATION, DOWNSTREAM OF                        DIFFUSER
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
  FLOW RATE (KG/S)                                 0.
  FAN EFFICIENCY (PCT)                                    -I
POWER REQUIREMENT (MWE)                            0.
COST($1000) (ACCT. 312.4.5)                        0.


SEED FEED SYSTEM ....

TYPE
SEED FLOW (KG/S)                                   .47343
POTASIUM CARBONATE (K2CO3)                        8.85311E-02
POTASIUM SULFATE (K2SO4)                           .38490
POWER REQUIREMENT (MWE)                            0.
COST ($1000) (ACCT. 317.6)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 1 (Cont'd)

```
MAIN COMBUSTOR ....

TYPE-NUMBER OF STAGES                                 2
DIMENSIONS          (1ST STAGE, 2ND STAGE, ETC.)
  LENGTH (M)                                         2.4326               1.7730
  DIAMETER (M)                                       1.0812               1.1820
  VOLUME (M**3)                                      1.7370               1.9454
COMBUSTION CONDITIONS
  PRESSURE (ATM)                                     5.4811
  EXIT TEMPERATURE (DEG K)                           2800.4
  EXIT FLOW RATE (KG/S)                              32.417
SLAG REMOVAL (PCT)                                   90.000
RESIDENCE TIME (MICRO-SEC)
  1-ST STAGE
  2-ND STAGE
COMBUSTOR HEAT LOSSES (MWT)                          15.000
COOLING SYSTEM TYPE
  INLET TEMPERATURE (DEG K)                                  -1
  OUTLET TEMPERATURE (DEG K)                                 -1
  FLOW RATE (KG/S)                                           -1
NUMBER OF MODULES                                     1
KEY COMPONENT
MINIMUM USEFUL LIFE OF KEY COMPONENT (HRS)
REPLACEMENT TIME OF KEY COMPONENT (HRS)
COST ($1000)

NOZZLE ....
NOZZLE EXIT MACH NUMBER                              .91047
NOZZLE HEAT LOSS (MWT)                               2.7000
COST($1000) (ACCT.317.2.1)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 1 (Cont'd)

```
CHANNEL ....

TYPE                                                SEG. FARADAY
DIMENSIONS
  INLET (MXM)                                        .41189     X    .20594
  OUTLET (MXM)                                      1.0263      X    .58899
  LENGTH (M)                                        11.325
SLAG REMOVAL (PCT)
ISENTROPIC EFFICIENCY (PCT)                         60.838
INLET CONDITIONS
  PRESSURE (ATM)                                    3.3145
  TEMPERATURE (DEG K)                               2657.6
  MACH NUMBER                                        .91047
  FLOW RATE (KG/S)                                  32.417
OUTLET CONDITIONS
  PRESSURE (ATM)                                     .71989
  TEMPERATURE (DEG K)                               2241.6
  MACH NUMBER                                        .83577
SURFACE TEMPERATURE (DEG K)                         1800.0
HEAT LOSS (MWT)                                     15.761
PEAK ELECTRODE CURRENT DENSITY (A/CM**2)                   -1
MAXIMUM HALL FIELD (KV/M)                           3.5000
COOLING WATER
  PRESSURE (ATM)                                     13.61
  TEMPERATURE (DEG K)                               311.02
  FLOW RATE (KG/S)                                   58.26
  NUMBER OF CHANNELS
  MINIMUM USEFUL LIFE (HRS)
REPLACEMENT TIME (HRS)
COST ($1000) (ACCT. 317.2.2)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 1 (Cont'd)

```
DIFFUSER ....

TYPE
DIMENSIONS
  INLET (MXM)                                        1.0263      X    .58899
  OUTLET (MXM)                                       3.2843      X    1.8848
  LENGTH (M)                                         7.9337
ISENTROPIC EFFICIENCY (PCT)                          45.000
INLET CONDITIONS
  TEMPERATURE (DEG K)                                2241.6
  PRESSURE (ATM)                                     .71989
  MACH NUMBER                                        .83577
  FLOW RATE (KG/S)                                   32.417
OUTLET CONDITIONS
  TEMPERATURE (DEG K)                                2056.7
  PRESSURE (ATM)                                     .07553
  MACH NUMBER                                        0.
SURFACE TEMPERATURE (DEG K)
HEAT LOSS (MWT)                                      20.000
COOLING WATER INLET
  PRESSURE (ATM)                                     176.20
  TEMPERATURE (DEG K)                                525.7
  FLOW RATE (KG/S)                                   41.9
COOLING WATER EXIT
  PRESSURE (ATM)                                     171.79
  TEMPERATURE (DEG K)                                612.25
  NUMBER OF CHANNELS
  MINIMUM USEFUL LIFE (HRS)
REPLACEMENT TIME (HRS)
BOUNDRY LAYER CONTROLS
COST ($1000) (ACCT. 317.2.4)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 1 (Cont'd)

```
MAGNET ....

TYPE                                                SUPER COND.
DIMENSIONS
  LENGTH (M)                                            12
  INLET DIAMETER (M)                                    1.7
  OUTLET DIAMETER (M)                                   1.7
FIELD STRENGTH (TESLA)
  PEAK                                               6.0000
  AVERAGE                                                     -1
CURRENT DENSITY (A/CM**2)
ENERGY STORAGE (JOULES)
WEIGHT (LBS)                                                  -1
COST ($1000) (ACCT. 317.3)                                    -1
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION (Cont'd)

```
RADIANT BOILER ....

TYPE
DIMENSIONS
  INLET (MXM)                                             -I  X           -I
  OUTLET (MXM)                                            -I  X           -I
  LENGTH (M)                                              -I
ISENTROPIC EFFICIENCY (PCT)                               -I
INLET CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
  MACH NUMBER
  FLOW RATE (KG/S)                                        -I
OUTLET CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
  VELOCITY (M/S)
DWELL TIME (SEC)
HEAT TRANSFER AREA (M**2)                                 -I
MAXIMUM TEMPERATURE GRADIENT (DEG F/SEC)
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
  FLOW RATE (KG/S)                                        -I
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
THERMAL DUTY (MWT)                                        -I
COST($1000) (ACCT,312,3,1)                                -I
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 1 (Cont'd)

```
HIGH TEMPERATURE AIR HEATER ....

TYPE                                                OIL FIRED METAL
NUMBER OF MODULES
DIMENSIONS
  HEIGHT (M)
  DIAMETER (M)
  FLOW AREA (M**2)
SLAG REMOVAL (PCT)
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                               -1
  TEMPERATURE (DEG K)                                 0.
  MACH NUMBER
  FLOW RATE (KG/S)                                             -1
  DUCT DIAMETER (M)
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                               -1
  TEMPERATURE (DEG K)                                          -1
  VELOCITY (M/S)
AIR INLET CONDITIONS
  PRESSURE (ATM)                                      5.6510
  TEMPERATURE (DEG K)                                 546.76
  VELOCITY (M/S)
  FLOW RATE (KG/S)                                    19.945
AIR OUTLET CONDITIONS
  PRESSURE (ATM)                                      5.4815
  TEMPERATURE (DEG K)                                 1005.0
  VELOCITY (M/S)
DWELL TIME (SEC)
LOSSES
  VALVE LEAKAGE (PCT)                                 0.
  VALVE COOLING (MWT)                                          -1
  CORE HEAD LOSS (MWT)                                0.
THERMAL DUTY (MWT)                                    10.038
COST($1000) (ACCT.317.5.2--4)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 1 (Cont'd)

```
SUPERHEATER ....

TYPE
DIMENSIONS
  LENGTH (M)                                                       =I
  WIDTH (M)                                                        =I
  HEIGHT (M)                                                       =I
SLAG REMOVAL (PCT)
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                                   =I
  TEMPERATURE (DEG K)                                              =I
  FLOW RATE (KG/S)                                                 =I
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                                   =I
  TEMPERATURE (DEG K)                                              =I
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                                   =I
  TEMPERATURE (DEG K)                                              =I
  FLOW RATE (KG/S)                                                 =I
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                                   =I
  TEMPERATURE (DEG K)                                              =I
THERMAL DUTY (MWT)                                                 =I
COST($1000) (ACCT. 312.4.3)                                        =I
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 1 (Cont'd)

```
REHEATER ....

TYPE
DIMENSIONS
  LENGTH (M)                                                -I
  WIDTH (M)                                                 -I
  HEIGHT (M)                                                -I
SLAG REMOVAL (PCT)
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                            -I
  TEMPERATURE (DEG K)                                       -I
  FLOW RATE (KG/S)                                          -I
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                            -I
  TEMPERATURE (DEG K)                                       -I
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                            -I
  TEMPERATURE (DEG K)                                       -I
  FLOW RATE (KG/S)                                          -I
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                            -I
  TEMPERATURE (DEG K)                                       -I
THERMAL DUTY (MWT)                                  0.
COST($1000) (ACCT.312.4.4)                                  -I
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 1 (Cont'd)

```
LOW TEMPERATURE AIR HEATER ....

TYPE
DIMENSIONS
  LENGTH (M)                                              -I
  WIDTH (M)                                               -I
  HEIGHT (M)                                              -I
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
  FLOW RATE (KG/S)                                        -I
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
AIR INLET CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
  FLOW RATE (KG/S)                                        -I
AIR OUTLET CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
THERMAL DUTY (MWT)                                0.
COST($1000) (ACCT,317,5,5)                                -I
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 1 (Cont'd)

```
ECONOMIZER NO. 2 ....

DIMENSIONS
  LENGTH (M)                                                    =I
  WIDTH (M)                                                     =I
  HEIGHT (M)                                                    =I
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                                =I
  TEMPERATURE (DEG K)                                           =I
  FLOW RATE (KG/S)                                              =I
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                                =I
  TEMPERATURE (DEG K)                                           =I
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                                =I
  TEMPERATURE (DEG K)                                           =I
  FLOW RATE (KG/S)                                              =I
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                                =I
  TEMPERATURE (DEG K)                                           =I
THERMAL DUTY (MWT)                                              =I
COST($1000) (ACCT.312.4.2)                                      =I
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 1 (Cont'd)

```
ECONOMIZER NO. 1 ....

DIMENSIONS
  LENGTH (M)                                                    -1
  WIDTH (M)                                                     -1
  HEIGHT (M)                                                    -1
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                                -1
  TEMPERATURE (DEG K)                                           -1
  FLOW RATE (KG/S)                                              -1
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                                -1
  TEMPERATURE (DEG K)                                           -1
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                                -1
  TEMPERATURE (DEG K)                                           -1
  FLOW RATE (KG/S;                                              -1
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                                -1
  TEMPERATURE (DEG K)                                           -1
THERMAL DUTY (MWT)                                              -1
COST($1000) (ACCT.312.4.1)                                      -1


GAS CLEAN UP ....

TYPES                                       (QUENCH/SCRUB)
LOCATIONS
LOSSES
 PRESSURE (PCT)
 THERMAL (MWT)
REMOVAL EFFICIENCY (PCT)
POWER REQUIRED (MWE)                             0.
COST($1000) (ACCT.312.5.1)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 1 (Cont'd)

```
EXHAUST EMISSIONS ....

PARTICULATE ( G/J)
NOX ( G/J)
SOX ( G/J)
TRACE ELEMENTS ( G/J)



PLANT COOLING ....

TYPE
PART MODULES
DIMENSIONS
  HEIGHT (M)                                                   -1
  DIAMETER (M)                                                 -1
CONDENSER PRESSURE (ATM)                                       -1
THERMAL DUTY (MWT)                                         53.3
TEMPERATURE (DEG K)                                            -1
COOLING WATER
  FLOW RATE (KG/S)                                             -1
  MAKE UP (PCT)
POWER REQUIREMENTS (MWE)                               0.
COST ($1000)                                                   -1



SEED MANAGEMENT ....

TYPE
RECOVERY (PCT)
REGENERATION (PCT)
TYPE OF REGENERATION PROCESS
LOCATION
POWER REQUIREMENTS (MWE)                               0.
COST ($1000)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 2

```
OVERALL SYSTEM PERFORMANCE ....

COAL INPUT (MWT)                                   150.00
REFERENCE COAL                                  M. ROSEBUD
OPERATING MODE
PLANT LIFE (YEARS)
NET POWER OUTPUT (MWE)                             19.193
GROSS MHD POWER (MWE)                              27.889
GROSS STEAM POWER (MWE)                            0.
MHD ENTHALPY EXTRACTION (PCT)                      14.586
PLANT EFFICIENCY (PCT)                             12.795
STEAM CYCLE EFFICIENCY (PCT)                                -1
PLANT CAPITAL COST ($1000)                        160350.
REFERENCE ATMOSPHERE
  PRESSURE (ATM)                                   .78695
  DRY BULB TEMPERATURE (DEG K)                     268.30
  RELATIVE HUMIDITY (PCT)                          40.000
STEAM CONDITIONS
  MAIN TURBINE THROTTLE PRESSURE (ATM)                      -1
  MAIN TURBINE THROTTLE TEMPERATURE (DEG K)          NA     -1
  REHEAT TEMPERATURE (DEG K)                                -1

POWER CONSUMPTION
  COMPRESSOR POWER                                 7.8047
  RECIR. PUMP POWER                                0.
  SEC. AIR BLOWER                                  0.
  DRAFT FAN POWER                                  0.
  ELECTRO PRECIP POWER                             0.
  COOLING TWR CIRC PUMP                            0.
  COAL HANDLING AND PROCESSING                     .86036
  MHD MAGNET POWER                                3.16276E-02
  SEED HANDLING                                    0.
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 2 (Cont'd)

```
COAL HANDLING AND PROCESSING

RAW COAL SIZE (TOP SIZE AS DELIVERED, IN)          2.0000
RAW COAL MOISTURE CONTENT (MAX PCT H2O)            22.700
RAW COAL HHV (J/KG)                               2.07705E+07
RAW COAL FLOW RATE (KG/S)                          7.2220
COAL TO COMBUSTOR (MESH)                          200
MOISTUTURE CONTENT (PCT)                           5.0000
COAL FLOW RATE TO COMB. (KG/S)                     5.8764
TRANSPORT MEDIUM
  MECHANISM                                       INERT GAS
  RATIO                                           1.00000E-01
DRYING MEDIUM
  FLOW RATE (KG/S)                                         -I  }
  TEMPERATURE IN (DEG K)                                   -I  } 6.58 MWt HEAT TO DRYER
  TEMPERATURE OUT (DEG K)                                  -I  }
POWER REQUIREMENT (MWE)                            .86036
COST($1000) (ACCT. 312.1)
COST($1000) (ACCT. 317.1--5, 317.7.1)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 2 (Cont'd)

```
OXIDIZER SUPPLY ....

OXYGEN PLANT ....
AMOUNT OF O2 ENRICHMENT (PCT)                        57.500
O2 FLOW RATE (KG/S)                                  3.9017
COST($1000) (ACCT. 317.7.2)

MAIN AIR COMPRESSOR
   TYPE OF COMPRESSOR                              AXIAL FLOW
   TYPE OF INTERCOOLING                              No
   RATED INLET PRESSURE (ATM)                        .78695
   RATED DISCHARGE PRESSURE (ATM)                    5.6510
   INLET TEMPERATURE (DEG K)                         288.30
   RELATIVE HUMIDITY (PCT)                           40.000
   ACTUAL FLOW (KG/S)                                29.506
   ADIABATIC EFFICIENCY (PCT)                        83.000
   SHAFT POWER (MWE)                                 7.8047
   LUBE SYSTEM POWER (MWE)                           0.
OXIDIZER PREHEAT TEMPERATURE (DEG K)                 1533.0
COST($1000) (ACCT. 317.5.7)


SECONDARY AIR INJECTIVE
   LOCATION, DOWNSTREAM OF                         DIFFUSER
   PRESSURE (ATM)                                            -1
   TEMPERATURE (DEG K)                                       -1
   FLOW RATE (KG/S)                                  0.
   FAN EFFICIENCY (PCT)                                      -1
POWER REQUIREMENT (MWE)                              0.
COST($1000) (ACCT. 312.4.5)                          0.


SEED FEED SYSTEM ....

TYPE
SEED FLOW (KG/S)                                     .58458
POTASIUM CARBONATE (K2CO3)                           .10932
POTASIUM SULFATE (K2SO4)                             .47527
POWER REQUIREMENT (MWE)                              0.
COST ($1000) (ACCT.317.6)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 2 (Cont'd)

```
MAIN COMBUSTOR ....

TYPE-NUMBER OF STAGES                                      2
DIMENSIONS
  LENGTH (M)                                              2.4326          1.7730
  DIAMETER (M)                                            1.0812          1.1820
  VOLUME (M**3)                                           1.7370          1.9454
COMBUSTION CONDITIONS
  PRESSURE (ATM)                                          5.4811
  EXIT TEMPERATURE (DEG K)                                2792.2
  EXIT FLOW RATE (KG/S)                                   39.891
SLAG REMOVAL (PCT)                                        90.000
RESIDENCE TIME (MICRO-SEC)
  1-ST STAGE
  2-ND STAGE
COMBUSTOR HEAT LOSSES (MWT)                               15.000
COOLING SYSTEM TYPE                                        H20
  INLET TEMPERATURE (DEG K)                               379.21  -1
  OUTLET TEMPERATURE (DEG K)                              450.0   -1
  FLOW RATE (KG/S)                                         58.26  -1
NUMBER OF MODULES                                          1
KEY COMPONENT
MINIMUM USEFUL LIFE OF KEY COMPONENT (HRS)
REPLACEMENT TIME OF KEY COMPONENT (HRS)
COST ($1000)  (ACCT. 317.2.1)

NOZZLE ....
NOZZLE EXIT MACH NUMBER                                   .90151
NOZZLE HEAT LOSS (MWT)                                    2.7000
COST($1000) (ACCT.317.2.1)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 2 (Cont'd)

```
CHANNEL ....

TYPE
DIMENSIONS
  INLET (MXM)                                        .45839     X    .22919
  OUTLET (MXM)                                       1.1482     X    .66294
  LENGTH (M)                                         11.322
SLAG REMOVAL (PCT)
ISENTROPIC EFFICIENCY (PCT)                          62.726
INLET CONDITIONS
  PRESSURE (ATM)                                     3.3329
  TEMPERATURE (DEG K)                                2644.4
  MACH NUMBER                                        .90151
  FLOW RATE (KG/S)                                   39.691
OUTLET CONDITIONS
  PRESSURE (ATM)                                     .72926
  TEMPERATURE (DEG K)                                2221.6
  MACH NUMBER                                        .82489
SURFACE TEMPERATURE (DEG K)                          1800.0
HEAT LOSS (MWT)                                      16.049
PEAK ELECTRODE CURRENT DENSITY (A/CM**2)                   -I
MAXIMUM HALL FIELD (KV/M)                            3.5000
COOLING WATER
  PRESSURE (ATM)                                      13.61
  TEMPERATURE (DEG K)                                311.02
  FLOW RATE (KG/S)                                    58.26
  NUMBER OF CHANNELS
  MINIMUM USEFUL LIFE (HRS)
REPLACEMENT TIME (HRS)
COST ($1000) (ACCT. 317.2.2)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 2 (Cont'd)

```
DIFFUSER ....

TYPE
DIMENSIONS
  INLET (MXM)                                    1.1482      X   .66294
  OUTLET (MXM)                                   3.6742      X   2.1214
  LENGTH (M)                                     8.9100
ISENTROPIC EFFICIENCY (PCT)                      45.000
INLET CONDITIONS
  TEMPERATURE (DEG K)                            2221.6
  PRESSURE (ATM)                                 .72928
  MACH NUMBER                                    .82489
  FLOW RATE (KG/S)                               39.891
OUTLET CONDITIONS
  TEMPERATURE (DEG K)                            2092.6
  PRESSURE (ATM)                                 .88393
  MACH NUMBER                                    0.
SURFACE TEMPERATURE (DEG K)
HEAT LOSS (MWT)                                  20.000
COOLING WATER INLET
  PRESSURE (ATM)                                 176.2
  TEMPERATURE (DEG K)                            525.7
  FLOW RATE (KG/S)                                41.9
COOLING WATER EXIT
  PRESSURE (ATM)                                  171.79
  TEMPERATURE (DEG K)                             612.3
  NUMBER OF CHANNELS
  MINIMUM USEFUL LIFE (HRS)
REPLACEMENT TIME (HRS)
BOUNDRY LAYER CONTROLS
COST ($1000) (ACCT. 317.2.4)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 2 (Cont'd)

MAGNET	
TYPE	SUPER COND.
DIMENSIONS	
LENGTH (M)	12
INLET DIAMETER (M)	1.7
OUTLET DIAMETER (M)	1.7
FIELD STRENGTH (TESLA)	
PEAK	6.0000
AVERAGE	-1
CURRENT DENSITY (A/CM**2)	
ENERGY STORAGE (JOULES)	
WEIGHT (LBS)	-1
COST ($1000) (ACCT. 317.3)	-1

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 2 (Cont'd)

```
RADIANT BOILER ....

TYPE
DIMENSIONS
  INLET (MXM)                                                         =I  X               =I
  OUTLET (MXM)                                                        =I  X               =I
  LENGTH (M)                                                          =I
ISENTROPIC EFFICIENCY (PCT)                                           =I
INLET CONDITIONS
  PRESSURE (ATM)                                                      =I
  TEMPERATURE (DEG K)                                                 =I
  MACH NUMBER
  FLOW RATE (KG/S)                                                    =I
OUTLET CONDITIONS
  PRESSURE (ATM)                                                      =I
  TEMPERATURE (DEG K)                                                 =I
  VELOCITY (M/S)
DWELL TIME (SEC)
HEAT TRANSFER AREA (M**2)                                             =I
MAXIMUM TEMPERATURE GRADIENT (DEG F/SEC)
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                                      =I
  TEMPERATURE (DEG K)                                                 =I
  FLOW RATE (KG/S)                                                    =I
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                                      =I
  TEMPERATURE (DEG K)                                                 =I
THERMAL DUTY (MWT)                                                    =I
COST($1000) (ACCT.312.3.1)                                            =I
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 2 (Cont'd)

```
HIGH TEMPERATURE AIR HEATER ....

TYPE
NUMBER OF MODULES                                  4
DIMENSIONS
  HEIGHT (M)
  DIAMETER (M)
  FLOW AREA (M**2)                                4.0371
SLAG REMOVAL (PCT)
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                             0.
  MACH NUMBER
  FLOW RATE (KG/S)                                        -I
  DUCT DIAMETER (M)
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
  VELOCITY (M/S)
AIR INLET CONDITIONS
  PRESSURE (ATM)                                  5.6510
  TEMPERATURE (DEG K)                             546.76
  VELOCITY (M/S)
  FLOW RATE (KG/S)                                29.506
AIR OUTLET CONDITIONS
  PRESSURE (ATM)                                  5.4815
  TEMPERATURE (DEG K)                             1533.0
  VELOCITY (M/S)
DWELL TIME (SEC)
LOSSES
  VALVE LEAKAGE (PCT)                             0.
  VALVE COOLING (MWT)                                     -I
  CORE HEAD LOSS (MWT)                            0.
THERMAL DUTY (MWT)                                33.391
COST($1000) (ACCT.317.5.2--4)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 2 (Cont'd)

```
SUPERHEATER ....

TYPE
DIMENSIONS
  LENGTH (M)                                                    -1
  WIDTH (M)                                                     -1
  HEIGHT (M)                                                    -1
SLAG REMOVAL (PCT)
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                                -1
  TEMPERATURE (DEG K)                                           -1
  FLOW RATE (KG/S)                                              -1
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                                -1
  TEMPERATURE (DEG K)                                           -1
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                                -1
  TEMPERATURE (DEG K)                                           -1
  FLOW RATE (KG/S)                                              -1
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                                -1
  TEMPERATURE (DEG K)                                           -1
THERMAL DUTY (MWT)                                              -1
COST($1000) (ACCT. 312.4.3)                                     -1
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 2 (Cont'd)

```
REHEATER ....

TYPE
DIMENSIONS
  LENGTH (M)                                              -I
  WIDTH (M)                                               -I
  HEIGHT (M)                                              -I
SLAG REMOVAL (PCT)
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
  FLOW RATE (KG/S)                                        -I
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
  FLOW RATE (KG/S)                                        -I
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
THERMAL DUTY (MWT)                                0.
COST($1000) (ACCT.312.4.4)                                -I
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 2 (Cont'd)

```
LOW TEMPERATURE AIR HEATER ....

TYPE
DIMENSIONS
  LENGTH (M)                                                  -1
  WIDTH (M)                                                   -1
  HEIGHT (M)                                                  -1
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                              -1
  TEMPERATURE (DEG K)                                         -1
  FLOW RATE (KG/S)                                            -1
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                              -1
  TEMPERATURE (DEG K)                                         -1
AIR INLET CONDITIONS
  PRESSURE (ATM)                                              -1
  TEMPERATURE (DEG K)                                         -1
  FLOW RATE (KG/S)                                            -1
AIR OUTLET CONDITIONS
  PRESSURE (ATM)                                              -1
  TEMPERATURE (DEG K)                                         -1
THERMAL DUTY (MWT)                                  0.
COST($1000) (ACCT.317.5.5)                                    -1
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 2 (Cont'd)

```
ECONOMIZER NO. 2 ....

DIMENSIONS
  LENGTH (M)                                                      -1
  WIDTH (M)                                                       -1
  HEIGHT (M)                                                      -1
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                                  -1
  TEMPERATURE (DEG K)                                             -1
  FLOW RATE (KG/S)                                                -1
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                                  -1
  TEMPERATURE (DEG K)                                             -1
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                                  -1
  TEMPERATURE (DEG K)                                             -1
  FLOW RATE (KG/S)                                                -1
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                                  -1
  TEMPERATURE (DEG K)                                             -1
THERMAL DUTY (MWT)                                                -1
COST($1000) (ACCT.312.4.2)                                        -1
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 2 (Cont'd)

```
ECONOMIZER NO. 1 ....

DIMENSIONS
  LENGTH (M)                                                  -I
  WIDTH (M)                                                   -I
  HEIGHT (M)                                                  -I
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                              -I
  TEMPERATURE (DEG K)                                         -I
  FLOW RATE (KG/S)                                            -I
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                              -I
  TEMPERATURE (DEG K)                                         -I
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                              -I
  TEMPERATURE (DEG K)                                         -I
  FLOW RATE (KG/S)                                            -I
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                              -I
  TEMPERATURE (DEG K)                                         -I
THERMAL DUTY (MWT)                                            -I
COST($1000) (ACCT.312.4.1)                                    -I


GAS CLEAN UP ....

TYPES                                                   (QUENCH/SCRUB)
LOCATIONS
LOSSES
 PRESSURE (PCT)
 THERMAL (MWT)
REMOVAL EFFICIENCY (PCT)
POWER REQUIRED (MWE)
COST($1000) (ACCT.312.5.1)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 2 (Cont'd)

```
EXHAUST EMISSIONS ....

PARTICULATE ( G/J)
NOX ( G/J)
SOX ( G/J)
TRACE ELEMENTS ( G/J)



PLANT COOLING ....

TYPE
PART MODULES
DIMENSIONS
  HEIGHT (M)                                              -1
  DIAMETER (M)                                            -1
CONDENSER PRESSURE (ATM)                                  -1
THERMAL DUTY (MWT)                                  53.8
TEMPERATURE (DEG K)                                       -1
COOLING WATER
  FLOW RATE (KG/S)                                        -1
  MAKE UP (PCT)
POWER REQUIREMENTS (MWE)                          0.
COST ($1000)                                              -1



SEED MANAGEMENT ....

TYPE
RECOVERY (PCT)
REGENERATION (PCT)
TYPE OF REGENERATION PROCESS
LOCATION
POWER REQUIREMENTS (MWE)                          0.
COST ($1000)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 3

```
OVERALL SYSTEM PERFORMANCE ....

COAL INPUT (MWT)                                        150.00
REFERENCE COAL                                        M. ROSEBUD
OPERATING MODE
PLANT LIFE (YEARS)
NET POWER OUTPUT (MWE)                                  23.904
GROSS MHD POWER (MWE)                                   34.551
GROSS STEAM POWER (MWE)                                 0.
MHD ENTHALPY EXTRACTION (PCT)                           16.314
PLANT EFFICIENCY (PCT)                                  15.936
STEAM CYCLE EFFICIENCY (PCT)                                 -1
PLANT CAPITAL COST ($1000)                             173340.
REFERENCE ATMOSPHERE
  PRESSURE (ATM)                                        .78695
  DRY BULB TEMPERATURE (DEG K)                          288.30
  RELATIVE HUMIDITY (PCT)                               40.000
STEAM CONDITIONS
  MAIN TURBINE THROTTLE PRESSURE (ATM)                   163.3
  MAIN TURBINE THROTTLE TEMPERATURE (DEG K)              811.1
  REHEAT TEMPERATURE (DEG K)                                 -1

POWER CONSUMPTION
  COMPRESSOR POWER                                      9.7474
  RECIR. PUMP POWER                                     0.
  SEC. AIR BLOWER                                       0.
  DRAFT FAN POWER                                       0.
  ELECTRO PRECIP POWER                                  0.
  COOLING TWR CIRC PUMP                                 0.
  COAL HANDLING AND PROCESSING                          .86036
  MHD MAGNET POWER                                     3.91823E-02
  SEED HANDLING                                         0.
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 3 (Cont'd)

```
COAL HANDLING AND PROCESSING

RAW COAL SIZE (TOP SIZE AS DELIVERED, IN)           2.0000
RAW COAL MOISTURE CONTENT (MAX PCT H2O)             22.700
RAW COAL HHV (J/KG)                                2.07705E+07
RAW COAL FLOW RATE (KG/S)                           7.2220
COAL TO COMBUSTOR (MESH)                           200
MOISTUTURE CONTENT (PCT)                            5.0000
COAL FLOW RATE TO COMB. (KG/S)                      5.8764
TRANSPORT MEDIUM
  MECHANISM                                        INERT GAS
  RATIO                                            1.00000E-01
DRYING MEDIUM
  FLOW RATE (KG/S)                                         -1 }
  TEMPERATURE IN (DEG K)                                   -1 }(6.58 MWt HEAT TO DRYER)
  TEMPERATURE OUT (DEG K)                                  -1 }
POWER REQUIREMENT (MWE)                             .86036
COST($1000) (ACCT. 312.1)
COST($1000) (ACCT. 317.1--5, 317.7.1)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 3 (Cont'd)

```
OXIDIZER SUPPLY ....

OXYGEN PLANT ....
AMOUNT OF O2 ENRICHMENT (PCT)                        25.630
O2 FLOW RATE (KG/S)                                  2.1803
COST($1000) (ACCT. 317.7.2)

MAIN AIR COMPRESSOR
  TYPE OF COMPRESSOR                               AXIAL FLOW
  TYPE OF INTERCOOLING                                 No
  RATED INLET PRESSURE (ATM)                         .78695
  RATED DISCHARGE PRESSURE (ATM)                     5.8257
  INLET TEMPERATURE (DEG K)                          288.30
  RELATIVE HUMIDITY (PCT)                            40.000
  ACTUAL FLOW (KG/S)                                 36.991
  ADIABATIC EFFICIENCY (PCT)                         85.000
  SHAFT POWER (MWE)                                  9.7474
  LUBE SYSTEM POWER (MWE)                            0.05
OXIDIZER PREHEAT TEMPERATURE (DEG K)                 1755.0
COST($1000) (ACCT. 317.5.7)


SECONDARY AIR INJECTIVE
  LOCATION, DOWNSTREAM OF                          RAD.BOILER
  PRESSURE (ATM)                                          *I
  TEMPERATURE (DEG K)                                     *I
  FLOW RATE (KG/S)                                   4.8918
  FAN EFFICIENCY (PCT)                                    *I
POWER REQUIREMENT (MWE)                              0.
COST($1000) (ACCT. 312.4.5)


SEED FEED SYSTEM ....

TYPE
SEED FLOW (KG/S)                                     .67161
POTASIUM CARBONATE (K2CO3)                           .12559
POTASIUM SULFATE (K2SO4)                             .54602
POWER REQUIREMENT (MWE)                              0.
COST ($1000) (ACCT. 317.6)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 3 (Cont'd)

```
MAIN COMBUSTOR ....

TYPE-NUMBER OF STAGES                                      2
DIMENSIONS
  LENGTH (M)                                              2.4326          1.7730
  DIAMETER (M)                                            1.0812          1.1820
  VOLUME (M**3)                                           1.7370          1.9454
COMBUSTION CONDITIONS
  PRESSURE (ATM)                                          5.4810
  EXIT TEMPERATURE (DEG K)                                2800.0
  EXIT FLOW RATE (KG/S)                                   45.742
SLAG REMOVAL (PCT)                                        90.000
RESIDENCE TIME (MICRO-SEC)
  1-ST STAGE
  2-ND STAGE
COMBUSTOR HEAT LOSSES (MWT)                               15.000
COOLING SYSTEM TYPE                                        H2O
  INLET TEMPERATURE (DEG K)                                379.2  -I
  OUTLET TEMPERATURE (DEG K)                               450.0  -I
  FLOW RATE (KG/S)                                          58.26 -I
NUMBER OF MODULES                                          1
KEY COMPONENT
MINIMUM USEFUL LIFE OF KEY COMPONENT (HRS)
REPLACEMENT TIME OF KEY COMPONENT (HRS)
COST ($1000)    (ACCT. 317.1.6-7)

NOZZLE ....
NOZZLE EXIT MACH NUMBER                                   .89421
NOZZLE HEAT LOSS (MWT)                                    2.7000
COST($1000) (ACCT.317.2.1)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 3 (Cont'd)

```
CHANNEL ....

TYPE
DIMENSIONS
  INLET (MXM)                                        .49243     X   .24622
  OUTLET (MXM)                                       1.2493     X   .70778
  LENGTH (M)                                         11.322
SLAG REMOVAL (PCT)
ISENTROPIC EFFICIENCY (PCT)                          64.476
INLET CONDITIONS
  PRESSURE (ATM)                                     3.3505
  TEMPERATURE (DEG K)                                2650.0
  MACH NUMBER                                        .89421
  FLOW RATE (KG/S)                                   45.742
OUTLET CONDITIONS
  PRESSURE (ATM)                                     .68292
  TEMPERATURE (DEG K)                                2209.1
  MACH NUMBER                                        .81056
SURFACE TEMPERATURE (DEG K)                          1600.0
HEAT LOSS (MWT)                                      16.285
PEAK ELECTRODE CURRENT DENSITY (A/CM**2)                      *I
MAXIMUM HALL FIELD (KV/M)                            3.5000
COOLING WATER
  PRESSURE (ATM)                                     13.61
  TEMPERATURE (DEG K)                                311.02
  FLOW RATE (KG/S)                                    58.26
  NUMBER OF CHANNELS
  MINIMUM USEFUL LIFE (HRS)
REPLACEMENT TIME (HRS)
COST ($1000) (ACCT. 317.2.2)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 3 (Cont'd)

DIFFUSER ....

TYPE			
DIMENSIONS			
INLET (MXM)	1.2495	X	.70778
OUTLET (MXM)	3.9977	X	2.2649
LENGTH (M)	9.5783		
ISENTROPIC EFFICIENCY (PCT)	45.000		
INLET CONDITIONS			
TEMPERATURE (DEG K)	2209.1		
PRESSURE (ATM)	.68292		
MACH NUMBER	.81056		
FLOW RATE (KG/S)	45.742		
OUTLET CONDITIONS			
TEMPERATURE (DEG K)	2109.0		
PRESSURE (ATM)	.82280		
MACH NUMBER	0.		
SURFACE TEMPERATURE (DEG K)			
HEAT LOSS (MWT)	20.000		
COOLING WATER INLET			
PRESSURE (ATM)	176.2		
TEMPERATURE (DEG K)	525.7		
FLOW RATE (KG/S)	41.92		
COOLING WATER EXIT			
PRESSURE (ATM)	171.79		
TEMPERATURE (DEG K)	612.25		
NUMBER OF CHANNELS			
MINIMUM USEFUL LIFE (HRS)			
REPLACEMENT TIME (HRS)			
BOUNDRY LAYER CONTROLS			
COST ($1000) (ACCT. 317.2.4)			

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 3 (Cont'd)

MAGNET ....

TYPE	SUPER COND.
DIMENSIONS	
LENGTH (M)	12
INLET DIAMETER (M)	1.7
OUTLET DIAMETER (M)	1.7
FIELD STRENGTH (TESLA)	
PEAK	6.0000
AVERAGE	-I
CURRENT DENSITY (A/CM**2)	
ENERGY STORAGE (JOULES)	
WEIGHT (LBS)	-I
COST ($1000) (ACCT. 317.3)	-I

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 3 (Cont'd)

```
RADIANT BOILER ....

TYPE
DIMENSIONS
  INLET (MXM)
  OUTLET (MXM)
  LENGTH (M)
ISENTROPIC EFFICIENCY (PCT)
INLET CONDITIONS
  PRESSURE (ATM)                                          .82280
  TEMPERATURE (DEG K)                                     2069.3
  MACH NUMBER
  FLOW RATE (KG/S)                                        50.633
OUTLET CONDITIONS
  PRESSURE (ATM)                                          .79812
  TEMPERATURE (DEG K)                                     1900.0
  VELOCITY (M/S)
DWELL TIME (SEC)
HEAT TRANSFER AREA (M**2)
MAXIMUM TEMPERATURE GRADIENT (DEG F/SEC)
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                          176.20
  TEMPERATURE (DEG K)                                     567.85
  FLOW RATE (KG/S)                                        31.459
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                          171.79
  TEMPERATURE (DEG K)                                     627.35
THERMAL DUTY (MWT)                                        13.854
COST($1000) (ACCT.312.3.1)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 3 (Cont'd)

```
HIGH TEMPERATURE AIR HEATER ....

TYPE
NUMBER OF MODULES                                   4
DIMENSIONS
  HEIGHT (M)
  DIAMETER (M)
  FLOW AREA (M**2)
SLAG REMOVAL (PCT)
COMBUSTION GAS INLET CONDITIONS                      NA
  PRESSURE (ATM)                                             -I
  TEMPERATURE (DEG K)
  MACH NUMBER
  FLOW RATE (KG/S)                                           -I
  DUCT DIAMETER (M)
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                             -I
  TEMPERATURE (DEG K)                                        -I
  VELOCITY (M/S)
AIR INLET CONDITIONS
  PRESSURE (ATM)                                    5,6509
  TEMPERATURE (DEG K)
  VELOCITY (M/S)
  FLOW RATE (KG/S)                                  36,991
AIR OUTLET CONDITIONS
  PRESSURE (ATM)                                    5.4814
  TEMPERATURE (DEG K)                               1755.0
  VELOCITY (M/S)
DWELL TIME (SEC)
LOSSES
  VALVE LEAKAGE (PCT)                               0.
  VALVE COOLING (MWT)                                        -I
  CORE HEAD LOSS (MWT)
THERMAL DUTY (MWT)                                  52.606
COST($1000) (ACCT.317.5.2--4)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 3 (Cont'd)

```
SUPERHEATER ....

TYPE
DIMENSIONS
  LENGTH (M)                                             5.0160
  WIDTH (M)                                              3.8188
  HEIGHT (M)                                             3.8188
SLAG REMOVAL (PCT)
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                         .79812
  TEMPERATURE (DEG K)                                    1900.0
  FLOW RATE (KG/S)                                       50.633
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                         .77417
  TEMPERATURE (DEG K)                                    1200.0
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                         171.79
  TEMPERATURE (DEG K)                                    627.35
  FLOW RATE (KG/S)                                       31.459
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                         167.50
  TEMPERATURE (DEG K)                                    811.13
THERMAL DUTY (MWT)                                       51.774
COST($1000) (ACCT. 312.4.3)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 3 (Cont'd)

```
REHEATER ....

TYPE
DIMENSIONS
  LENGTH (M)                                              =I
  WIDTH (M)                                               =I
  HEIGHT (M)                                              =I
SLAG REMOVAL (PCT)
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                          =I
  TEMPERATURE (DEG K)                                     =I
  FLOW RATE (KG/S)                                        =I
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                          =I
  TEMPERATURE (DEG K)                                     =I
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                          =I
  TEMPERATURE (DEG K)                                     =I
  FLOW RATE (KG/S)                                        =I
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                          =I
  TEMPERATURE (DEG K)                                     =I
THERMAL DUTY (MWT)                                0.      
COST($1000) (ACCT.312.4.4)                                =I
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 3 (Cont'd)

```
LOW TEMPERATURE AIR HEATER ....

TYPE
DIMENSIONS
  LENGTH (M)                                              -I
  WIDTH (M)                                               -I
  HEIGHT (M)                                              -I
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                             0.
  FLOW RATE (KG/S)                                        -I
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
AIR INLET CONDITIONS
  PRESSURE (ATM)
  TEMPERATURE (DEG K)
  FLOW RATE (KG/S)
AIR OUTLET CONDITIONS
  PRESSURE (ATM)
  TEMPERATURE (DEG K)
THERMAL DUTY (MWT)
COST($1000) (ACCT.317.5.5)                                -I
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 3 (Cont'd)

```
ECONOMIZER NO. 2 ....

DIMENSIONS
  LENGTH (M)                                                -I
  WIDTH (M)                                                 -I
  HEIGHT (M)                                                -I
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                            -I
  TEMPERATURE (DEG K)                                       -I
  FLOW RATE (KG/S)                                          -I
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                            -I
  TEMPERATURE (DEG K)                                       -I
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                            -I
  TEMPERATURE (DEG K)                                       -I
  FLOW RATE (KG/S)                                          -I
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                            -I
  TEMPERATURE (DEG K)                                       -I
THERMAL DUTY (MWT)                                          -I
COST($1000) (ACCT.312.4.2)                                  -I
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 3 (Cont'd)

```
ECONOMIZER NO. 1 ....

DIMENSIONS
  LENGTH (M)                                                  -I
  WIDTH (M)                                                   -I
  HEIGHT (M)                                                  -I
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                              -I
  TEMPERATURE (DEG K)                                         -I
  FLOW RATE (KG/S)                                            -I
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                              -I
  TEMPERATURE (DEG K)                                         -I
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                              -I
  TEMPERATURE (DEG K)                                         -I
  FLOW RATE (KG/S)                                            -I
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                              -I
  TEMPERATURE (DEG K)                                         -I
THERMAL DUTY (MWT)                                            -I
COST($1000) (ACCT.312.4.1)                                    -I


GAS CLEAN UP ....

TYPES                                                 (QUENCH/SCRUB)
LOCATIONS
LOSSES
 PRESSURE (PCT)
 THERMAL (MWT)
REMOVAL EFFICIENCY (PCT)
POWER REQUIRED (MWE)
COST($1000) (ACCT.312.5.1)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 3 (Cont'd)

```
EXHAUST EMISSIONS ....

PARTICULATE ( G/J)
NOX ( G/J)
SOX ( G/J)
TRACE ELEMENTS ( G/J)



PLANT COOLING ....

TYPE
PART MODULES
DIMENSIONS
  HEIGHT (M)                                                   -I
  DIAMETER (M)                                                 -I
CONDENSER PRESSURE (ATM)                                       -J
THERMAL DUTY (MWT)                                      120.3
TEMPERATURE (DEG K)                                            -I
COOLING WATER
  FLOW RATE (KG/S)                                             -I
  MAKE UP (PCT)
POWER REQUIREMENTS (MWE)
COST ($1000)                                                   -I



SEED MANAGEMENT ....

TYPE
RECOVERY (PCT)
REGENERATION (PCT)
TYPE OF REGENERATION PROCESS
LOCATION
POWER REQUIREMENTS (MWE)
COST ($1000)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 4

```
OVERALL SYSTEM PERFORMANCE ....

COAL INPUT (MWT)                                          150.00
REFERENCE COAL                                         M. ROSEBUD
OPERATING MODE
PLANT LIFE (YEARS)
NET POWER OUTPUT (MWE)                                    28.40
GROSS MHD POWER (MWE)                                     41.175
GROSS STEAM POWER (MWE)                                     -
MHD ENTHALPY EXTRACTION (PCT)                             17.371
PLANT EFFICIENCY (PCT)                                    14.20
STEAM CYCLE EFFICIENCY (PCT)                                      -I
PLANT CAPITAL COST ($1000)                              270000.
REFERENCE ATMOSPHERE
  PRESSURE (ATM)                                          .78695
  DRY BULB TEMPERATURE (DEG K)                            288.30
  RELATIVE HUMIDITY (PCT)                                 40.000
STEAM CONDITIONS
  MAIN TURBINE THROTTLE PRESSURE (ATM)                    163.31
  MAIN TURBINE THROTTLE TEMPERATURE (DEG K)               811.11
  REHEAT TEMPERATURE (DEG K)                                      -I


POWER CONSUMPTION
  COMPRESSOR POWER                                        12.246
  RECIR. PUMP POWER                                       0.9
  SEC. AIR BLOWER                                         0.0
  DRAFT FAN POWER                                         2.0
  ELECTRO PRECIP POWER                                    0.04
  COOLING TWR CIRC PUMP                                   0.60
  COAL HANDLING AND PROCESSING                            .86036
  MHD MAGNET POWER                                       2.48815E-02
  SEED HANDLING
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 4 (Cont'd)

```
COAL HANDLING AND PROCESSING

RAW COAL SIZE (TOP SIZE AS DELIVERED, IN)              2.0000
RAW COAL MOISTURE CONTENT (MAX PCT H2O)                22.700
RAW COAL HHV (J/KG)                                   2.07705E+07
RAW COAL FLOW RATE (KG/S)                              7.2220
COAL TO COMBUSTOR (MESH)                              200
MOISTUTURE CONTENT (PCT)                               5.0000
COAL FLOW RATE TO COMB. (KG/S)                         5.8764
TRANSPORT MEDIUM
  MECHANISM                                            FLUEGAS
  RATIO                                               1.00000E-01
DRYING MEDIUM
  FLOW RATE (KG/S)                                      13.2
  TEMPERATURE IN (DEG K)                               800.7
  TEMPERATURE OUT (DEG K)                              391.2
POWER REQUIREMENT (MWE)                                 .86036
COST($1000) (ACCT. 312.1)
COST($1000) (ACCT. 317.1--5, 317.7.1)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 4 (Cont'd)

```
OXIDIZER SUPPLY ....

OXYGEN PLANT ....
AMOUNT OF O2 ENRICHMENT (PCT)                              0.
O2 FLOW RATE (KG/S)                                        0.
COST($1000) (ACCT. 317.7.2)                                0.

MAIN AIR COMPRESSOR
  TYPE OF COMPRESSOR                                     AXIAL FLOW
  TYPE OF INTERCOOLING                                     NO
  RATED INLET PRESSURE (ATM)                               .78695
  RATED DISCHARGE PRESSURE (ATM)                           5.8257
  INLET TEMPERATURE (DEG K)                                288.30
  RELATIVE HUMIDITY (PCT)                                  40.000
  ACTUAL FLOW (KG/S)                                       46.472
  ADIABATIC EFFICIENCY (PCT)                               85.000
  SHAFT POWER (MWE)                                        12.246
  LUBE SYSTEM POWER (MWE)                                  0.
OXIDIZER PREHEAT TEMPERATURE (DEG K)                       1917.3
COST($1000) (ACCT. 317.5.7)


SECONDARY AIR INJECTION
  LOCATION, DOWNSTREAM OF                                DIFFUSER
  PRESSURE (ATM)                                                 -I
  TEMPERATURE (DEG K)                                            -I
  FLOW RATE (KG/S)                                         4.8918
  FAN EFFICIENCY (PCT)                                           -I
POWER REQUIREMENT (MWE)
COST($1000) (ACCT. 312.4.5)


SEED FEED SYSTEM ....

TYPE
SEED FLOW (KG/S)                                           .78183
POTASIUM CARBONATE (K2CO3)                                 .14620
POTASIUM SULFATE (K2SO4)                                   .63563
POWER REQUIREMENT (MWE)
COST ($1000)(ACCT. 317.6)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 4 (Cont'd)

```
MAIN COMBUSTOR ....

TYPE-NUMBER OF STAGES                                     2
DIMENSIONS       1ST STAGE    2ND STAGE   ETC.
  LENGTH (M)                                              2.4326        1.7730
  DIAMETER (M)                                            1.0812        1.1820
  VOLUME (M**3)                                           1.7370        1.9454
COMBUSTION CONDITIONS
  PRESSURE (ATM)                                          5.482
  EXIT TEMPERATURE (DEG K)                                2800.0
  EXIT FLOW RATE (KG/S)                                   53.152
SLAG REMOVAL (PCT)                                        90.000
RESIDENCE TIME (MICRO-SEC)
  1-ST STAGE
  2-ND STAGE
COMBUSTOR HEAT LOSSES (MWT)                               15.000
COOLING SYSTEM TYPE                                       H2O
  INLET TEMPERATURE (DEG K)                               379.21
  OUTLET TEMPERATURE (DEG K)                              450.00
  FLOW RATE (KG/S)                                        58.258
NUMBER OF MODULES                                          1
KEY COMPONENT
MINIMUM USEFUL LIFE OF KEY COMPONENT (HRS)
REPLACEMENT TIME OF KEY COMPONENT (HRS)
COST ($1000) (ACCT. 317.1.6-7)

NOZZLE ....
NOZZLE EXIT MACH NUMBER                                   .88866
NOZZLE HEAT LOSS (MWT)                                    2.7000
COST($1000) (ACCT.317.2.1)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 4 (Cont'd)

CHANNEL ....

TYPE			
DIMENSIONS			
INLET (MXM)	.53183	X	,26591
OUTLET (MXM)	1,3346	X	,74772
LENGTH (M)	11,322		
SLAG REMOVAL (PCT)			
EFFICIENCY (PCT)			
INLET CONDITIONS			
PRESSURE (ATM)	3,3613		
TEMPERATURE (DEG K)	2646,5		
MACH NUMBER	,88866		
FLOW RATE (KG/S)	53,152		
OUTLET CONDITIONS			
PRESSURE (ATM)	,68047		
TEMPERATURE (DEG K)	2197,3		
MACH NUMBER	,80378		
SURFACE TEMPERATURE (DEG K)	1800,0		
HEAT LOSS (MWT)	16,650		
PEAK ELECTRODE CURRENT DENSITY (A/CM**2)		-1	
MAXIMUM HALL FIELD (KV/M)	3,5000		
COOLING WATER			
PRESSURE (ATM)	13,609		
TEMPERATURE (DEG K)	311,02		
FLOW RATE (KG/S)	58.258		
NUMBER OF CHANNELS			
MINIMUM USEFUL LIFE (HRS)			
REPLACEMENT TIME (HRS)			
COST ($1000) (ACCT. 317.2.2)			

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 4 (Cont'd)

```
DIFFUSER ....

TYPE
DIMENSIONS
  INLET (MXM)                                   1.3346      X    .74772
  OUTLET (MXM)                                  4.2707      X   2.3927
  LENGTH (M)                                    10.160
EFFICIENCY (PCT)                                45.000
INLET CONDITIONS
  TEMPERATURE (DEG K)                           2197.5
  PRESSURE (ATM)                                .68047
  MACH NUMBER                                   .60376
  FLOW RATE (KG/S)                              53.152
OUTLET CONDITIONS
  TEMPERATURE (DEG K)                           2126.6
  PRESSURE (ATM)                                .81812
  MACH NUMBER                                   0.
SURFACE TEMPERATURE (DEG K)
HEAT LOSS (MWT)                                 20.000
COOLING WATER INLET
  PRESSURE (ATM)                                176.20
  TEMPERATURE (DEG K)                           525.00
  FLOW RATE (KG/S)                              41.921
COOLING WATER EXIT
  PRESSURE (ATM)                                171.79
  TEMPERATURE (DEG K)                           612.25
  NUMBER OF CHANNELS                             1
  MINIMUM USEFUL LIFE (HRS)
REPLACEMENT TIME (HRS)
BOUNDRY LAYER CONTROLS
COST ($1000) (ACCT. 317.2.4)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 4 (Cont'd)

MAGNET ....

TYPE	SUPER COND.
DIMENSIONS	
LENGTH (M)	12
INLET DIAMETER (M)	1.7
OUTLET DIAMETER (M)	1.7
FIELD STRENGTH (TESLA)	
PEAK	6.0000
AVERAGE	-I
CURRENT DENSITY (A/CM**2)	
ENERGY STORAGE (JOULES)	
WEIGHT (LBS)	-I
COST ($1000) (ACCT. 317.3)	-I

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 4 (Cont'd)

```
RADIANT BOILER ....

TYPE
DIMENSIONS
  INLET (MXM)
  OUTLET (MXM)
  LENGTH (M)
EFFICIENCY (PCT)
INLET CONDITIONS
  PRESSURE (ATM)                                  .81812
  TEMPERATURE (DEG K)                             2088.7
  MACH NUMBER
  FLOW RATE (KG/S)                                58.044
OUTLET CONDITIONS
  PRESSURE (ATM)                                  .79358
  TEMPERATURE (DEG K)                             2000.0
  VELOCITY (M/S)
DWELL TIME (SEC)
HEAT TRANSFER AREA (M**2)                                 -I
MAXIMUM TEMPERATURE GRADIENT (DEG F/SEC)
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                  171.79
  TEMPERATURE (DEG K)                             612.25
  FLOW RATE (KG/S)                                41.921
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                  167.50
  TEMPERATURE (DEG K)                             625.28
THERMAL DUTY (MWT)                                8.6207
COST($1000) (ACCT.312.3.1)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 4 (Cont'd)

```
HIGH TEMPERATURE AIR HEATER ....

TYPE
NUMBER OF MODULES
DIMENSIONS
  HEIGHT (M)
  DIAMETER (M)
  FLOW AREA (M**2)
SLAG REMOVAL (PCT)
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                      -I
  TEMPERATURE (DEG K)                       0.
  MACH NUMBER
  FLOW RATE (KG/S)                                    -I
  DUCT DIAMETER (M)
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                      -I
  TEMPERATURE (DEG K)                                 -I
  VELOCITY (M/S)
AIR INLET CONDITIONS
  PRESSURE (ATM)                            5.6509
  TEMPERATURE (DEG K)                       1100.0
  VELOCITY (M/S)
  FLOW RATE (KG/S)                          46.472
AIR OUTLET CONDITIONS
  PRESSURE (ATM)                            5.4814
  TEMPERATURE (DEG K)                       1917.3
  VELOCITY (M/S)
DWELL TIME (SEC)
LOSSES
  VALVE LEAKAGE (PCT)                       0.
  VALVE COOLING (MWT)                                 -I
  CORE HEAD LOSS (MWT)                      0.
THERMAL DUTY (MWT)                          46.236
COST($1000) (ACCT.317.5.2--4)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 4 (Cont'd)

```
SUPERHEATER ....

TYPE
DIMENSIONS
  LENGTH (M)                                       5.6240
  WIDTH (M)                                        4.0887
  HEIGHT (M)                                       4.0887
SLAG REMOVAL (PCT)
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                   .79358
  TEMPERATURE (DEG K)                              2000.0
  FLOW RATE (KG/S)                                 58.044
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                   .76977
  TEMPERATURE (DEG K)                              1200.0
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                   167.50
  TEMPERATURE (DEG K)                              625.28
  FLOW RATE (KG/S)                                 41.921
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                   163.31
  TEMPERATURE (DEG K)                              811.11
THERMAL DUTY (MWT)                                 67.805
COST($1000) (ACCT. 312.4.3)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 4 (Cont'd)

```
REHEATER ....

TYPE
DIMENSIONS
  LENGTH (M)                                              -I
  WIDTH (M)                                               -I
  HEIGHT (M)                                              -I
SLAG REMOVAL (PCT)
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
  FLOW RATE (KG/S)                                        -I
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
  FLOW RATE (KG/S)                                        -I
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
THERMAL DUTY (MWT)                                0.
COST($1000) (ACCT.312.4.4)                                -I
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 4 (Cont'd)

```
LOW TEMPERATURE AIR HEATER ....

TYPE
DIMENSIONS
  LENGTH (M)                                              10.184
  WIDTH (M)                                               4.5530
  HEIGHT (M)                                              4.5530
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                          .76977
  TEMPERATURE (DEG K)                                     1200.0
  FLOW RATE (KG/S)                                        58.044
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                          .74668
  TEMPERATURE (DEG K)                                     800.74
AIR INLET CONDITIONS
  PRESSURE (ATM)                                          5.8257
  TEMPERATURE (DEG K)                                     545.80
  FLOW RATE (KG/S)                                        46.472
AIR OUTLET CONDITIONS
  PRESSURE (ATM)                                          5.6509
  TEMPERATURE (DEG K)                                     1100.0
THERMAL DUTY (MWT)                                        28,547
COST($1000) (ACCT.317.5.5)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 4 (Cont'd)

```
ECONOMIZER NO. 1 ....

DIMENSIONS
  LENGTH (M)                                                      -I
  WIDTH (M)                                                       -I
  HEIGHT (M)                                                      -I
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                       .74668
  TEMPERATURE (DEG K)                                  800.74
  FLOW RATE (KG/S)                                     58.044
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                       .72428
  TEMPERATURE (DEG K)                                  425.00
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                       180.60
  TEMPERATURE (DEG K)                                  429.80
  FLOW RATE (KG/S)                                      41.90
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                       176.10
  TEMPERATURE (DEG K)                                  525.7
THERMAL DUTY (MWT)                                     24.453
COST($1000) (ACCT.312.4.2)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 4 (Cont'd)

```
ECONOMIZER NO. 1 ....

DIMENSIONS
  LENGTH (M)                                                  -I
  WIDTH (M)                                                   -I
  HEIGHT (M)                                                  -I
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                              -I
  TEMPERATURE (DEG K)                                         -I
  FLOW RATE (KG/S)                                            -I
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                              -I
  TEMPERATURE (DEG K)                                         -I
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                              -I
  TEMPERATURE (DEG K)                                         -I
  FLOW RATE (KG/S)                                            -I
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                              -I
  TEMPERATURE (DEG K)                                         -I
THERMAL DUTY (MWT)                                            -I
COST($1000) (ACCT,312,4,1)                                    -I


GAS CLEAN UP ....

TYPES                                                      ESP
LOCATIONS
LOSSES
 PRESSURE (PCT)
 THERMAL (MWT)
REMOVAL EFFICIENCY (PCT)
POWER REQUIRED (MWE)                                   0.
COST($1000) (ACCT,312,5,1)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 4 (Cont'd)

```
EXHAUST EMISSIONS ....

PARTICULATE ( G/J)
NOX ( G/J)
SOX ( G/J)
TRACE ELEMENTS ( G/J)



PLANT COOLING ....

TYPE
PART MODULES
DIMENSIONS
  HEIGHT (M)                                               -I
  DIAMETER (M)                                             -I
CONDENSER PRESSURE (ATM)                                   -I
THERMAL DUTY (MWT)                                 149.6
TEMPERATURE (DEG K)                                        -I
COOLING WATER
  FLOW RATE (KG/S)                                         -I
  MAKE UP (PCT)
POWER REQUIREMENTS (MWE)
COST ($1000)                                               -I



SEED MANAGEMENT ....

TYPE
RECOVERY (PCT)                                        90.0
REGENERATION (PCT)
TYPE OF REGENERATION PROCESS
LOCATION
POWER REQUIREMENTS (MWE)                          0.
COST ($1000)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 5

```
OVERALL SYSTEM PERFORMANCE ....

COAL INPUT (MWT)                                          150.00
REFERENCE COAL                                         M. ROSEBUD
OPERATING MODE
PLANT LIFE (YEARS)
NET POWER OUTPUT (MWE)                                     28.40
GROSS MHD POWER (MWE)                                     41.175
GROSS STEAM POWER (MWE)                                      -
MHD ENTHALPY EXTRACTION (PCT)                             17.371
PLANT EFFICIENCY (PCT)                                     18.9
STEAM CYCLE EFFICIENCY (PCT)                                       -I
PLANT CAPITAL COST ($1000)                               271000.
REFERENCE ATMOSPHERE
  PRESSURE (ATM)                                          .78695
  DRY BULB TEMPERATURE (DEG K)                            288.30
  RELATIVE HUMIDITY (PCT)                                 40.000
STEAM CONDITIONS
  MAIN TURBINE THROTTLE PRESSURE (ATM)                    163.31
  MAIN TURBINE THROTTLE TEMPERATURE (DEG K)               811.11
  REHEAT TEMPERATURE (DEG K)                                       -I
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 5 (Cont'd)

```
COAL HANDLING AND PROCESSING

RAW COAL SIZE (TOP SIZE AS DELIVERED, IN)          2.0000
RAW COAL MOISTURE CONTENT (MAX PCT H2O)            22.700
RAW COAL HHV (J/KG)                               2.07705E+07
RAW COAL FLOW RATE (KG/S)                          7.2220
COAL TO COMBUSTOR (MESH)                          200
MOISTUTURE CONTENT (PCT)                           5.0000
COAL FLOW RATE TO COMB. (KG/S)                     5.8764
TRANSPORT MEDIUM
  MECHANISM                                        FLUEGAS
  RATIO                                           1.00000E-01
DRYING MEDIUM
  FLOW RATE (KG/S)                                   13.2
  TEMPERATURE IN (DEG K)                            800.7
  TEMPERATURE OUT (DEG K)                           391.2
POWER REQUIREMENT (MWE)                             86036
COST($1000) (ACCT. 312.1)
COST($1000) (ACCT. 317.1--5, 317.7.1)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 5 (Cont'd)

```
OXIDIZER SUPPLY ....

OXYGEN PLANT ....
AMOUNT OF O2 ENRICHMENT (PCT)                       0.
O2 FLOW RATE (KG/S)                                 0.
COST($1000) (ACCT. 317.7.2)                         0.

MAIN AIR COMPRESSOR
  TYPE OF COMPRESSOR                              AXIAL FLOW
  TYPE OF INTERCOOLING                              NO
  RATED INLET PRESSURE (ATM)                        .78695
  RATED DISCHARGE PRESSURE (ATM)                    5.8257
  INLET TEMPERATURE (DEG K)                         288.30
  RELATIVE HUMIDITY (PCT)                           40.000
  ACTUAL FLOW (KG/S)                                46.472
  ADIABATIC EFFICIENCY (PCT)                        85.000
  SHAFT POWER (MWE)                                 12.246
  LUBE SYSTEM POWER (MWE)                           0.
OXIDIZER PREHEAT TEMPERATURE (DEG K)                1917.3
COST($1000) (ACCT. 317.5.7)


SECONDARY AIR INJECTION
  LOCATION, DOWNSTREAM OF                         DIFFUSER
  PRESSURE (ATM)                                          -I
  TEMPERATURE (DEG K)                                     -I
  FLOW RATE (KG/S)                                  4.8918
  FAN EFFICIENCY (PCT)                                    -I
POWER REQUIREMENT (MWE)
COST($1000) (ACCT. 312.4.5)


SEED FEED SYSTEM ....

TYPE
SEED FLOW (KG/S)                                    .78183
POTASIUM CARBONATE (K2CO3)                          .14620
POTASIUM SULFATE (K2SO4)                            .53563
POWER REQUIREMENT (MWE)
COST ($1000) (ACCT. 317.6)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 5 (Cont'd)

```
MAIN COMBUSTOR ....

TYPE-NUMBER OF STAGES                                          2
DIMENSIONS        1ST STAGE    2ND STAGE   ETC.
  LENGTH (M)                                                2.4326        1.7730
  DIAMETER (M)                                              1.0812        1.1820
  VOLUME (M**3)                                             1.7370        1.9454
COMBUSTION CONDITIONS
  PRESSURE (ATM)                                            5.482
  EXIT TEMPERATURE (DEG K)                                  2800.0
  EXIT FLOW RATE (KG/S)                                     53.152
SLAG REMOVAL (PCT)                                          90.000
RESIDENCE TIME (MICRO-SEC)
  1-ST STAGE
  2-ND STAGE
COMBUSTOR HEAT LOSSES (MWT)                                 15.000
COOLING SYSTEM TYPE                                         H2O
  INLET TEMPERATURE (DEG K)                                 379.21
  OUTLET TEMPERATURE (DEG K)                                450.00
  FLOW RATE (KG/S)                                          58.258
NUMBER OF MODULES                                             1
KEY COMPONENT
MINIMUM USEFUL LIFE OF KEY COMPONENT (HRS)
REPLACEMENT TIME OF KEY COMPONENT (HRS)
COST ($1000) (ACCT. 317.1.6-7)

NOZZLE ....
NOZZLE EXIT MACH NUMBER                                     .88866
NOZZLE HEAT LOSS (MWT)                                      2.7000
COST($1000) (ACCT.317.2.1)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 5 (Cont'd)

```
CHANNEL ....

TYPE
DIMENSIONS
  INLET (MXM)                                              .53183     X   .26591
  OUTLET (MXM)                                             1.3346     X   .74772
  LENGTH (M)                                               11.322
SLAG REMOVAL (PCT)
EFFICIENCY (PCT)
INLET CONDITIONS
  PRESSURE (ATM)                                           3.3613
  TEMPERATURE (DEG K)                                      2646.5
  MACH NUMBER                                              .88866
  FLOW RATE (KG/S)                                         53.152
OUTLET CONDITIONS
  PRESSURE (ATM)                                           .68047
  TEMPERATURE (DEG K)                                      2197.3
  MACH NUMBER                                              .80378
SURFACE TEMPERATURE (DEG K)                                1600.0
HEAT LOSS (MWT)                                            16.650
PEAK ELECTRODE CURRENT DENSITY (A/CM**2)                          -I
MAXIMUM HALL FIELD (KV/M)                                  3.5000
COOLING WATER
  PRESSURE (ATM)                                           13.609
  TEMPERATURE (DEG K)                                      311.02
  FLOW RATE (KG/S)                                         58.258
  NUMBER OF CHANNELS
  MINIMUM USEFUL LIFE (HRS)
REPLACEMENT TIME (HRS)
COST ($1000) (ACCT. 317.2.2)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 5 (Cont'd)

```
DIFFUSER ....

TYPE
DIMENSIONS
   INLET (MXM)                                        1.3346      X    .74772
   OUTLET (MXM)                                       4.2707      X    2.3927
   LENGTH (M)                                         10.160
EFFICIENCY (PCT)                                      45.000
INLET CONDITIONS
   TEMPERATURE (DEG K)                                2197.3
   PRESSURE (ATM)                                     .68047
   MACH NUMBER                                        .60378
   FLOW RATE (KG/S)                                   53.152
OUTLET CONDITIONS
   TEMPERATURE (DEG K)                                2126.6
   PRESSURE (ATM)                                     .81812
   MACH NUMBER                                        0.
SURFACE TEMPERATURE (DEG K)
HEAT LOSS (MWT)                                       20.000
COOLING WATER INLET
   PRESSURE (ATM)                                     176.20
   TEMPERATURE (DEG K)                                525.66
   FLOW RATE (KG/S)                                   41.921
COOLING WATER EXIT
   PRESSURE (ATM)                                     171.79
   TEMPERATURE (DEG K)                                612.25
   NUMBER OF CHANNELS                                  1
   MINIMUM USEFUL LIFE (HRS)
REPLACEMENT TIME (HRS)
BOUNDRY LAYER CONTROLS
COST ($1000) (ACCT. 317.2.4)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 5 (Cont'd)

```
MAGNET ....

TYPE                                                    SUPER COND.
DIMENSIONS
  LENGTH (M)                                                12
  INLET DIAMETER (M)                                        1.7
  OUTLET DIAMETER (M)                                       1.7
FIELD STRENGTH (TESLA)
  PEAK                                                   6.0000
  AVERAGE                                                         -I
CURRENT DENSITY (A/CM**2)
ENERGY STORAGE (JOULES)
WEIGHT (LBS)                                                      -I
COST ($1000) (ACCT. 317.3)                                        -I
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 5 (Cont'd)

```
RADIANT BOILER ....

TYPE
DIMENSIONS
  INLET (MXM)
  OUTLET (MXM)
  LENGTH (M)
EFFICIENCY (PCT)
INLET CONDITIONS
  PRESSURE (ATM)                                          .81812
  TEMPERATURE (DEG K)                                     2088.7
  MACH NUMBER
  FLOW RATE (KG/S)                                        58.044
OUTLET CONDITIONS
  PRESSURE (ATM)                                          .79358
  TEMPERATURE (DEG K)                                     2000.0
  VELOCITY (M/S)
DWELL TIME (SEC)
HEAT TRANSFER AREA (M**2)                                        -I
MAXIMUM TEMPERATURE GRADIENT (DEG F/SEC)
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                          171.79
  TEMPERATURE (DEG K)                                     612.25
  FLOW RATE (KG/S)                                         23.5
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                          167.50
  TEMPERATURE (DEG K)                                     625.28
THERMAL DUTY (MWT)                                         13.2
COST($1000) (ACCT.312.3.1)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 5 (Cont'd)

```
HIGH TEMPERATURE AIR HEATER ....

TYPE
NUMBER OF MODULES
DIMENSIONS
  HEIGHT (M)
  DIAMETER (M)
  FLOW AREA (M**2)
SLAG REMOVAL (PCT)
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                     0.79
  TEMPERATURE (DEG K)                                1950.
  MACH NUMBER
  FLOW RATE (KG/S)                                    58.044
  DUCT DIAMETER (M)
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                      0.77
  TEMPERATURE (DEG K)                                1370.9
  VELOCITY (M/S)
AIR INLET CONDITIONS
  PRESSURE (ATM)                                    5.6509
  TEMPERATURE (DEG K)                               1100.0
  VELOCITY (M/S)
  FLOW RATE (KG/S)                                  46.472
AIR OUTLET CONDITIONS
  PRESSURE (ATM)                                    5.4814
  TEMPERATURE (DEG K)                               1917.3
  VELOCITY (M/S)
DWELL TIME (SEC)
LOSSES
  VALVE LEAKAGE (PCT)                               0.
  VALVE COOLING (MWT)                                        -I
  CORE HEAD LOSS (MWT)                              0.
THERMAL DUTY (MWT)                                  46.236
COST($1000) (ACCT.317.5.2--4)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 5 (Cont'd)

```
SUPERHEATER ....

TYPE
DIMENSIONS
  LENGTH (M)
  WIDTH (M)
  HEIGHT (M)
SLAG REMOVAL (PCT)
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                  .77358
  TEMPERATURE (DEG K)                             1370.9
  FLOW RATE (KG/S)                                58.044
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                  .75177
  TEMPERATURE (DEG K)                             1200.0
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                  167.50
  TEMPERATURE (DEG K)                             625.28
  FLOW RATE (KG/S)                                 23.50
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                  163.31
  TEMPERATURE (DEG K)                             811.11
THERMAL DUTY (MWT)                                 12.90
COST($1000) (ACCT. 312.4.3)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 5 (Cont'd)

```
REHEATER ....

TYPE
DIMENSIONS
  LENGTH (M)                                                      -I
  WIDTH (M)                                                       -I
  HEIGHT (M)                                                      -I
SLAG REMOVAL (PCT)
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                                  -I
  TEMPERATURE (DEG K)                                             -I
  FLOW RATE (KG/S)                                                -I
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                                  -I
  TEMPERATURE (DEG K)                                             -I
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                                  -I
  TEMPERATURE (DEG K)                                             -I
  FLOW RATE (KG/S)                                                -I
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                                  -I
  TEMPERATURE (DEG K)                                             -I
THERMAL DUTY (MWT)                                        0.
COST($1000) (ACCT,312,4,4)                                        -I
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 5 (Cont'd)

```
LOW TEMPERATURE AIR HEATER ....

TYPE
DIMENSIONS
  LENGTH (M)                                              10.184
  WIDTH (M)                                               4.5530
  HEIGHT (M)                                              4.5530
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                            .751
  TEMPERATURE (DEG K)                                     1200.0
  FLOW RATE (KG/S)                                        58.044
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                          .74668
  TEMPERATURE (DEG K)                                     800.74
AIR INLET CONDITIONS
  PRESSURE (ATM)                                          5.8257
  TEMPERATURE (DEG K)                                     545.80
  FLOW RATE (KG/S)                                        46.472
AIR OUTLET CONDITIONS
  PRESSURE (ATM)                                          5.6509
  TEMPERATURE (DEG K)                                     1100.0
THERMAL DUTY (MWT)                                        28.547
COST($1000) (ACCT.317.5.5)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 5 (Cont'd)

```
ECONOMIZER NO. 1 ....

DIMENSIONS
  LENGTH (M)                                                          •I
  WIDTH (M)                                                           •I
  HEIGHT (M)                                                          •I
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                              .74668
  TEMPERATURE (DEG K)                                         800.74
  FLOW RATE (KG/S)                                            58.044
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                              .72428
  TEMPERATURE (DEG K)                                         425.00
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                              180.60
  TEMPERATURE (DEG K)                                         429.80
  FLOW RATE (KG/S)                                              23.5
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                              176.10
  TEMPERATURE (DEG K)                                          590.5
THERMAL DUTY (MWT)                                              17.9
COST($1000) (ACCT.312.4.2)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 5 (Cont'd)

```
ECONOMIZER NO. 2 ....

DIMENSIONS
  LENGTH (M)                                               -I
  WIDTH (M)                                                -I
  HEIGHT (M)                                               -I
COMBUSTION GAS INLET CONDITIONS
  PRESSURE (ATM)                                           -I
  TEMPERATURE (DEG K)                                      -I
  FLOW RATE (KG/S)                                         -I
COMBUSTION GAS OUTLET CONDITIONS
  PRESSURE (ATM)                                           -I
  TEMPERATURE (DEG K)                                      -I
WATER/STEAM INLET CONDITIONS
  PRESSURE (ATM)                                           -I
  TEMPERATURE (DEG K)                                      -I
  FLOW RATE (KG/S)                                         -I
WATER/STEAM EXIT CONDITIONS
  PRESSURE (ATM)                                           -I
  TEMPERATURE (DEG K)                                      -I
THERMAL DUTY (MWT)                                         -I
COST($1000) (ACCT,312,4,1)                                 -I


GAS CLEAN UP ....

TYPES                                                  ESP
LOCATIONS
LOSSES
 PRESSURE (PCT)
 THERMAL (MWT)
REMOVAL EFFICIENCY (PCT)
POWER REQUIRED (MWE)                                0.
COST($1000) (ACCT,312,5,1)
```

MHD FACILITY
PERFORMANCE ANALYSIS DATA
CONFIGURATION 5 (Cont'd)

```
EXHAUST EMISSIONS ....

PARTICULATE ( G/J)
NOX ( G/J)
SOX ( G/J)
TRACE ELEMENTS ( G/J)



PLANT COOLING ....

TYPE
PART MODULES
DIMENSIONS
  HEIGHT (M)                                               .I
  DIAMETER (M)                                             .I
CONDENSER PRESSURE (ATM)                                   .I
THERMAL DUTY (MWT)                                  98.8
TEMPERATURE (DEG K)                                        .I
COOLING WATER
  FLOW RATE (KG/S)                                         .I
  MAKE UP (PCT)
POWER REQUIREMENTS (MWE)
COST ($1000)                                               .I



SEED MANAGEMENT ....

TYPE
RECOVERY (PCT)                                       90.0
REGENERATION (PCT)
TYPE OF REGENERATION PROCESS
LOCATION
POWER REQUIREMENTS (MWE)                          0.
COST ($1000)
```

APPENDIX E

RELATIVE DEVELOPMENT CATEGORIES FOR MHD SYSTEMS

RELATIVE DEVELOPMENT CATEGORIES MHD SYSTEMS

The relative status of the development of major components and systems for the MHD combined cycle power plant are noted in Table E-1 and Figure E-1. These category definitions were developed for the ETF study(1) program and had been retained for the relative assessment of risk used in this study.

Table E-1 is a reprint of the ETF component technology development status codes and criteria found in the MHD ETF Criteria Document. Application of the criteria to the possible selection of systems and components proposed for the MHD-ETF design resulted in a system "tree" for MHD-ETF, Figure E-1, which has been extracted from the Westinghouse MHD-ETF Conceptual Design Report, Volume II. This "tree" contains development status data for all components and systems included in the ETF Reference Design evaluated herein, as well as for additional items reflecting the conceptual level of the design and other possible ETF design path choices, and for basic balance-of-plant systems such as Instrumentation and Control and Fire Protection. The significant developmental items are invariably those associated with the hot air and gas systems, coal and seed systems, or the superconducting magnet, as shown on the tree.

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(1) Report FE-2363-2, "MHD-ETF Conceptual Design," Volume II: Selection, Scaling and Preliminary Test Plan, Westinghouse Electric Corporation, Advanced Energy Systems Division, April 1978.

TABLE E-1

ETF COMPONENT TECHNOLOGY DEVELOPMENT STATUS CODES

APPLICATION RATING	EQUIPMENT STATUS	PERFORMANCE DATA BASE	EXTRAPOLATION FROM PERFORMANCE DATA BASE	WORK REQUIRED	R&D PROGRAM CHARACTERISTICS	
					RATIONALE	SUCCESS PROBABILITY
Established (A)	Firm selections can be made. Equipment is commercially available in form required.	Sufficient	None	Mininal, routine applications engineering.	Not Applicable	Not Applicable
Near Term (B)	A number of equipment candidates are identified. Candidates are commercial or near commercial.	Incomplete	Short extrapolations from existing data base are involved.	Confirmatory testing and minimal R&D.	Straight-forward	Virtually Certain
Developmental (C)	Equipment not previously designed, but engineering data base exists for design.	Incomplete; important gaps exist.	Large extrapolations from existing data required.	Considerable R&D is required.	A credible rationale exists. Alternative avenues are evident.	Good to excellent.
Speculative (D)	Equipment not previously designed with major materials, design or manufacturing uncertainties.	Sparse or Absent	Highly speculative or not possible.	Extensive R&D is required.	Rationale is not clear, or requires a break-through or serendipity.	Fair to poor.

*Reprinted from the MHD ETF Criteria Document, Table 8-1.

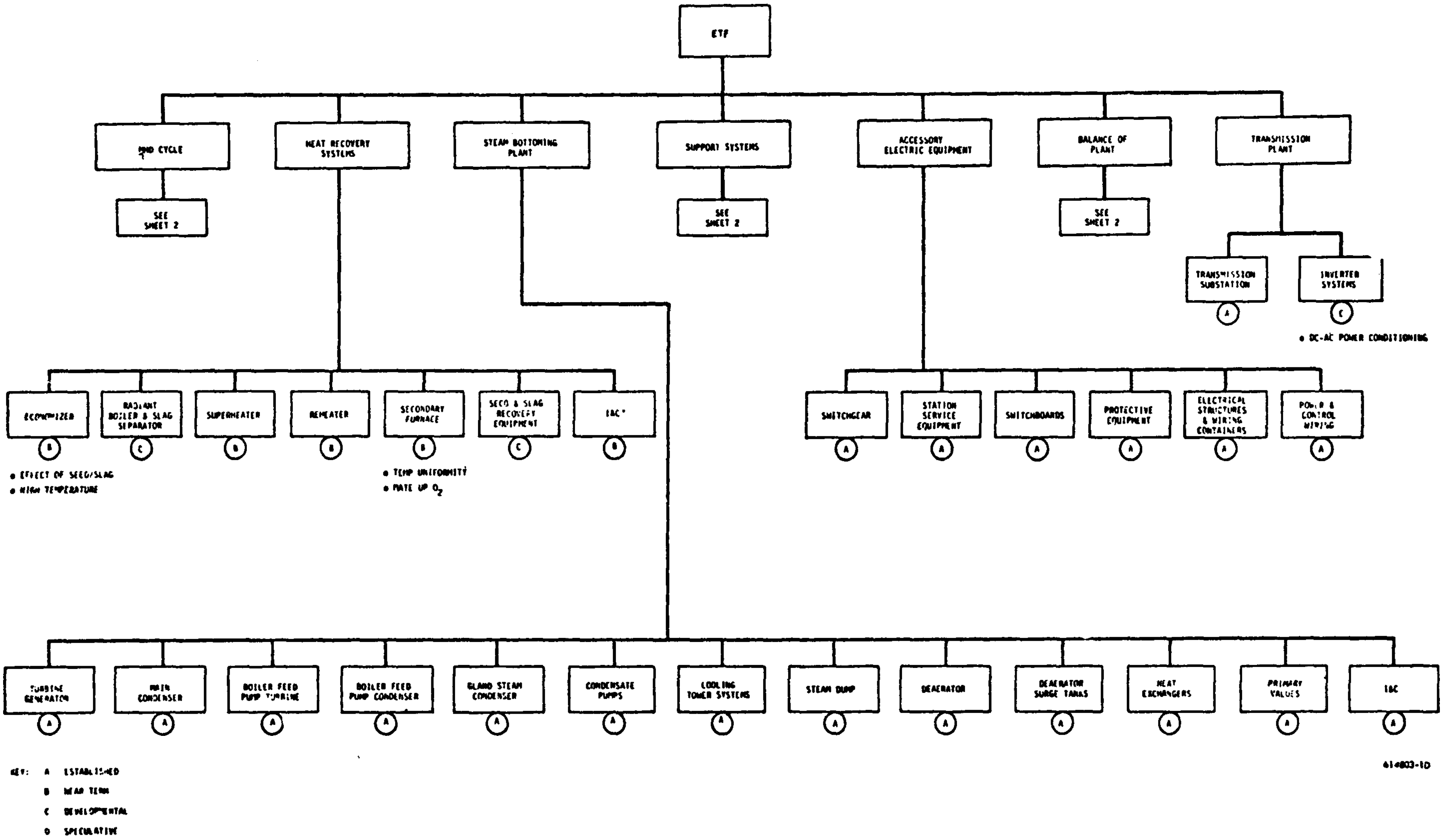

Figure E-1. ETF Systems - Development Classification (Sheet 1)

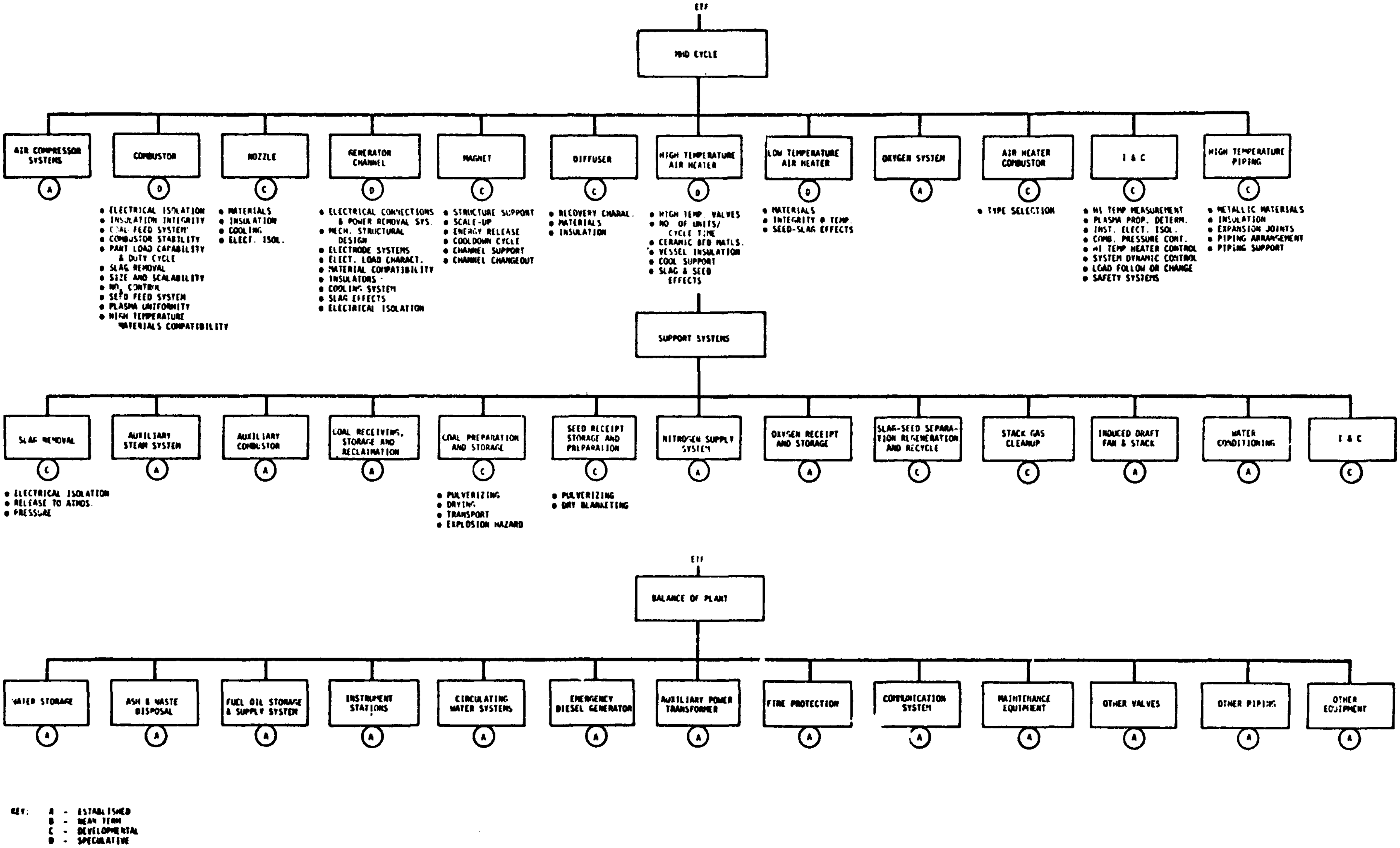

Figure E-1. ETF Systems - Development Classification (Sheet 2)

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